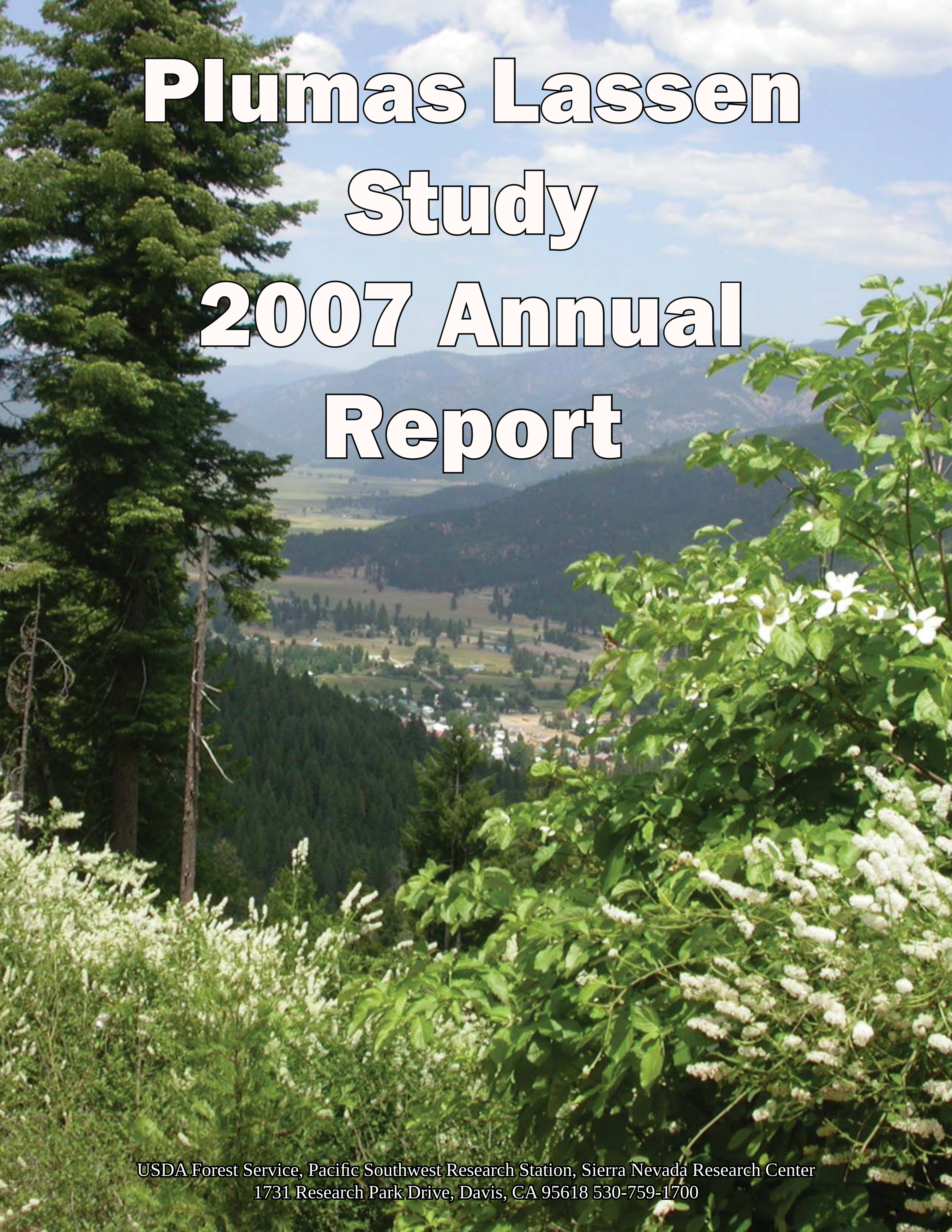
Plumas Lassen Study 2007 Annual Report



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Response Variable Modules

Introduction

The Pacific Southwest Region and the Pacific Southwest Research Station agreed in 2002 to jointly develop and fund an administrative study to fill management information needs concerning the relationship between management-caused changes in vegetation and their effects on spotted owl habitat and population dynamics. The detailed discussions explaining how this program was started is provided in previous Annual Reports. Copies of previous Annual Reports for this program are available on the Sierra Nevada Research Center web site (www.fs.fed.us/psw/programs/snrc) or upon request.

This is the sixth such Annual Report that we have compiled. The primary purpose of this is to provide a periodic synopsis of what we have been learning so all interested parties can remain abreast of the progress. Research products resulting from this effort will be disseminated as they are ready and this will vary from module to module, project to project, and from year to year. We expect that there will be a continuous flow of findings documented primarily with publications in both refereed journals and other publication outlets. The cadre of scientists, support staff, students, and others contributing to this effort will also be making oral presentations and providing other kinds of outreach materials to help inform interested parties and our peers on the results of this work.

We provide some review information here to reinforce the intent of our work. This background information provides a general overview on the purpose of this research program and helps set the context for the report. We have had to remind many interested parties and in particular our own program administrators that we embarked on the project virtually from square one. A project of this magnitude and ambition is difficult to initiate under the best of circumstances. When a research program begins work in a new area, addressing large geographic areas with complex questions on a busy landscape that is already subject to many other demands, it is not easy to establish all the field activities and produce results quickly.

However, we now believe we have emerged from the initiation phase and we have collected an impressive amount of information. Many publications are in development and we expect to provide useful information in the immediate future. Of course much of our research purpose depends on forest management treatments to be put in place and then observe short and even long term response to those treatments. Such treatments are now being executed in some locations and thus some of our potentially most significant work has only recently begun. Observations of response after treatments will logically take place in the ensuing years. If funding can be sustained we intend to continue to follow up with further data collection, field observations and insights addressing the questions we have posed.

We recognize that response of different elements of the forest can occur immediately after treatments however it is also possible that response can occur slowly and not be recognized for some period of time depending on the response variable of interest. Alternatively it is also possible that some response variables exhibit a notable initial response and then return to a state similar to that of before the treatments. Thus we believe it is prudent to look at a fairly long period of post treatment response if possible, even if funding limitations require scheduling follow-up work in stages over time with periods of inactivity.

Purpose of the Study

This study is interdisciplinary by design, examining at least five groups of response variables (spotted owls, small mammals, terrestrial birds, vegetation, and fuels conditions) through collaboration between researchers of the USDA Forest Service Pacific Southwest Research Station (PSW) and cooperators from the Universities of California, Berkeley and Davis, and the PRBO Conservation Science. The study addresses some of the most significant uncertainties that confound management decisions in the Sierra Nevada today, including in the HFQLG Pilot Project Area. How do old-forest-dependent species respond to vegetation management over space and time? Do fuels management approaches effectively address fuels loadings without negatively affecting species viability? How effective are landscape level fuels management strategies in modifying fire behavior and reducing the extent and severity of wildland fire? These and related questions are the focus of the work being done in this study.

Objectives of Study

The original overarching objective of this proposed research was to address an array of related ecological questions in a coordinated, integrated effort, thereby providing empirical data to inform future management decisions. The landscape scale of this design was both the driving force addressing the key questions as well as the largest impediment to successful construction of a scientifically credible experimental design and implementation in the field. Our research team believes that assessing many of the key elements of forest ecosystems should be done over larger spatial and temporal scales than has typically been investigated in past research. The important difference we are investigating is the response to changes in forest structure and composition over space and time rather than simply site specific and immediate response. We believe this difference is especially relevant to forest management practices that are designed for large landscapes, executed over relatively long time frames, such as landscape level fuels treatment strategies.

This research program is designed to address the three principal issues described below. These issues are specifically addressed through research questions and attending investigational approaches tailored for five different research components of this research program. These specific questions are detailed in the individual study plans for each module. Here we simply highlight the main objectives of the integrated research program and summarize the primary research questions that we plan to pursue.

- ***Wildland Fire Behavior and Protection.*** How do landscape level fuels and silvicultural treatments affect potential fire behavior and effects? Are specific combinations of defensible fuel profile zones (DFPZs) and subsequent individual tree selection or area treatments to thin the matrix effective in reducing the extent and severity of wildland fires? Are realized fire management benefits consistent with hypothesized results in reducing fire risk and altering fire behavior?

- ***Landscape Dynamics.*** How do combinations of DFPZs, subsequent individual tree selection or area treatments to thin the matrix, group selection, riparian protection standards, and species-specific protection measures affect landscape dynamics such as forest structure, composition, and succession at multiple scales of space and time?

- ***Species Viability.*** Induced by a forest management regime, how will old-forest dependent species, particularly the California spotted owl and its prey base comprised of various species of small mammals, respond to changes in vegetation composition, structure, and distribution over space and time? How is response to treatments manifested at the individual and population levels of biological organization?

Below we provide brief summary statements that capture the essence of the questions we are pursuing under this research agenda. Once again we direct you to the detailed study plans for further information on each module of this research program.

The specific management questions that are being addressed within the five different research components are:

Fuels and Fire Module

1. Current conditions: measurement of vegetation and fuels at the landscape scale
2 Fire modeling: how might current conditions (above) affect fire *behavior* and *effects?*
3. Effects of treatments: how might landscape-scale treatments change fire behavior and effects (as measured by using simulation programs such as FlamMap)?
4. Fire and habitat model integration (how can we address fuels management objectives in ways compatible with sensitive species conservation?).

Vegetation Module

1. What are the effects of canopy reduction due to thinning treatments on understory microclimate and shrub cover? How do we accurately measure changes in canopy cover to meet management prescriptions?
2. What are the appropriate ecological conditions to induce regeneration of shade-intolerant conifer species?
3. How does ecosystem resilience to forest harvesting, particularly group selection silviculture, vary across landscape gradients of precipitation and soil type?

Small Mammal Module

1. What are the habitat associations of the different taxa of small mammals found in coniferous forests in the northern Sierra Nevada (objective of developing refined yet functional models of habitat associations)? What is the relative abundance and distribution of these taxa with respect to forest structure and composition?
2. Estimate values of the demographic parameters (for example, population size, reproductive output, survivorship, and mortality rates) of these taxa.
3. Estimate values for spatial patterns (for example, home range area and configuration) for these taxa.

Bird Community Module

1. Do current forest management practices promote an ecologically balanced forest ecosystem that supports sustainable populations of the breeding bird community over time?
2. What are the critical local-scale habitat components and landscape-scale composition elements that should be managed for in order to sustain the avian community over time (20 to 50 years)? Can we predict species composition, abundance, and distribution in response to future landscape treatments?
3. How do, or will, a suite of avian species that are associated with a wide range of forest conditions respond to fuels treatments, at the local and landscape scales in the short (one to five years) and long term (five to 20 years)?
4. Do Spotted Owl protected activity centers provide high quality habitat for the broader avian community? What are the differences in the avian community composition within owl territories compared to the surrounding landscape?

California Spotted Owl Module

1. What are the associations among landscape fuels treatments and CSO density, distribution, population trends and habitat suitability at the landscape-scale?
2. What are the associations among landscape fuels treatments and CSO reproduction, survival, and habitat fitness potential at the core area/home range scales?
3. What are the associations among landscape fuels treatments and CSO habitat use and home range configuration at the core area/home range scale?
4. What is the population trend for CSOs in the northern Sierra Nevada and what factors account for variation in population trend?
5. Are barred owls increasing in the northern Sierra Nevada, what factors are associated with their distribution and abundance, and are they associated with reduced CSO territory occupancy?
6. Does West Nile Virus affect the survival, distribution and abundance of California spotted owls in the study area?

Progress to Date

Given that we have completed a sixth year of work we are beyond the initiation phase and many findings are beginning to take shape. Some results, based on primarily pretreatment data, are crystallizing and findings are being reported. Some of the work described here includes activities from other locations but are potentially relevant to the Plumas and Lassen National Forest landscape, thus they are included in this summary. A preliminary list of completed and anticipated publications is summarized below:

FIRE AND FUELS MODULE

Menning, K.M., and S.L. Stephens. (2008: draft complete, being submitted to Landscape Ecology). "Potential forest fire behavior as a function of three weather scenarios and two landscape fuels treatments based on a fuels and vegetation landscape derived from fine-grain IKONOS satellite imagery, Sierra Nevada (USA)." Draft being submitted to Landscape Ecology.

Menning, K.M., and S.L. Stephens. 2007. Fire Climbing in the Forest: a semi-qualitative, semi-quantitative approach to assessing ladder fuel hazards, Western Journal of Applied Forestry 22(2): 88-93.

Menning, K. M. and S. L. Stephens (2006). Modeling Landscape Fire Behavior and Effects in the Northern Sierra Nevada. 3rd International Fire Ecology and Management Congress, San Diego, CA.

Menning, K. M. and S. L. Stephens (2006). Landscape-scale Fire Risk Wildlife Habitat Considered Jointly. 21st Annual Symposium of the United States Regional Chapter of the International Association for Ecology (US IALE), San Diego, CA.

Menning, K. M. and S. L. Stephens (2006). Assessing Ladder Fuels in Forests. 3rd International Fire Ecology and Management Congress, San Diego, CA.

Menning, K.M., and S. L. Stephens (2005) Fire rising in the forest: Ladder fuel hazard assessment using a mixed qualitative and quantitative approach, Ecological Society of America, August 7-12, 2005, Montreal Canada. (Abstract attached to end of report).

Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) Linking fire and wildlife habitat in California: Spectral entropy canopy diversity analysis. UK Centre for Ecology and Hydrology, Monks Wood, Cambridgeshire, England, UK. November 21, 2005.

Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) Spatial Ecological Links Between Fire, Forests and Habitat in the Plumas-Lassen Administrative Project. Geographic Information Centre Seminar: City University, London, London, England UK. November 22, 2005.

Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) Forest Structural Diversity: Spectral Entropy Canopy Diversity Analysis. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland. December 5, 2005.

Publications Planned for 2008

Menning, K. M. and S. L. Stephens. "Spectral Entropy Canopy Diversity Analysis (SpECDA) used to Assess Variability in Forest Structure and Composition" to be submitted to Photogrammetric Engineering and Remote Sensing.

Menning, K. M., S. L. Stephens, J. Keane, D. Kelt, and others. "Integrated modeling of fire and California Spotted Owl habitat conditions given different weather and landscape treatment scenarios" To be submitted to a journal mutually agreed upon.

Menning, K. M. and S. L. Stephens. "Fire Behavior and Effects as a Result of Defensible Fuel Profile Zones" To be submitted to International Journal of Wildland Fire.

Menning, K. M. and S. L. Stephens. "Landscape Forest Variability across the Northern Sierra Nevada" To be submitted to Landscape Ecology.

VEGETATION MODULE

Papers planned

Models of Resource-Dependent Growth for Sierran Mixed-Conifer Saplings.
Seth Bigelow, Malcolm North, and Will Horwath.
Summary: We document the relationship between light and growth rate for saplings of the six dominant species of mixed conifer stands, and quantitatively determine the minimum light requirement for rapid growth of shade-intolerant pines.
Status: In revision. Resubmit to Forest Ecology and Management by end April, 2008.

Resistance to alteration in landscape connectivity from small clearfell harvesting in a patchy, ecotonal conifer forest. Seth Bigelow and Sean Parks.
Summary: Group selections as currently implemented in patchy east-side forest did not disrupt connectivity (as assessed by percolation) for the most part. We demonstrate a new method for predicting probably of habitat fragmentation due to forest operations in patchy landscapes. Aerial-photography-based canopy cover estimates were far higher than ground-based estimates.
Status: Being written. Submit to Ecology and Society or The Open Forest Science Journal by July 2008.

Understory light in mixed-conifer forest: effects of fuels treatments and group selection silviculture.
Seth Bigelow, Carl Salk, Malcolm North.

Summary: We show the effects of thinning to various cover levels on the understory light environment, and infer probable effects on tree species composition (particularly comparing shade-tolerant and intolerant species) with data on seedling height growth in response to light.
Status: In data analysis. Submit by October, 2008.

Fuels Treatment and Group Selection Effects on Fire Climate.
Malcolm North, Seth Bigelow.
Summary: Air temperature and humidity, wind speed, and fuel moisture, duff and mineral soil moisture were measured for 3 yrs prior thinning to 1 yr after (end of 2008 season). Did treatments affect fire climate and soil moisture dynamics?
Status: Requires one more year of data collection. Submit mid-2009, 2 years after thinning.

Group selection harvest impacts in an ecotonal environment.
Seth Bigelow, Malcolm North.
Summary: We measured soil water dynamics in natural gaps, group selection openings, and closed canopy stands in patchy east-side forest. Natural gaps had rocky soil which prevented tree establishment. Despite large differences in canopy cover inside and outside group openings there were no measurable differences in soil water dynamics.
Status: Data collection complete. Submit 2009.

SMALL MAMMAL MODULE

Theses

Coppeto, S. A. 2005. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada, California. M.S. Thesis, University of California, Davis, 39 pp.

Innes, R.J. 2006. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. M.S. Thesis, University of California, Davis, 31 pp.

Smith, J.R. *In Prep*. Home range and habitat selection of the northern flying squirrel (*Glaucomys sabrinus*) in northeastern California. M.S. Thesis, University of California, Davis. Winter 2009.

Peer-reviewed

Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2006. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. Journal of Mammalogy 87:402-416.

Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, J. A. Wilson, P. A. Stine. 2007. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy 88(6): 1523-1531.

Innes, R. J., D. H. Van Vuren, D. A. Kelt. 2008. Characteristics and use of tree houses by dusky-footed woodrats in the northern Sierra Nevada. Northwestern Naturalist 89(2).

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2008. Home range and activity of northern flying squirrels (*Glaucomys sabrinus*) in the Sierra Nevada. Southwestern Naturalist.

Submitted

Wilson, J. A., D. A. Kelt, D, H, Van Vuren, and M. Johnson. *Submitted*. Population dynamics of small mammals in relation to cone production in four forest types in the northern Sierra Nevada. Western North American Naturalist.

Mabry, K.E., and Wilson, J. A. *Submitted*. Trapping rodents in a cautious world: the effects of disinfectants on trap success. American Midland Naturalist.

In Preparation

Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. Sullivan, J. A. Wilson, and N. Reid. *In Prep*. Different scales tell different tales: niche conservatism vs. niche differentiation in chipmunks in the northern Sierra Nevada. To be determined. Spring 2008.

Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, and J. A. Wilson. *In Prep*. Spatial organization of the dusky-footed woodrat (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. To be determined. Winter 2008.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. *In Prep*. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). To be determined. Spring 2008.

Presentations

Coppeto, S. A., D. A. Kelt, J. A. Wilson, D. H. Van Vuren, and M. L. Johnson. 2004. Habitat selection by small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.

Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2005. Spatial scale and habitat use of small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2004. Factors affecting the distribution and use of dusky-footed woodrat (*Neotoma fuscipes*) houses. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.

Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2005. Space use and social organization of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. B. Johnson, J.A. Wilson. 2006. Habitat relations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.

Smith, W. 2006. Ecology of *Glaucomys sabrinus*: habitat, demography, and community relations. Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

Wilson, J.A., and K.E. Mabry. 2005. Trap disinfection to reduce Hantavirus risk: does it also reduce small mammal trapability? Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the IX International Mammalogical Conference, Sapporo, Japan.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2006. Home range and activity of the northern flying squirrel (Glaucomys sabrinus) in the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.

TERRESTRIAL BIRD MODULE

Publications in Prep

Landscape effects on songbird abundance in the Northern Sierra – submitted March 2008 – Journal of Wildlife Management.

Avian community composition in the context of Spotted Owl management in the Sierra Nevada – submitted April 2008 – Forest Ecology and Management.

Habitat use and productivity of two shrub dependent bird species in clear cut plantations in the Sierra Nevada – submitted spring 2008 – The Condor.

Short-term response of the avian community to Aspen enhancement timber harvest treatments – submitted summer 2008 – Restoration Ecology.

Presentations

Using Birds to Guide National Forest Management in the Sierra Nevada – oral presentation – International Partner's in Flight Conference – 2/16/08 – McAllen, TX.

Managing Disturbance Associated Habitats for Birds in the Sierra Nevada – invited oral presentation – Region 5 Forest Management Conference – 2/6/08 – Reno, NV.

Managing Aspen Habitat for Birds in the Sierra Nevada– invited oral presentation at: Aspen Delineation Project – Aspen Workshop – 9/12/2007 – Lassen National Forest.

Ecological Significance of Lake Almanor Meadows to Birds – oral presentation at Almanor Basin Watershed Advisory Committee Workshop on meadow management – 8/7/07 - Chester, CA.

Using Birds to Guide Forest Management in the HFQLG Area: Results from 2002 – 2006 – invited oral presentation – USFS Region 5 biologist conference – 5/23/07 - Sacramento, CA & PLAS symposium 3/2007.

Other Outreach

"Birds in the Park" – presentation on managing coniferous forest for birds and bird banding demonstration in collaboration with Lassen Volcanic National Park – over 200 park visitors participated 7/22/07.

Sierra Nevada Conservancy Field Trip – 5/1/2007 – Westwood, CA.

Aspen Workshop – invited to participate in the event co-sponsored by the Lassen National Forest, Aspen Delineation Project, and Sierra Forest Legacy – 9/13/2007.

Led Plumas Audubon Society Field Trip – 10/3/2007 – Chester, CA.

Bird Banding Field Trip – coordinated outreach field trips with the Lassen National Forest to view bird banding and discuss the use of birds as indicators in forest management, PLAS study, and PRBO – 7/25/2007, 8/8/2007.

Integration with Management

We provided input to several important Forest Service projects in 2007 in an effort to integrate our results to help guide forest management in the Sierra Nevada. In addition we:

1. Updated the "Interactive GIS Project" with 2007 avian monitoring data. This product can be used by forest planners in the region to determine the presence/absence or abundance of all species detected in the study area.

2. Updated the Lassen National Forest interactive GIS CD with presence/absence data of each woodpecker species at every point count station ever surveyed by PRBO in the district. We also conducted a tutorial of its application and use with ARD biologist Mark Williams.

3. Continued distribution with positive feedback for our white papers integrating avian monitoring data into science based recommendations for managing four important Sierra habitat types for birds.

OWL MODULE

Keane, J.J., J.A. Blakesley, C.V. Gallagher, D.L. Hanson, P.A. Shaklee, and D.W.H. Shaw. Status and Distribution of the Barred Owl in the Sierra Nevada. To be submitted to the Condor.

Keane, J.J., J.A. Blakesley, C.V. Gallagher, D.L. Hanson, P.A. Shaklee, and D.W.H. Shaw. Nest-site habitat characteristics of California spotted owls in the northern Sierra Nevada. To be submitted to Journal of Wildlife Management.

Keane, J.J., J.A. Blakesley, C.V. Gallagher, D.L. Hanson, P.A. Shaklee, and D.W.H. Shaw. Landscape nesting habitat characteristics of California spotted owls in the northern Sierra Nevada. To be submitted to the Journal of Wildlife Management.

Keane, J.J., J.A. Blakesley, J.R. Dunk, and S.A. Parks. Predictive habitat suitability models of California spotted owls for assessing effects of forest management and fuels treatments. To be submitted to Ecological Applications or Forest Ecology and Management.

Keane, J.J., J.A. Blakesley, C.V. Gallagher, D.L. Hanson, P.A. Shaklee, and D.W.H. Shaw. Diets of California spotted owls in the northern Sierra Nevada. To be submitted to Forest Ecology and Management.

Dunk, J.R., J.J. Keane, and S.A. Parks. Predictive habitat suitability models of northern goshawks for assessing effects of forest management and fuels treatments in the northern Sierra Nevada. To be submitted to Ecological Applications or Forest Ecology.

J.J. Keane , J.R. Dunk, and S.A. Parks. Landscape habitat patterns and predictive habitat suitability models for northern goshawks in the Lake Tahoe Basin, Sierra Nevada. To be submitted to Journal of Wildlife Management or Forest Ecology and Management.

J.J Keane, J.R. Dunk, and T. Gaman. Nest-site characteristics of northern goshawks in the southern Sierra Nevada. To be submitted to Condor.

J.J. Keane, B.Woodbridge, and S.A. Parks. Conservations status and distribution of the northern goshawk in California. To be submitted to the Journal of Biogeography or Biological Conservation.

J.J Keane and J.R. Dunk. Predictive habitat modeling of California spotted owl and northern goshawk habitat in the Sierra Nevada. To be submitted to Ecological Applications.

B. Woodbridge, J.J. Keane, J.R. Dunk, and J. Hawley. Habitat conservation assessment for northern goshawks in California. To be published as a GTR.

J.J. Keane. Effectiveness of artificial great horned owls for capturing northern goshawks. To be submitted to the Journal of Raptor Research or Journal of Field Ornithology.

J.J. Keane and B. Woodbridge. Effectiveness of broadcast surveys for detecting northern goshawks. To be submitted to the Wildlife Society Bulletin.

J.J. Keane, E.B. Jepsen, L.A. Tierney and C.V. Gallagher. Effectiveness of survey techniques for detecting great gray owls. To be submitted to the Journal of Wildlife Management.

Summary

This work represents some significant scientific study that has occurred over the last six years. Our original expectation was to continue for up to another three years within the HFQLG Pilot Project area to capture adequate post-treatment data. However, when we began this study the pilot project was scheduled to end in 2005 and since then it has been extended twice, now to 2012 to enable the complete pilot project to be implemented. If funding support persists we will continue to pursue filed work for perhaps two to three more field seasons. Upon completion of the field work the remainder of the effort will be devoted to data analysis and reporting.

At the conclusion of the pilot project the HFQLG Act requires the Forest Service to commission a team of scientists to evaluate the pilot project and provide the Forest

Service with guidance on the efficacy of the work and what were the environmental consequences on the natural resources of the geographic region. The results of these studies will contribute valuable, objective scientific insights that managers can use to develop subsequent management direction for the Plumas and Lassen National Forests, as well as other National Forest lands in the northern Sierra Nevada such as the portions of the Tahoe National Forest that contain similar ecological conditions. A team, lead by the Gifford Pinchot Institute, has been assembled for this purpose and they have begun their work as of the fall of 2007. Our research team will assist and cooperate with the Pinchot Team in every way we can.

We cannot ignore or deny the fact that designing a credible and useful research program in this area has been challenging. We want to be clear to all interested parties that the Pacific Southwest Research Station was asked to become involved in this project and for the purposes stated in the introduction above and we responded with the intent to provide as much new scientific learning as would be possible. PSW knew that we would be entering into efforts that would have many more challenges than research projects typically encounter. Our goal was to contribute as much as we could to the better understanding of forest ecosystem response to fuels and other forest management practices as they are manifested at a landscape scale.

We understand there is some uncertainty and sometimes controversy over how various forest elements will respond to planned forest management practices. This is likely to be the case under any chosen management regime. The objective of PSW was to tackle the difficult scientific challenges derived from the salient management questions. PSW, as a research organization, remains wholly objective in executing this charge. We have assembled an excellent team of scientists with the appropriate areas of expertise and we have done the best we can to design our work to address the important questions. Many of these questions present significant challenges to experimental design of field ecology experiments and management constraints further constrain our ability to test questions with traditional hypothesis testing approaches. We expect to make the most of these opportunities in advancing our scientific understanding of forest ecosystem response to management practices.

Chapter 1:
Fuels and Fire at the Landscape Scale

March 14, 2008

Research Team

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Project staff in 2006

- Nicholas Delaney, field assistant and full time project staff beginning autumn 2006 and ending May 2007

Project Goals 2007-8

We are investigating how landscape-level fuels and silvicultural treatments affect potential fire behavior and fire effects under different weather scenarios across the forested landscape of the Plumas National Forest project area. This analysis is critical for assessing the potential of severe or extensive fire occurring on the landscape. Initial results from this process are presented at length in the section of this paper entitled, “Results: Completed in 2007”.

In addition to our primary goal, both fuels treatments and fire alter forest structure, pattern and composition and thereby modify wildlife habitat that depends on the vegetation. Our assessments of potential change to landscape-scale vegetation will be instrumental when coupled with assessments of wildlife habitat conducted by the owl research module funding is available. We hope to completed this phase of the work in 2008.

Research Objectives and Overview

Past management activities including fire suppression, timber harvesting, and livestock grazing have changed the structure and composition of many coniferous forests in the western United States, particularly those that once experienced frequent, low-moderate intensity fires (Biswell 1961; Hartesveldt and Harvey 1967; Parsons and Debenedetti 1979; Beesley 1995; Erman 1996; Menning 2003). These changes in vegetation have altered habitat for a variety of species. Correspondingly, changes in vegetation and fuel loading have changed the probability of fire spreading across the landscape.

The USDA Forest Service aims to actively manage vegetation with the goal of reducing the probability of large, intense, or severe fires while minimizing negative effects on wildlife habitat and ecosystem stability. Proposed treatments include group selections and defensible fuel profile zones (DFPZs). Group selection treatments involve the harvest of all trees smaller than 30” diameter at breast height (DBH) over a one to two acre area (Stine et al. 2002). DFPZs are areas with extensive forest thinning intended to reduce surface and canopy fuel loads. They are also known as shaded fuel breaks and are designed to allow access for active fire suppression. DFPZs are spatially-extensive, covering hundreds to thousands of hectares (Stine et al. 2002).

Currently, there is limited information on the effects of landscape fuels treatments on reducing severe fire behavior and effects, especially at the landscape scale (Erman 1996; Agee et al. 2000; Fites-Kaufman et al. 2001). Elsewhere in the Sierra Nevada, group selections have been shown to have little effect on the landscape-level behavior of fire (Stephens and Finney 2002); the proposed group selections in the Plumas, however, retain more large trees per acre than typical group selections. To date, the modeled effects of group selections with large tree retention have not been published for this forest type.

Assessing the effects of these vegetation management strategies—group selections and DFPZs—across the forested ecosystems of the Plumas and Lassen National Forests is the goal of the Plumas-Lassen Administrative Study (Stine et al. 2002). The study is composed of five research teams with distinct focuses: California spotted owls, small mammals, songbirds, fuels and fire, and vegetation. Due to practical considerations of a study as spatially extensive as this, we have to mix research with monitoring. The overall study does not comprise a formal scientific experiment in that the scientists involved have little control over actual treatments. The study amounts to far more than monitoring, however, in that we are independently assessing a large landscape and modeling changes to that landscape given a set of prescriptive treatments.

For the Fuels and Fire Module, which is the focus of this study plan, we aim to address the landscape-scale effects of the proposed forest treatments by answering a suite of questions: First, what are current conditions, in terms of fuel loads and vegetation, measured directly in the field? Second, what is the current potential fire behavior and effects given these measured fuel and vegetation conditions? Third, how would landscape fuels treatments affect vegetation condition and fire behavior and effects?

Fourth, in addition to these efforts to characterize fuels and fire relationships, it is essential to link results of our research with findings from the other research modules (figure 1). It is clear that any landscape-level fuels or forest management strategy will affect many interrelated components of forest ecosystems (Erman 1996; Bahro 2004). Therefore, it is important to understand the synergistic effects between potential treatments and various areas of concern—forest conditions, risks of severe or extensive fire, and habitat alteration. Our goal in answering this fourth question is to produce an analytical model in which we integrate maps of current conditions with models that project responses of fire behavior and effects given prescriptions of treatment and weather scenarios. The vegetation component of the current conditions maps would act simultaneously as input to the Spotted Owl Module’s habit suitability models. By coupling these data layers and models between research modules we will model the likely effect of a landscape fuels strategy on both *fire* and *owl habitat* given various prescriptions and weather scenarios.

Taken together, these four research goals form the top level of a hierarchical set of research goals that may be best expressed in a table. Hence, we have shown these research objectives and their supporting details and questions in Table 1. Details supporting the modeling efforts follow the table.

Fig 1: Ecosystem Relationships Examined in PLAS
(Topics addressed in this module emphasized in bold)

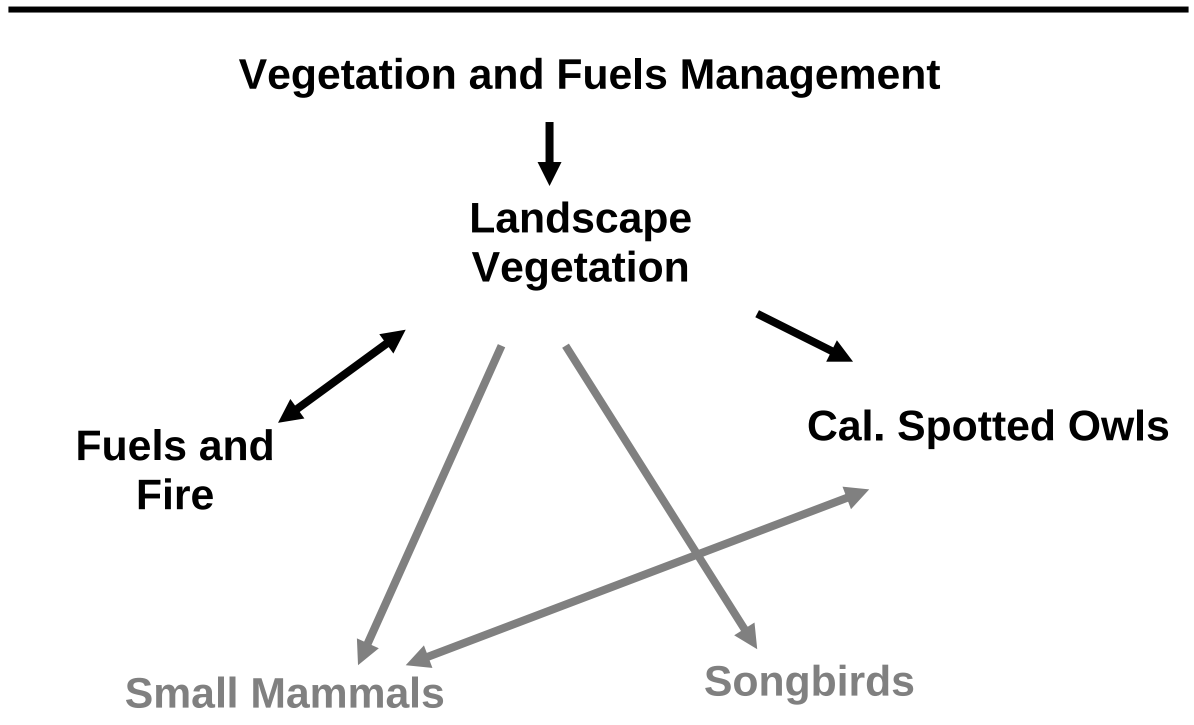


Table 1: Fuels and Fire Module: Summary of hierarchical arrangement of study topics

1.0 Current conditions: measurement of vegetation and fuels at the landscape scale
    1.1 Current vegetation: What are current vegetation conditions prior to treatment?
        1.1.1 Forest sampling in the field (forest plots)
        1.1.2 Remote sensing of forest conditions
            1.1.2.1 Forest and vegetation classification (IKONOS imagery)
            1.1.2.2 Forest structural diversity analysis (IKONOS imagery)
    1.2 Current fuels: What are current fuel loads prior to treatment?
        1.2.1 Fuels sampling in the field (forest plots)
        1.2.2 Ladder fuels: probability of fire ascending forest canopy (LaFHA)
        1.2.3 Integration of data sources into a fuel model/map for the study area

2.0 Fire modeling: how might current conditions (above) affect fire *behavior* and *effects*?
    2.1 Fire *behavior*: What is the range of potential fire behavior given current conditions & a range of weather scenarios? (FARSITE & FlamMap models)
    2.2 What are likely *effects* of fire behavior on these landscapes as determined by simulation models? (Stephens approach using FARSITE & FlamMap outputs)
    2.3 Temporal dynamics of forest stands, including tree growth (FVS)

3.0 Effects of treatments: how might landscape-scale treatments change fire behavior and effects (using FlamMap)?
    3.1 Group Selections (GS) and Defensible Fuel Profile Zones (DFPZs)
        3.1.1 Measure: how does the installation of GSs & DFPZs affect fuel loads?
        3.1.2 Model: how does the placement of GSs & DFPZs affect potential fire behavior? Do they reduce the probability of catastrophic fire under extreme weather conditions?
        3.1.3 Modeling: how does the installation of GSs & DFPZs affect fire effects such as mortality to different species and size classes of trees? Would the reduction in fire extent and intensity reduce the severity of canopy fires?
    3.2 Spatial allocation and efficiency: DFPZs and Strategically Placed Landscape Area Treatments (SPLATs)
        3.2.1 How does the installation of alternative treatments affect fuel loading?
        3.2.2 How does the placement of alternative treatments affect potential fire behavior?
        3.2.3 How do different levels of management intensity (extent of treatment) affect the treatment's ability to reduce the size or intensity of fires?
        3.2.4 What effect would alternative treatments have on resulting fire *effects*?

4.0 Fire and habitat model integration
    4.1 Correlate spectral entropy canopy diversity with habitat variables
    4.2 Model interaction between vegetation management and both fuels and fire, and owl habitat given current conditions, prescriptions and weather scenarios

Study Area

Our study area is a subset of the Plumas National Forest in Northern California, USA. The Plumas and Lassen National Forests cover hundreds of thousands of acres, and sampling an area this size with a limited field crew and small remote sensing budget is beyond our capacity. As a result, we have chosen to focus on the study area's treatment units (TU) 2, 3 and 4 (Stine et al. 2002), which present widely varying topographical conditions and contain a variety of owl habitat quality. The total area of these three TUs is about 60,000 ha (150,000 ac) (Keane 2004). Vegetation varies widely through this region, presenting a good opportunity to examine fire behavior and end effects across a spectrum of conditions. The town of Quincy lies directly eastward of TU 4 and would be immediately affected by fire in this area and the resulting smoke. In addition, TU 2 has been evaluated to have high quality spotted owl habitat while areas 3 and 4 have lower qualities (Keane 2004). As a result, these three treatment units present a good range of conditions in which to conduct this research and test our model integration.

Vegetative cover in this area is primarily mixed conifer forest. The mixed conifer forest community comprises a mix of three to six conifers and several hardwoods (Barbour and Major 1995; Holland and Keil 1995; Sawyer and Keeler-Wolf 1995). Common conifers include ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*P. jeffreyi*), sugar pine (*P. lambertiana*), incense-cedar (*Calocedrus decurrens*), Douglas fir (*Pseudotsuga menziesii)* and white fir (*Abies concolor*). Red fir (*Abies magnifica*) is common at higher elevations where it mixes with white fir (Holland and Keil 1995; Sawyer and Keeler-Wolf 1995). At mid to lower elevations, common hardwoods include California black oak (*Quercus kelloggii*) and canyon live oak (*Q. chrysolepis*) (Rundel et al. 1995).

In addition, a number of species are found occasionally in or on the edge of the mixed conifer forest: western white pine (*P. monticola*) at higher elevations, lodgepole pine (*P. contorta*) in cold air pockets and riparian zones, western juniper (*Juniperus occidentalis*) on dry sites, California hazelnut (*Corylus cornuta*), dogwood (*Cornus spp.*) and willow (*Salix spp.*) in moister sites, California bay (*Umbellularia californica*) and California nutmeg (*Torreya californica*) in lower, drier areas (Griffen and Critchfield 1976; Holland and Keil 1995; Rundel et al. 1995).

A variety of vegetation types currently comprise the matrix of covers in which the mixed conifer forest is arrayed. Vegetation in the matrix ranges from chaparral on exposed, poorly watered south and west facing slopes to oak woodlands and riparian meadows. At higher elevations, particularly toward the Bucks Lake Wilderness, some red fir may be found in pure stands (personal experience).

Methods

This study is conducted under a passive adaptive management framework administered by the USDA Forest Service; we have no control over the implementation of the landscape fuels treatments. The HFQLG Act outlines the landscape fuels treatment strategies, and defines the types of timber harvest to be implemented. Decisions on the timing and placement of fuels treatments will be determined at a local level by the Plumas National Forest.

We do have control over the data collection and modeling aspects of the project. Our research topics (table 1) can be divided into several methodological groupings. Here, we present summaries of methodologies for field data collection, remote sensing, and model integration. Data are collected from a series of field plots (discontinuous data) as well as from satellites (continuous forest canopy data). Additional data products are derived through modeling.

Methods: Field data collection

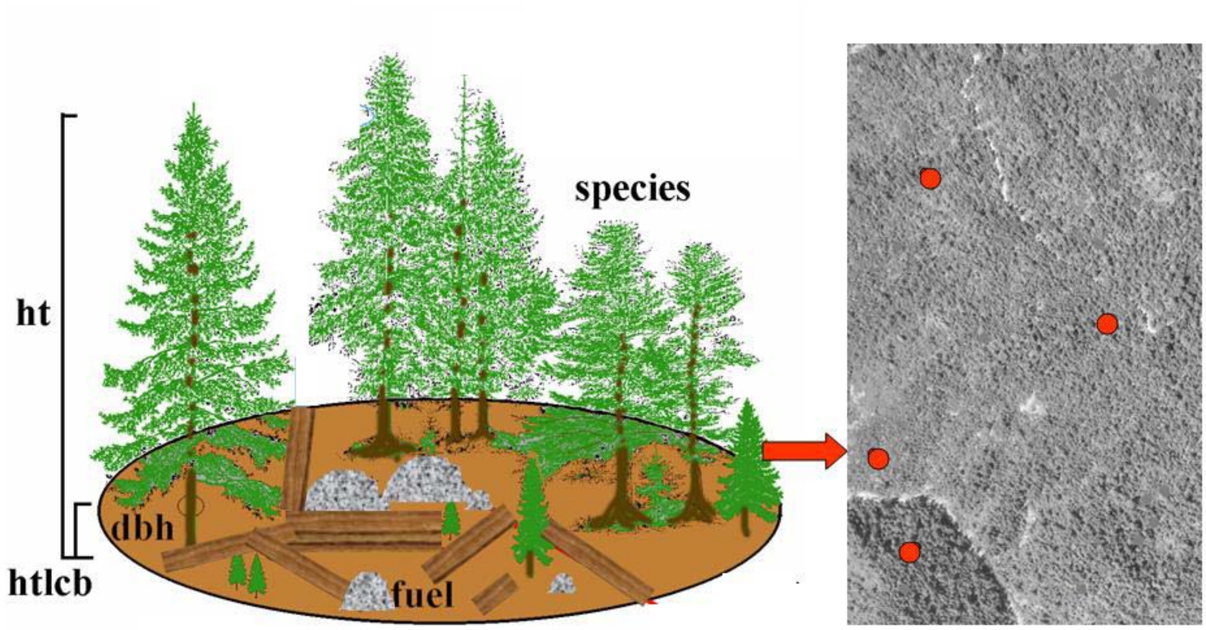
Plot Layout and Design

Data on forest cover and fuels is being collected in 0.05ha (0.125 ac) plots 12.6m (41.3 ft) in radius (figure 2). Plot locations are established using a stratified-random approach. Strata of elevation, aspect and vegetation type were defined using the layers previously supplied by the contractor VESTRA (Stine et al. 2002). This process resulted in data being collected from over 600 plot locations in treatment units 2, 3 and 4. In addition to the randomly-stratified plot locations described above, similar data have been collected at locations identified by the other modules: plots are located at each owl nesting site and mammal study grid in the three treatment units.

Forest Structure and Composition; Site Data

We collect data on tree species, diameter at breast height (DBH), categorical estimate of

Figure 2: Data sources: field plots and satellite imagery
(plots shown scattered on landscape on satellite image to right)



height, and height to lower crown (see Appendix A for sample data sheet). Site data collected include location (using high-precision GPS), slope, and aspect. Canopy cover is assessed at 24 points (every 1 meter) along two linear fuels transects (described below).

Ground based sampling of ladder, surface, and ground fuels

Surface and ground fuels are sampled in each plot using the line intercept method (Brown 1974; Brown et al. 1982). Ground and surface fuels are sampled along two transects radiating from plot center. The first transect is located along a random azimuth and the second falls 90 degrees clockwise from it. We sample 1 and 10 hour fuels from 10-12 meters along each transect, 100 hour fuels from 9-12 meters, and 1000 hour fuels data from 1-12 meters. Duff and litter depth (cm) are measured at 5 and 8 meters along each transect. Maximum litter height is additionally sampled at three locations from 7 to 8m (Brown 1974; Brown et al. 1982). Total fuel loads for the sites are occularly estimated using fuel photo series developed for the Northern Sierra Nevada and Southern Cascades (Blonski and Schramel 1993).

Ladder Fuel Hazard Assessment (LaFHA)

We have devised and implemented a mixed quantitative-expert system for assessing ladder fuels (submitted paper). The Ladder Fuel Hazard Assessment (LaFHA) requires a trained field crew member to rapidly assess the presence and continuity of fuel ladders in each of four quadrants in a plot using a flowchart. The first step is to determine the presence of low aerial fuels: the fuels that would create sufficient flame lengths to reach several meters from the forest floor. Sparse vegetation, or vegetation widely distributed, probably has too little fuel per volume of air to create and sustain large flames. Therefore, we define a clump of low aerial fuels to be brush or small trees covering an area of at least 4 square meters (2m x 2m) with gaps of less than 50cm. If it is particularly dense, or tall and brushy, a clump may cover a small area. A particularly dense clump may cover as little as $2m^2$ on the forest floor, for example. Branchy dead fuel or stems may be included in the assessment. The size and density of these clumps of fuel and vegetation are based upon personal experience (S. Stephens, K. Menning). If there is no clumping of low aerial fuels, the site would fall in the two lowest ladder fuel hazard categories (C, D); conversely, if there is a clumping of low aerial fuels, the site would fall in one of the two higher-risk categories (A, B). It is important to note that isolated clumps of low aerial fuels, well removed from any ladders, are discounted. Letters (A, B, C, and D) are assigned to hazard ratings instead of numbers to prevent confusion: categories are not of interval or ratio quality (e.g., “Is category 4 twice as risky as category 2?” No, we would not know the quantitative relationship without a direct test).

The second step is to make a determination about the vertical continuity of the fuel ladder from the ground to the canopy. Gaps of more than 2m might be enough to prevent the spread of flames vertically (S. Stephens). Vegetation with gaps of less than 2m from the ground to the upper canopy may present a good ladder to conduct flames. Sparse vegetation lowers the probability and reduces the quality of the ladder. The technician is expected to look at the vegetation and determine whether there are gaps of 2m or more. If the maximum gap is less than 2m, then the site would be categorized as the higher hazard of the two options.

After placing the site in one of the four categories (A, B, C, or D), the technician records the minimum height to live crown (HTLCB) and the size of the maximum gap in the best ladder. These two values may later be used to help verify the classification is correct. The process is repeated for each of the four quadrants of the plot.

The effect of slope is not considered during the hazard evaluation in the field, slope data are used later, to modify the hazard rating. Because the effect of slope on flame length is non-linear (Rothermel 1972), the slope must have a non-linear multiplicative effect on the hazard rating. Final analysis of the plot is performed in the laboratory by combining the ratings of the four quadrants and applying a non-linear slope factor. A plot with one quadrant of high ladder fuel hazard and three low hazard ratings is certainly not as great a risk as a plot with continuous, high-risk ladders in each quadrant. While this semi-quantitative, semi-qualitative process is experimental, and the exact numerical relationships between slope and hazard are yet to be determined, we feel the method has merit; importantly, the field crews report consistent ratings after training and repetition (K. Menning).

Methods: Remote sensing

Initial results of IKONOS imagery indicate that we will be able to use this imagery for classification of landscape vegetation. As a result, we have dropped the LANDSAT imagery analysis. Instead, all our effort in remote sensing goes into analyzing the IKONOS imagery. This high spatial resolution imagery is being used to provide information on continuous forest pattern, structure, cover and variability using methods developed by Menning (2003) including spectral entropy canopy diversity analysis (SpECDA—see appendix E of Fuel and Fire Study Plan). These data and analyses have the benefit of being linked to analyses of vegetation and wildlife habitat conducted by other researchers in the project (see model integration, below). In 2003, high-resolution (1-4m) IKONOS imagery of several treatments was collected covering treatment units 3 and 4. In 2004, IKONOS imagery covering TU 2 and 3—overlapping the data collected in 2003—was collected to provide additional coverage of the area with high owl population. Remote sensing data were processed, orthorectified and mosaicked in 2006 and 2007.

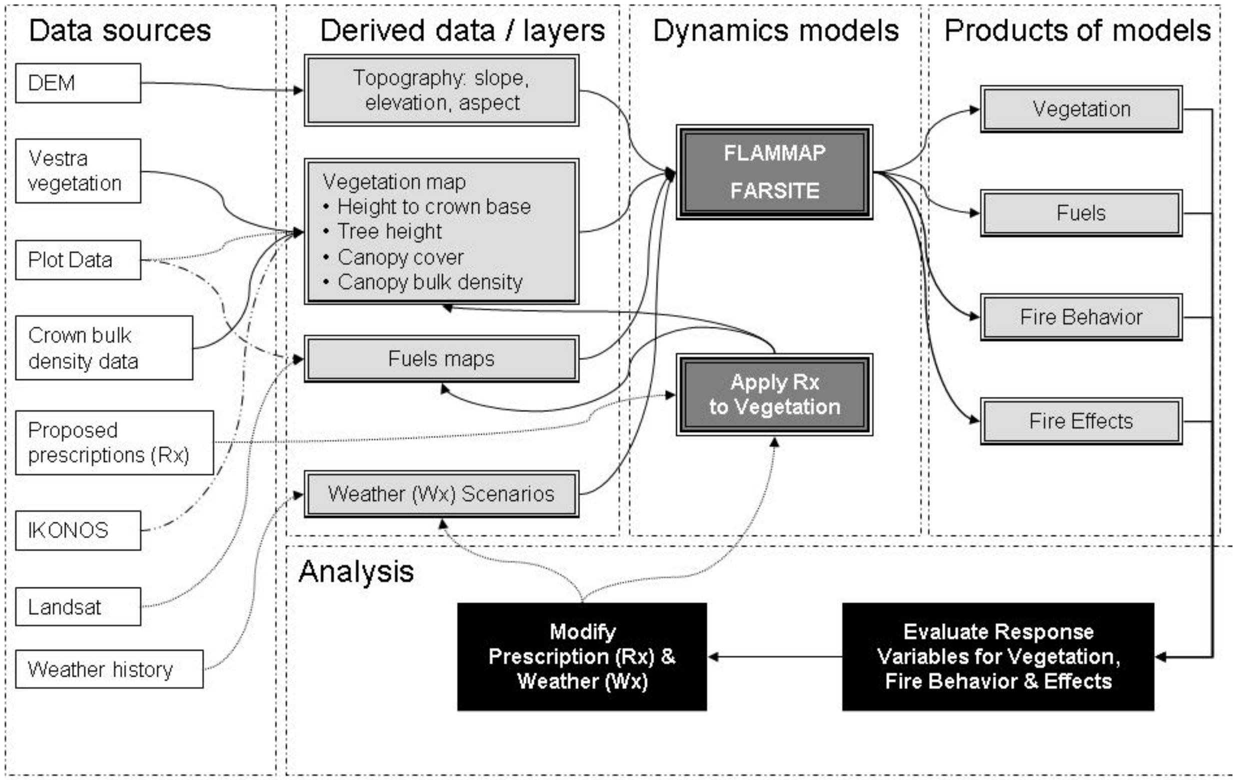
Methods: Data Processing, Analysis and Model Integration

Fire behavior models require maps of vegetation, topography, and fuels, as well as weather scenarios, in order to model the spatial behavior of fire (figure 3). These data are integrated from a variety of different sources. Development of the vegetation map has been described above, in the remote sensing methodology. Topographic variables—slope, elevation and aspect—are mapped across the study area using pre-existing Digital Elevation Models (DEM) on a 30x30m grid. Assembling fuels maps requires that fuels be measured at select sites (a discontinuous set) and then extrapolated across the landscape where fire may burn (continuous coverage). Fire modeling will be conducted in two major phases: first, we will evaluate fire behavior and potential at one time, either the current condition or post-treatment, using Farsite and Flammap; second, we will use Forest Vegetation Simulator (FVS) to create a dynamic simulation of change through time at the stand level.

Calculation of Fuel Loads and Development of Fuel Models

Many fuel inventories done in the Sierra Nevada have assumed that the fuel particles being inventoried had similar properties to those found in the northern Rocky Mountains (Brown 1974) but Van Wagtendonk's work in quantifying Sierra Nevada surface and ground fuel properties allows custom fuel load equations to be developed for a site-specific project such as this. This methodology previously has been used to produce accurate estimates of fuel loads (Stephens 2001). Additional validation of these fuel load coefficients are provided by Menning's research in Sequoia National Park (Menning 2003). As tree species in the northern Sierra Nevada are the same as those sampled by Menning and van Wagtendonk, the data should be relevant to this study site.

Figure 3: PLAS Landscape Vegetation, Fuels and Fire



Menning 2005-03-07

Field measurements provide data on species mixes and fuel particle size distribution. Using these data, ground and surface fuel loads are calculated by using equations developed for Sierra Nevada forests (van Wagtendonk et al. 1996; van Wagtendonk and Sydoriak 1998; Menning 2003) as well as the production of fine fuels as determined by field measurements. Coefficients required to calculate all surface and ground fuel loads are arithmetically weighted by the basal area fraction (percent of total basal area by species) that are collected in the plots.

Plot based fuel measurements are being used to create a set of customized and spatially-extensive fuel models for the study area (Burgan and Rothermel 1984) for this area. Fuel model development includes a stochastic element to more closely model actual field conditions that have a large amount of spatial heterogeneity. Stochastic fuel models are being produced for each stratum identified using van Wagtendonk and Root's methods (forest type, aspect, seral stage, etc.). Plot data provide crown cover, height to live crown base, and average tree height at each site. Canopy bulk density estimates are based on previous work by Stephens (Stephens 1998). All of these spatially-discontinuous data derived from plot-specific measurements are extrapolated across the landscape using the remote sensing imagery maps of vegetation.

Simulations: Potential fire behavior

Potential fire behavior is being estimated using a similar technique developed by Stephens (1998) but at much broader spatial scales. The effectiveness of the different restoration treatments will be assessed with computer models such as FARSITE (Finney 1996; Finney 1998; Finney 2000) and FlamMap (Finney 2003). FARSITE is a deterministic, spatial, and temporal fire behavior model that requires as inputs fuel measurements and models; topographic data, including slope, aspect, and elevation; forest structural data including canopy cover, tree height, height-to-live crown base, and canopy bulk density; and weather. A historic fire occurrence map is being produced to estimate the probability of ignitions in the study area. Data come from the Plumas National Forest archives and current GIS layers. This derived map will be used to generate an actual ignition point in each FARSITE simulation. FlamMap is similar to FARSITE but does not use a user-determined ignition but burns the entire landscape using one set of weather data. These models will be used to quantify the potential fire behavior of the different treatment approaches.

The duration of each simulation would be seven days, a period that approximates the duration of many landscape-scale wildfires in the Sierra Nevada before they are contained (Stephens, personal experience). Weather scenarios using data from the 70th (moderate), 90th (severe) and 97th (extreme) percentile conditions is being used and this data is being collected from local weather stations. Fire simulations would be constrained by suppression activities. Constrained simulations will use realistic suppression elements (15 person hand crews, aircraft, bulldozers, etc.; Stephens, personal experience).

Outputs from the fire simulation include GIS files of fire line intensity (kW/m), heat per unit area (kW/square meter), rate of spread (m/s)**,** area burned (ha), emissions (tons) and if spotting and crowning occurred. Scorch height (m) would be calculated from fireline intensity, air temperature, and wind speed. This information will be used to compare the effects of the different landscape level restoration treatments on altering fire behavior.

Simulation: Fire effects

After the fire has passed, the effects of the fire linger: trees die, exposed soils erode, and insects invade. Some fire effects such as tree mortality are being modeled using the GIS outputs from the FARSITE and FlamMap simulations coupled to previously-tested quantitative models that estimate tree mortality (Stephens and Finney 2001). In addition to the tree-mortality measure of fire severity, the amount of bare mineral soil exposed by the simulated fires is being estimated for each 30m by 30m pixel.

Simulation: landscape dynamics over time

The second major phase of fire modeling takes advantage of the temporal dynamics of the Forest Vegetation Simulator (FVS) model. We will place the DFPZs on our virtual landscape at the probable time of their occurrence and use the model to grow trees in all other areas at the same time. The resulting landscape can then be evaluated for fuel loading and fire potential.

Results: Completed in 2007

We completed two papers in the last year. Our analysis of Ladder Fuel Hazards was published in the Western Journal of Applied Forestry: Menning, K. M. and S. L. Stephens (2007). "Ladder Fuel Hazard Assessment: A Semi-Qualitative, Semi-Quantitative Approach." Western Journal of Applied Forestry 22(Number 2 April): 88-93.

In addition, we have completed a draft of a paper integrating our work on remote sensing, image processing, GIS, and fire modeling. It is being submitted to the journal Landscape Ecology. Key findings from that paper are presented in the following section.

These results were achieved despite a severe loss of funding that resulted in the termination of our full time assistant and postdoctoral researcher. Any future efforts depend upon renewed funding.

2008 Report: Potential forest fire behavior as a function of three weather scenarios and two landscape fuels treatments based on a fuels and vegetation landscape derived from fine-grain IKONOS satellite imagery, Sierra Nevada (USA)

Submitted to Landscape Ecology; ***Authors:*** Kurt M. Menning and Scott L. Stephens

Abstract

Landscape-scale forest fuels treatments are intended to prevent fires from sweeping across broad swaths of the landscape in moderate and severe weather conditions. Treatments such as defensible fuel profile zones (DFPZs) both resist the spread of fire and provide safe access for fire fighters. While DFPZs are intended for moderate and severe conditions, the effects they would have during extreme fire weather remains largely unknown. At the same time, many uncharacteristically extensive fires occur during extreme fire weather conditions. In order to determine what benefits DFPZs would offer in extreme conditions we conducted sets of fire simulations to compare fire behavior in three weather scenarios—moderate, severe and extreme—and two fuels treatment conditions: the current, untreated condition, and post-DFPZ fuels treatment. Using IKONOS imagery, we created a fine-grain vegetation and fuels layer and created another post-treatment layer with DFPZs on the landscape. We chose ten stochastically-determined ignitions and simulated fire in FARSITE for 3 days without suppression. Some ignitions led to fires that were affected by DFPZs while others were not. Fires not encountering DFPZs were statistically similar to those on the untreated landscape. Fires encountering DFPZs, however, experienced reductions in all measures of fire behavior—extent, perimeter, number of individual fires, and spot fires—of at least 50% under moderate and severe conditions. Contrary to expectations, the greatest benefit occurred with fires burning under extreme conditions. Simulations under extreme weather showed reductions in all fire measures exceeding 70%.

While it is thought that DFPZs would likely fail in extreme conditions, we found that they offered the greatest benefit in these conditions.

Introduction

A century or more of extensive logging and fire suppression had enormous impacts on the forests of the Sierra Nevada (Kilgore and Taylor 1979; Parsons and Debenedetti 1979; McKelvey et al. 1996; Beaty and Taylor 2001; Keeley and Fotheringham 2001; DellaSala et al. 2004). In recent decades, increasing fuel loads and risks of uncharacteristically severe and extensive fire, coupled with concern about forest management impacts on wildlife and timber yield, have led to concerns about the most effective means to manage forests given changing conditions and goals (Stephens and Ruth 2005; Menning 2007). In 1993, a citizens group was founded in 1993 in the town of Quincy, California, by an unusual coalition of individuals concerned with timber yield and economics, fire risk and wildlife habitat (Ingalsbee 2005). Dissatisfied with Forest Service land management, the Quincy Library Group eventually proposed a series of landscape fuels breaks, or defensible fuel profile zones (DFPZs). Congress and the Forest Service decided to implement a set of these DFPZs on the landscape (Stine et al. 2002; Ingalsbee 2005).

Defensible Fuel Profile Zones are designed to provide three primary functions: provide safe access for fire fighters, limit fire behavior to prescribed levels (e.g., limit flame lengths at the 90th percentile weather condition to 48”), and create conditions in which canopy fires are less likely to spread: minimal ladder fuels (Menning and Stephens 2007) and a well-spaced canopy. These DFPZs are designed to withstand fire in severe conditions—the 90th weather percentile. The utility of DFPZs in more extreme conditions is not known, however, it is often thought that they will fail and yield little benefit to stopping uncharacteristic landscape-scale fires (Hardy 2005).

As part of the research team tasked with evaluating the system (Stine et al. 2002), we evaluated whether DFPZs would significantly modify fire behavior at the landscape scale. In discussions with some forest service employees and QLG members we were encouraged to study fire weather scenarios well-beyond severe fire weather. Many large, severe wildfires occur at the 97th to 98th weather percentile, for example. At the same time, a number of people discouraged us from simulating more extreme weather scenarios on the grounds that as the DFPZs were likely to fail in more extreme conditions we should not evaluate their effectiveness under conditions in which they were certain to fail. As analysts, we determined that we must test the landscape fuels treatments in the extreme conditions under which uncharacteristically-severe fires would occur; these are the fires that most people worry about.

To test the effectiveness of DFPZs at moderating large fires, we conducted sets of simulations of landscape-scale fire behavior under three weather scenarios—moderate, severe, and extreme—and two treatment conditions: pre-treatment, or current-conditions, and post-DFPZ treatment (Table 1). The matrix of results allowed us to directly compare the effectiveness of treatments by examining fires from the same ignitions burning under the same weather conditions. At the same time, we were able to compare how the same ignitions would lead to different fire behavior given different weather scenarios.

Table 1: matrix of simulations: three weather scenarios and two treatment options.		**Weather Scenario**		
		Moderate	**Severe**	**Extreme**
Treatment	**Pre-treatment (current condition)**	**?**	**?**	**?**
	Post-DFPZ treatment	**?**	**?**	**?**

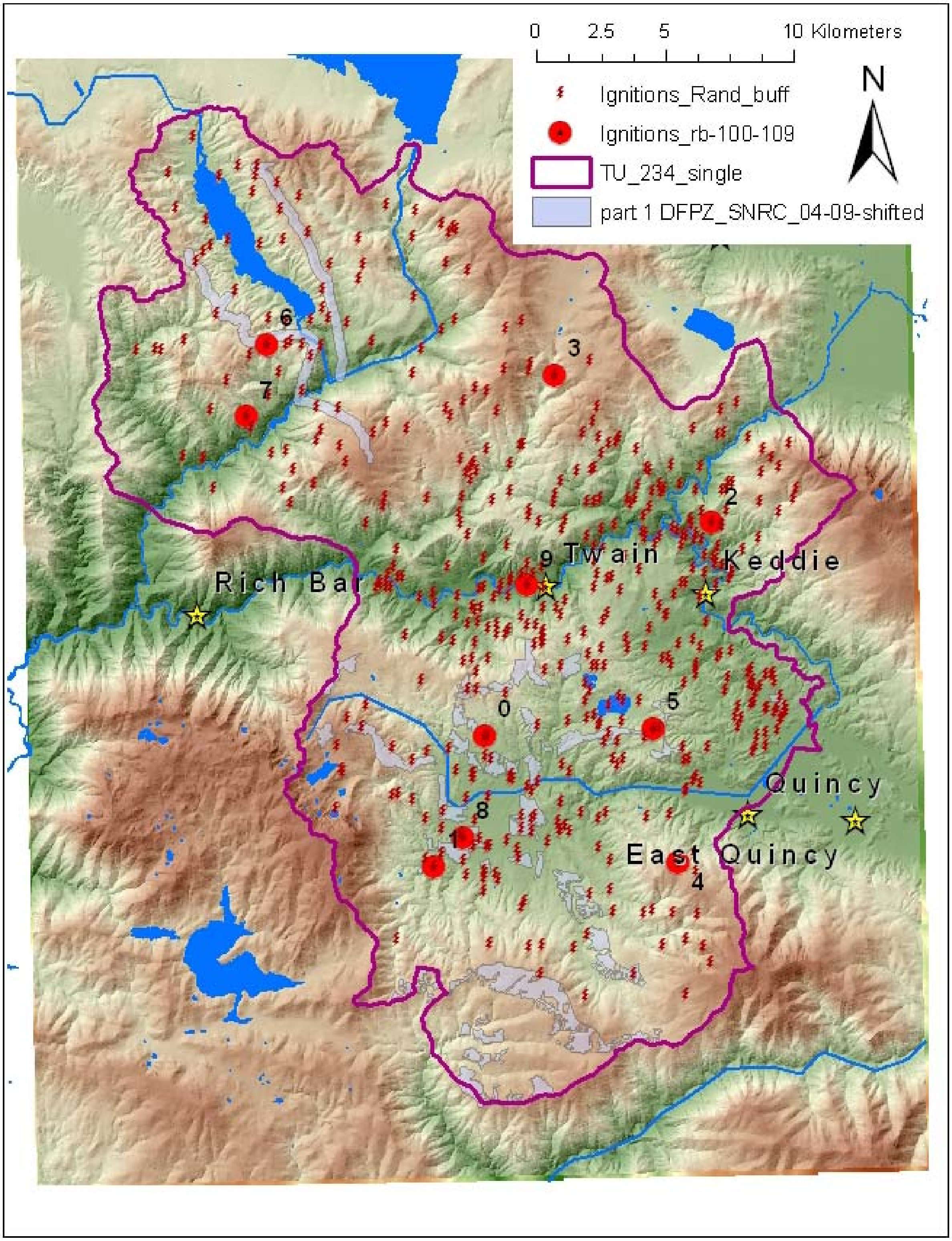
In order to make fire simulations as realistic as possible, we acquired high-resolution remote imagery (IKONOS) of the region to generate a fine-grain (4 m by 4 m pixel) map of fuels and vegetation. The fine-grain imagery creates a more realistic fine-scale intermixing of fuels types and characteristics than can be gained from simply mapping stand boundaries and assigning characteristics. Forests in this area, for example, are often mixed with chaparral and grass across the span of tens of meters. Further, we anticipated that fine-scale mapping of vegetation and fuels would lead to more accurate depictions of fire spread and reduce the need to superimpose impenetrable fire breaks—such fire breaks often fail to contain in extreme conditions.

Methods

Field site and conditions

The Plumas National Forest is located in the northern Sierra Nevada, California (USA). The climate is Mediterranean with a predominance of winter precipitation totaling about 1600 mm per year. The forest in the study area ranges from approximately 1000-1500 m elevation and spans over 60,000 ha (150,000 acres) (Figure 1).

Figure 1: overall map showing location (latitude, longitude), candidate and modeled ignitions, towns, and DFPZs.



Vegetation on this landscape is primarily Sierra Nevadan mixed conifer forest (Schoenherr 1992; Barbour and Major 1995), a mix of conifers and several hardwoods: white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*Pinus lambertiana*), ponderosa pine (*P. ponderosa*), Jeffrey pine (*P. jeffreyi*), incense-cedar (*Calocedrus decurrens*), and California black oak (*Quercus kelloggii*). Montane chaparral and some grasslands are interspersed with the forest (Schoenherr 1992; Barbour and Major 1995). Tree density varies by fire and timber management activity, elevation, slope, aspect, and edaphic conditions. The typical fire regime is frequent, low-severity fire with patches of high-severity canopy fire with fire return intervals of 10-30 years (Caprio and Swetnam 1995; McKelvey et al. 1996; Sierra Nevada Ecosystem Project 1996; Skinner and Chang 1996; Stephens and Collins 2004).

Creation of model layers

Ignitions

A database of historic fire ignitions for the last thirty years was acquired from the Forest Service (Charbonnier 2006). Each historic ignition that occurred within a one square mile section was marked as being located at the center of that section. Based on this mapping method, if four fires occurred in a section, then all four would be mapped with the same ignition point at the center of the section.

To create an ignition probability map for fire modeling, we created a one-to-one probability coverage by generating one random potential ignition within 0.5 mile (0 .8 km) of each historic ignition using ESRI's ArcMap 9.2. As a result, spatial density of potential ignitions matches the spatial density of historic ignitions. To limit the possibility that simulated fires would start near the boundary of the area and burn outside where we had no data on forest and fuel conditions, and where we could not measure spatial extent, we internally buffered the study area in ArcMap to ensure each candidate ignition was located at least 1 km from the edge of the study area. We randomly chose ten potential ignitions from thousands of candidates on the stochastic ignition map (Figure 1).

DFPZ Fuels Treatments

Acquiring a consistent map of proposed DFPZ projects posed a challenge. We acquired separate “current” DFPZ coverages from the Forest Service’s Sierra Nevada Research Center (SNRC) and Plumas National Forest. Comparing the two sets, we found that many DFPZ projects that had been spatially planned were modified. Others that had been detailed had their spatial designation removed and were assigned generally, leaving large tracts of land as potential locations for DFPZs. In one case, a potential DFPZ was changed from a specific location to cover an entire district of the Plumas National Forest. Further, some districts had completed detailed DFPZ planning while others lagged in the process. As a result, we created a DFPZ map as systematically as possible. First, we removed any DFPZ designations where the area was treated prior to our acquisition of remote imagery of the area. Thus, any pre-existing DFPZ that modified vegetation and would appear on the imagery was eliminated; we didn’t want to reapply a potential treatment to the landscape where it already had altered vegetation mapped using the imagery. Second, when specific areas that had been allocated on the ground were changed into general designations covering entire landscapes, we retained the earlier, more specific version for our modeling. Third, when DFPZ projects had been revised and made more detailed, we chose the latest mapped version. Fourth, according to some records some “thinning” projects were considered parts of DFPZs while others were not (HFQLG 2004 Program of Work Accomplishments; Plumas National Forest; HFQLG Proposed Program of Work FY 2005, Plumas National Forest; HFQLG Program of Work, FY05 to FY09, Plumas National Forest). In order to resolve ambiguity in definitions, we corresponded with agents of the Forest Service (Felker and Dillingham 2007) to resolve conflicts and create a realistic DFPZ map.

Remote sensing and image processing

High resolution IKONOS imagery covering part of the study area was acquired from Space Imaging in 2003 and another, overlapping section, in 2004. In both cases the prescribed acquisition was intended to be near the summer solstice at noon to ensure minimal topographic and tree shadowing. Imagery in 2003 was collected on June 30 at 12:08 pm local time in two scenes with a sun angle azimuth of 138.5 and elevation of 69.1 degrees. Due to poor weather as well as budget transfer constraints in 2004, image acquisition was delayed until September 3 at 12:08 pm. The three scenes in 2004 were acquired with a sun angle azimuth of 155.1 and elevation of 54.9 degrees. Overlap between the two years was approximately 50%.

Both acquisitions had identical prescriptions: 1 m panchromatic and 4 m multispectral imagery collected with an upgraded and narrowed field of view (72-90 degrees from azimuth). Delivered products were not radiometrically or geometrically corrected but were sent in a GeoOrtho kit. We completed radiometric corrections in our lab to minimize backscatter and distortion due to atmospheric moisture and haze. We used PCI Geomatica 9.1’s EASI modeler module to apply sun angle corrections. Dark target haze removal corrections were completed using lakes in the scenes as targets. These radiometrically-corrected images were spatially corrected—orthorectified—using Geomatica 9.1’s Orthoengine module. To support this effort, ground control points (GCPs) had been collected in the field using a Trimble GeoXT Global Positioning System (GPS) with hurricane antenna with sub meter accuracy using wide-angle area support (WAAS). After the orthorectification was completed we evaluated the results using twelve independent ground reference points. The analysis indicated the five scenes of the imagery were accurate within 2.0, 2.6, 2.8, 3.4 and 3.6 m with an overall average of 2.9 m. Each of these measures is within a single 4 m pixel of the multispectral imagery and so the resulting orthorectification was deemed precise and consistent enough to use. A mosaic of all five scenes was created using Erdas Imagine 9.0's mosaic function.

Creation of fuels layers

Fuel characteristics were mapped from the IKONOS mosaic using supervised classification. Five layers were created as inputs to the FARSITE fire area simulator (version 4.1.054): vegetation and fuel type, canopy cover, crown base height, crown height, and crown bulk density (Finney 1998). We mapped vegetation and fuel types applying fuel types described in Scott and Burgan (Scott and Burgan 2005). The national Landfire (Keane 2007) project uses these fuel types and we were able to apply a reduced set drawing on extensive personal field time in the area. We chose fuel type TL1 to represent defensible fuel profile zones (DFPZs)—shaded duel breaks—because the fuel and vegetation characteristics most closely match actual DFPZs. Forest Service technicians confirmed our set of fuel types was appropriate for the area.

Table 2: Fuel model table values were modified from those used in LANDFIRE

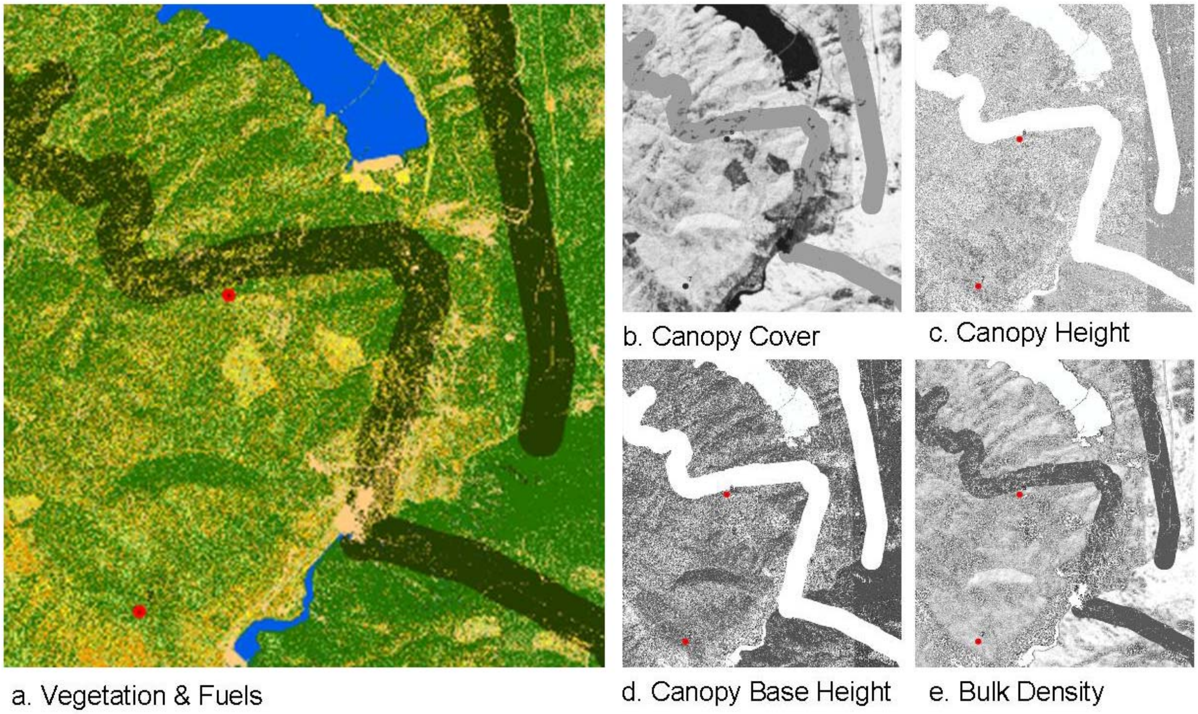
#	*Scott & Burgan Fuel Model*	*Description*	*Occurrence in study area*	*Initial Canopy Cover (%)*	*Canopy Bulk Density (kg/m^3)*	*Canopy Height (m)*	*Canopy Base Height (m)*
98	NB8	Water	• Major water bodies	0	0	0	0
99	NB9	Bare ground	• Bare ground, talus, roads, urban areas	0	0	0	0
102	GR2	Grass – Low load dry grass	• Extensive grasslands in American & Indian Valleys	0	0	0	0
122	GS2	Grass-shrub moderate loading, dry	• South facing slopes • Recovering timber harvest	0	0	0	0

			areas				
147	SH7	Shrub – chaparral	• Chaparral type, dense, south and west aspects	0	0	0	0
165	TU5	Timber-shrub	• South aspects only • Dominant classification by Landfire (>50% of landscape)	0.25	tracks canopy coverage from 0-0.25	20	1
181	TL1	Timber with compact, low volume fuel bed. Used for DFPZ designation.	• Red fir, and higher white fir areas • *Fresh timber operations, DFPZs, just after cuts*	0.9	tracks canopy cover 0-0.25	35	7
186	TL6	Hardwood with fuel understory	• Aspen stands • Oak stands in riparian areas	0.75	tracks canopy cover 0-0.25	15	5
184	TL4	Conifer with moderate litter/fuel load	• Extensive	0.9	tracks canopy cover 0-0.25	25	3
185	TL5	Conifer with higher litter load	• Northern aspects only	0.9	tracks canopy cover 0-0.25	30	3

Supervised classification of vegetation and fuel models was completed in Erdas Imagine 9.0. Training sites for were chosen using the high resolution panchromatic imagery as well as the multispectral IKONOS mosaic. Between five and ten training sites were chosen for each class (Table 2) with emphasis on minimal intermixing of other vegetation types in the training sample.

Four additional data layers were created for input into FARSITE. Canopy cover was linked to the vegetation and fuel type. Vegetation classes were initially assigned a canopy cover value (Table 2). Under an individual tree, canopy cover, by definition, is very high. Canopy cover drops as multiple trees in an area are considered and the gaps between them expose the ground. Hence, we applied a high canopy cover value—90%—to forest vegetation types. To accept these values in a fine-grain mosaic would be problematic, however. To create a more realistic set of continuous values for the canopy cover, we smoothed the canopy cover values (7x7 pixel FAV filter, PCI Geomatica). The resulting canopy cover across the landscape ranges from zero, where no trees are classified, to 90% for pure, almost completely overlapping stands that occasionally occurred on northern aspects. As a result of the smoothing, however, patches of forest usually average a more realistic and variable 30-80% canopy cover, depending on tree density. Predictably, the densest stands grow on northern aspects and this is where the canopy cover is highest. Canopy height and crown base height were assigned as set values for each vegetation and fuel class (Table 2). Values were compared with those used for these classes by the Landfire team and were comparable.

Figure 2: Five input layers for FARSITE simulations: vegetation and fuels, canopy cover, canopy base height, canopy height, and bulk density. These layers are shown are post-DFPZ installation for illustration purposes. Canopy cover and bulk density were modeled conditionally so as not to raise values above existing values.



a. Vegetation & Fuels

b. Canopy Cover

c. Canopy Height

d. Canopy Base Height

e. Bulk Density

As we were unable to differentiate different species of conifers, we assigned a standard bulk density for each class and made it respond to the canopy cover. Thus, where canopy cover is high, bulk density is assumed to be high (up to 0.1 kg/m^3) and where canopy cover is low, so is bulk density. All values were multiplied by a correcting factor of 2.5 (Stpephens, unpublished data).

To create the post-treatment landscape files we altered a copy of the original vegetation by changing the vegetation and fuel in areas where DFPZs would be created: we compared the two coverages—vegetation and fuels along with DFPZs—in PCI's EASI modeling module. In every raster cell in which a DFPZ treatment was planned, we conditionally changed the vegetation and fuel values. If the vegetation and fuel type was any kind of forest cover with surface fuels, we changed it to TL1, the designation of a sparse forest with little surface fuel. If the vegetation and fuel value was grassland or woodland, we left the value the same. Thus, we did not “create” a forest where none was previously; these areas retained their non-forest characteristics. Areas that did have forest were redefined to have DFPZ characteristics. We believe this conditional technique creates a realistic mosaic of forest and non-forest types as a planned DFPZ extends across the landscape.

The additional four layers for FARSITE simulations were created using this post-treatment vegetation and fuels layer using the same steps as before. Only values in areas with DFPZ treatments were modified. For canopy cover we applied conditional modeling to avoid artificially inflating canopy cover in low-density areas. According to the Forest Service (Collin Dillingham, unpublished data), the average canopy cover after DFPZ installation in the Plumas National Forest was 29%. Hence, in our model, if the canopy cover was greater than 29% we reduced it to 29%. If it was lower than 29% we retained the lower value.

Fire Weather

Weather data were drawn from the remote access weather station (RAWS) in Quincy, CA from a recent ten year period and processed in Fire Family Plus (version 3.05). We chose this ten year period rather than a longer duration as we wanted to simulate conditions given the likely continuing warming and drying this region has experienced in the last decade. Data were collected for three weather scenarios—moderate, severe, and extreme (Table 3).

Table 3: Fire weather data from Quincy for the period from June 20 to September 20, covering the years from 1997 to 2006, inclusive. Fuel moistures were calculated using South and Southwest winds which are typical during fires. Enhanced winds in the last column were applied for only the peak burning time each day: 1300 to 1600 hours. At other times, winds were at the levels set in for Extreme conditions.

	Scenario and Percentile of Weather Conditions			
Scenario	Moderate	Severe	Extreme	Extreme with Enhanced Winds
Weather Percentile	70	90	97.5	97.5
Fire Weather				
Relative Humidity	13	10	7	7
Temperature (Fº)	94	100	104	104
Wind (mph)	6	7	9	26.4
Fuel Moistures (FM)				
1 hour	2.4	2	1.6	1.6
10 hour	3.7	3.1	2.8	2.8
100 hour	8.5	7.3	7.7	7.7
1000 hour	9.5	8.6	9.2	9.2
Herbaceous FM	37	34.9	36	36
Woody FM	72	71	70.6	70.6

Wind data for the extreme scenario were enhanced because the RAWS data tend to underestimate actual wind speeds during fire events (Crosby and Chandler 2004). A number of individuals in the Forest Service and our lab had expressed concern about how realistic the winds were in the extreme scenario (9 mph). To create a more likely extreme weather scenario in which a fire might create its own fire weather and sustain strong winds for long periods, we used Fire Family Plus to calculate the maximum hourly winds for each month during the same period. The overall average of these sustained winds during the fire season of the ten year period was 26.4 mph.

Fire modeling

All fire model simulations were completed on a single dual processor computer operating Windows XP and running Farsite (version 4.1.054). Simulations were conducted using 30m perimeter and distance resolution over three twenty-four hour periods (24, 48 and 72 hours).

Model parameters included setting timestep to 30 minutes. Fire behavior options included enabling crownfire (standard setting, not Scott and Reinhardt), embers from torching trees, spot fire growth (5%), and fire-level distance checking. Fire acceleration, post-frontal calculations and dead fuel moistures were set to default. Duration was limited to 72 hours beginning in the midst of the fire season, beginning August 12 at 4pm and extending to august 15 at 4pm. Fuels conditioning was initiated seven days in advance (8/5). Simulation options were set to preserve intact enclaves and operate with four simulation threads.

Spatial and temporal settings were chosen for practical reasons. A practical constraint, given the number of simulation runs to be conducted was the number of days a simulation took to complete, as well as computational calculation limitations on high-resolution vegetation and fuel maps. Medium-sized fires modeled at a 4 m spatial setting would take at least five days to run. Large fires much longer.

In addition, we wanted to focus on the physical potential of fire independent of human intervention; to add in human suppression efforts at this stage would result in our analysis being clouded by subjective suppression efforts when the goal was actually to evaluate fuel treatment effects given identical weather conditions. We limited the length of the simulation, however, as people certainly would begin to suppress a fire within the first 72 hours; simulating un-suppressed fires beyond that period was considered unnecessary. After the physical effects—independent of human suppression—are understood through this work, we will be able to add in an analysis of human suppression efforts and effectiveness.

Results

Six fires were simulated for each stochastic ignition: three given the current, pre-treatment landscape, and three after. For each of the two treatment conditions—pre and post treatment—there were three weather scenarios. Maps of fire extent from a select set of these simulations are presented in Figure 3. Data from the set of all simulations are shown in Figure 4 and Table 4. Installation of DFPZs reduced spot fires by about a third in moderate and severe conditions and 51% in the extreme with enhanced winds scenario. Similarly, the largest percent reduction of burned area (-33%), perimeter (-42%) and number of fires (-44%) occured in the extreme winds scenario.

Figure 3: Six simulations of fires starting from ignition 0. Images are paired left and right by weather scenario—moderate, severe, and extreme—and arranged vertically by fuel treatment. All fire events in the left column occurred on the landscape depicting current conditions—before fuels treatment; fires depicted in the right-hand column were simulated after the installation of DFPZ fuels treatments. With the exception of the vegetation and fuel characteristics in the DFPZ zones (shown in very dark green), the landscapes are identical.

Figure 4: Data from all simulations, regardless of effect of fuels treatments. I = initial conditions (pre-treatment); P = post-DFPZ treatment. Lines are paired: solid represents Initial conditions, dashed = post. Time data are shown on the horizontal axis with measurements made after 1 day (24 hours), 2 days and 3 days.

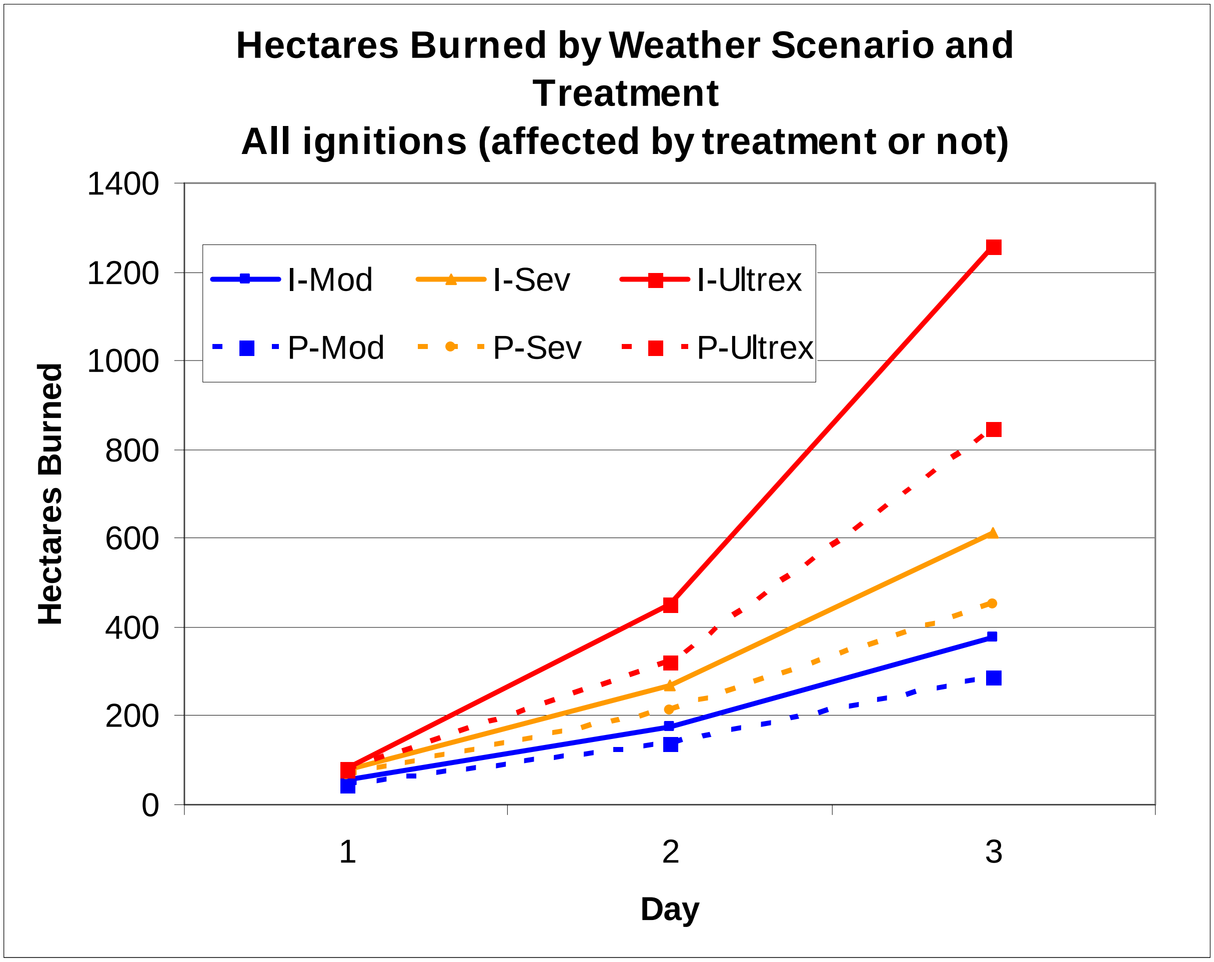


Table 4: Data collected from the set of all simulated fires, regardless of the influence of DFPZs. Ten ignitions were modeled, each with three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

Fire Status		Initial pre-treatment scenarios				Post-treatment scenarios				Percent Change			
Weather	Day	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots
Moderate	1	55	10	118	23	45	8	92	22	-18	-20	-22	-4
	2	177	27	276	26	137	19	173	15	-23	-30	-37	-42
	3	378	44	425	30	288	33	295	20	-24	-25	-31	-33
Severe	1	79	16	184	29	67	14	158	23	-15	-13	-14	-21
	2	270	39	387	38	211	30	304	31	-22	-23	-21	-18
	3	612	71	776	65	451	52	528	45	-26	-27	-32	-31
Extreme + winds	1	83	18	205	29	80	18	212	34	-4	0	3	17
	2	450	88	1143	134	323	65	831	102	-28	-26	-27	-24
	3	1256	200	2606	277	847	117	1453	136	-33	-42	-44	-51

Due to the stochastic nature of the spatial location of ignitions, however, DFPZs affected some fires and not others. As they burned across the virtual landscape, some fires encountered DFPZs on the first day, some later, and some not at all. In order to minimize subjectivity in determining the timing, strength or intensity of a DFPZ’s influence on fire behavior, we simply analyzed the fires after they burned the full period—72 hours—and categorized them as influenced by a DFPZ or not. Predictably, data from fires unaffected by the placement of DFPZs indicated marginal change. In Figure 5, paired lines of pre- and post- treatment should be essentially co-linear. Differences are due to stochastic variables of spotting as FARSITE is otherwise a deterministic program. Fires burning under moderate and severe weather conditions were similar before and after fire with no percent change for any statistical category higher than 8% by the third day (Table 5). In the extreme with enhanced winds scenarios, total area burned on the “treated” landscape vacillated between being higher and lower than the untreated landscape and ended up, due to random effect of spot fires, slightly higher; spot fires were 50% higher in the post-treatment scenario after 3 days.

Figure 5: Simulated fires *not* affected by treatments. Given the lack of a treatment effect, there should be little difference between paired lines.

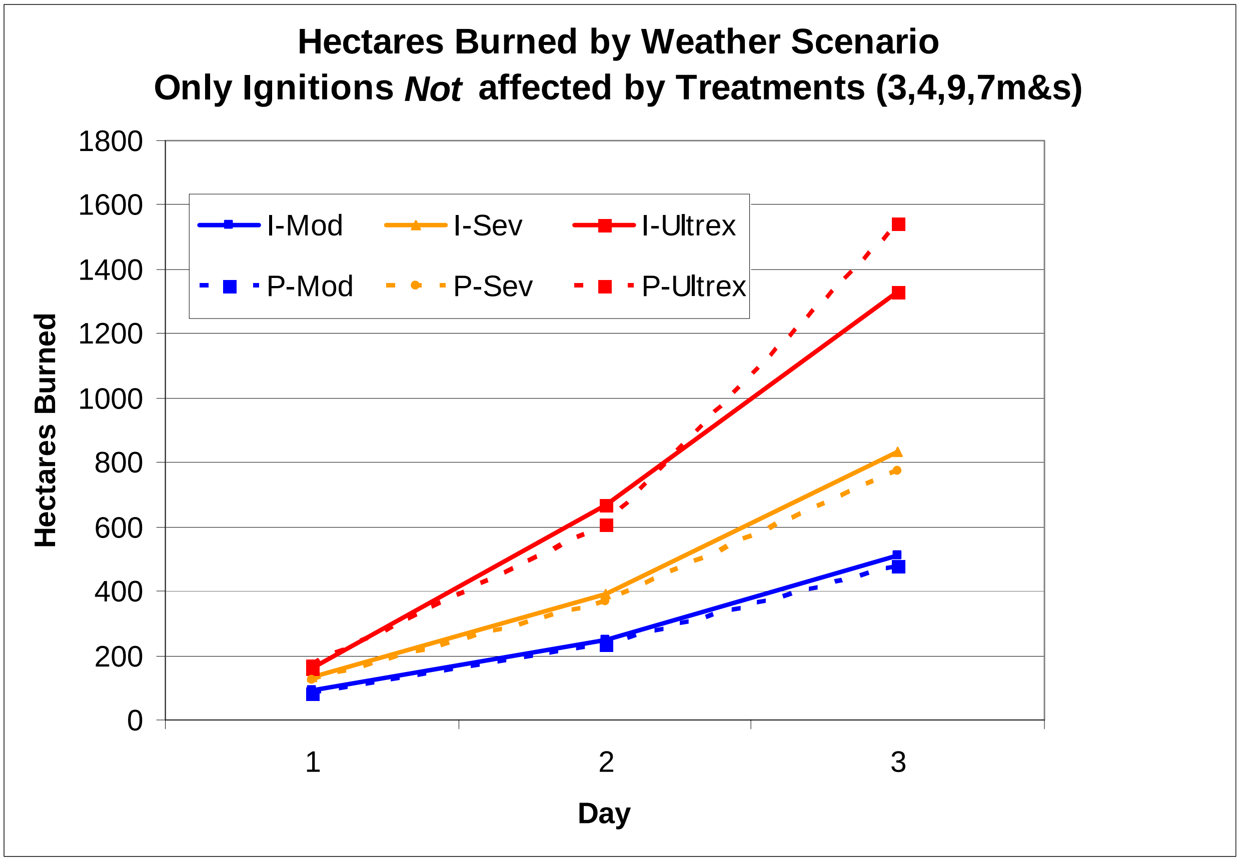


Table 5: Data collected from the set of simulated fires that did not encounter DFPZs while burning. Simulations cover three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

Fire Status		Initial pre-treatment scenarios				Post-treatment scenarios				% change			
Weather	Day	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots
Moderate	1	92	16	198	38	83	14	173	44	-10	-13	-13	16
	2	250	34	360	30	235	32	319	30	-6	-6	-11	0
	3	511	56	546	37	477	52	503	37	-7	-7	-8	0
Severe	1	133	25	288	35	126	24	300	44	-5	-4	4	26
	2	391	51	537	54	369	50	549	61	-6	-2	2	13
	3	833	86	984	87	773	83	946	94	-7	-3	-4	8
Extreme + winds	1	159	32	410	43	172	40	531	84	8	25	30	95
	2	670	108	1468	168	607	122	1753	231	-9	13	19	38
	3	1331	171	2107	175	1542	207	2791	263	16	21	32	50

In scenarios in which fires were affected by DFPZs, the fuel breaks had a dramatic impact on all measures of fire behavior. Hectares burned by fire after treatment in the extreme with enhanced winds scenario was less than burned by fire under severe conditions on an untreated landscape at all three time-steps (Figure 6). Similarly, by the close of the third day of simulation, all measures—burned area, perimeter, number of fires and spots—in all three weather scenarios dropped by fifty percent or more (Table 6). In the extreme with enhanced winds scenarios, all measures declined by 71 to 79 percent.

Figure 6: Data from the fire simulations that encountered or were limited by landscape fuels treatments while burning. In contrast with sites not affected by DFPZs, these ignitions should be strongly affected and there should be a big difference between treatments for each weather scenario.

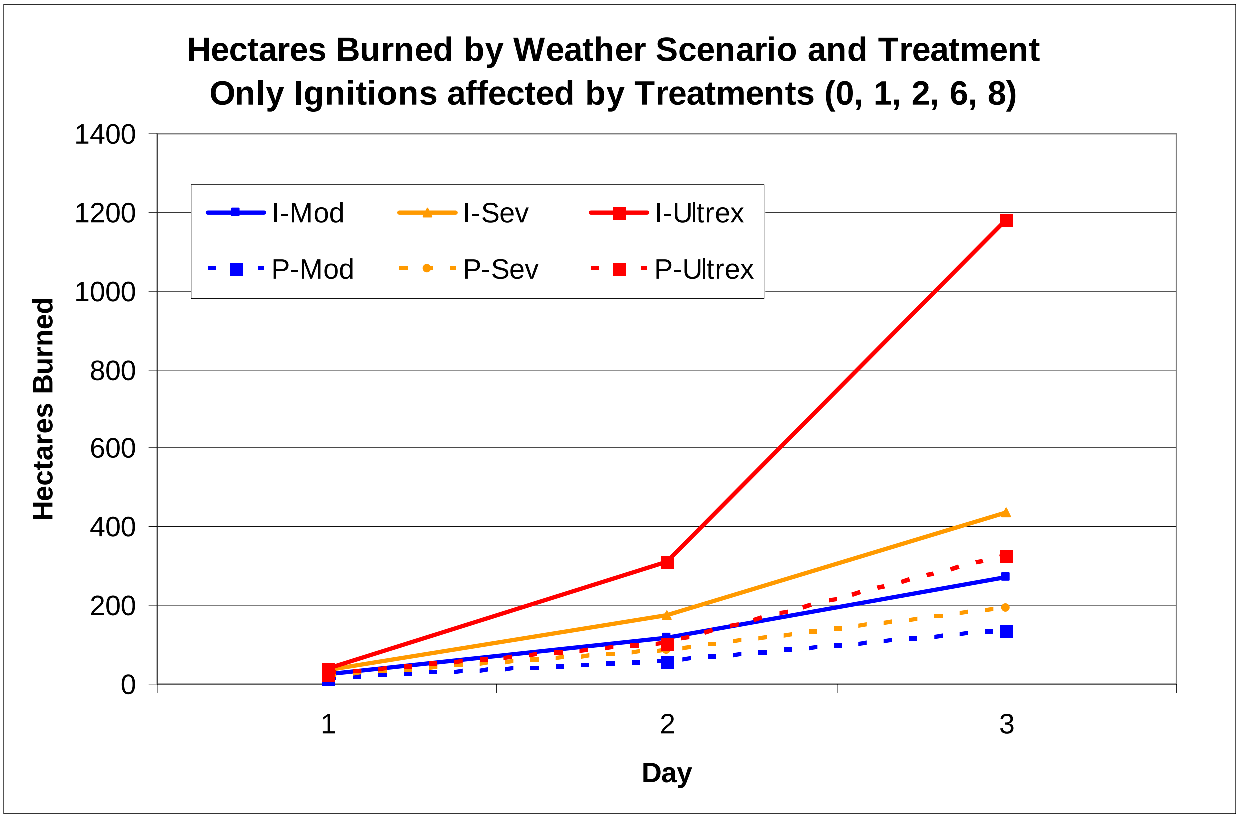
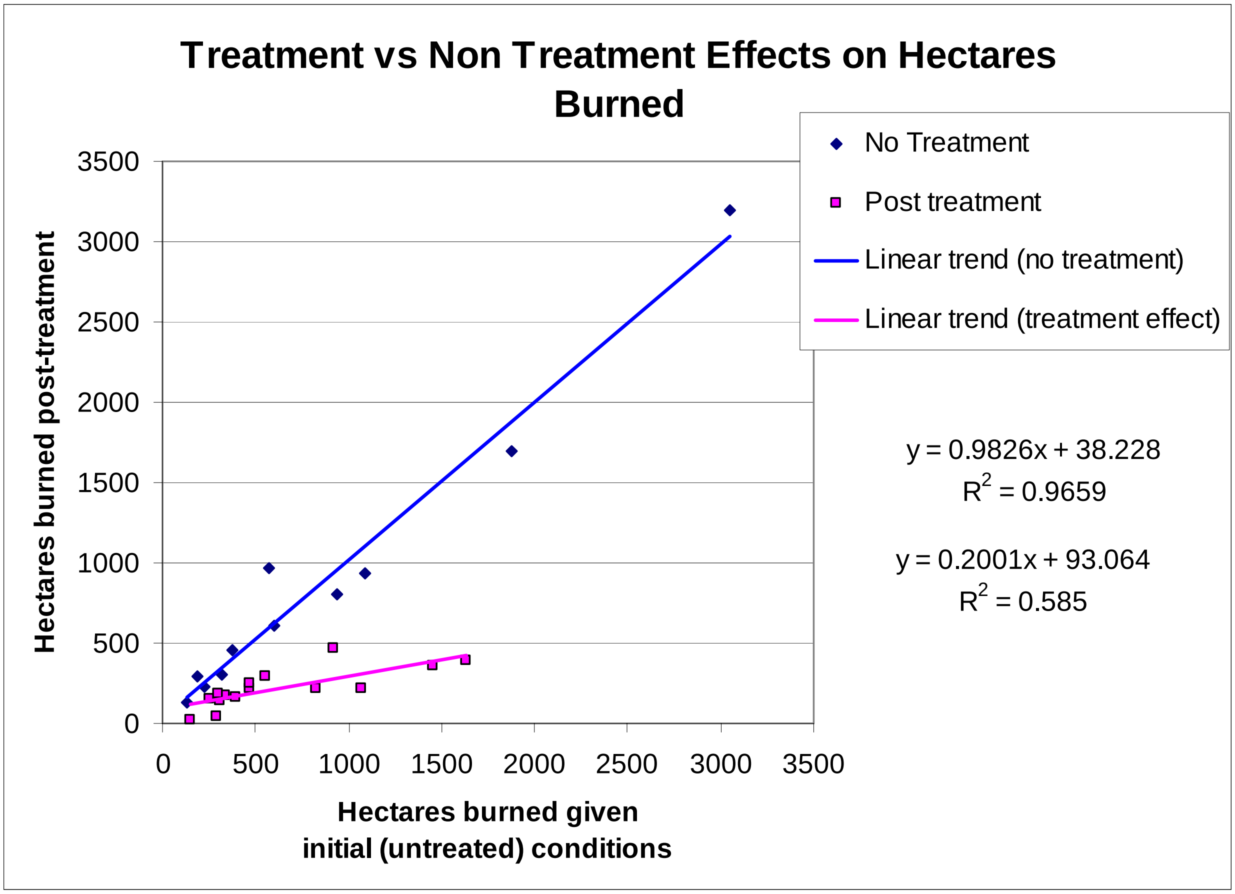


Table 6: Data collected from the set of simulated fires that were affected or contained by DFPZs while burning. Simulations cover three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

Fire Status		Initial pre-treatment scenarios				Post-treatment scenarios				% change			
Weather	Day	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots	Area	Perim	Fires	Spots
Moderate	1	25	6	53	11	15	4	26	6	-40	-33	-51	-45
	2	118	21	208	22	58	9	56	3	-51	-57	-73	-86
	3	272	34	329	25	136	17	129	7	-50	-50	-61	-72
Severe	1	37	10	101	24	20	5	44	6	-46	-50	-56	-75
	2	174	30	267	25	85	14	108	7	-51	-53	-60	-72
	3	435	59	609	48	194	27	194	6	-55	-54	-68	-88
Extreme + winds	1	38	11	117	27	24	6	56	10	-37	-45	-52	-63
	2	311	80	1018	123	104	24	205	14	-67	-70	-80	-89
	3	1182	231	3168	378	327	66	734	79	-72	-71	-77	-79

If there is no treatment effect, an XY graph of pre- and post-treatment hectares burned should be a straight line with a slope of 1. In Figure 7, we contrast the two groups of fire simulations—those affected by DFPZs and those not. As predicted, the no-effect group has a slope near 1 (0.98). In sharp contrast, in scenario pairs affected by the fuels treatments, the line is nearly flat (slope 0.20): ignitions that led to large fires before treatment grew only into much smaller fires after treatment. Total suppression would yield a post-treatment slope of 0. The larger the difference between pre- and post-treatment trend lines, the stronger the effect of the treatment.

Figure 7: Comparison of hectares burned before treatment (horizontal axis) and after (vertical). A positive treatment effect is shown by a flattening out of the line to the horizontal. A line with slope of 1 indicates there is no change in fire behavior as a result of treatment. The blue / no-treatment line approaches a slope of 1, as predicted. The pink line mapping fires limited by DFPZs indicates there is a large reduction in fire size for all fires that encounter a treated area.



Discussion

Analysis

As expected, installation of landscape-scale fuel breaks (DFPZs) significantly reduced the extent of the overall fire as well as the numbers of individual fires and spots. Contrary to expectation, however, DFPZs had the largest effect on fires burning in extreme conditions with enhanced winds. Because the DFPZs had been designed to reduce the spread of fire, particularly crown fire, at the 90th percentile, it had been expected that they would “fail” in extreme conditions. In contrast, these landscape fuels treatments provided the largest benefit under the most extreme conditions and with the largest fires (Figures CC and EE, Table 6). Fires burning under extreme with enhanced winds conditions experienced proportionately greater benefit from DFPZ treatments even if the treatment was designed for the 90th percentile. All measures of fire extent were reduced by at least 70% after three days of burning (Table 5).

As a check, we confirmed that simulations with landscapes where DFPZs did not affect fires during the burning period showed little to no change between the pre- and post-treatment scenarios. Only the random nature of spot fires led to some higher fire metrics after 3 days (Figure 5, Table 5).

From these results we draw the conclusion that impeding the spread of fires with a landscape fuel treatment is more important than changing the on-site conditions of how fire would behave if it got to a site. In short, these data suggest that it is better to prevent fires in extreme weather from getting to a site than engaging in fuels reduction at that site itself. To do this, landscape fuel breaks need to be created and distributed prior to fire.

Comments on the remote sensing, fuels mapping and fire modeling

The fine-grain modeling effort itself is promising. Instead of characterizing a landscape as being divided up into homogenous polygons with clean breaks between then, this approach leads to a more realistic intermix of grass, chaparral and forest, or other vegetation and fuel types. In reality, fuels certainly vary significantly at a fine scale like this (Menning 2003). Further, the approach allows us to dispense with the unrealistic approach of creating impermeable fire breaks where roads and streams are located. Forest Service roads may block ground fire spread, but forest canopy may actually reach across the roads providing connectivity in extreme fires. In reality, these breaks resist the spread of fire rather than entirely stop it—

particularly under extreme conditions. Our method results in various degrees of permeability across streams and roads due to the fine grain nature of the imagery.

Future directions

We would like to extend this top-down supervised classification fuel mapping approach to a bottom-up, field data-driven approach. A fuels map built from extensive field data would be even more powerful. Such an approach would have more detailed data on crown base and total heights, and canopy cover.

The results here suggest that comparing different landscape fuels treatment approaches—DFPZs as well as strategically placed landscape area treatments, or SPLATs (Finney 2001; Stephens and Ruth 2005))—would be a good way to compare their efficiency in modifying fire behavior. Our remote sensing and modeling approach allows us to create any post-treatment landscape for comparison with current conditions.

Further simulation approaches could include expert-opinion driven suppression efforts. Indeed, DFPZs are intended not only to reduce fire intensity, severity, rate of spread, and occurrence of crown fire, but to allow safe access for fire crews to engage in suppression. Now that we are beginning to understand the physical behavior of fire under these different weather and treatment scenarios we can begin considering the role of human intervention. Having results indicating that landscape fuels treatments can positively modify fire behavior— even in extreme weather conditions—is critical for any such modeling or planning effort.

Acknowledgements

Funding for this project was supplied by the USDA Forest Service, Region 5, as well as the Plumas National Forest. Randy Karels, Bridget Tracy, Suzanne Lavoie and others collected data in the field. Nicholas Delaney both collected field data and toiled in the lab working on remote sensing, GIS and fire modeling.

Publications and Presentations 2005-8

- Menning, K.M., and S.L. Stephens (2008: draft complete, being submitted to Landscape Ecology). "Potential forest fire behavior as a function of three weather scenarios and two landscape fuels treatments based on a fuels and vegetation landscape derived from fine-grain IKONOS satellite imagery, Sierra Nevada (USA)." Draft being submitted to Landscape Ecology.

- Menning, K.M., and S.L. Stephens (2007) Fire Climbing in the Forest: a semi-qualitative, semi-quantitative approach to assessing ladder fuel hazards, Western Journal of Applied Forestry.

- Menning, K. M. and S. L. Stephens (2006). Modeling Landscape Fire Behavior and Effects in the Northern Sierra Nevada. 3rd International Fire Ecology and Management Congress, San Diego, CA.

- Menning, K. M. and S. L. Stephens (2006). Landscape-scale Fire Risk Wildlife Habitat Considered Jointly. 21st Annual Symposium of the United States Regional Chapter of the International Association for Ecology (US IALE), San Diego, CA.

- Menning, K. M. and S. L. Stephens (2006). Assessing Ladder Fuels in Forests. 3rd International Fire Ecology and Management Congress, San Diego, CA.

- Menning, K.M., and S. L. Stephens (2005) “Fire rising in the forest: Ladder fuel hazard assessment using a mixed qualitative and quantitative approach,” Ecological Society of America, August 7-12, 2005, Montreal Canada. (Abstract attached to end of report).

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Linking fire and wildlife habitat in California: Spectral entropy canopy diversity analysis*. UK Centre for Ecology and Hydrology, Monks Wood, Cambridgeshire, England, UK. November 21, 2005.

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Spatial Ecological Links Between Fire, Forests and Habitat in the Plumas-Lassen Administrative Project*. Geographic Information Centre Seminar: City University, London, London, England UK. November 22, 2005.

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Forest Structural Diversity: Spectral Entropy Canopy Diversity Analysis*. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland. December 5, 2005.

Goals for 2008

Having collected the field data, processed the remote imagery and having completed fire modeling, we are ready to conduct additional modeling exercises with SPLATs and other treatments, as well as suppression. Also, we would like to initiate the integrative modeling of fire and habitat scenarios with John Keane and the owl.

Expected Products (Deliverables)

In addition to the above goals, results will be published regularly in the Plumas-Lassen Administrative Study Annual Reports. We will present results directly, as they are derived, to interested parties. More formal scientific publications are targeted covering a variety of areas including a validation of the LaFHA approach being piloted in this study that was published in 2007, performing SpECDA analyses of forest structure and its variability, fire behavior and effects, integrated model results with the Owl Module, and assessments of the efficiency of DFPZs and other treatments in moderating the landscape-level effects of fire.

Additional Publications Planned for 2008

- Menning, K. M. and S. L. Stephens. "Spectral Entropy Canopy Diversity Analysis (SpECDA) used to Assess Variability in Forest Structure and Composition" to be submitted to Photogrammetric Engineering and Remote Sensing.
- Menning, K. M., S. L. Stephens, J. Keane, D. Kelt, and others. "Integrated modeling of fire and California Spotted Owl habitat conditions given different weather and landscape treatment scenarios" To be submitted to a journal mutually agreed upon.
- Menning, K. M. and S. L. Stephens. "Fire Behavior and Effects as a Result of Defensible Fuel Profile Zones" To be submitted to International Journal of Wildland Fire.
- Menning, K. M. and S. L. Stephens. "Landscape Forest Variability across the Northern Sierra Nevada" To be submitted to Landscape Ecology.

Additional publications based on analysis of the field data, remote sensing products, and results of integrative modeling with Keane.

Data Management and Archiving

All data will be archived with the USDA Forest Service's Sierra Nevada Research Center (SNRC) in Davis, California, as well as the Fire Science Lab (Stephens Lab) at the University of California, Berkeley. Some derived products will be put on-line by the SNRC or Stephens Lab.

Appendix A: Model integration with California Spotted Owl team (Keane)

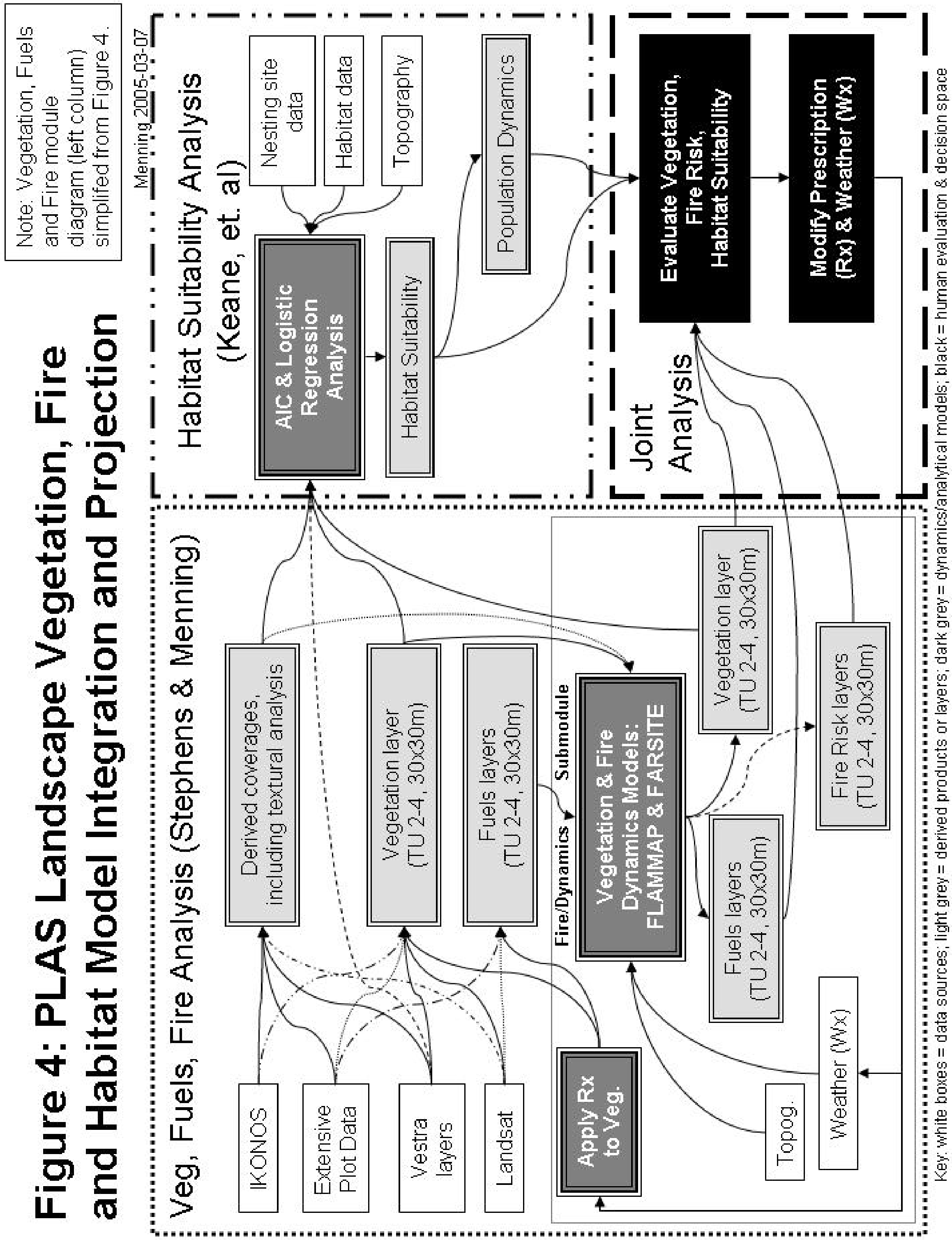


Figure 4: PLAS Landscape Vegetation, Fire and Habitat Model Integration and Projection

Note: Vegetation, Fuels and Fire module diagram (left column) simplifed from Figure 4.

Menning 2005-03-07

Appendix C: Budget projections: Proposed budget 2008

Landscape Fuel & Fire in the PLAS

10/13/06

PI: Dr. Scott Stephens
Postdoctoral coordinator: Kurt Menning

Item		**FY2006-7** **Budg. request**
Salaries and Benefits		
	Principal investigator (Stephens 0.5 months)	4,191
	Benefits, 25%	1,048
	Postdoc (Menning: 1.0 FTE)	43,000
	Benefits, 23%	9,890
	Undergrads (0): full time summer	0
	Benefits, 5%	0
	Assistant for academic year (1.0)	29,000
	Benefits, 23%	6670
	Total Salaries & Benefits	**93,799**
Rent, Communications, Utilities		**0**
	Forestry camp operations	
Travel	Per diem	500
	Rental vehicles, gas	500
	Fire modeling & training expenses	0
	Conference travel	3,000
	Total travel	**4,000**
Contractual Services		
	Imagery	0
	Software processing and licensing	500
	Total contractual services	**500**
Materials and Supplies		
	Lab supplies	500
	Field supplies	0
	Computer equipment	500
	Total materials & supplies	**1,000**
Overhead: indirect costs to UCB (0%), USDA Coop		0
Annual Funding requested for year		**99,299**

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Chapter 2:
Vegetation Module

Plumas/Lassen Administrative Study Vegetation Module
Forest Restoration in the Northern Sierra Nevada:
Impacts on Structure, Fire Climate, and Ecosystem Resilience.

Report of Activities during 2007

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Will Horwath, Professor, Department of Land, Air, and Water Resources

OBJECTIVES

The vegetation module of the Plumas-Lassen Administrative Study studies how changes in the forest canopy affect ecosystem functioning, including 1) microclimate, 2) growth and competition of shrubs and juvenile trees, 3) understory diversity, and 4) landscape continuity. The module objectives are:

1) determine the effects of reduction in tree canopy cover on microclimate, fuels dryness, and other factors contributing to flammability of the forest understory, and

2) determine effects of reduction in tree canopy cover on light, soil moisture, and other factors influencing composition and growth of the understory plant community.

3) examine stand- and landscape-level impacts of group-selection silviculture

Research approaches include stand-level experimental manipulations, measurement of plant growth and survival along existing environmental gradients, and assessment of impacts of routine (i.e., non-experimental) forest management activities.

RESEARCH ACTIVITIES 2007

Study on Effects of Experimental Thinning and Group Selection on Forest Structure, Fire Climate, and Plant Communities in West-Side Mixed-Conifer Forest.

(*Seth Bigelow, Malcolm North, Keith Perchemlides*)

The treatments for this study took place in May and June 2007. A feller-buncher felled trees and placed them in piles, and a skidder took them to landings outside the experimental plots. There, branches were removed, trees were cut to length, and merchantable logs were placed on log trucks. Measuring equipment and markers for sampling sites were replaced immediately following treatments. Treatments were completed early enough in the season that many post-treatment measurements were done.

Changes in canopy cover and light with treatments

Canopy cover was measured before and after treatments with vertical sighting tube (GRS densitometer) held at head height: 400 measurements in a 2.5 acre sampling site in the center of the 22 acre thinning plots or the smaller group selection plots. Light was measured from canopy photographs taken at breast height with a digital camera equipped with a fisheye lens (Table 1).

There was an average post-treatment canopy cover of 56% in sites with a 50% target, 49% cover in sites with a 30% target, and 12% residual cover in group selection openings. We identified several possible reasons for difficulties in reaching canopy cover targets. First, archaeological features were identified at several sites after it was too late to relocate treatments, placing unexpectedly large areas off-limits to forest operations. Second, one site may have intentionally been logged lightly after loggers received negative feedback from Timber Sale Administrators about stands logged earlier in the process. Third, errors may have been made by the marking crew. We emphasize that our studies have not been compromised by discrepancies between target and actual canopy cover, because our studies rely on small-scale spatial variation within plots as independent variables.

Treatment	Canopy Cover (%)		Area with light >25 mol m^{-2} d^{-1} (%)	
	Before	After	Before	After
Control	78	77	1	1
50%	69	56	8	9
30%	68	49	3	11
Group	70	12	7	87

Table 1. Overstory canopy cover and understory light before and after application of experimental thinning and group selection treatments. Average values from three plots. Light is proportion of sampling sites with enough light for regeneration of shade-intolerant pine species.

Our studies in the Plumas National Forest have identified 25 mol m^{-2} d^{-1} (40 percent of full sun; PFS) as a threshold light level for triggering rapid growth of shade-intolerant pines (Fig. 1). We detected little change in the 50% canopy cover plots in proportion of plots above the 25 mol m^{-2} d^{-1} threshold, but there was an increase in the proportion of plot area above the threshold in the 30% target plots (Table 1). A large proportion (87%) of the group selection openings had enough light to support rapid growth of shade-intolerants.

Immediate post-treatment data on stand structure, understory microclimate (air temperature, soil temperature and moisture, fuel moisture, windspeed) and fuels have not been processed yet. We anticipate that an additional season of data collection will be required to yield reliable data on understory microclimate.

Studies on performance of mixed-conifer saplings with respect to light and other factors (*Seth Bigelow, Carl Salk, and Malcolm North*).

The field component of these studies is complete. One manuscript based on this work is being revised and another is in preparation.

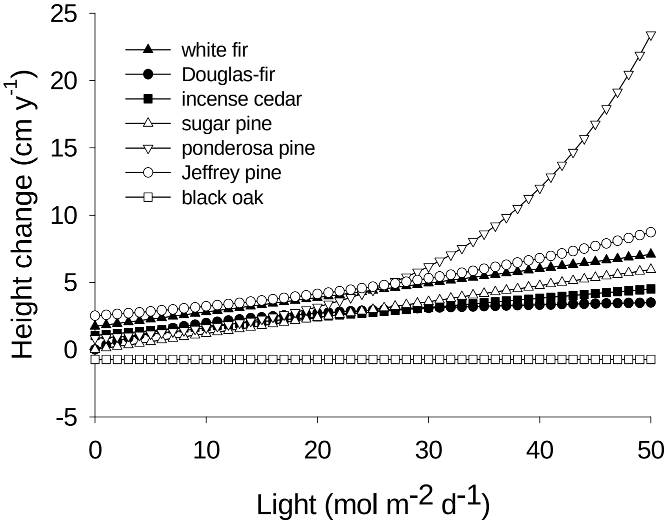

Figure 1. Seedling height growth in relation to understory light: ponderosa pine shows rapid growth at light above threshold of 25 mol m^{-2} d^{-1} (40 percent of full sun).

Resilience to harvest disturbance in patchy east-side forests
(Seth Bigelow, Sean Parks, Malcolm North)

This study evaluates stand- and landscape-level impacts of group-selection silviculture applied in east-side forests where areas of continuous forest cover are interspersed with grassy openings. Field work for the stand-level study was completed in 2005; minimal impacts on soil water and microclimate were detected. The landscape study asks whether group selection openings will disrupt structural continuity of the landscape. Our work on four landscape areas where multiple group selection harvests were done in 2001-2002 (Red Clover and Stony Ridge projects) has indicated that under some landscape conditions and scales of analysis, landscape continuity can be disrupted by group selection silviculture (Fig. 2).

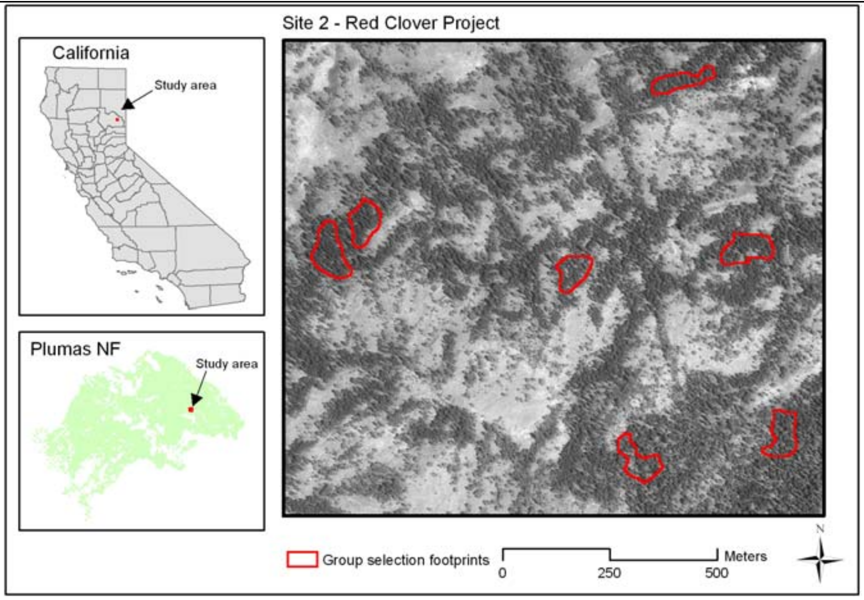

Figure 2. One of four landscapes where group selection silviculture was analyzed. Pretreatment photo is shown: red circles indicate locations where group selection openings were placed.

This year we generated guidelines for predicting conditions under which landscape continuity is vulnerable to perturbation. We focused on the interaction between level of forest canopy cover (habitat) at the scale of the landscape (i.e., the probability of habitat, p(H)), and probability of pixels of canopy/habitat being adjacent to one another (p(H|H)). Using the computer to randomly generate landscape models at different levels of p(H) and p(H|H) and asking whether an organism could travel across each landscape, we found a well-defined relationship between amount of habitat, probability of habitat self-adjacency, and the connectedness or probability of percolation of the landscape. There was good agreement between this theoretically predicted probability of landscape percolation, and the patterns of percolation we observed in the Red Clover and Stony Ridge projects (Fig. 3). This suggests that forest managers may be able to use our findings to reliably predict which landscapes are at risk of fragmentation of forested cover when group selection openings are placed in them.

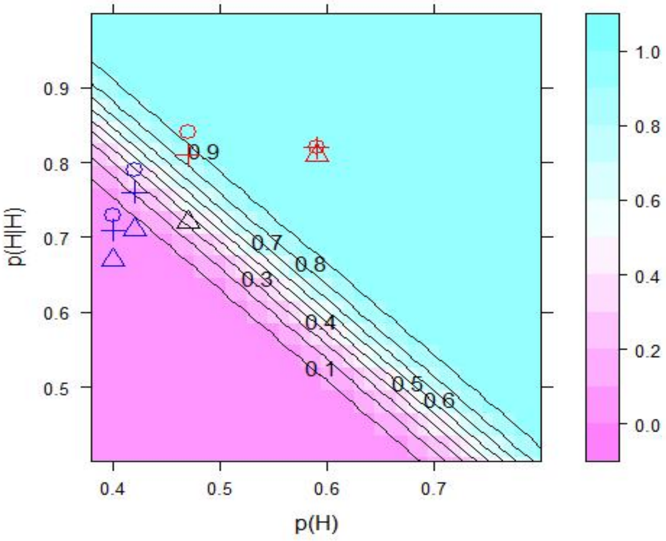

Figure 3. Percolation behavior of east-side landscapes under group selection silviculture compared to predicted probability of percolation. Each vertical group of symbols represents one landscape analyzed at 3 scales: 3 m (circle), 10 m (plus), or 30 m (triangle). Red symbol color denotes landscape that percolated before and after treatment, blue denotes landscape that did not percolate before treatment, and black indicates landscape that percolated before treatment but did not percolate afterwards. Pink background indicates low predicted probability of percolation, teal background indicates high predicted probability. Numbers indicate probability of percolation associated with individual contour lines. Note location of black triangle: the one landscape whose continuity was disrupted by group selection harvest fell close to the contour line for 50% probability of percolation.

Outreach

Vegetation module personnel gave three public presentations on their work:

Plumas-Lassen study symposium, Quincy, CA, March 2007.

Annual Meeting of the Ecological Society of America, August 2007, San Jose, California. Poster presentation: Light thresholds for competitive reversals in Sierran conifers: Enhancing the restoration component of fuels-reduction canopy thinnings.

Annual Meeting of the Society for Conservation Biology, Bay Area chapter, January 2008, Davis, California. Oral presentation: Light thresholds for competitive reversals in Sierran conifers: Enhancing the restoration component of fuels-reduction canopy thinnings.

Chapter 3:
Small Mammal Distribution, Abundance, and Habitat Relationships

2007 Annual Report

Submitted February 2008

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EXECUTIVE SUMMARY

In this document we report on the Mammal Module of the Plumas-Lassen Administrative Study (PLAS). A pilot study was conducted September-November 2002, the study design was incorporated in 2003, and 2007 marked the fifth year of implementation of the study. As of the end of the 2007 field season, all of the proposed treatments have been implemented, thus everything we report in 2007 reflect post-treatment conditions and all data reported prior to 2007 reflect pretreatment conditions.

The information provided in this report is intended to provide background information on the pre-treatment and post-treatment status of small mammals in a variety of forested habitat types, determine habitat associations of many small mammal species, particularly the principle prey of the California spotted owl (i.e., dusky-footed woodrat, *Neotoma fuscipes*; northern flying squirrel, *Glaucomys sabrinus*), and provide resource managers with important habitat attributes to manage for to ensure a sustainable mammalian community.

In 2006, Robin Innes, who has been with the project since 2002, succeeded James Wilson as Project Leader of the Mammal Module of the PLAS. Robin continued as Project Leader in 2007. James Wilson continues to improve manuscripts initiated during his time as a postdoctoral fellow with the PLAS, as a staff member at University of Nebraska, Omaha. To date, we have had two graduate students at the University of California, Davis successfully complete their graduate work with the PLAS. In 2005, Stephanie Coppeto completed her graduate work on the habitat associations of small mammals at multiple spatial scales. In 2006, Robin Innes completed her graduate work on habitat selection by dusky-footed woodrats. In 2006, Jaya Smith joined the Mammal Module and will complete his graduate work in 2007. Jaya is studying the home range and habitat use of the northern flying squirrel.

INTRODUCTION

Small mammals play vital roles in forest ecosystems, serving as important consumers and dispersers of seeds, fruits, and fungi (Carey et al. 1999; Gunther et al. 1983; Maser and Maser 1988; Pyare and Longland 2001), and as prey for mammalian and avian predators, including many species of concern in the Sierra Nevada (e.g., California spotted owl, *Strix occidentalis occidentalis*; northern goshawk, *Accipiter gentilis*; fisher, *Martes pennanti*; and marten, *M. americana*; Carey et al. 1992; Forsman et al. 1984; Zielinski et al. 1983). Given their essential interactions with flora and fauna across multiple trophic levels (e.g., Carey et al. 1992; Forsman et al. 1984), changes in the distribution and abundance of small mammals could substantially affect the dynamics of forest communities. This makes small mammals valuable subjects for the integrative research necessary to fully understand the ecological responses of spotted owls and other species to forest management practices.

Here we report on the Mammal Module of the PLAS, one of five integrated study modules intended to evaluate land management strategies within the area covered by the Herger-Feinstein Quincy Library Group Forest Recovery Act (HFQLG) Pilot Project. Understanding how small mammal communities respond to different forest management regimes at macrohabitat (i.e., stand-level, landscape) and microhabitat (trap-level, home range) scales would provide valuable feedback to other PLAS modules. We plan to develop predictive small mammal habitat models to forecast how individual species will respond to forest management treatments and test these models by assessing the impacts of forest management treatments on small mammal abundance and species diversity. We will do this by monitoring several independent populations of small mammals for multiple years before and after forest management treatments are applied, developing demographic profiles (e.g., survival, reproduction) of species, and obtaining detailed measurement of habitat characteristics. To sample and monitor these small mammal populations, we have established permanent (long-term grids) and temporary (landbird grids) live-trapping grids located throughout Plumas National Forest (PNF).

In addition to the valuable feedback that can be gained by determining how the full compliment of small mammals responds to different forest management regimes, we will more closely examine the responses of several key small mammals to forest management practices. Due to differing seasonal energy requirements, hibernating and non-hibernating small mammals are likely to be effected differently by forest management practices. Hibernation may reduce mortality of small mammals during the winter months through conservation of energy and protection from predators (Broadbooks 1970), with mortality rate more heavily influenced by the quantity and quality of food caches (Post et al. 1993) and body condition prior to hibernation (Murie and Boag 1984), parameters which can be related to forest productivity. Non-hibernating small mammals may exhibit elevated mortality during the winter months due to increased levels of thermal stress, limited food resources, and exposure to predators. Thus, our objective was to evaluate the effects of forest management treatments on the ecology of both hibernating and non-hibernating species groups.

Key non-hibernating small mammals in the northern Sierra Nevada include the northern flying squirrel (*Glaucomys sabrinus*) and dusky-footed woodrat (*Neotoma fuscipes*). Northern flying squirrels and dusky-footed woodrats are the principle prey of the California spotted owl (Carey et al. 1992; Rosenberg et al. 2003), a species of concern in California due to its dependence upon late-seral forest ecosystems (United States Department of the Interior 2003), which are among the most highly altered ecosystems in the Sierra Nevada (Beardsley et al. 1999; Franklin and Fites-Kaufman 1996). For example, some populations of northern flying squirrel appear to be depressed by the intensity of spotted owl predation (Carey et al. 1992), and high woodrat biomass may reduce the area requirements of the spotted owl (Carey et al. 1990; Zabel et al. 1995). Thus, northern flying squirrels and dusky-footed woodrats are an important focus of our study module.

Northern flying squirrels are nocturnal, arboreal rodents located throughout the northern latitudes of the United States, and Canada (Wells-Gosling and Heaney 1984), and frequently associated with forests with high densities of large trees (Smith et al. 2004, 2005). Northern flying squirrels act as a major dispersal agent for hypogeous fungal spores, which are important for nutrient and water uptake by host trees (Fogel 1980). Although they are typically associated with mesic northern forests, northern flying squirrels are also found throughout the Sierra Nevada where they experience a much more xeric landscape as compared to the rest of their range; as a result, populations of northern flying squirrel inhabiting the Sierra Nevada may be quite different from those inhabiting the more mesic forests of Oregon, Washington, and Alaska. Specifically, northern flying squirrels may be more sensitive to wetter regions in the Sierra Nevada where truffles, their primary food source, are more abundant. This disjunctive distribution of food resources may drive differences in northern flying squirrel biology, suggesting that northern flying squirrels may exhibit a more clumped distribution, lower overall densities, increased competition for suitable nest trees, and larger individual home ranges; thus, northern flying squirrels in the Sierra Nevada may be affected differently by forest management practices than populations in other parts of their range. We used live-trapping and radiotelemetry techniques to determine the abundance and distribution, habitat use, and home range of northern flying squirrels in the Sierra Nevada, compared this with data from other parts of their distribution, and evaluated the effects of forest management practices on this species within the area covered by the HFQLG Pilot Project.

The dusky-footed woodrat is a nocturnal, semi-arboreal rodent found throughout northern California and Oregon that inhabits a wide variety of densely vegetated habitats, including chaparral, juniper woodland, streamside thickets, and deciduous or mixed forests with well-developed undergrowth (Carraway and Verts 1991). Dusky-footed woodrats play an important role in community dynamics. As mentioned previously, they are prey for many avian and mammalian predators, including the California spotted owl. Additionally, the availability of woodrat houses may influence species richness for small mammals, reptiles, amphibians, and invertebrates (Cranford 1982; M'Closkey et al. 1990; Merritt 1974; Vestal 1938). Thus, promoting quality habitat for the dusky-footed woodrat may provide a variety of ecological values in managed forests, for example in the form of increased biodiversity, with important consequences for forest conservation (Carey et al. 1999). We used live-trapping and radiotelemetry to determine the abundance and distribution, habitat use, and home range of dusky-footed woodrats in the Sierra Nevada, and evaluate the effects of forest management practices on this species. Specifically, our first objective was to test for an association between woodrat abundance and abundance of California black oak (*Quercus kelloggii*), an important food source (Atsatt and Ingram 1983; Cameron 1971; Meserve 1974). Our second objective was to evaluate the importance of microhabitat variables to dusky-footed woodrats at 2 levels, placement of houses within mixed-conifer habitat and use of houses. Dusky-footed woodrats construct conspicuous, conical houses on the ground using sticks, bark, and plant cuttings, and sometimes also on limbs or in cavities of trees (Fargo and Laudenslayer 1999). Given the investment involved in building, maintaining, and defending a house, we predicted that houses should be distributed such that they minimize energetic costs in movement, yet maximize individual fitness components (Manley et al. 1993), such as access to food, protection from predators, and a thermally suitable microclimate (Atsatt and Ingram 1983). Thus, we evaluated ground and tree house-site selection of houses by dusky-footed woodrats by comparing house sites with nearby random sites. Since only a subset of available houses is used by woodrats at any one time (Carey et al. 1991; Cranford 1977; Lynch et al. 1994), some houses may be more suitable than others. We evaluated house suitability by comparing characteristics of used and unused ground houses and availability and use of house trees. Because woodrats defend their house against conspecifics, subadults might be forced to settle in lower quality houses (Vestal 1938), thus, we also evaluated whether subadults selected houses differently from those selected by adults. Our third objective was to examine the spatial organization of dusky-footed woodrats. A population's spatial organization has important implications for population dynamics, as well as the genetic structure of a population (e.g., Dunning et al. 1992, Lambin and Krebs 1991; Sugg et al 1996).

Other key small mammals include two diurnal, hibernating rodents, the golden-mantled ground squirrel (*Spermophilus lateralis*) and chipmunks (*Tamias sp.*), which are also important prey species of the northern goshawk, a species of increasing concern to resource managers due to the species sensitivity to the effects of forest management. As mentioned previously, the body condition of individual small mammals appears critical to hibernation and over-winter survival (Lenihan & Van Vuren 1996; Murie & Boag 1984). Body condition may also influence reproduction; for example, small mammals that are heavier on emergence form hibernation may produce larger litters (Dobson et al. 1999) that are more likely to be successfully weaned (Neuhaus 2004). Additionally, first-year over-winter survival of juvenile small mammals is positively related to pre-hibernation body mass (Bennett 1999; Lenihan & Van Vuren 1996). Body condition can also affect behavior; for example, juvenile dispersal may be influenced by body condition (Barash 1974) since body fat may be an important cue for dispersal, with lighter individuals dispersing later than heavier individuals (Barash 1974; Nunes et al. 1998). Offspring condition at the time of dispersal may be influenced not only by post-weaning food acquisition by the juvenile, but also by maternal condition (Dobson et al. 1999). Although body condition is important to all animals, it is particularly so for hibernating ground-squirrels, which face a short active season (<5 months) and require large energy reserves.

Thus, our objective was to evaluate the influence of forest management practices at they relate to forest productivity on the body condition of the golden-mantled ground squirrel, a species found commonly at higher elevations (>2000 m) in the Sierra Nevada, where the length of the snow-free growing season could severely limit the animal's ability to acquire enough energy to sustain activity and support reproduction (Armitage 1989). We measured the amount of fat reserves (i.e., body condition) using the total body electrical conductivity (ToBEC) method (Koteja 1996; Walsberg 1988), used radiotelemetry methods to document dispersal and maternal home range, and developed a model which relates offspring natal dispersal to body condition, and incorporates the influence of maternal condition on these factors.

Chipmunks are forest-associated, semi-arboreal rodents that constitute a considerable portion of the small-mammal biomass in an area, making them important prey for a variety of mammalian and avian predators (Vaughan 1974). Additionally, chipmunks are important consumers and dispersers of seeds (Briggs and Vander Wall 2004; Vander Wall 1992,), and may contribute to the natural regeneration of some species of plants by caching seeds (Aldous 1941). Small mammals cache seeds beneath the layer of decaying vegetation on the forest floor (scatter-hoarding), where they stand a better chance of germinating than those remaining on the surface litter (Sumner and Dixon 1953), or deposit seeds in underground burrows where seeds can not establish seedlings (larder-hoarding). Chipmunks scatter-hoard seeds more frequently than other small mammals, thus potentially having a greater impact on seedling establishment (Hollander and Vander Wall 2004). If soil-moisture levels have been altered due to fire, logging, or weather patterns, the ability of chipmunks to retrieve cached seeds may be reduced, thus promoting germination of a larger proportion of seeds after disturbance (Briggs and Vander Wall 2004;Vander Wall 2000). However, if chipmunks are very abundant, they can prevent normal regeneration of some plants, particularly pines, by eating their seeds, which may contribute to the generation of dense brushfields that could further hider the return of timber (Smith and Aldous 1947, Tevis 1953). We were particularly interested in two species that occur commonly throughout PNF, the long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunks. These sympatric species are similar in body mass, diet, and general resource utilization, and thus are likely to compete locally. Similar species often coexist by partitioning habitat. However, detecting differences in habitat affinities is influenced by spatial scale. Our objective was to investigate the abundance, distribution, and habitat associations of the long-eared and Allen's chipmunks at three spatial scales in PNF and evaluate the affect of forest management practices on these species.

OBJECTIVES

The primary objective of the Mammal Module is to evaluate small mammal responses to different forest management practices, and to model these responses in terms of demography, spatial distribution, and habitat associations at local and landscape scales. To meet the primary objective, we will address the following:

1. Determine small mammal habitat associations at macro- and microhabitat scales.
2. Develop demographic profiles of small mammal populations inhabiting a variety of habitat types.

3. Develop predictive small mammal habitat models, based on the results of objectives 1-2, to forecast how individual species will respond to forest management treatments.
4. Quantitatively assess the impacts of forest management treatments on small mammal abundance and species diversity.
5. Determine small mammal population trends, evaluate how populations are changing temporally, and assess the factors responsible for the observed trends.
6. Evaluate the spatial distribution (i.e., home range), social organization (i.e., home range overlap), and habitat selection (i.e., den use, house use) of the principle prey of the California spotted owl, the northern flying squirrel and dusky-footed woodrat.
7. Determine the fitness correlates of a hibernating small-mammal, the golden-mantled ground squirrel, to forest management.
8. Evaluate the taxonomy and habitat affinities of two sympatric chipmunks, the long-eared and Allen's chipmunks, at multiple spatial scales.

METHODS

Live-trapping

Capture-recapture data obtained from the live-trapping methods described herein allow us to measure population parameters such as abundance, density, and frequency of occurrence of individual small mammal species and small mammal species richness and diversity, and permit the measurement of habitat use, availability and selection (Lancia et al. 1996, Litvaitis et al. 1996). Live-trapping methods are useful for making comparisons of small mammal communities across time, locations, habitats, and land-use treatments. We established several different live-trapping designs, each appropriate to the small mammal community or species of interest.

Long-term grids

To provide base-line information on small mammal populations inhabiting major forest types, and to quantitatively assess the impacts of forest management treatments on small mammal abundance and species diversity, we established 21 long-term grids using controls and pre- and post-treatment data. In 2007, all of the proposed treatments were implemented. All data collected between 2003 and 2006 were collected prior to any treatments to determine baseline conditions. In 2003, we established 18 semi-permanent, live-trapping grids (Fig. 1a); we established 3 additional long-term grids in 2005. Twenty grids consist of a 10 x 10 array of Sherman traps (Model XLK, 7.6 x 9.5 x 30.5 cm, H. B. Sherman Traps, Inc., Tallahassee, FL, USA) with 10 m spacing, nested within a larger 6 x 6 grid of 72 Tomahawk traps (Model 201, 40.6 x 12.7 x 12.7 cm, Tomahawk Live Trap, Tomahawk, WI, USA; 1 ground, 1 arboreal) with 30 m spacing (Fig. 1b). The remaining long-term grid was constrained by road configuration such that the array of Sherman traps was nested within a 4 x 9 grid of 72 Tomahawk traps (30 m trap spacing; 1 ground, 1 arboreal). Arboreal traps were placed approximately 1.5 to 2 m above the ground on a haphazardly-selected tree located <10 m from the grid point; arboreal traps may or may not be placed on the same tree each trapping session. Ground traps were placed within 1 m of the grid point under protective cover, such as a shrub or log, at small mammal burrow entrances, and along small-mammal run-ways, when possible.

We trapped all long-term grids (n=21) in 2007. All grids had 120 trap stations and covered 2.25 ha (3.24 ha with a ½ inter-trap distance buffer) of contiguous forest. Arboreal Tomahawk traps were removed from all grids on August 1, 2004 because of consistently poor capture rates; however, arboreal Tomahawk traps were again used in 2005 and thereafter, and capture rates were improved by placing the trap entrance flush against the tree bole, fastening the trap more securely to the tree, and switching to more a desirable bait mixture, in accordance with the recommendations of Carey et al. (1991).

The 18 long-term grids established in 2003 were placed in 5 principal forest types as described by Coppeto et al. (Publications #1 and #2). Forest types were defined by the dominant live tree species representing ≥ 70% of total tree composition, and included white fir (*Abies concolor, n* = 4), red fir (*A. magnifica*, *n* = 3), mixed fir (co-dominant mix of white fir and Douglas-fir, *Pseudotsuga menziesii*, *n* = 5), mixed conifer (*n* = 3), and pine-cedar (co-dominant mix of yellow pine, ponderosa pine–*Pinus ponderosa* and Jeffrey pine–*P. jeffreyi*, and incense cedar, *Calocedrus decurrens*, *n* = 3). In 2005, sampling grids were established in group selects located in white fir (n=2) and mixed-conifer (n=1) habitats. In an effort to more fully integrate our module with those of other research modules of the PLAS, Wilson et al. (Publication #5) used alternative forest type classes for these grids, as follows: white fir (n=9), red fir (n=3), Douglas fir (n=3), and ponderosa pine (n=3). According to this classification, the 3 group selects established in 2005 were placed within white fir habitat. Overall, PNF is dominated by white fir and Douglas fir so these forest types had proportionally more trapping grids placed within them. Common shrubs in the region include mountain rose (*Rosa woodsii*), Sierra gooseberry (*Ribes roezlii*), serviceberry (*Amelanchier utahensis*), bush chinquapin (*Chrysolepis sempervirens*), green- and white-leaf manzanita (*Arctostaphylos patula* and *A. viscida*), mountain dogwood (*Cornus nuttallii*), mountain whitethorn and deer brush (*Ceanothus cordulatus* and *C. intigerrimus*), bitter cherry (*Prunus emerginata*), and huckleberry oak (*Quercus vaccinifolium*). Pinemat manzanita (*Arctostaphylos nevadensis*) occurred almost exclusively in red fir forests, and buck brush (*Ceanothus cuneatus*) predominantly in pine-cedar/ponderosa pine forests.

Twelve of the long-term grids were placed within the experimental management plots established by the Vegetation Module of the PLAS. These 12 study plots were placed in 3 groups of 4 study plots, consisting of 1 control plot and 3 experimental plots (1 group select plot, 1 light thin, and 1 heavy thin). The remaining 9 study plots were not established in groups. Minimum distance among long-term grids (n=21) was 1 km with the exception of 4 grids that were 700-900 m apart. In 2006, one individual golden-mantled ground squirrel was documented to move between two grids in red-fir habitat. No small mammals were documented to move between any other long-term grids in any year.

Long-term grids were trapped monthly (May-October) during 2003-2004 and biannually (June, Oct) during 2005-2006. We sampled once in 2007 (July-August) because logging and prescribed burn activities at treatment grids restricted sampling activities. Trapping sessions consisted of 4 consecutive trap-nights. Sherman and Tomahawk traps were set and baited every evening just before dusk, and checked just after dawn; Sherman traps were then closed until dusk whereas Tomahawk traps were re-baited and checked again at mid-day, a minimum of 2 hours after the first trap check, at which point they were closed until dusk. This resulted in all traps remaining closed from 12:00 – 16:00. This enabled us to sample both diurnal and nocturnal species while reducing deaths that result from heat exposure during the hottest part of the day. Field technicians were thoroughly trained and rotated among grids each trapping session, to reduce the variability in capture success due to differences among technicians.

Prior to August 2005, all traps were baited with crimped oats and black oil sunflower seeds lightly coated in peanut butter; thereafter, traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. We changed the bait because the latter bait is recommended for capturing the difficult-to-capture northern flying squirrel (Carey et al. 1991). Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, synthetic bedding material (nonabsorbent polyethylene batting), and natural cover (e.g., bark, moss) or cover boards, were provided as needed for thermal insulation. After the trap session was completed, bait was deposited on the ground at the grid point and all traps were removed.

Demographic profiles.—Population demographics will be modeled by species using program MARK. Species that do not have enough individuals to generate detailed capture history will be modeled using the minimum number known alive (MNKA) parameter. Monthly or seasonal survival and population densities will be modeled for each species by habitat type using the Cormack-Jolly-Seber data type in program MARK. Suitable habitat parameters, such as cone production, will be incorporated into population models and can be used to identify habitat variables that are linked to population parameters using multivariate analyses.

Landbird grids

To complement the data collected at our long-term grids and more fully integrate our live-trapping efforts with that of other modules, we established temporary, small-mammal trapping grids at a subset of Landbird Module census points in 2006 and 2007. Eight to 10 census points within each landbird census transect were randomly selected for small mammal sampling; selection of census transects was stratified to include transects located throughout (former) treatment units 2-5. At each census point, a 2 x 2 array of live-traps with 50 m spacing was established by pacing 35 m from the census point in the four cardinal directions (north, south, east and west; Fig. 2). The live-trapping grids covers 0.25 ha (1 ha with a ½ inter-trap distance buffer). All live-trapping methods were designed to optimize the capture and recapture of the northern flying squirrel, the most difficult to capture small mammal in our study area, and in this way provide the best means of trapping for the full suite of small mammals, including the dusky-footed woodrat (Carey et al. 1991). The live-trap array we used ensured that the 4 trap-stations resided within the 50 m radius vegetation plot that was established by the Landbird

Module to access vegetation characteristics around each census point, and provided the recommended spacing between trap-stations and the suggested minimum number of trap-stations per home range area recommended for the northern flying squirrel (Carey et al. 1991).

One Sherman and 2 Tomahawk (1 ground, 1 arboreal) traps were placed at each point in the array; thus, each array consisted of 12 live-traps. Arboreal Tomahawks were placed 1.5 to 2 m above the ground on the largest tree within a 10-m radius of the grid point. The largest tree was chosen since large trees provide better support for the trap, thus improving functionality of the trap and improving capture success (Carey et al. 1991). Ground traps were placed within 1 m of the grid point and were placed under protective cover, such as a shrub or log, at small mammal burrow entrances, and along small-mammal run-ways, when possible.

Landbird grids were sampled during May – September 2006 and 2007. Each landbird grid trapping session consisted of 2 sets of 4 consecutive trap-nights each; each set was separated by 3 nights when no trapping was conducted, thus allowing a period of rest for animals from the stress of capture and handling (Carey et al. 1991). This trapping scheme ensured a duration short enough to avoid changes in the sampled population due to births, deaths, immigration, and emigration, and long enough to maximize the number of captures and recaptures of northern flying squirrels and other small mammals (Carey et al. 1991). All traps were set and baited every evening just before dusk; baiting was completed in 3-4 hours. Trap check began just after dawn and completed within 4-6 hours; thus, all traps were closed prior to 12:00 and remained closed until after 15:00 each day.

All traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, natural cover (i.e., bark, moss) or cover boards and synthetic bedding material (nonabsorbent polyethylene batting) were provided as needed for thermal insulation for all traps. To encourage capture and recapture of small mammals and to avoid damage to traps by black bear, traps were emptied of bait between trap sets and bait was deposited at the grid point. At the end of the trapping session, traps were again emptied of bait and bait was deposited on the ground at the grid point, and all traps were permanently removed.

Species Richness.— We analyzed species richness indices for each sampled landbird census point. Species richness is defined as the total number of species detected over the course of the trapping session. We utilized a restricted list of species that excluded species that are not accurately surveyed using our live-trapping method (e.g., shrews, skunks, hares). Following the completion of data collection in 2007, we plan to begin more detailed analyses of this data in close collaboration with the Landbird Module.

Northern flying squirrels

We captured and radiocollared northern flying squirrels at long-term grids, landbird grids, and at areas predicted to have moderate and high suitability for northern flying squirrels, hereafter flying squirrel transects. At long-term grids and landbird grids, northern flying squirrels were collared only in areas where triangulation was feasible, which required fairly large areas of habitat with one or two roads bisecting the area. In 2004, animals were captured and radiocollared at 3 long-term study grids located in upper elevation (2,100 m) red-fir habitat. Additional transects bisecting or parallel to original transects were established during 2005-2007 in order to increase the area covered and increase capture success. The 3 long-term grids and intervening habitat are hereafter referred to as study site FS-1. In 2005, we established a second study site, hereafter study site FS-2, in mixed-conifer forest located at 1,500 m elevation; in 2006 and 2007, additional transects bisecting or parallel to original transects were established. Study site FS-2 was selected using a GIS-based northern flying squirrel habitat-relations model developed using available information from the literature, which predicted poor, moderate, and high suitability habitat for northern flying squirrels. Although we established many live-trapping transects (>10) in areas predicted to have high and moderate suitability, study site FS-2 was the only study site to yield successful captures in an area where triangulation was also feasible; study site FS-2 was predicted to have moderate suitability for northern flying squirrels.

We primarily established flying squirrel transects along riparian areas, due to the importance of this habitat type to northern flying squirrels reported by Meyer and North (2005). If habitat, road configuration, and topography were suitable, we used a live-trapping grid (i.e., several parallel transects) to maximize the number of captures. We used a combination of Sherman and Tomahawk traps, typically 1 Sherman and 2 Tomahawk (1 ground, 1 arboreal) traps, spaced 40-50 m apart by pacing. Sherman and Tomahawk traps were set and baited every evening just before dusk, and checked just after dawn; all traps remained closed from 12:00 – 16:00. Prior to August 2005, all traps were baited with crimped oats and black oil sunflower seeds lightly coated in peanut butter; thereafter, traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, natural cover (i.e., bark, moss) or cover boards and synthetic bedding material (nonabsorbent polyethylene batting) were provided as needed for thermal insulation for all traps.

Dusky-footed woodrats

Four study sites (1,450–1,750 m elevation; Fig. 3) where established in early-seral forest (30–40 years post-logging), representative of the Sierra Nevada westside mixed-conifer forest type characterized by California black oak, sugar pine (*Pinus lambertiana*), ponderosa pine, Jeffrey pine, white fir, Douglas-fir, and incense cedar. All study sites had a brushy understory consisting primarily of deer brush, buck brush, and mountain whitethorn, with lesser coverage by green- and whiteleaf manzanita, and mountain dogwood. Each study site included 2–4 habitat types, which varied in composition of overstory and understory dominants, canopy closure, and aspect. Habitat type was defined by GIS data layers provided by the USDA, Forest Service. Study sites WR-1 and WR-2 had moderately sloping topography; sites WR-3 and WR-4 had mixed terrain or undulating topography. Because woodrat activities extended somewhat into adjacent habitats, we trapped woodrats at all houses located within approximately 3 home range diameters (ca. 180 m—Lynch et al. 1994, Cranford 1977, Sakai and Noon 1997) of each study site, to ensure that all woodrats potentially influencing the spatial structure at each study site were identified. Historic logging activities and fire suppression practices contributed to heterogeneity within study sites, with abundant dead wood as well as shrubby gaps interspersed with patches of closed canopy forest. Recent (<5 yr) management activities (e.g., prescribed burns, logging) have created open understory and overstory conditions in areas between study sites. Study sites lay 1.2–2.8 km apart, and no woodrats were recorded moving between study sites.

We systematically searched for woodrat houses in the spring and fall of 2004-2006 by walking overlapping belt transects that covered each study site. In addition, woodrat houses were opportunistically located at all study sites during a concurrent radiotelemetry study of woodrat movements. Each house was marked and its location mapped (≤1 m) using a GPS unit (Trimble Navigation, Ltd., Sunnyvale, California; GeoExplorer, GeoXT), and volume was estimated as a cone using measurements of length, width, and height.

Woodrats are active year-round, but our study was limited to the snow-free period (May-October). We documented house use by livetrapping in the spring (May–June) and late summer-early fall (August–September) of 2004-2006 with 4 Sherman live-traps (H.B. Sherman Traps, Inc., Tallahassee, Florida; 7.6 × 9.5 × 30.5 cm) set at the base of each house for 4 consecutive nights; longer trapping efforts (>4 consecutive nights) do not yield higher success (Carey et al. 1999; Laudenslayer and Fargo 1997; Willy 1992). Traps were baited with raw oats and sunflower seeds coated with peanut butter and opened at dusk and checked at dawn. Synthetic batting was provided for thermal insulation. Traps were set at all houses within each study site.

Golden-mantled ground squirrels

We studied golden-mantled ground squirrels at a long-term grid located in red-fir habitat at an elevation of 2,100 m during 2003-2005. Animals were captured with Tomahawk traps baited with rolled oats and sunflower seeds coated with peanut butter, set in the early morning and checked at mid-morning and noon. In 2003 and 2004, we experimentally manipulated maternal diets by supplying supplemental food to a sample of adult females (treatment females, n=6), to assess the effects of maternal condition on offspring growth and fat development as well as exploratory and dispersal distance, and compared treatment and control mothers (n=6) and their offspring. These 12 females were randomly assigned to control (n = 6) or treatment (n = 6) groups, uniquely marked with numbered Monel ear tags, and fitted with radio-collars. We radiotracked treatment squirrels animals to their burrows in late afternoon and dispensed ca. 30 g of black oil sunflower seeds per day of supplementation down the burrow opening. Supplemental feeding began on 1 September 2003 and took place 4 days per week until all individuals entered hibernation in early October. Individuals in the control group were trapped at the same interval as the treatment group, but were not provided supplemental food. We evaluated the effectiveness of food supplementation by comparing the slope of mass gain in female squirrels for control vs. treatment groups during the 2003 field season, with initial mass treated as a covariate. All females survived through the summer and entered hibernation. In spring 2004, we relocated and captured 7 study animals (3 treatment, 4 control), which were fitted with new radiocollars and radiotracked until their offspring (3 females had 2 offspring, while the fourth female had 3) emerged in early July. In 2005, we studied additional unmanipulated females (n=9) and their offspring (9 male, 5 female) to augment our data on control females and their offspring dispersal distances.

We attempted to capture all females and their offspring on a monthly basis to measure mass, body condition, and head+body length. At each capture we returned individuals to our field laboratory; there we chemically immobilized them with ketamine hydrochloride (100 mg/ml KCl), removed their radiocollars, and recorded rectal temperature, total mass to the nearest 0.1 g, and head+body length (measured as tip of nose to anus). We quantified body fat using the ToBEC method (Walsberg 1998, Koteja 1996). Conductivity was measured on anesthetized animals using an EM-SCAN SA-3000 body composition analyzer (EM-SCAN, Springfield, IL, USA). Pulawa & Florant (2000) calibrated the ToBEC machine for golden-mantled ground squirrels, and we used their calibration curve to obtain fat-free mass for our samples. Following analysis, the radio-collar was reattached, and the animal was allowed to recover before release at the site of capture.

Mothers and offspring were radiolocated from July-October 2003-2005. Location of all adult females was determined by triangulation ≥ 3 times daily for ≥ 5 days/mo from July to September 2003. Burrows were located by homing after animals had settled into their burrows for the night and locations were measured using a handheld GPS unit accurate to ca. 3 m. Burrow locations used for hibernation were noted to facilitate relocation of individuals the following spring. For use in calculating offspring exploratory behavior, we calculated 95% kernel home ranges for each mother.

Dispersal was defined as establishing a new home range distinct from the natal home range, and was identified using adaptive kernel home range estimators which produced two home ranges for offspring; one encompassed the natal burrow and one was the final place of residence before hibernation. Dispersal distance was calculated as the linear distance between the point of initial capture (mother's burrow) and the final location for a particular individual (presumed hibernaculum). We defined exploratory movements as round-trip visits to locations that were > 1 radius of the mother's home range from the offspring's initial point of capture.

All statistical analyses were performed using SAS (SAS Institute 2000). Comparisons of monthly maternal and offspring mass and percent fat were analyzed using a repeated measures analysis of variance (rmANOVA) with initial mass or percent fat as a covariate. All measures of percent fat and mass were log transformed prior to analyses. Analyses of offspring exploratory and dispersal distance were analyzed using a 2-way ANOVA with sex and treatment as explanatory factors. Because dispersal parameters usually are not normally distributed and because we had small sample sizes, all data were log transformed prior to analyses. Comparisons of the rate of mass or fat gain between treatment and control groups was quantified with linear regression (PROC REG) with tests of slope (β) and intercept differences. All data are presented as means ± standard error, and all differences were considered significant at $\alpha = 0.05$.

Chipmunks

Chipmunk species in PNF display considerable overlap in habitat requirements, diet, and activity. Two chipmunk species, the long-eared and Allen's chipmunk, are frequently captured during our live-trapping efforts. These species overlap greatly in external characteristics and are thus difficult to identify in the field (Clawson et al. 1994; Gannon and Forbes 1995). To date, the only sure means to identify these species is by using skeletal features obtained by sacrificing animals. To evaluate the habitat affinities and distribution of these chipmunks, we first needed a non-lethal means of identifying them in the field. First, we collected representative samples of chipmunks to identify species through the use of pubic bones, and collected tissue samples from these known species to develop molecular markers for non-lethal identification of chipmunk species in the future. We collected a sample of reference chipmunks throughout PNF by salvaging animals from trap mortalities at long-term grids and euthanizing a small portion of animals from landbird grids ($\leq$3 chipmunks per census transect). So as to avoid affecting capture-recapture data, animals were only collected on the last day of the trapping session. All specimens were frozen and submitted to the University of California, Davis Natural History Field Museum. Individuals collected were prepared as standard museum specimens (full skeleton plus skin) and tissues (e.g., liver, heart, muscle, and kidney) were collected for use in molecular analyses. Next, we collected tissue samples (small sections (< 1 mm) of ear pinna stored in cryovials containing 95% ethanol and stored in a freezer) from all chipmunks captured at long-term grids, landbird grids, and flying squirrel transects. Then, tissue samples and specimens were sent to the University of Idaho for molecular analysis to determine species identification; outside funding was secured for these analyses. Finally, we collected data on various aspects of each chipmunk's appearance. During 2005-2007, we recorded the presence of six external characteristics that have been suggested to visually distinguish between the two species. These are ear patch size and color, face stripe color and curvature, length and shape of the ear, and body color. We will use these data to compare external characteristics with molecular identification and skeletal features to determine what characteristics, if any, are reliable for species identification. Once we have identified individuals to species, it is then possible to examine habitat use and management implications for these species.

Animal handling

Similar animal handling protocols were used regardless of live-trapping sampling design. Captured animals were transferred to a mesh handling bag, identified to species, marked with numbered Monel ear tags (National Band & Tag Co., Newport, Kentucky), weighed, aged, measured (e.g., ear length, hind foot length), examined for reproductive status, and released at the point of capture. Total processing time for an experienced technician was generally <2 minutes. Reproductive condition for males was noted as either scrotal (enlarged and scrotal testes) or non-scrotal (reduced and abdominal testes); for females, the vagina was noted as either perforate (thereby receptive) or imperforate (not receptive), the vulva as either swollen or not, and the animal as lactating (nipples were enlarged and/or reddened, reflecting nursing offspring), or not. Animals were aged based upon a combination of weight, pelage (juvenile: gray, subadult: intermediate, and adult: brown), and reproductive condition (juvenile/subadult: nonreproductive, adult female: pregnant/lactating, and adult male: scrotal).

At initial capture, a tissue sample was collected from each animal. Tissue samples were collected by snipping the terminal 1 mm of ear tissue using sterile surgical scissors and placing the tissue in a Nunc cryovial with 95% Ethanol. Tissue samples were placed in a freezer for long-term storage to preserve genetic material for current and future studies. Prior to 2006, we collected tissue samples from dusky-footed woodrats and chipmunks. In 2006, we collected tissue samples from all captured animals. In 2007, we collected tissue samples from chipmunks and northern flying squirrels.

Any trap mortality, including incidental trap deaths, is thoroughly documented, and specimens are frozen and submitted to the University of California, Davis Field Museum of Natural History, in accordance with the permitting requirements of the California Department of Fish and Game and used for the educational and research purposes of the PLAS, and other interests. All field work and handling procedures are approved by the University of California, Davis Animal Use and Care Administrative Advisory Committee protocol (#10394), and meet guidelines recommended by the American Society of Mammalogists (Animal Care and Use Committee 1998).

Radiotelemetry

Movement data obtained from the radiotelemetry methods described herein allow us to measure home range, movement patterns, and social organization of individuals, permit the detailed measurement of habitat use and selection, and document the location and frequency of use of denning, nesting, and resting sites (Lancia et al. 1996, Litvaitis et al. 1996). Radiotelemetry methods are useful for making comparisons of small mammal movements and space use across time, locations, habitats, and land-use treatments. We applied radiocollars to a subset of dusky-footed woodrats and northern flying squirrels and radiolocated them during the day during resting activities and at night during foraging activities.

Radiotransmitter application

During 2003-2006, we applied radio transmitters to northern flying squirrels and dusky-footed woodrats. In 2007, we applied radio transmitters to northern flying squirrels only. A 4.0 g collar-type radio transmitter (Holohil Systems Ltd., Model PD-2C) was placed on the neck of individuals. Woodrats and northern flying squirrels were lightly sedated with ketamine hydrochloride (100mg/ml), or a combination of ketamine, xylazine, and saline solution, injected into the thigh muscle to facilitate application of radio-collars. Animals were allowed to fully recover from anesthesia prior to being released at the point of capture. Radiotelemetry activities of newly collared individuals were initiated after a 24-hour acclimation period succeeding their release.

Homing

To document the location and frequency of use of denning, nesting, and resting sites we used homing techniques. For northern flying squirrels, diurnal locations were determined once per day, sporadically in 2003-2005 and 1-2 days per week in 2006 and 2007. For dusky-footed woodrats, diurnal locations were determined once per day, sporadically in 2003 and 3 days per week in 2004 and 2005 and 1-2 days per week in 2006. Locations were marked and accurately (≤ 1 m) mapped using a Trimble GPS unit.

Triangulation

Nocturnal telemetry sessions using triangulation techniques occurred during 5 nights per month in 2003 and 8-10 nights per month during 2004-2007. We used a Yagi antenna and a hand-held radiotelemetry receiver (Model R-1000, Communications Specialists, Orange, CA, USA) to obtain the location of radiocollared animals. Compass bearings for the radio-collared animal were obtained by using a hand-held compass and bisecting the signal drop-offs. Fixed telemetry stations, mapped to within 1 m accuracy using a Trimble GPS unit were located remotely from the transmitter's position to avoid disturbance of the radio-tagged animal. Technicians worked in synchronized teams to achieve 3 (or more) directional bearings within as short a time interval as possible (typically <15 minutes). Radiolocations were obtained for each animal 2-3 times per night, a minimum of 2.5 hours and 1 hour apart for dusky-footed woodrats and northern flying squirrels, respectively, to avoid serial correlation (Swihart and Slade 1988, Taulman and Smith 2004). Observers subjectively ranked their confidence in the accuracy of a signal based on signal flux due to animal movement, topography, vegetation, and distance, using a scale from 1-10, where 1 represents no confidence (signal faint and fluxing, signal drop-offs indistinct) and 10 represents high confidence (signal strong and steady, signal drop-offs distinct); these rankings were then divided into 3 categories: low (1-3), medium (4-6), and high (7-10) confidence. Haskell and Ballard (2007) determined that a similar ranking was correlated with absolute bearing error and could be used to increase the accuracy of location estimates. The timing of nightly telemetry was varied from dusk until dawn to ensure that radiolocations were sampled at different times of activity. Field technicians were thoroughly trained and rotated among stations and study sites each radiotelemetry session, to reduce the error due to differences among technicians. To ensure the accuracy of the triangulation method, triangulation systems were tested each night during regular radiotelemetry activities using 1-2 "dummy" collars placed within each study area; technicians did not know dummy collar locations, and the dummy collars were moved about once per week. To assess bearing error rates, dummy collar locations were determined and compared to their actual location.

Home range analysis

Northern flying squirrels.—We combined locations determined via homing and triangulation to estimate each animal's home range using 2 methods, the minimum convex polygon method (MCP, Fig. 4), and the kernel method (Fig. 5; Fuller et al. 2005). For MCP, a home range is defined by drawing lines that connect the outermost points to form a contained area. This area can be sub-sampled for habitat quality or compared with home ranges of different individuals by looking at area and overlap of home ranges. The kernel method uses utilization distributions to estimate focal points of activity within the home range. This method weighs areas with a high density of points more heavily than areas with fewer points to generate “core areas” (Silverman 1986, Worton 1989). Examining core areas can be informative; for example, by examining differences between animal focal areas and other less used areas within or outside the home range. We used the maximum-likelihood estimator method (Lenth 1981) in the software program Locate III (Nams 2006) to estimate locations and error ellipses for triangulations. We used several criteria to evaluate bearing data and determine animal locations. These included convergence of bearings, presence of outliers, number of bearings (≥ 3), and signal rank. All bearings with low confidence were excluded from analysis. Bounce was an issue that contributed to large error at our study sites. To address this issue, we removed the two most divergent bearings until no fewer than 4 bearings were used for triangulation. This was possible because in 2007 we typically took 6 simultaneous bearings for each animal. Accepted locations were analyzed in Ranges6 (Kenward et el. 2003). We estimated home range (95%) and core range (50%) using the minimum convex polygons (MCP) and fixed kernel (FK) methods (Kenward 2001).

During 2004 and 2005, we calculated an index of activity for northern flying squirrel throughout the night. We measured the distance between each location and the nearest known den tree. These distances were used to generate a time series of distances each individual was found from its nearest den tree. We constrained this analysis to the period between 18:00 and 06:00 as that represented the active time for flying squirrels (Weigl and Osgood 1974). Analysis of home range size and nocturnal activity was performed for northern flying squirrels using a 2 x 2 factorial design, with habitat (FS-1: red fir, FS-2: mixed conifer) and time of night (4 categories) as primary factors, and sex (male, female) as the secondary factor. PROC MIXED was used to calculate F-test values, and Satterthwaith’s approximation was used to calculate the degrees of freedom for the error term (SAS Institute 2000). If there were no significant interactions, differences in the main effects were compared using the PDIFF option in the LSMEANS statement. Differences in terms with significant interactions were compared using the SLICE option in the LSMEANS. All data are presented as means ± standard error, and all differences were considered significant at $\alpha = 0.05$.

Dusky-footed woodrats.— We used radiotelemetry to determine space use of woodrats during 2004 to 2006 at study sites WR-1 and WR-2 (Fig. 3). We used the maximum-likelihood estimator method (Lenth 1981) in the software program Locate III (Nams 2006) to estimate locations and error ellipses for triangulations. We excluded all triangulations for which >50% of bearings received a rank of low confidence. Locations ≥1 km from the station to the transmitter also were excluded (Schmutz and White 1990). We used Ranges6 (Kenward et el. 2003) to calculate incremental area analysis, home range, core area, and overlap among individuals. All analyses used a combination of nocturnal movement locations and diurnal locations obtained from trapping and homing. Because a given woodrat was often found multiple times at 1 house, we used only 1 diurnal location per house to avoid biasing core area estimates towards house locations, resulting in about 80% of locations being nocturnal.

Minimum convex polygon (MCP—Mohr 1947) and fixed kernel (FK—Worton 1989) methods were used to calculate home range and core area. MCP home range (95%) and core area (50%) were calculated using the arithmetic mean (Nams 2006). Incremental plots of home range size versus number of locations were inspected for each individual using Ranges6 to check that the range area reached an asymptote; if an asymptote was not observed, then that individual was excluded from further analysis (Kenward 2001). We found that a minimum of 16 (mean=24.5±1.3) locations was required to reach an asymptote in home range area using MCP. In addition, woodrats that were radiocollared for <30 days were also excluded because of the short duration. Application of these criteria resulted in the exclusion of 12 collared woodrats (2 in 2004; 7 in 2005; 2 in 2006), all of which appeared to have been killed by predators shortly after collaring. In addition, 5 collared woodrats (2 in 2004; 3 in 2005; 0 in 2006) were excluded from analyses because they were transient or resided outside of the study areas. Fixed kernel volume contours (95% home range, 50% core area) were calculated utilizing the least-squares cross-validation method in Ranges6 for those animals with ≥30 locations (Seaman et al. 1999, Millspaugh et al. 2006); application of this criteria resulted in the exclusion of 17 additional individuals for FK analyses.

We calculated an index of overlap (OI; Minta 1992), with possible values ranging from 0 (no overlap) to 1 (100% overlap). For each study site and year, we calculated OI for home ranges and core areas for each male-male, male-female, and female-female pair. We only included woodrats whose home ranges overlapped with ≥1 other home range. All overlap calculations were based on MCP home ranges and core areas, because we did not want to exclude any potentially interacting individuals from overlap calculations, and to facilitate comparison with previous studies (e.g., McEachern 2005).

We assessed synchronous and asynchronous sharing and successive occupancy of houses by all radiocollared woodrats based on diurnal locations, when woodrats are inactive within their houses. Duration of house sharing was determined by assuming sharing occurred between successive radiolocations. We examined placement of houses within core areas using FK because it relies on probability distributions, which indicate areas of intense use (Seaman and Powell 1996).

All statistical tests were performed using JMP IN 5.1.2 (SAS Institute 2004) and significance was set at α=0.05 and Bonferroni-corrected for multiple comparisons, when appropriate. Only 10% of woodrats were radiocollared for two consecutive years, thus we considered data from different years to be different samples. Differences among groups were analyzed using analysis of variance (ANOVA) after transformation to meet assumptions of normality (Kutner et al. 2005). The Wilcoxon rank scores test was used to test for differences between groups when data could not be transformed to meet assumptions of normality.

Vegetation

Long-term grids

Coppeto et el. (Publications #1 and #2) provides a detailed analysis of the macro- and microhabitat associations of the full compliment of small mammal communities within 18 long-term grids established within 5 habitat types in PNF during 2003-2004. The

Mammal Module staff did not measure the macro- or microhabitat characteristics on the long-term study grids 2005-2007, although the Vegetation Module has continued to monitor habitat and microclimate characteristics on a portion of these plots.

Cone Counts.—To evaluate the effects of conifer seed production on small mammal abundance, we measured cone production during fall of 2003, 2004, 2006, and 2007 using 10 randomly selected individual trees of each species on each long-term grid. For this we selected mature dominant or codominant trees with pointed crowns, as tall as or taller than the surrounding canopy, sufficiently far apart that their crowns did not touch. For grids with <10 individual trees of a given species, additional trees were found as close to the grid as possible (<500 m). The same trees were counted in each year within the same 2-wk period to prevent confounding temporal factors. Counting was performed by standing at a distance of ≥1.5x the tree height and visually counting cones using binoculars. For each tree we recorded tree height, diameter at breast height (DBH), species, and crown class. Temporal differences in cone production were determined using repeated measures analysis of variance (rmANOVA) with year, habitat type, and species as treatments, and individually counted trees as the repeated measure.

Landbird grids

Microhabitat characteristics were sampled at landbird grids May-October, 2006 and 2007. All measurements were recorded within a 1-m radius circular plot (3.14 m^2) centered at each grid point. We followed the protocols and definitions established by Stephanie Coppeto (Publications #1 and #2); however, we measured canopy closure using a Moosehorn with an 8.5 × 8.5 cm grid viewed at eye-level (1.7 m) from the center of the plot, and recorded the number of squares obscured by vegetation, as opposed to using hemispherical photographs, due to logistical constraints. We visually estimated percent cover of the same 12 ground cover and recorded 3 species richness variables (Publication #2, Table 1). We used the following ground cover classes: 0, rare, 1, 5, 10, 15, …, 90, 95, 99, and 100%, since these cover classes approximate a normal distribution. In addition, we tallied the number of trees of each species at each point using a Panama gauge. All ocular estimates were performed by trained observers.

Northern flying squirrels

Den use.— We documented northern flying squirrel den locations during homing activities, and a number of measurements were taken at these dens to determine the habitat preferences of squirrels. These data will be used to test for tree use versus availability. We recorded the DBH, species, condition (live tree, snag), den height, and type (cavity or external) of each den tree. We measured habitat characteristics at den locations and paired random points. Den plots were centered on the den tree, and paired with a plot whose outer edge intersected the outer edge of the den plot. All trees ≥10 cm DBH within an 18 m radius (0.1 ha) were measured and species recorded. Additionally, decay characteristics (fungi present, cavities) were noted and epiphyte loads estimated according to the methods of Bakker and Hastings (2002) to see if northern flying squirrels showed any preferential selection of den trees within sites. All trees <10 cm DBH were tallied. Estimates were taken of ground cover to the nearest percent. Dominant over- and understory trees were recorded as well. Spherical densiometers were used to take canopy measurements in a randomly selected direction at the edge of the plot, with 3 successive measurements at 90° from the first. Canopy readings were also taken at the plot center. Two randomly chosen transects were used to estimate coarse woody debris. Degree of decay, length, diameter and both ends, and species were recorded. All woody debris ≥10-cm diameter at the largest end were measured and recorded. Percent slope at each site was estimated using a clinometer. We measured habitat characteristics at 78 northern flying squirrel dens and 78 paired comparison plots during 2006–2007.

Dusky-footed woodrats

Macrohabitat selection.—To determine if woodrat density was positively related to California black oak abundance, we estimated California black oak density (ha^{-1}) at each study site by counting trees ≥5 cm DBH during September 2005 in 10 x 100 m belt transects placed in a stratified random fashion, such that ≈ 10% of the total area was sampled. We regressed mean adult woodrat density (2004 and 2005 combined) on oak density. Because California black oaks begin to produce acorns in substantial quantities (>9 kg) at about 80 years of age (≈ 33 cm DBH—McDonald 1969), we ran separate analyses on small (<33 cm DBH) and large (≥33 cm DBH) oaks. We assessed the relationship between mean adult woodrat density and California black oak density among the 4 study sites with simple linear regression using JMP IN 5.1.2 (SAS Institute 2004). Because we predicted a positive association, we used a 1-tailed test. We ran residual diagnostics to confirm that the model was appropriate for the data set (Neter et al. 1996).

Microhabitat selection.—We measured microhabitat variables within a 4-m radius circle (50.3 m^2) centered on 144 houses and 144 paired random sites during September–November 2003, May–October 2004, and May–September 2005. Plot size was based upon ocular estimates of patch size at woodrat houses (i.e., the microhabitat changed beyond a 4-m radius). We randomly selected 66% and 87% of houses at sites WR-1 and WR-2, respectively, where houses were more abundant, and sampled 100% of houses at sites WR-3 and WR-4.

At each woodrat house, we visually estimated percent cover of 3 ground cover variables and measured density and cover of shrubs, trees, snags, stumps, and logs (Table 2). We determined density of short and tall shrubs by counting individual stems. To determine if woodrats were selecting for greater density and basal area of smaller trees, we measured density (ha^{-1}) and basal area ($m^2 ha^{-1}$) of tree species in 4 DBH classes modified from Bell and Dilworth (1993): sapling, poletimber, small sawtimber, and large sawtimber. California black oak may be important at the microhabitat level as well as the macrohabitat level; hence, we excluded California black oak trees from tree density and basal area calculations and examined the presence of small (<33 cm DBH) and large (≥33 cm DBH) oaks separately. We recorded the presence of large (≥30 cm DBH) snags because we observed that woodrats frequently accumulate debris in the cavities of large snags. We measured tree and snag diameters using a diameter tape. We measured the diameter at root collar (DRC) of stumps using a measuring tape, and recorded the presence of large (≥30 cm DRC) stumps because these were big enough to provide a platform for debris. We measured the diameter and length of logs using calipers and a measuring tape, and the volume of each log (m^3ha^{-1}) was estimated as a frustrum paraboloid using log length and diameters at both ends (Bell and Dilworth 1993). The percent of canopy closure was quantified using a Moosehorn with an 8.5 × 8.5 cm grid viewed at eye-level (1.7 m) from the center of the plot, and the number of squares obscured by vegetation was recorded. Slope was measured using a clinometer. All ocular estimates were performed by one observer (RJI).

We also sampled, with replacement, the same vegetation and structural characteristics at paired points located a random distance (10–50 m) and a random direction from the center of each house. Random sites were constrained to lie within the same habitat type as the paired house. The distance requirement ensured that the random sites fell outside of the sampled house site, but within the estimated home range of a dusky-footed woodrat (1,942–4,459 m^2—Cranford 1977; Lynch et al. 1994).

House-site selection.—We used conditional logistic regression (CLR) to predict the odds of finding a house at a certain location given the explanatory variables. CLR can fit a model based on conditional probabilities that "condition away" or adjust out the grouped effect (Stokes et al. 2001). We considered each house-random pair to be separate strata, adjusted out subject-to-subject (i.e., house-to-house) variability and concentrated on within-subject (i.e., house-to-random) information. In this way, CLR conditions out variability due to macrohabitat differences and concentrates on variability due to microhabitat preference. Quantitative comparisons of microhabitats are possible by examining odds ratios, which indicate the increased likelihood of the outcome with each unit increase in the predictor given the covariate pattern (Keating and Cherry 2004).

Prior to CLR analyses, we examined Spearman's rank correlations between variables to identify collinearity. Variables that were highly correlated ($r_s \geq |0.7|$) and those that explained similar biological phenomena were not included together in multivariate models (e.g., sapling density and sapling basal area, $r_s = 0.98$; Hosmer and Lemeshow 1989). In addition, we performed univariate CLR using PROC PHREG in SAS 8.02 (SAS Institute 2001) to reduce the number of candidate variables for model building. We compared microhabitat variables between house and random sites and included habitat type ($n = 10$) as an interaction term in each single-variable model because we hypothesized that some variables might respond differently among habitats. We retained those variables with P-values ≤ 0.25 from log-likelihood ratio tests or variables that had significant habitat type interactions (Hosmer and Lemeshow 1989).

We then performed multivariate CLR to determine which combination of microhabitat variables best discriminated between house and random sites. We built CLR models using forward stepwise selection using the screening criteria recommended by Hosmer and Lemeshow (1989—$P = 0.15$ to enter and $P = 0.20$ to remove), so as not to exclude potentially important variables from the model. At each step, we selected the model with the lowest Akaike's Information Criterion (AIC) value, and combined this model with all other variables (Table 3); the best model was that with the lowest AIC value, and any model within 2 AIC points of the best model was considered to be a competing model (Burnham and Anderson 1998). The final model(s) were those for which all coefficients were significant. We examined model residual chi-square and residual diagnostics to further assess model goodness-of-fit (Hosmer and Lemeshow 1989; Stokes et al. 2000).

House use.—We used a reverse stepwise multiple logistic regression (MLR) no-intercept model to determine if there were combinations of microhabitat variables that best distinguished houses used and unused by adult woodrats, and to compare houses used by adults and subadults. All 21 variables were included in MLR models; in addition, we included house volume (above versus below the median of 0.3 m^3; "large" versus "small," hereafter) to determine if house size influenced use (Vestal 1938). MLR was applied using JMP IN 5.1.2 (SAS Institute 2004). Only houses used exclusively by an adult or a subadult were included in analyses; houses at which an adult and a subadult were captured at least once during the 4-day trapping session were omitted from analyses comparing adult and subadult house use, resulting in the omission of 6 houses in 2004 (4.2%) and 4 houses in 2005 (2.8%). Juvenile woodrats were excluded from all analyses. Significance level for all tests was set at $\alpha = 0.05$. All means are presented as ± standard error.

Tree house characteristics and use.— We examined tree house characteristics and use during 2004 to 2006 at 2 study sites WR-1 and WR-2 (Fig. 3). Ground houses were those located on the soil surface or on downed wood. Tree houses were characterized as either built within a tree cavity or externally on limbs. For all tree houses, we recorded whether the tree was alive or a snag and the species of live trees. We measured diameter at breast height (dbh; cm) of a random sample of the trees in which houses were found (88% and 83% of house trees at study sites 1 and 2, respectively). We determined tree availability by counting all trees and snags (≥5 cm dbh) in randomly located, 4-m radius circular plots (72 at site 1, 77 at site 2), and recorded tree and snag characteristics for each plot. We based house use analyses on radiotelemetry locations during the daytime period of inactivity determined using homing. For each woodrat, we calculated the proportion of radio locations occurring at each house type (ground or tree), then averaged across individuals and years by sex. We tested for differences in tree house use between sexes each month using the Wilcoxon rank scores test. Because we found no difference in proportional availability and use of houses between sites, results from the 2 study sites were combined for all analyses.

Acorn Counts.—We hypothesized that there would be a positive relationship between adult dusky-footed woodrat density and annual acorn crop; therefore acorn production of California black oak was measured on 25 and 28 trees located at woodrat study sites WR-1 and WR-2, respectively. Dusky-footed woodrat study sites WR-3 and WR-4 had insufficient densities of mature oaks to estimate mast crops at these locations. Mature (≥33 cm DBH), dominant or co-dominant California black oak trees with visible crowns in a variety of conditions (e.g., mistletoe, bole cavities, broken tops) were arbitrarily selected as sample trees without a priori knowledge of the acorn production potential of the trees and somewhat stratified to include a range of sizes (range: 33.7-75.2 cm DBH). Sample trees were permanently marked with aluminum tags for future surveys. We recorded DBH, height, crown width and condition since these factors are known to influence acorn yield (Macdonald 1969). We visually estimated acorn production in early September, just prior to acorn drop when acorns are most readily visible, using the methods developed by Garrison et al. (1998) for California black oak in Placer County, California. One observer made counts in two randomly selected parts of the tree by visually dividing the tree's live crown into a lower and upper half and further dividing each half into thirds. A random numbers table was used to select a subdivision in the lower and upper halves for counting. Binoculars were used to scan the crown and the observer counted as many apparently viable acorns as possible within 15 seconds. Visual counts of acorns for the two 15 second count periods were combined to yield a total count for a 30 second period. Visual counts of California black oak acorns using this method have been shown to be an adequate index of overall acorn production as well as the amount of acorns available as food for wildlife (Garrison et al. 1998).

RESULTS AND DISCUSSION

We have been making steady progress towards our objectives. In 2007, we completed several projects. In addition to successfully completing an extensive (1 May-1 November) field season, our study module has produced quality peer-reviewed publications and other products. In 2007, we had 3 manuscripts in publication, 2 manuscripts in review, and several more in preparatory stages. We have chosen to present the abstracts of our published, submitted, or in preparation manuscripts herein as a representation of the work that we have completed to date. Publications #3, #6, #9, and #11 are new to this year's annual report

Long-term grids

One of our objectives for the long-term grid data is to determine small mammal habitat associations at macro- and microhabitat scales (Objective #1). We have examined this at our long-term grids and include this summary herein (Publications #1 and #4). Another objective for our long-term grid data was to determine small mammal population trends, evaluate how populations are changing temporally, and assess the factors responsible for the observed trends (Objective #5). We have documented the dynamics of small mammal abundance at long-term grids since 2003, and we have currently evaluated trends using data from 2003-2004, and include this summary herein (Publication #8). In 2007, the planned treatments were implemented and data on small mammals were collected immediately after the treatments were completed. This coming field season we will collect the first full year of post-treatment data. We will analyze data obtained at long-term grids pre-treatment (2005-2006) and post-treatment (2007-2008) to assess the impacts of forests management treatments on small mammal abundance and species diversity (Objective #4).

Publications #1 and #4: Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada

Effective management strategies require an understanding of the spatial scale at which fauna use their habitat. Towards this end, small mammals were sampled in the northern Sierra Nevada, California, over 2 years (2003-2004) at 18 live-trapping grids among 5 forest types (Fig. 1a). Macrohabitats were defined by overstory tree composition, and 19 microhabitat variables were measured at all trap stations (Table 1). Macrohabitat and year explained 93% of variation in abundance of deer mice (*Peromyscus maniculatus*), whereas 69% was explained by microhabitat and year. Variation in abundance of *Tamias* sp. (long-eared and Allen's chipmunk) was slightly better explained by microhabitat and year (70%) than by macrohabitat and year (67%). Red fir forests supported significantly more mice and chipmunks than mixed conifer and pine-cedar forests, and more chipmunks than mixed fir forests. Five of 6 uncommon species were significantly associated with macrohabitat type; golden-mantled ground squirrels, northern flying squirrels, and *Microtus* sp. (long-tailed vole–*M. longicaudus*; Mountain vole–*M. montanus*) were captured almost exclusively in red fir forests, whereas dusky-footed woodrats and California ground squirrels were found in pine-cedar, mixed fir, and mixed-conifer forests. The first 2 axes of a canonical correspondence analysis on microhabitat variables explained 71% of variation in combined small mammal abundance. Microhabitat associations varied among species but were driven primarily by canopy openness, shrub cover, and shrub richness. Although much of the small mammal fauna appeared to select habitat at both spatial scales studied, CCA using macrohabitat as a covariate revealed that microhabitat explained much less of the variation in small mammal abundance than did macrohabitat. Still, the strongest scale of association may be species-dependent and hierarchical in nature.

Publication #8: Population dynamics of small mammals in relation to cone production in four forest types in the northern Sierra Nevada

We studied the small mammal assemblage in 4 forest types (white fir, red fir, Douglas fir, and ponderosa pine) in the Sierra Nevada of California for 2 consecutive field seasons (2003-2004). We also assessed cone production by dominant conifer species in both years. Cone production was greater overall in fall 2003, but varied within forest type and between conifer species (Fig. 6). Parallel to this, mean maximum densities of deer mice increased in 2004 (from 0.7 - 7.3 ind./ha to 65.7 - 112.7 ind./ha; Fig. 7). Numbers of golden-mantled ground squirrels were similar in both years, and displayed the typical pattern of a hibernating species, with low densities in May (6.6 ± 0.2), peak densities in September (24.5 – 32.5 ind./ha), and declines in October (9.2 ± 4.8; Fig. 8). Long-eared chipmunks reached higher densities in red fir (48.2 ± 13.4 ind./ha) and Douglas-fir forests (36.0 ± 13.5 ind./ha) than in white fir forests (7.6 ± 2.7 ind./ha), and all populations peaked in September. Allen's chipmunk remained at lower densities than long-eared chipmunks except during September 2004, when populations of the former reached high densities (54.6 ± 26.8 ind./ha; Fig. 9). Survival of deer mice was dependant on an interaction between forest type and month with additive effects of winter and 2003 fall mean cone production. Golden-mantled ground squirrel survival varied by month whereas survival in both species of chipmunk varied by an interaction of forest type and month + winter (Table 4). Dusky-footed woodrats were present at lower elevations and reached greatest densities in ponderosa pine forests. Northern flying squirrels were uncommonly captured and found predominantly in red fir forests.

Publication #9: Trapping rodents in a cautious world: the effects of disinfectants on trap success.

Recommendations for hantavirus prevention include disinfecting traps that have captured small mammals. However, the potential effects of disinfection on small mammal trappability have not been thoroughly investigated. We conducted an experiment to compare the effects of 2 disinfectants (Lysol and household bleach) on trappability of 3 small mammal species (deer mice, chipmunks, and golden-mantled ground squirrels). We established triplicate trap grids in 2 forest types (red fir and mixed conifer), each consisting of a 6 x 6 array of Sherman live traps placed at 10 m intervals. Traps were given 1 of 3 treatments: control (water), Lysol, or bleach; and were placed such that the 3 treatments alternated in a regular pattern. Traps were run for 4 consecutive nights with application of each treatment daily. We found a difference in the trappability of deer mice between years; however we did not detect a statistically significant difference in trappability due to disinfection for any of the 3 study species. Within deer mice, disinfectant effects on capture probability were not supported by model selection in Program MARK. These results indicate that although populations may fluctuate temporally and spatially, trap disinfection does not have a significant effect on small mammal trappability.

2007 Field Season

During the 2007 field season we captured and marked a total of 732 individuals of 10 species. Predominant species in the study area included deer mice, brush mice (*Peromyscus boylii*), long-eared and Allen's chipmunks, California ground squirrels (*Spermophilus beecheyi*), golden-mantled ground squirrels, dusky-footed woodrats, Douglas squirrels (*Tamiasciurus douglasii*), long-tailed voles, and northern flying squirrels. Incidental mammals captured included shrews (*Sorex* sp.) and western gray squirrels (*Sciurus griseus*).

In 2007, abundance of mice and chipmunks reached levels not observed since 2004 (Fig. 10-11). We noticed a marked increase in capture rate of northern flying squirrels at long-term grids in 2005, 2006, and 2007 as compared with 2003 and 2004 (Fig. 13). This marked increase in northern flying squirrel abundance is likely the result of an improved bait mixture and arboreal trap placement, protocols implemented in the fall of 2005; however data since 2005 indicate that northern flying squirrel abundance has steadily increased over the past 3 years, particularly within mixed-conifer forest, a trend which cannot be explained by differences in sampling protocols. Interestingly, during this time woodrat abundance at long-term grids steadily declined, and presence of woodrats in 2007 remained only within mixed-fir habitat (Fig. 12), the only habitat within which northern flying squirrel abundance declined over the past 3 years.

Landbird grids

Landbird grids were established to compliment the data collected at our long-term study grids and more fully integrate our live-trapping efforts with that of other modules. The 2007 field season marks the second and final year of data collection at landbird grids. In the near future we plan to begin more detailed analyses of this data in close collaboration with the Landbird Module.

2007 Field Season

We sampled small mammals at 192 points within 24 transects located in 4 (former) treatment units in 2007. During the 2007 field season we captured and marked a total of

1,528 individuals of 12 species. Species captured included dusky-footed woodrats, deer and brush mice, long-eared and Allen's chipmunks, California and golden-mantled ground squirrels, mountain, long-tailed, and California red-backed (Clethrionomys occidentalis) voles, Douglas squirrels, and northern flying squirrels. Incidental mammals captured included shrews, snowshoe hare (*Lepus americanus*), striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), short-tailed weasel (*Mustela erminea*), and ringtail (*Bassariscus astutus*).

In total, we sampled small mammals at 367 points within 44 landbird transects across 4 (former) treatment units at a total of 1,468 trap locations for 11,396 trap nights, and captured 2,513 individual small mammals during 2006 and 2007. Deer mice (n=1,041) were captured at 75% of points and were the most commonly captured species followed by chipmunks (47% Allen's chipmunk, n=781; 28% long-eared chipmunk, n=261), brush mice (23%, n=188), golden-mantled ground squirrels (11%, n=93), northern flying squirrels (10%, n=58), California ground squirrels (10%, n=65), dusky-footed woodrats (8%, n=54), and Douglas squirrels (4%, n=17). Other species were captured at ≤2% of plots. We measured habitat characteristics in 3.14 m^2 plots centered about trap locations at all trap locations in 2006 and 2007 (n=1,468).

In 2007, we captured 36 northern flying squirrels (24 males, 12 females) at 15 landbird transects and 14 of these were recaptured. A majority (82%) of northern flying squirrels were captured in tree traps, emphasizing the importance of this trapping method. Two individuals captured at 2 landbird transects were radiocollared. In addition, we captured 12 dusky-footed woodrats (6 males, 6 females) at 5 landbird transects; 7 of these were recaptured.

In total, we captured 58 flying squirrels at landbird transects during 2006-2007. Most notably, nearly 30% of all flying squirrel captures occurred at a single transect (transect 223 in TU 2). Also, over 50% of dusky-footed woodrat captures occurred at 2 transects (BLH2 and HAL2 in TU3). We determined small mammal species richness at all sites sampled in 2006 and 2007 (Fig. 14-17). Species richness ranged from 0-5. Mean species richness was greatest at TU-2 (2.59, n=82), and TU-5 (2.46, n=80), followed by TU-4 (1.95, n=113) and TU-3 (1.88, n=92). In the future we hope to examine how landbird species richness compares to small mammal species richness at a site (i.e., are areas of high landbird species richness also areas of high small mammal species richness?).

Northern flying squirrels

We have captured and radiotracked northern flying squirrels since 2004 in an effort to evaluate the abundance and distribution, habitat use, and home range of this important species (Objective #6). We have examined data from 2004-2005 and include this summary herein (Publication #7). We continued these efforts during 2006 and 2007 to increase our sample size and improve our statistical power; 2007 marks the final year of northern flying squirrel radiotracking. Data from 2006 and 2007 will be included in an additional publication (Publication #3).

Publication #7: Home range and activity of northern flying squirrels in the northern Sierra Nevada

We studied the northern flying squirrel in PNF using radiotelemetry. Fourteen northern flying squirrels from 2 forest types (mixed conifer and red fir; Fig. 18) were fitted with radiocollars and provided sufficient locations for home range analysis. We used 95% adaptive kernel and 95% minimum convex polygon (MCP) analysis to determine home ranges (Table 5). No sex differences and no differences in forest type were observed for home range size (Fig. 18). Mean kernel home range size was 25.7 ha for all squirrels. Mean distance to the nearest nest tree did not vary throughout the night; however, females tended to travel greater distances from nest trees (Fig. 20).

Publication #3: Home range and habitat selection of northern flying squirrels in the northern Sierra Nevada

Average home range size for female northern flying squirrels during 2006 using 95% MCP was 12.55 ha ± 2..58 and using 95% FK was 17.56 ha ± 5.67. Home range was only calculated for females, because of low numbers of successful male captures during this year. In 2007, average home range size for northern flying squirrels using 95% Minimum Convex Polygon was 8.27 ha ± 4.64 and using 95% Fixed Kernel was 6.97 ha ± 4.25. Each year, females were larger than males (2006: $_{\text{fem}}$ = 122.2 g, $_{\text{male}}$ = 102.0 g; *P* <0.0001; 2007: $_{\text{fem}}$ = 129.7 g, $_{\text{male}}$ = 103.6 g; *P* = 0.0039); however, home ranges of females and males were similar (*P* = 0.41).

Most dens (n=53) were located in cavities (49%), but some were external stick nests located on the limbs of trees (12%); 39% could not be identified because they were not visible to the observer. Preliminary results obtained using 53 dens and 53 paired random plots indicate that dens were distributed amongst various tree species and size classes. Most den trees were located in white fir (28%) and California black oak (26%; Table 6). However, comparison of use and availability indicate that California black oak may be used preferentially for den sites (Fig. 21). Many den trees were located in large sawtimber (≥53.4 cm dbh, 44%), but poletimber (10-27.9 cm dbh, 35%) and small sawtimber (28-53.3 cm dbh, 21%) were also used. Comparison of use and availability indicate that northern flying squirrels are using larger trees than those available (Table 6).

2007 Field Season

In 2006, we captured 55 northern flying squirrels (long-term grids, n=20; landbird grids, n=20; flying squirrel transects, n=15). We radiocollared 19 northern flying squirrels at 6 study sites. Of these, sufficient data to estimate home range was obtained for 7 northern flying squirrels. In 2007, we captured 77 northern flying squirrels (long-term grids, n=21; landbird grids, n=36; flying squirrel transects, n=20). We radiocollared 20 northern flying squirrels at 7 study sites. Of these, sufficient data to estimate home ranges was obtained for 17 northern flying squirrels.

To evaluate den use by northern flying squirrels, we measured habitat characteristics at 39 and 40 den trees in 2006 and 2007, respectively. We also measured the same characteristics at paired random points (n=79). During 2007, we conducted preliminary analyses of den-tree selection by northern flying squirrels.

Dusky-footed woodrats

We have captured and radiotracked dusky-footed woodrats since 2003 in an effort to evaluate the abundance and distribution, habitat use, and home range of this important species (Objective #6). To date, we have examined vegetation data obtained during 2004-2005 and include this summary herein (Publications #2, #5, and #6). In 2007, we prepared a manuscript on the spatial organization of dusky-footed woodrats (Publication #11). The 2006 field season marked the final year of data collection, so that we might focus our efforts on northern flying squirrel ecology during 2007 and analyze data obtained on woodrats from previous years.

Publication #2 and #5: Habitat selection by dusky-footed woodrats in managed mixed-conifer forest of the northern Sierra Nevada

Dusky-footed woodrats are important components of forest communities, including serving as a primary prey of the California spotted owl, a species of concern in California. We examined the macro- and microhabitat associations of the dusky-footed woodrat at 4 study sites within mixed-conifer forest of the northern Sierra Nevada, California, during 2003–2005. We investigated the importance of California black oak as a macrohabitat component for woodrats, and we examined microhabitat selection at 2 levels, house location and house use, by comparing house-site (n = 144) characteristics to random sites (n = 144) and characteristics of used and unused houses, respectively. We found a strong trend towards a positive relationship between woodrat density and large (≥33 cm diameter at breast height) oak density (Fig. 22), suggesting that large oaks are an important macrohabitat component for woodrats, probably because of their value as a food resource. At the microhabitat scale, house location was strongly influenced by the presence of large (≥30 cm diameter at root collar) stumps, but also by abundance of logs, steeper slopes, and lack of bare ground and mat-forming shrub cover (Table 7). Houses used by adults were not distinguishable from unused houses on the basis of microhabitat variables, suggesting that woodrats make decisions about microhabitat conditions at the time a house is built. Adult and subadult woodrats selected houses with different microhabitat characteristics, but this pattern was not consistent between years. In 2005, adults chose larger houses that were characterized by more logs and less poletimber, but we detected no such differences in 2004. Dusky-footed woodrats in the northern Sierra Nevada would benefit from management techniques that promote the growth and retention of large California black oaks and create abundant dead wood within a stand.

Publication #6: Characteristics and use of tree houses by dusky-footed woodrats in managed mixed-conifer forest of the northern Sierra Nevada

Dusky-footed woodrats are important components of forest communities, including serving as a primary prey of the California spotted owl, a species of concern in California. Because previous studies have focused on the more “typical” ground houses, little is known about tree houses, perhaps because their inconspicuous nature makes them difficult to locate (Fargo and Laudenslayer 1999). Our objective was to describe locations of tree houses and determine if dusky-footed woodrats used these houses preferentially.

Most houses (n=252) were located on the ground (58%), but many were also located in cavities of trees or snags (27%) or on the limbs of live trees (15%). Three houses were located aerially in shrubs (hence neither ground nor tree), and were excluded from analyses. Tree houses were located primarily in white fir, Douglas-fir, California black oak, and snags (Table 8). Comparison of use and availability suggests that white fir were preferred as locations for houses constructed on limbs. White fir were mostly smaller, understory trees with splayed branches suitable for supporting the woody debris used in house construction. Large California black oaks and snags were strongly preferred as sites for cavity houses, probably because their size and tendency to decay resulted in formation of cavities of sufficient size for constructing houses.

Individual woodrats used as many as 3 tree houses and 8 ground houses, and use of tree houses was common, with 70% of males and 73% of females using at least 1 tree house. We expected that tree houses might provide increased protection from predation, because houses on the ground were vulnerable to destruction by black bears, or provide better access to arboreal food sources. However, woodrats did not spend more time at tree houses than expected on the basis of availability (Table 9). Among tree houses, cavity locations seemed preferred to limb locations when compared with availability, perhaps because cavity locations were more protected, and there was some evidence that females used cavity locations more frequently than did males (Table 9). Use of tree houses increased during the late summer with a peak in October (Fig. 23), possibly because mast availability in the fall increased arboreal foraging opportunities. Females used tree houses more frequently than did males during June ($Z = -2.13$, $P = 0.032$) and July ($Z = -0.2.22$, $P = 0.026$), coincident with the time of reproduction, perhaps because tree houses offer enhanced protection for unweaned offspring.

Our results suggest that tree houses are a prevalent and frequently used resource for dusky-footed woodrats in mixed-conifer forest of the northern Sierra Nevada. Tree house use is most prevalent during late summer and fall, and large California black oaks and snags are the most important forest elements for tree house location because of the protected sites provided by their cavities.

Publication #11: Spatial organization of dusky-footed woodrats in managed mixed-conifer forest of the northern Sierra Nevada

The spatial organization of dusky-footed woodrats is poorly understood, especially in mixed-conifer forest, which is one of the most prevalent and intensively managed forest types in the Sierra Nevada (Franklin and Fites-Kaufman 1996). Woodrats in this region are a primary prey of the California spotted owl (Verner et al. 1992), a species of concern in California (United States Department of the Interior 2003); as a result, it has been suggested that resource managers increase the availability of woodrats to spotted owls (Sakai and Noon 1993, 1997). A population's spatial structure has important implications for population dynamics, as well as the genetic structure of a population (e.g., Dunning et al. 1992, Lambin and Krebs 1991; Sugg et al 1996). The goals of this study were to document the spatial organization of woodrats in mixed-conifer forest of the northern Sierra Nevada at 2 study sites across multiple years to compare patterns of space use by males and females, to examine variation is home range size and overlap across sites and years, and to compare the distribution of same-sex and opposite-sex neighbors to characterize the social mating system of this species (e.g., Ostfeld 1986, Topping and Millar 1996, Cooper and Randall 2007). Because critical resources are different for the sexes (Ostfeld 1990), we predicted that woodrats would exhibit reduced intersexual overlap of home ranges as compared with intrasexual overlap. Because woodrats are solitary and territorial, we expected to find territoriality of houses and placement of occupied houses within defended core areas.

Home range and core area.— We radiotracked 37 woodrats (13 males, 24 females) at study site 1, and 26 woodrats (11 males, 15 females) at study site 2 (Fig. 3) for a mean of 99 days (range 34-144), obtaining a mean of 43 locations (range 16-75). The home range estimators used in this study provided similar estimates, with MCP sizes of 0.17-7.38 ha and FK sizes of 0.24-7.96 ha for home range and MCP sizes of 0.06-2.99 ha and FK sizes of 0.09-3.06 ha for core area (Table 10). Each year, woodrats at site 2 had larger home ranges and core areas than woodrats at site 1 (all $P<0.0001$). At site 2, home range and core area estimates were larger in 2005 than 2004 and 2006 (all $P<0.01$); home range and core areas were similar among years at site 1. Mean sizes of male home range and core areas were similar to that of females at both sites each year, although males frequently had larger home ranges and core areas than females (Table 10).

Home range of woodrats at our study sites were similar to those reported elsewhere (0.2–5.8 ha—Lynch et al. 1994, Cranford 1977, Sakai and Noon 1997, McEachern 2005), and our estimates show similar variability in sizes of home ranges in rodents of similar body size (ca. 0.23 kg; e.g., Steele 1998, Verts and Carraway 2002, Whisson et al. 2007). In general, dusky-footed woodrats at our study sites (mean=1.2 ha, n=37 at site 1; mean=3.8 ha, n=26 at site 2) in mixed-coniferous forest and those reported for woodrats in coniferous forest (mean=4.7 ha—McEachern 2005) and juniper woodland (mean=1.4 ha—McEachern 2005) habitats appear to have much lower population density (range: 1-2 woodrats/ha) and much larger home ranges than those reported in riparian woodland (mean=0.2 ha, density range: 14-20 woodrats/ha—Cranford 1977), oak woodland (mean=0.4 ha, density 22 woodrats/ha—Lynch et al. 1994) and shrub field (mean=0.4, density: 80 woodrats/ha—Sakai and Noon 1993, 1997) habitats. Previous studies have suggested that habitat and food resource availability and distribution influences density of dusky-footed woodrats (Carey et al. 1992, 1999; Forsman et al. 1984; Sakai and Noon 1993, Publication #2 and #5), and thus the spatial organization of the species.

Home range boundaries are expected to change with response to resource-limiting factors that fluctuate across seasons and years (Cranford 1977, Anderson 1982, Slobodchikoff and Schulz 1988). Our study is the first to document variability of woodrat home ranges across multiple years. Woodrats in our study exhibited stable patterns in home range within sites across years; although in 2005, home ranges were larger at site 2 than any other year. This may be partially due to the exceptionally large home range of 1 male at this site in 2005. This male occupied the largest number of houses of any woodrat in the study (n=11), which spanned a distance >500 m and encompassed an area (2.3 ha) larger than nearly 60% of the home range estimates in this study. He overlapped with all females at the site, and shared houses with 50% of these. Woodrats at site 2 had consistently larger home range areas than woodrats at site 1, which may be partially attributed to differences in the availability and distribution of a preferred forage species, California black oak (Publication #2 and #5).

We found that males tended to have larger home range and core area sizes than females, a finding supported by studies of the spatial organization of dusky-footed woodrats in other habitats (Cranford 1977, Sakai and Noon 1997, McEachern 2005). A number of factors may account for the larger home ranges and greater mobility of male woodrats. One explanation for this pattern in our study is the larger body size (g) of males (245.0±6.1) as compared with females (211.3±4.2; McNab 1963); however we found that body size was not correlated with home range or core area size at our study sites. An alternative explanation is that the larger home ranges of males in our study may be due to reproductive behavior, with males searching larger areas to gain access to multiple females or females reducing home ranges to meet energy requirements of reproduction (Cooper and Randall 2007, Whisson et al. 2007).

Overlap.— Mean overlaps of home ranges and core areas did not differ between study sites and years, and we found no interactions between site, year, and overlap category (male-male, male-female, or female-female); therefore, we combined data among sites and years and tested for differences among overlap categories. Home range overlaps of same-sex (n=97, mean OI=0.35, range 0–0.84) and opposite-sex (male-male: n=29, mean OI=0.31, range 0–0.82; female-female: n=50, mean OI=0.26, range 0–0.77) pairs were similar (*P*=0.159). However, core area overlaps for male-female pairs (n=47, mean OI=0.34, range 0-78), we larger than either of the same-sex pairs (*P*=0.037); male-male pairs (n=12, mean OI=0.18, range 0-45) and female-female pairs (mean OI=0.18, range 0-60) exhibited similarly low overlap of core areas.

Woodrats tolerated a high degree of home range overlap with opposite-sex and same-sex neighbors (Fig. 24b). Male home ranges overlapped with an average of 2.4±0.4 neighboring males and 4.0±0.2 neighboring females, and female home ranges overlapped with an average of 2.5±0.2 neighboring males and 2.6±0.2 neighboring females. All males and females overlapped home ranges with ≥1 individual of the opposite sex, and nearly all overlapped home ranges with ≥1 individual of the same sex; for example, 96% of male home ranges overlapped with that of ≥1 neighboring male and 97% of female home ranges overlapped with that of ≥1 neighboring female.

Woodrats were less likely to share core areas than home ranges with other woodrats. Male core areas overlapped with an average of 1.0±0.3 neighboring male and 2.0±0.2 neighboring females, and female core areas overlapped with an average of 1.2±0.2 neighboring males and 0.8±0.1 neighboring females. Although woodrats tolerated a high degree of core area overlap with opposite-sex neighbors, woodrats tended to avoid core area overlap with same-sex neighbors (Fig. 24a); for example, 88% of males (n=21) and 79% of females (n=31) shared their core area with ≥1 neighbor of the opposite sex, whereas only 50% of males (n=12) and 59% of females (n=23) shared their core area with ≥1 neighbor of the same sex. Interestingly, a majority of females shared their core areas with a single neighboring male (65%, n=20), whereas a majority of males shared their core areas with multiple females (81%, n=17).

Because critical resources are different for the sexes (Ostfeld 1990), we expected that adult woodrat would exhibit reduced intersexual overlap of home range as compared with intrasexual overlap. Instead, we found that same-sex and opposite-sex pairs exhibited mean overlaps of home ranges that were similar (range: 0.25-0.37) and overlapped a mean of 2.8±0.13 (n=126) neighboring woodrats, indicating that individual woodrats were not defending large portions of their home range from conspecifics. Although woodrats tolerate a high degree of home range overlap with conspecifics, woodrats appeared to largely display intrasexual avoidance behavior of core areas. Core area overlap indicated that opposite-sex pairs shared substantially more core area (0.36) than same-sex pairs, and overlap of male-male pairs and that of female-female pairs was relatively low (0.18), as expected. Home range overlap would be expected to be highest when densities are highest; however, a high degree of home range overlap has been reported at varying woodrat population densities (e.g., Cranford 1977), which suggests the system of overlapping home ranges we report is likely not the result of woodrat density, but rather may be a reflection of dispersal patterns and associated mating system (Greenwood 1980, Pusey 1987).

House placement and sharing.— We located 252 woodrat houses (150 at site 1, 102 at site 2). We found no year or site differences in placement of occupied houses within core areas; therefore, we combined data across sites and years and tested for differences between sexes. Placement of houses appeared to occur predominantly within an individual's core area, and females were more likely to occupy houses placed within their core area than males ($Z= -1.99$, P=0.047); 82% of houses occupied by females occurred within female core areas, whereas 67% of houses occupied by males were placed within male core areas. Woodrats occupied between 2-11 houses, and frequently shifted occupancy among them. Duration of occupancy at a given house ranged 1–107 days.

Across all years and sites, 52% of males (n=33) and 49% of females (n=47) synchronously or asynchronously shared a house on ≥1 occasion. Synchronous sharing mostly involved opposite-sex pairs (94%, n=49), but synchronous sharing by female-female (4%, n=2) and male-male (2%, n=1) pairs also occurred. Most pairs (64%, n=25 pairs), including all same-sex pairs, were observed synchronously sharing a house only once. However, it was common for a given opposite-sex pair to synchronously share a house multiple times (41%, n=22 pairs), and for periods lasting 2–38 days. Although it was common for individuals to shift occupancy among multiple houses, a given opposite-sex pair found synchronously sharing a house multiple times usually shared the same house (89%, n=9 pairs). Only 1 opposite-sex pair was recorded synchronously sharing 2 houses about 90 m apart; 1 house was occupied by the male, and the other, by the female. Typically, a given female synchronously shared a house with only 1 male in a give year (90%, n=21 females), but males frequently shared a house with more than 1 female (57%, n=14 males). Males typically were found at the house occupied by the female (67%, n=14), although females were also found at the house occupied by the male (14%, n=3), and occasionally a house was occupied frequently by both individuals of a given pair such that occupancy by a certain individual was not possible to assign (19%, n=4). Synchronous house sharing between male-female pairs usually occurred in June (38%, n=19), July (34%, n=18), and August (25%, n=10), but also occurred in September (2%, n=2; Fig. 25). Males were observed synchronously at houses with females during periods when females were accompanied by unweaned young.

Many of the same pairs that shared houses synchronously also shared houses asynchronously (47%, n=30), and as many as 4 individuals were found to asynchronously share a single house. Asynchronous sharing of houses also occurred predominantly between male-female pairs (77%), but also occurred between female-female (10%) and male-male (13%) pairs. A majority of asynchronously sharing pairs shared a single house together (83%), but a given pair asynchronously shared as many as 2 (13%) or 3 (3%) different houses. Successive occupancy of houses occurred both within and between years. Males succeeded males (17%, n=18) and female succeeded females (17%) less frequently than opposite-sex pairs succeeded one another (67%). It was common for a house to have successive occupants across years (39%, n=173), and many were used by successive occupants every year of the study (13%).

Houses are a critical resource for woodrats. We found that woodrats frequently shifted occupancy among 2-11 houses, a majority of which were located within a woodrat's core area. However a substantial portion, particularly those of males, were scattered throughout a woodrat's entire home range. Other studies have found that an individual woodrat may use a single house (Linsdale and Tevis 1951, Wallen 1982) or multiple houses (Cranford 1977, Lynch et al. 1994) within their home range. Although house sites remain fixed, house occupancy may change according to the distribution of food resources, and maintenance of multiple houses throughout their range may be a strategy woodrats have adopted to more efficiently use a habitat where food resources vary spatially and temporally (Whisson et al. 2007). This is supported by evidence that woodrats at our study sites shifted occupancy from ground houses in the spring and summer to houses located in California black oak trees in the fall, when mast becomes available (Publication #6).

We found that house sharing was more common than previously reported. House sharing occurred frequently and repeatedly among same-sex pairs, with >50% of individuals sharing a house on at least one occasion. Captures of juveniles indicated that woodrats at our study sites likely have 1 litter in May or June per year, and occasionally have a second litter in August or September. We found that house sharing occurred primarily during June, July, and August and lasted for periods up to 38 days. This period was coincident with a peak in apparent breeding activity, and suggests that house sharing may be indicative of mated pairs.

The high degree of home range overlap and frequency of house sharing among dusky-footed woodrats we observed may be a consequence of a polygynous mating system and female natal philopatry, a common pattern in mammals; although, it is likely that a combination of interrelated factors, such as low population density and the pattern of food distribution and availability, contributed to the observed spatial organization. Our results provide important information for resource managers attempting to enhance woodrat populations for the benefit of its predators. The large home-range sizes of males and females, territorial behavior of core areas, placement of houses outside of core areas, and potential influence of spatially and temporally variable food resources should be considered in developing management strategy.

Golden-mantled ground squirrels

We captured and radiotracked golden-mantled ground squirrels during 2003-2005. Data analysis and manuscript preparation took place in 2006 and 2007; no additional data has been collected since 2005. The following summary (Publication #8) represents the culmination of this work and satisfies Objective #7.

Publication #8: Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels.

Maternal body condition may play an important role in determining natal dispersal distance. We developed a trans-generational model relating maternal body condition to natal dispersal distance in male and female offspring in ground squirrels (Fig. 26). We measured the effect of maternal body condition on offspring natal dispersal in golden-mantled ground squirrels in the Sierra Nevada of California. Mothers were allowed to forage normally (control, n = 6) or were provided with supplemental food (treatment, n = 6) prior to hibernation, and offspring dispersal distance was measured the following year. Not surprisingly, treatment mothers gained mass more rapidly than control mothers, although the proportion of fat in mothers did not differ between treatments (Fig. 27). Additionally, offspring from treatment mothers grew at a significantly faster rate, increased fat stores, and had greater mass than control offspring. Male offspring of treatment mothers dispersed 3x farther than those of control mothers (770 m vs. 213 m), whereas female offspring of control mothers dispersed 4.8x farther than those of treatment mothers (496 m vs. 102 m; Fig. 28). Dispersal distance was positively related to exploratory distance for both males and females (Fig. 29). In spite of low sample sizes, our data indicate that maternal body condition affects offspring growth, fat development, and dispersal, supporting our trans-generational model of offspring dispersal.

Chipmunks

We have live-trapped chipmunks at long-term grids, landbird grids, and flying squirrel transects since 2003. One of our objectives was to evaluate the habitat affinities of 2 species found commonly in PNF, long-eared and Allen's chipmunks, using data obtained from long-term grids during 2003-2004 (Objective #8). The following (Publication #10) is a summary of these results.

Publication #10: A multiple spatial scale perspective of the habitat affinities of sympatric long-eared and Allen's chipmunks.

Sympatric species that are similar in body mass, diet, and general resource utilization are likely to compete locally. Similar species often coexist by partitioning habitat. However, detecting differences in habitat affinities is influenced by spatial scale. We investigated the habitat associations of two ecologically similar chipmunk species – the long-eared chipmunk and the Allen's chipmunks – at three spatial scales in the northern Sierra Nevada, California. Locally, we censused these species over two years at 18 trapping grids, and recorded 19 microhabitat metrics at all trap stations. At a macrohabitat scale, we assessed relative abundances at different study sites as a function of forest type. Finally, at a landscape (e.g., geographic range) scale we examined digital vegetation information and calculated extent of range overlap. At this largest spatial scale, both species showed similar habitat affinities, with extensive overlap in distribution within the Sierra Nevada (Fig. 30). At the macrohabitat scale, both the species reached their highest mean abundance in red fir forests but showed divergent secondary affinities (Fig. 31). At the microhabitat scale, however, habitat affinities differed significantly. Logistic regression models indicate that microhabitat presence of long-eared chipmunks was associated positively with open canopies, cover by rocks, and multiple sapling species, and negatively with east and south facing, steep slopes (Table 11, Fig. 32). Allen's chipmunks shared the affinity for open canopies but differed in exhibiting a preference for traps on south facing slopes with multiple shrub species, and aversion to traps on hard substrates covered by litter and vegetation mats (e.g., Mahala mat—*Ceanothus prostratus*). Affinities at micro- and macrohabitat scales varied between sampling years, indicating that these species retain a degree of flexibility in habitat associations while maintaining segregation and minimizing the potential for competition (Table 12, Fig. 33).

2007 Field Season

We will continue to capture and collect chipmunks while performing live-trapping duties at long-term grids, landbird grids, and flying squirrel transects. In future analyses we hope to evaluate our technique of determining chipmunk species using external characteristics.

COLLABORATION

We have continued to maintain and improve collaborative efforts with all PLAS Modules. Most notably, we improved collaboration with the Landbird Module in 2006 and 2007 by establishing temporary trapping grids at songbird census stations. Vegetation and Fuels Modules have collected and continue to collect vegetation, fire and fuels, and microclimate data within some portion of our long-term and landbird trapping grids. We are currently coordinating an effort in which the Mammal Module will provide valuable feedback to the remote sensing analyses and resultant models developed by the Fire and Fuels Module. In the near future, we hope to initiate collaborative efforts with the Spotted Owl Module by working with them to examine the diet of the California spotted owl.

In 2007, we increased collaborative efforts with agencies and institutions outside of the PLAS. We collaborated with Janet Foley, a Professor with the University of California, Davis School of Veterinary Medicine, and her graduate student Nathan Nieto, providing them with blood and tissue from northern flying squirrels and western gray squirrels for a study on disease ecology. We collaborated closely with the directors of the University of California Davis McLaughlin Reserve, Cathy Koehler and Paul Aigner, who provided space to train our field crew prior to our housing becoming available at the University of California, Berkeley Forestry Camp. In exchange for housing and training facilities, we provided information on the abundance and distribution of small mammal species within a long-term study grid established on the reserve. We collaborate with the University of Idaho for molecular analyses to determine chipmunk species identification and worked together with them to secure outside funding for these analyses. Lastly, we work closely with the University of California Davis Natural History Field Museum to preserve specimens for research and educational purposes.

PUBLICATIONS

Theses

1. Coppeto, S. A. 2005. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada, California. M.S. Thesis, University of California, Davis, 39 pp.

2. Innes, R.J. 2006. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. M.S. Thesis, University of California, Davis, 31 pp.

3. Smith, J.R. *In Prep*. Home range and habitat selection of the northern flying squirrel (*Glaucomys sabrinus*) in northeastern California. M.S. Thesis, University of California, Davis. Winter 2009.

Peer-reviewed

4. Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2006. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. Journal of Mammalogy 87:402-416.

5. Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, J. A. Wilson, P. A. Stine. 2007. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy 88(6): 1523-1531.

6. Innes, R. J., D. H. Van Vuren, D. A. Kelt. 2008. Characteristics and use of tree houses by dusky-footed woodrats in the northern Sierra Nevada. Northwestern Naturalist 89(2).

7. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2008. Home range and activity of northern flying squirrels (*Glaucomys sabrinus*) in the Sierra Nevada. Southwestern Naturalist.

Submitted

8. Wilson, J. A., D. A. Kelt, D, H, Van Vuren, and M. Johnson. *Submitted*. Population dynamics of small mammals in relation to cone production in four forest types in the northern Sierra Nevada. Western North American Naturalist.

9. Mabry, K.E., and Wilson, J. A. *Submitted*. Trapping rodents in a cautious world: the effects of disinfectants on trap success. American Midland Naturalist.

In Preparation

10. Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. Sullivan, J. A. Wilson, and N. Reid. *In Prep*. Different scales tell different tales: niche conservatism vs. niche differentiation in chipmunks in the northern Sierra Nevada. To be determined. Spring 2008.

11. Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, and J. A. Wilson. *In Prep*. Spatial organization of the dusky-footed woodrat (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. To be determined. Winter 2008.

12. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. *In Prep*. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). To be determined. Spring 2008.

PRESENTATIONS

1. Coppeto, S. A., D. A. Kelt, J. A. Wilson, D. H. Van Vuren, and M. L. Johnson. 2004. Habitat selection by small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.

2. Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2005. Spatial scale and habitat use of small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

3. Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2004. Factors affecting the distribution and use of dusky-footed woodrat (*Neotoma fuscipes*) houses. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.

4. Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2005. Space use and social organization of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

5. Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. B. Johnson, J.A. Wilson. 2006. Habitat relations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.

6. Smith, W. 2006. Ecology of *Glaucomys sabrinus*: habitat, demography, and community relations. Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

7. Wilson, J.A., and K.E. Mabry. 2005. Trap disinfection to reduce Hantavirus risk: does it also reduce small mammal trapability? Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

8. Wilson, J. A., D. A. Kelt, and D. H. VanVuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

9. Wilson, J. A., D. A. Kelt, and D. H. VanVuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the IX International Mammalogical Conference, Sapporo, Japan.

10. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2006. Home range and activity of the northern flying squirrel (Glaucomys sabrinus) in the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.

PERSONNEL

This project is coordinated and supervised by Robin Innes. Paul Smotherman was the field crew supervisor. Field work in 2007 was conducted by Robin Innes, Chelsea Beebe, Denise Everhart, Brett Jesmer, Heidi Schott, Jaya Smith, and Paul Smotherman. This study was carried out under the guidance of Dr. Douglas Kelt, Dr. Dirk Van Vuren, and Dr. Michael Johnson, professors at the University of California Davis.

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FIGURES AND TABLES

Fig. 1. — Map of long-term grids in Plumas National Forest with a) locations of 18 long-term grids in 5 forest types and b) trap configuration within a long-term grid. Inset shows the location of the Forest in California. Map extracted from Coppeto et al. (2006).

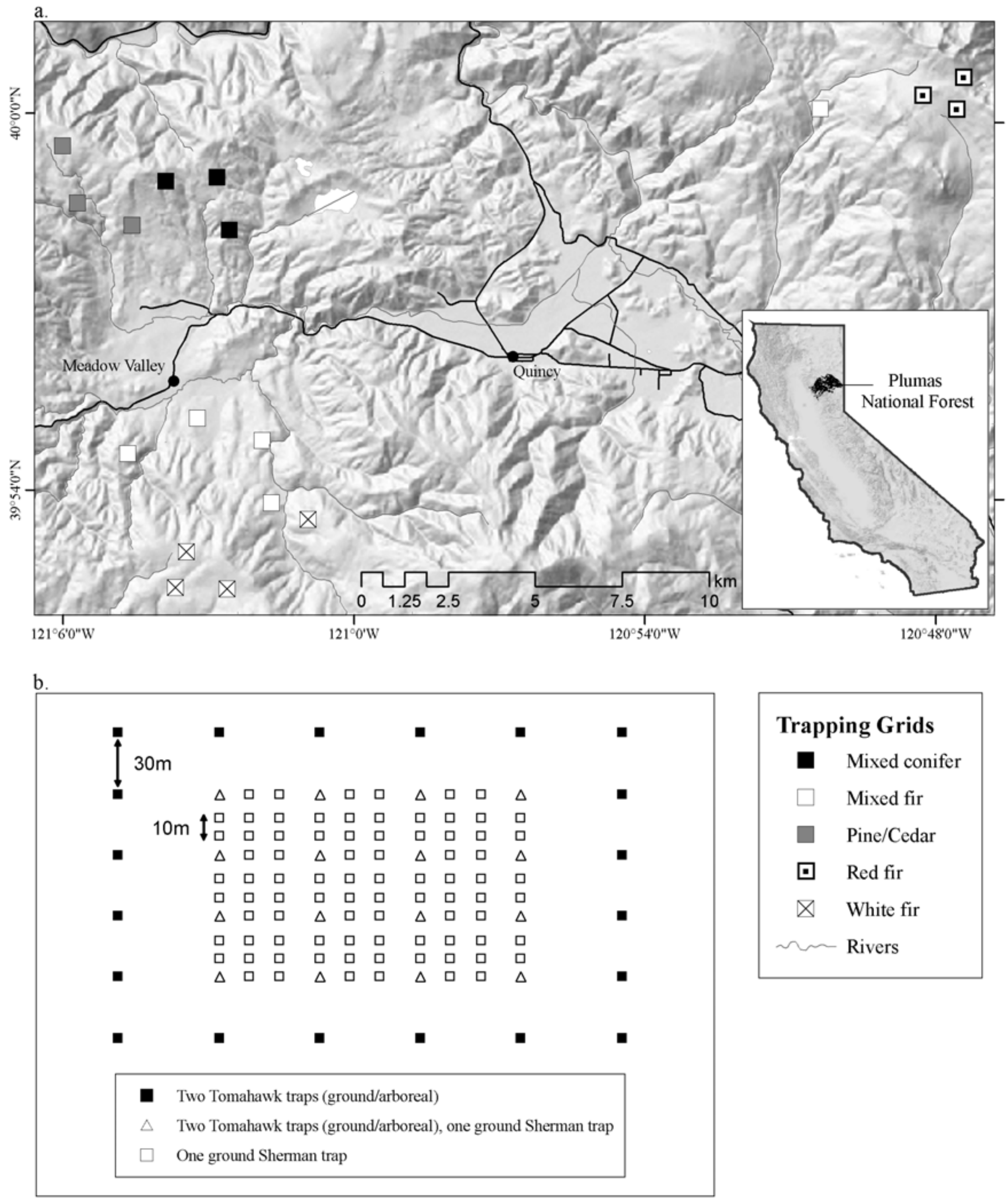

Fig. 2.— Schematic of trap configuration within a landbird grid.

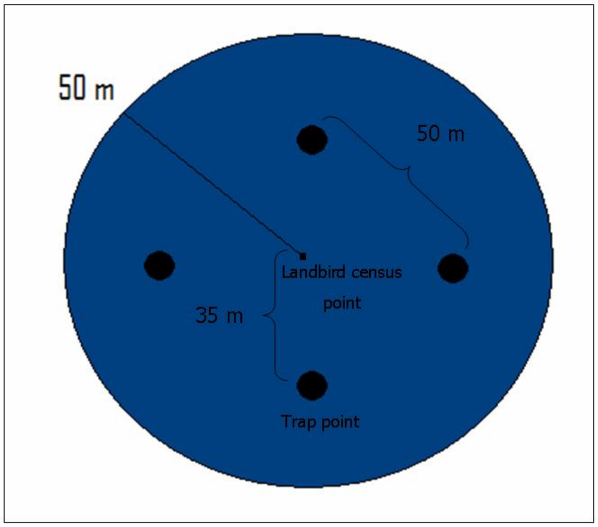

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Fig. 3.— Map of 4 dusky-footed woodrat study areas in Plumas National Forest (PNF), California. Numbers indicate study site location. Inset shows the location of PNF in California.

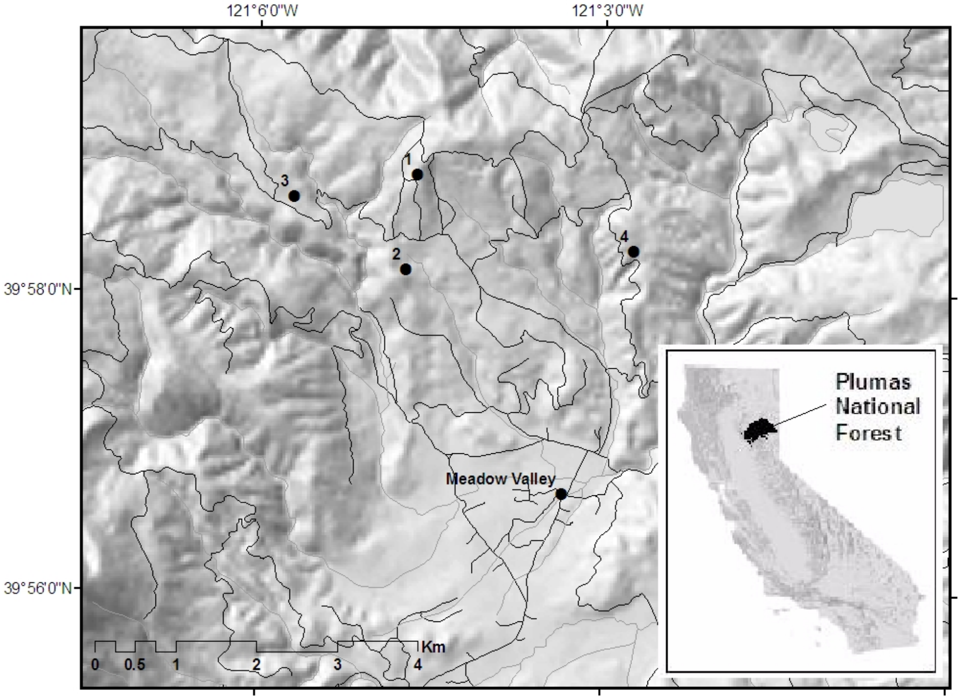

Table 1.—Description of microhabitat variables measured in 1-m radius (3.14m^2) plots at all long-term and landbird grid trap stations. Table from Coppeto et al. (2006).

Microhabitat Variable	**Description**
Ground Cover (%):	
Rocks	Exposed large rocks and stones
Bare ground	Exposed soil
Forbs and grasses	Herbaceous and flowering vegetation and grasses
Litter	Dead leaves, pine needles, wood chips, sawdust-like debris
Branches	Twigs with diameter <10cm
Small logs	Logs and stumps with diameter (within plot) of 10-50cm
Large logs	Logs and stumps with diameter (within plot) of >50cm
Live shrubs	Woody vegetation not considered sapling; height ≤2m[a]
Dead shrubs	Same description as for live shrub but with no living/no foliage
Vegetation mats	Near ground surface shrub cover (*Ceanothus prostratus*)
Saplings	Small trees with height ≤2m
Non-woody perennials[b]	Shrub- and forb-like vegetation lacking woody stems
Canopy openness (%)	Percent open sky above breast height (1.4m)
Shrub species richness	Number of distinct, live shrub species
Sapling species richness	Number of distinct, live sapling species
Substrate hardness	Ground hardness averaged across 4 randomly sampled points
Slope	Degree of ground surface decline/incline
Aspect	Probable direction of water flow from center of trap station

Fig. 4. — Minimum convex polygon home range estimate for an adult female northern flying squirrel (F14) at FS-2 in 2007. Numbers correspond to UTM coordinates.

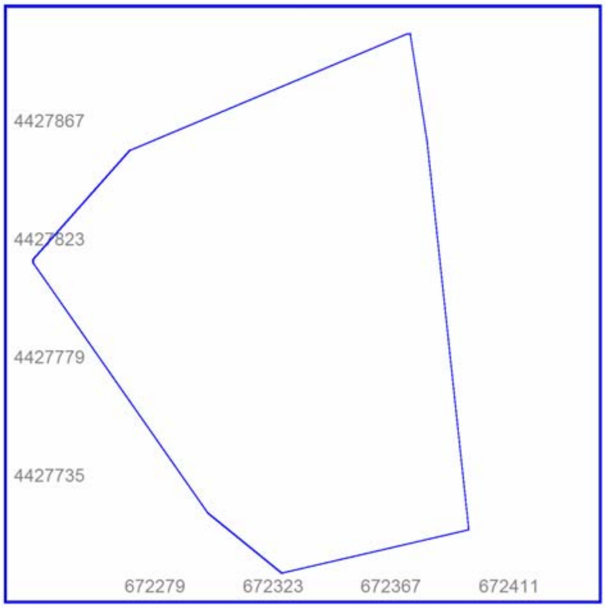

Fig. 5. — Fixed kernel home range estimate for an adult female northern flying squirrel (F14) at FS-2 in 2007. Like contours on a contour map, each line represents the degree of usage of the home range by the animal. As you go from the exterior to the interior, the animal uses the area more frequently. Numbers correspond to UTM coordinates.

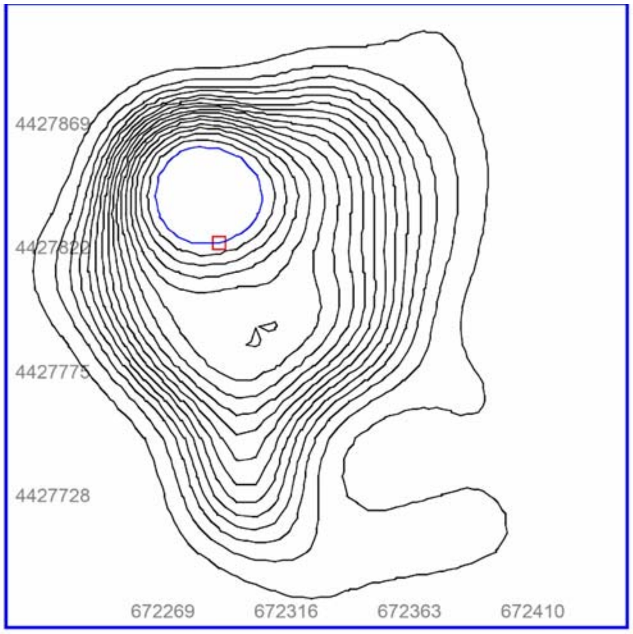

Table 2.— Description of habitat variables measured in 4-m radius plots at 144 dusky-footed woodrat houses and 144 random sites in the northern Sierra Nevada, California, 2003 – 2005.

Variable	**Description**
Stems of woody plants	
Low shrub	Woody stems <1 m tall, excluding mat-forming shrubs
High shrub	Woody stems ≥1 m tall and <5 cm dbh
Sapling	Woody stems 5.0 – 9.9 cm dbh
Poletimber	Woody stems 10.0 – 27.9 cm dbh
Small sawtimber	Woody stems 28.0 – 53.3 cm dbh
Large sawtimber	Woody stems ≥53.4 cm dbh
Small oak	*Quercus kelloggii* stems 5.0 – 32.9 cm dbh
Large oak	*Quercus kelloggii* stems ≥33.0 cm dbh
Dead wood	
Log	Downed, dead wood ≥1 m long and ≥5 cm at the narrowest end
Large snag	Standing dead wood ≥30 cm dbh and >1.3 m tall
Large stump	Standing dead wood ≥30 cm drc and 0.1 – 1.3 m tall
Ground cover (%)	
Bare ground	Exposed soil
Rock	Exposed boulders, cobble and gravel
Mat-forming shrub	Trailing, near ground surface (<0.3 m tall) woody stem cover (e.g., *Symphoricarpos rotundifolius*)
Other	
Canopy closure	Percent closed sky at eye-level (1.7 m)
Degree slope	Degree of ground surface decline/incline

Table 3.— Frequency, mean values and standard errors (SE) for microhabitat variables in 4-m radius plots centered at dusky-footed woodrat ground houses (n = 144) and paired random sites (n = 144) in Plumas National Forest, California, 2003 – 2005. Parameter estimates, *P*-values for the Wald chi-squared statistic, and Akaike Information Criteria (AIC) are presented from a univariate conditional logistic regression.

	Mean (SE)		Parameter			
Variable	**House site**	**Random site**	**estimate (SE)**	***P***	**AIC**	
Density (ha^{-1})						
Low shrub	19,054.2 (1,656.5)	24,552.4 (1,945.9)	−0.00003 (0.00001)	0.003	186.24	*
High shrub	9,950.0 (641.8)	6,761.1 (561.7)	0.0001 (0.00002)	<0.001	189.39	*
Sapling	494.4 (51.0)	418.1 (42.9)	0.0003 (0.0002)	0.241	200.20	*
Poletimber	395.8 (41.6)	381.9 (34.2)	0.0001 (0.0003)	0.774	201.54	
Small sawtimber	123.6 (15.3)	143.1 (16.7)	−0.0005 (0.0006)	0.385	200.86	
Large sawtimber	12.5 (4.0)	16.7 (4.6)	−0.0014 (0.0022)	0.514	201.20	
Log	845.7 (77.8)	717.1 (64.2)	0.0002 (0.0002)	0.218	188.95	*
Basal area (m^2ha^{-1})						
Sapling	2.0 (0.2)	1.6 (0.2)	0.0778 (0.0549)	0.157	199.47	*
Poletimber	8.2 (0.9)	9.0 (0.8)	−0.0087 (0.0126)	0.490	201.15	
Small sawtimber	13.3 (1.7)	16.3 (2.0)	-0.0059 (0.0053)	0.266	200.36	
Large sawtimber	4.1 (1.4)	4.9 (1.4)	−0.0027 (0.0068)	0.689	201.47	
Volume (m^3ha^{-1})						
Log	124.7 (18.2)	38.5 (7.5)	0.0048 (0.0015)	0.001	171.54	*
Ground cover (%)						
Bare ground	3.5 (0.5)	5.1 (1.0)	−0.1282 (0.0543)	0.018	192.71	*
Rock	1.3 (0.2)	2.8 (0.8)	−0.0216 (0.0148)	0.144	193.65	*
Mat-forming shrub	13.9 (1.2)	19.8 (1.7)	−0.0273 (0.0091)	0.003	189.43	*
Other						
Canopy closure (%)	67.8 (2.8)	64.2 (2.8)	0.0035 (0.0036)	0.331	199.29	
Degree slope	19.3 (0.7)	16.4 (0.6)	0.1257 (0.0311)	<0.001	199.29	*
Presence (no. plots)						
Small oak	40%	30%	0.5390 (0.2746)	0.050	197.63	*
Large oak	10%	3%	1.7912 (0.7636)	0.019	193.70	*
Large snag	4%	4%	0.0000 (0.5774)	1.000	201.63	
Large stump	49%	17%	1.4191 (0.2877)	<0.001	169.44	*

*Variables with *P*-values ≤0.25 from log-likelihood ratio tests were included in multivariate models predicting house sites from random sites

Fig. 6.—Mean fall cone production by the major conifers at long-term grids (n=18). Means were derived by counting cone production on 10 individual trees/species on each grid and averaging across forest types. Cones were counted visually during the fall of 2003 and 2004. Statistically significant differences are represented by different letters within each species and in each year.

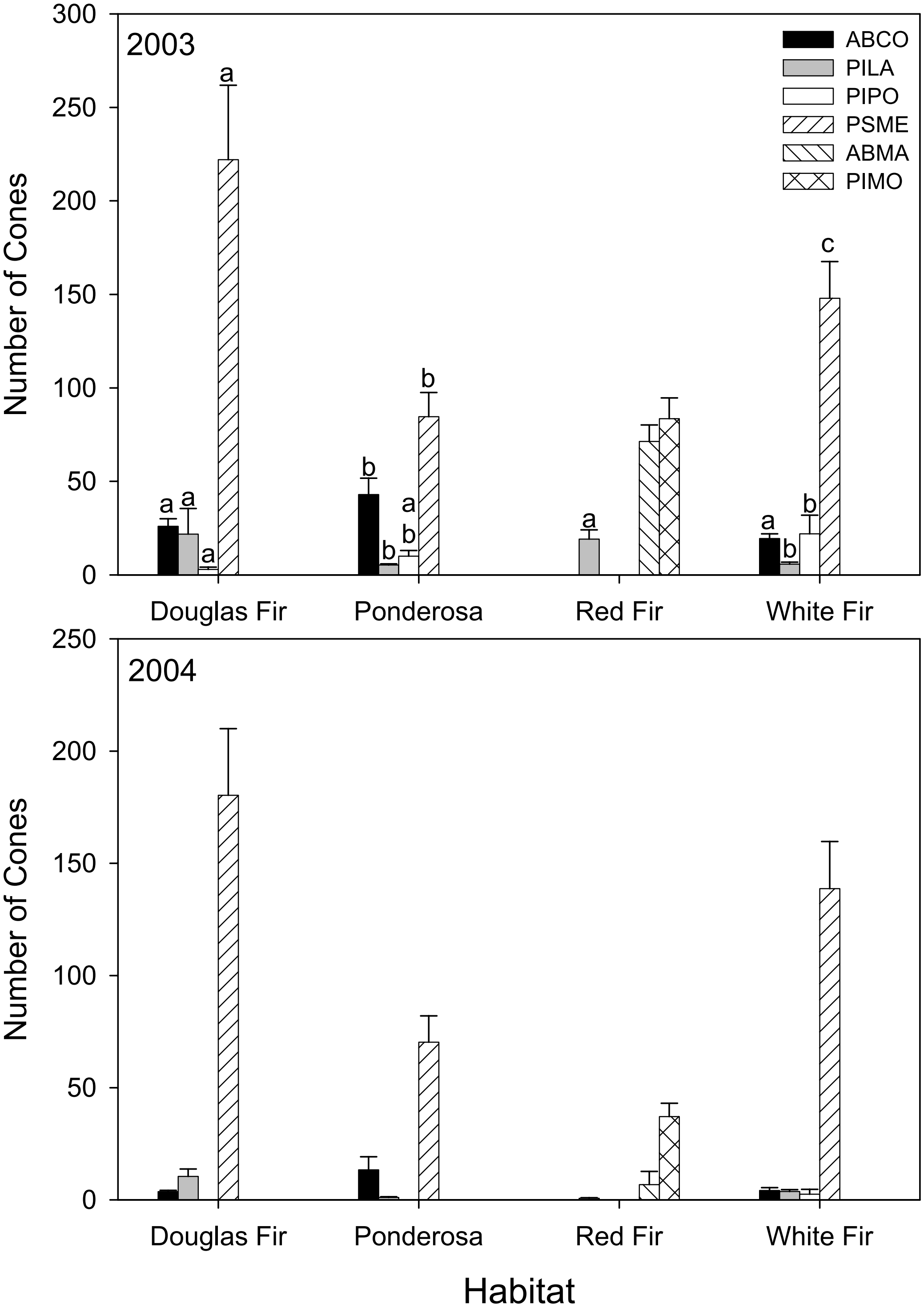

Fig. 7.— Mean monthly density (A) and survival (B) of deer mouse populations inhabiting four forest types in the northern Sierra Nevada: white fir, Douglas-fir, red fir, and ponderosa pine. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.

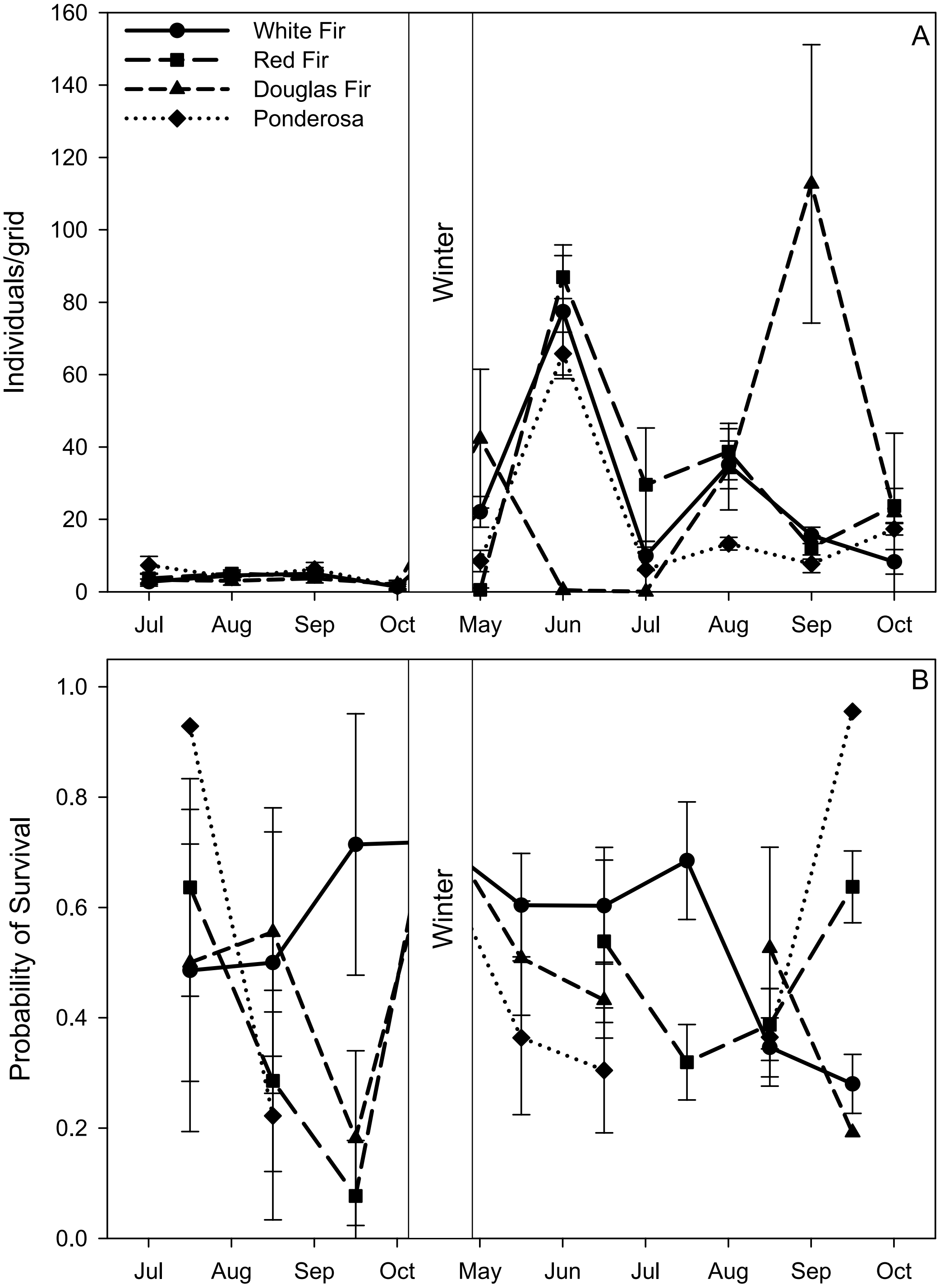

Fig. 8. — Mean monthly density (A) and survival (B) of golden-mantled ground squirrel populations inhabiting red fir forests in the northern Sierra. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.

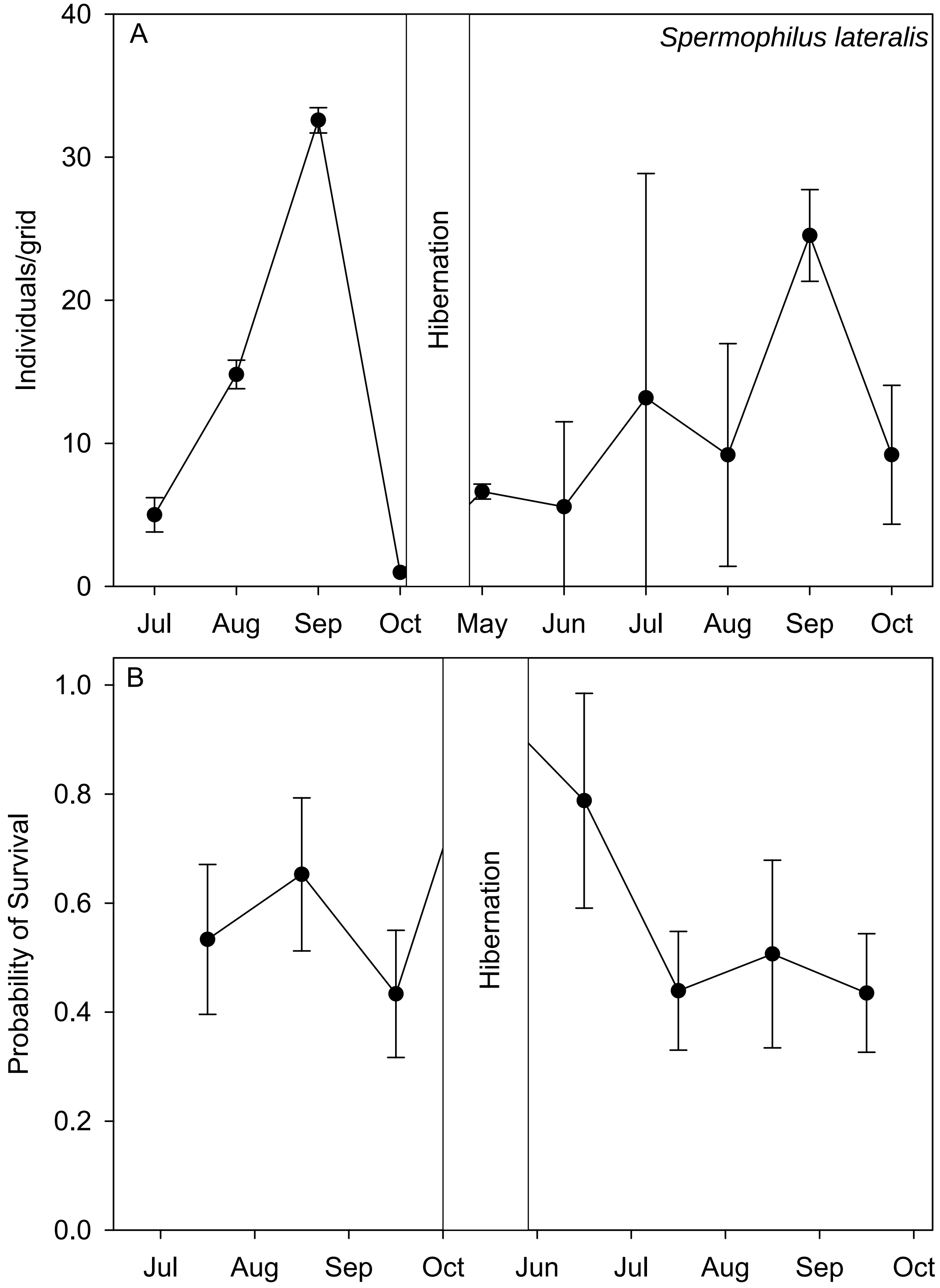

Fig. 9.—Mean monthly density of (A) long-eared chipmunk and (B) Allen's chipmunk, inhabiting three forest types (white fir, red fir, Douglas-fir) in the northern Sierra. Density estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.

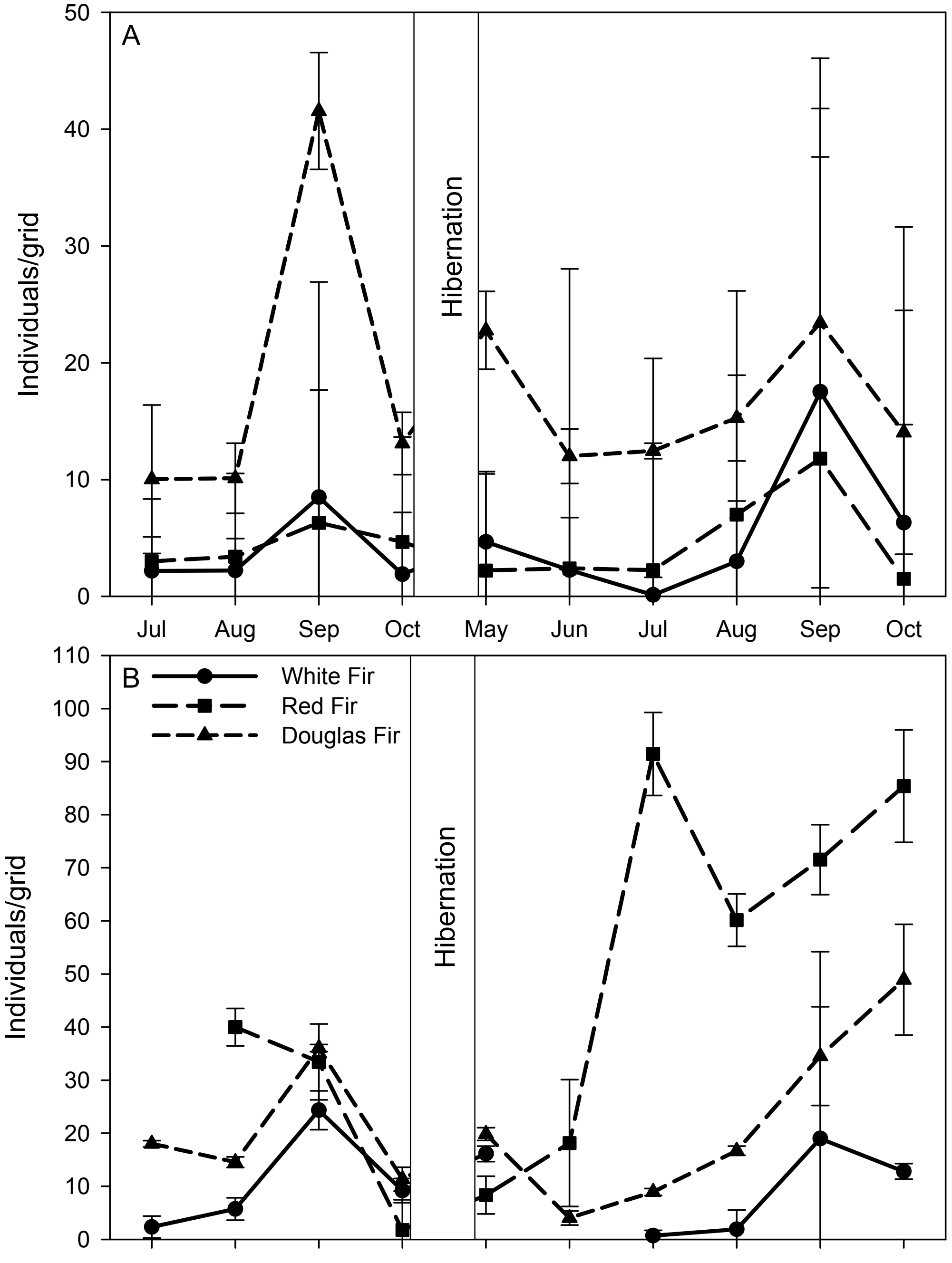

Fig. 10.— Mean abundance of mice (*Peromyscus sp*.) within 5 forest types within the Plumas National Forest, California, during 2003-2007.

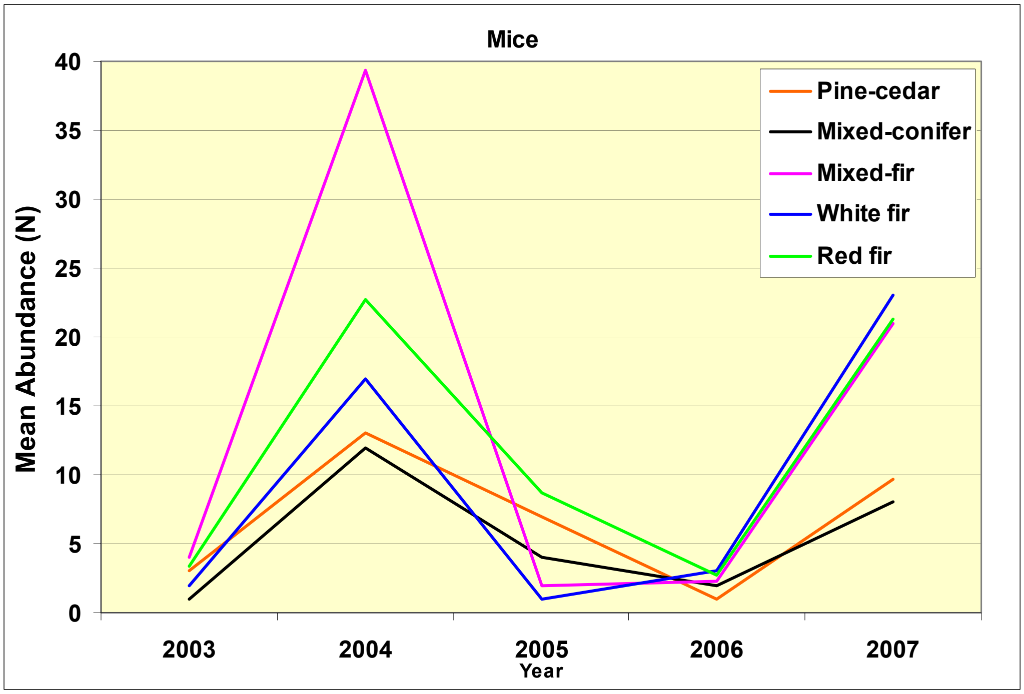

Fig. 11.— Mean abundance of chipmunks (*Tamias sp*.) within 5 forest types within the Plumas National Forest, California, during 2003-2007.

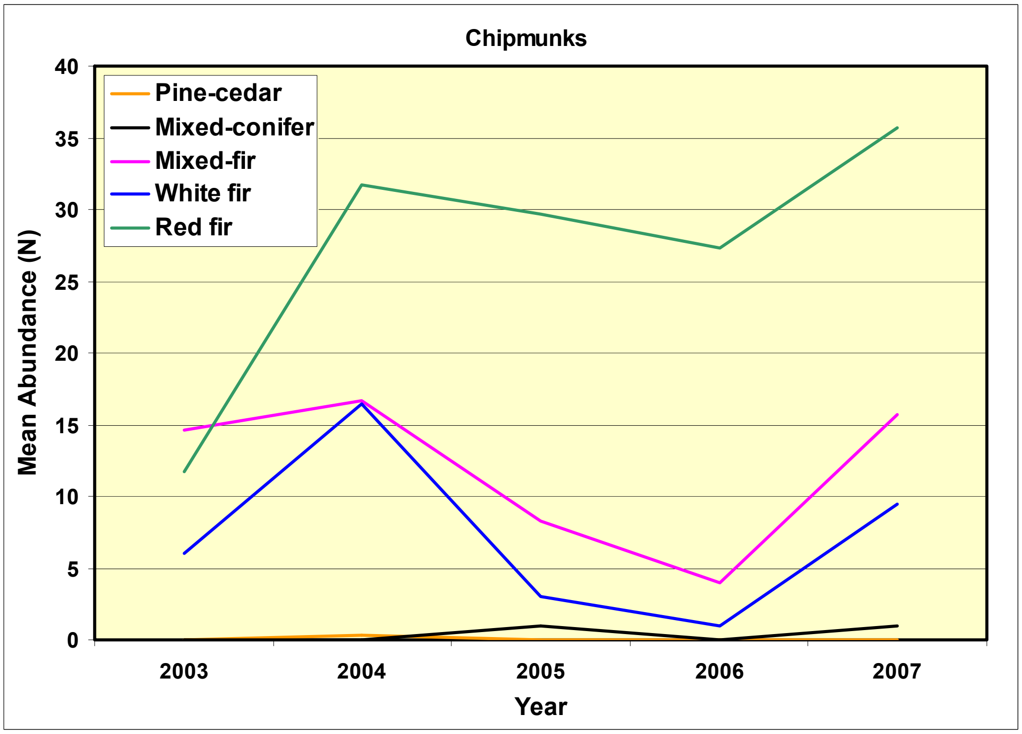

Fig. 12.— Mean abundance of dusky-footed woodrats within 5 forest types within the Plumas National Forest, California, during 2003-2007.

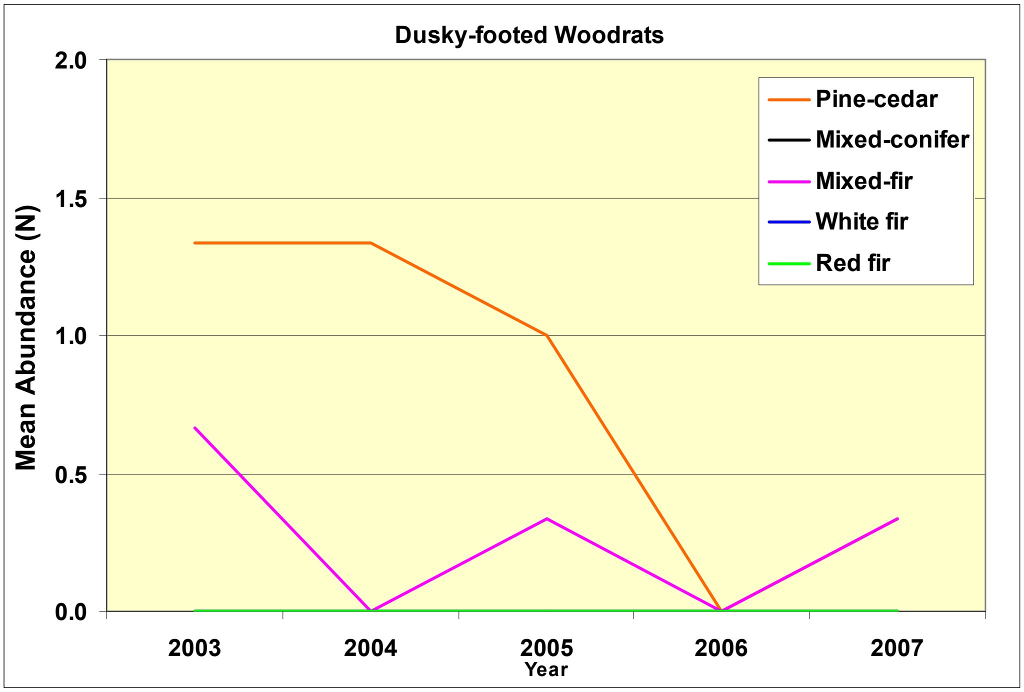

Fig. 13.— Mean abundance of northern flying squirrels within 5 forest types within the Plumas National Forest, California, during 2003-2007.

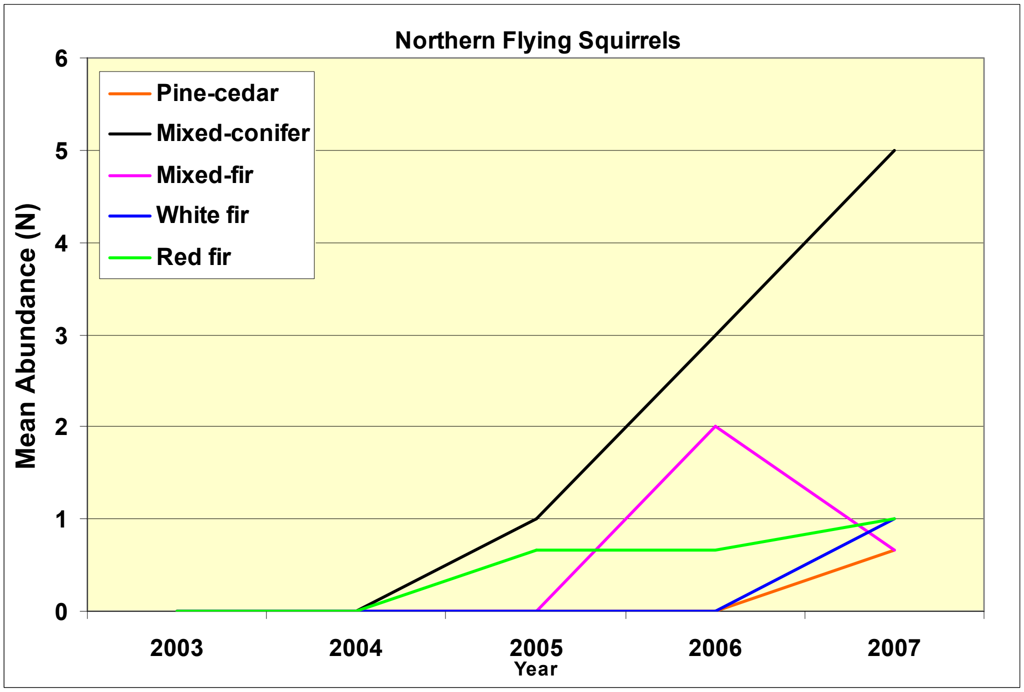

Table 4. — Results of the Program MARK analyses for 4 species of rodent in the northern Sierra Nevada. All species were analyzed individually using the Cormack-Jolly Seber data type. Best-fit models are shown for each species. Akaike's corrected information coefficient (AICc), adjusted for overdispersion, and the model weight relative to other less fit models is given. Data for other species were too sparse for analysis with Program MARK.

Species	Model	AICc	Weight	C-hat
Peromyscus maniculatus	Φ(habitat*t+overwinter+mean cones)p(habitat*t)	1740.6	0.99	1.85
Spermophilus lateralis	Φ(t)p(t)	358.2	0.96	1.14
Tamias quadrimaculatus	Φ(habitat*t+overwinter+mean cones)p(habitat*t)	923.5	1.00	1.22
Tamias senex	Φ(habitat*t)p(habitat*t)	683.2	0.60	1.23
	Φ(habitat*t+overwinter)p(habitat*t)	684.1	0.39	

Fig. 14.—Small mammal species richness in (former) treatment unit 2 of the PLAS study area during 2006-2007.

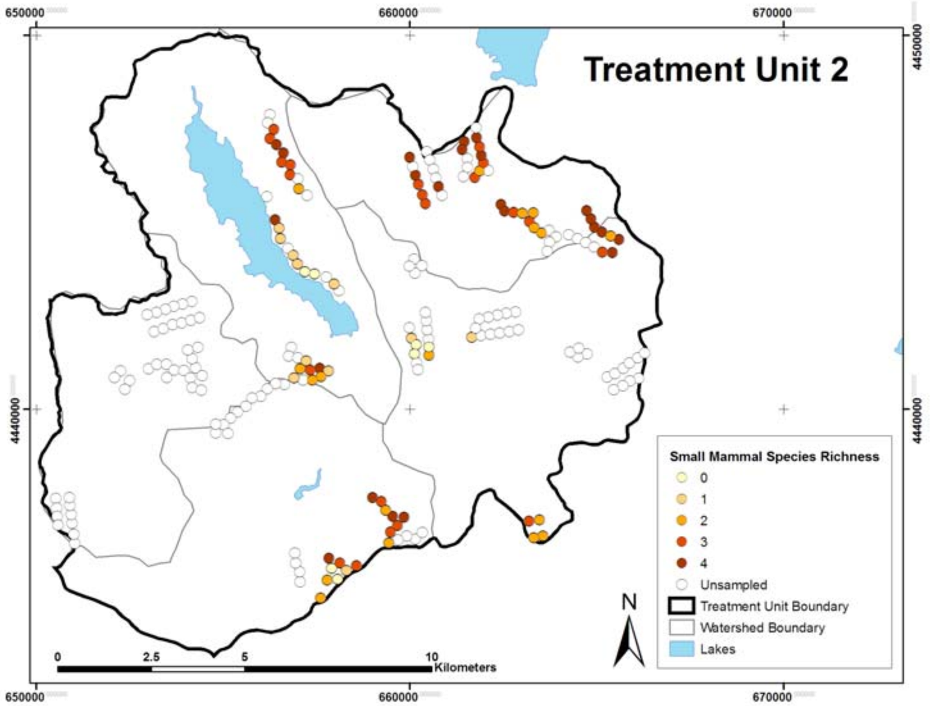

Fig. 15.—Small mammal species richness in (former) treatment unit 3 of the PLAS study area during 2006-2007.

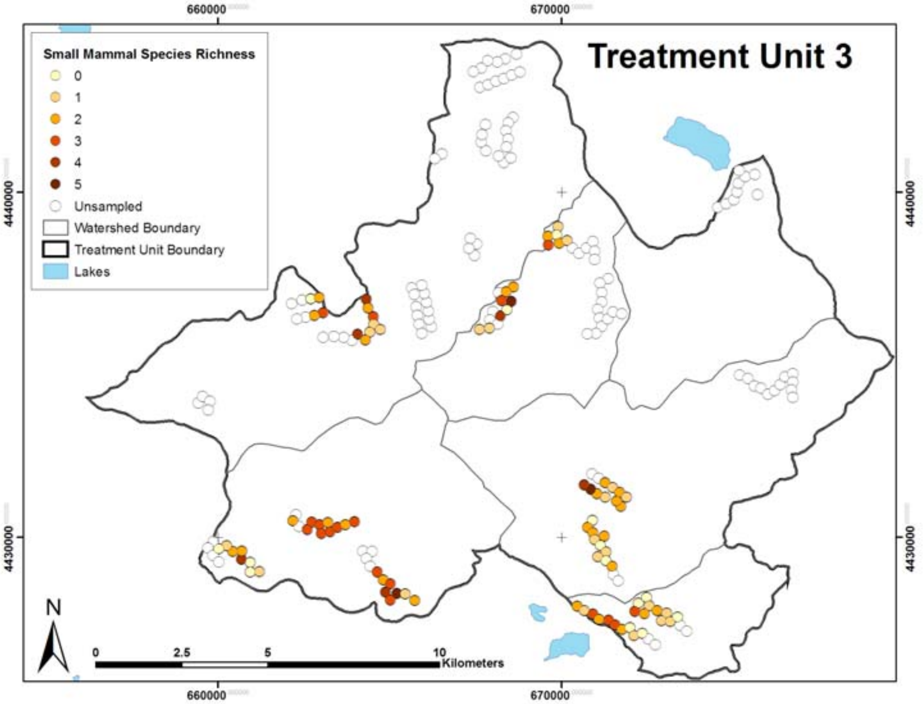

Fig. 16.—Small mammal species richness in (former) treatment unit 4 of the PLAS study area during 2006-2007.

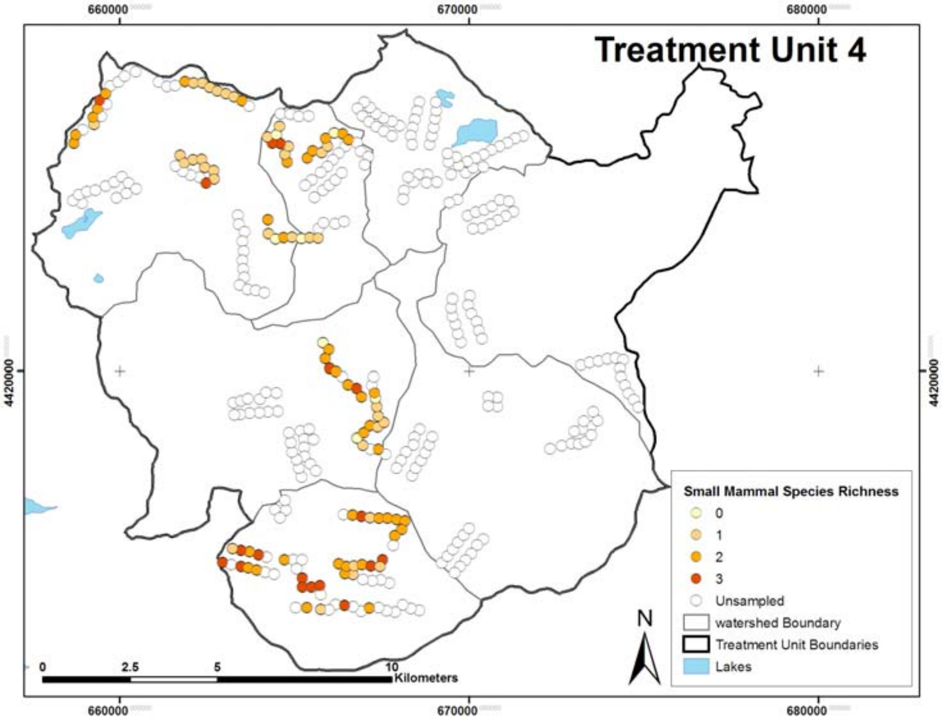

Fig. 17.—Small mammal species richness in (former) treatment unit 5 of the PLAS study area during 2006-2007.

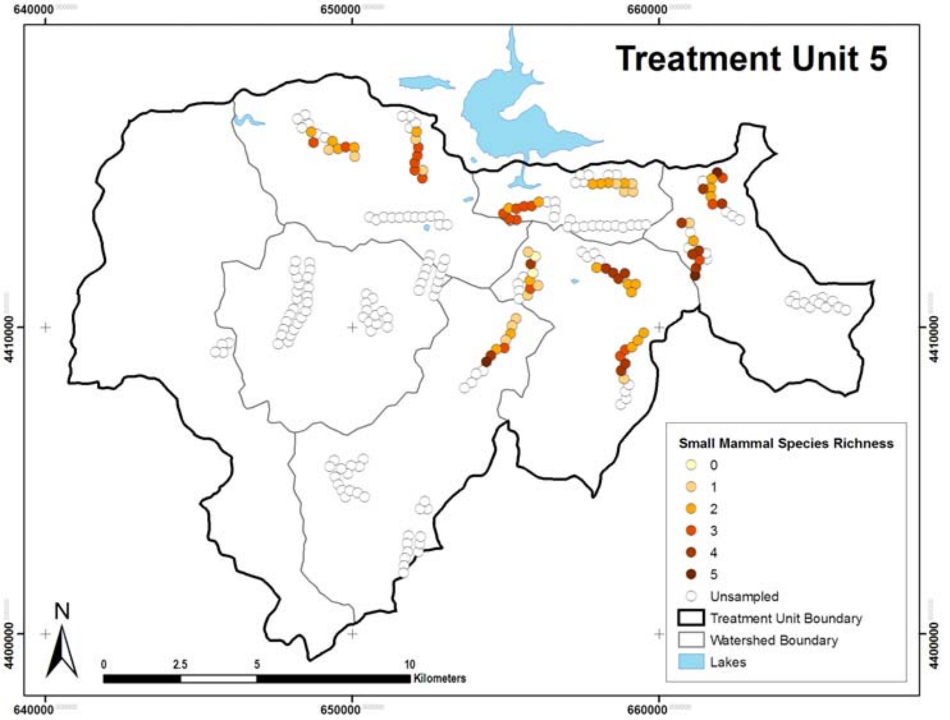

Table 5.—Home range of individual flying squirrels trapped during 2004-2005. Sex (male or female), Age (subadult or adult), mass (g), number of nests (nests), and home range size (ha) calculated with minimum convex polygon (MCP) or adaptive kernel (kernel) analyses. Unknown values are indicated by NA.

					Home Range Size (ha)	
ID	Sex	Age	Mass	Nests	95% MCP	95% Kernel
F1	F	A	125	NA	NA	NA
M1	M	A	127	3	26.1	23.0
M2	M	S	92	2	NA	NA
M3	M	A	104	2	83.4	39.8
F2	M	S	103	NA	NA	NA
F3	F	A	117	1	35.5	63.4
Archie	M	A	75	3	18.8	17.2
Brooser	M	A	75	3	19.5	24.8
Captain	M	A	91	NA	NA	NA
Delia	F	A	93	2	26.7	35.5
Emilio	M	A	96	NA	NA	NA
Feliz	M	A	104	2	24.8	39.4
Gulliver	M	J	78	3	4.5	4.7
Horatio	M	S	96	2	6.9	7.8
Isabella	F	A	99	1	25.1	31.4
Jelly	M	A	100	3	15.2	22.8
Kayto	M	A	73	NA	NA	NA
Layla	F	A	141	NA	NA	NA
Madeline	F	A	NA	1	8	13.0
Ninja	M	A	139	1	12.7	11.7

Fig. 18.—Home range extent of northern flying squirrels at 2 studies sites: FS-1 (red fir habitat, upper image) and FS-2 (mixed-conifer habitat, lower image). Home ranges represent the results of adaptive kernel analyses and show frequency of use with lighter shades representing areas of higher use (95, 75 and 50%).

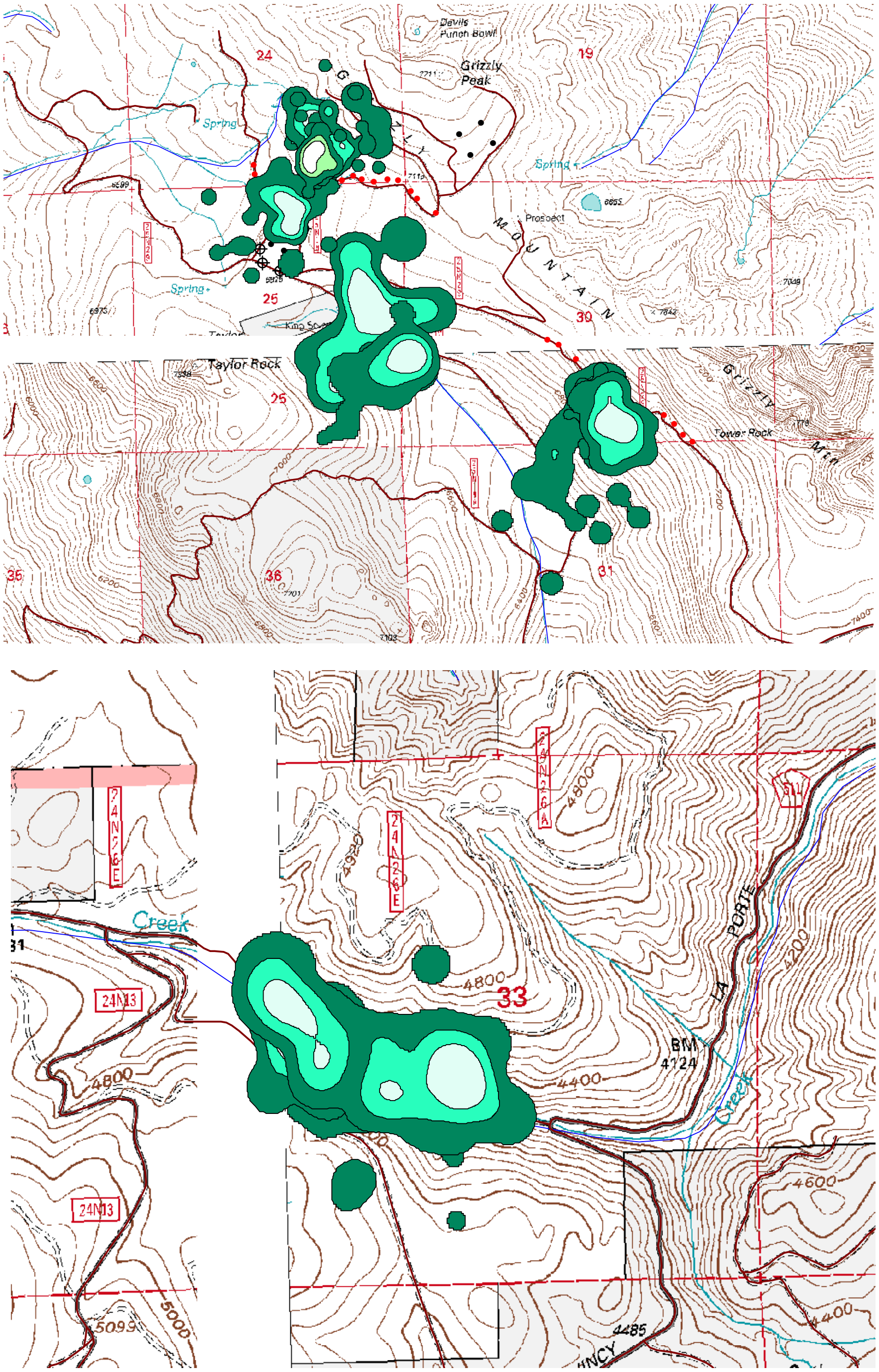

Fig. 19.—Mean home range size (ha) of male and female northern flying squirrels 2004-2005 in the northern Sierra Nevada. Mean home range size represents the 95% adaptive kernel estimates.

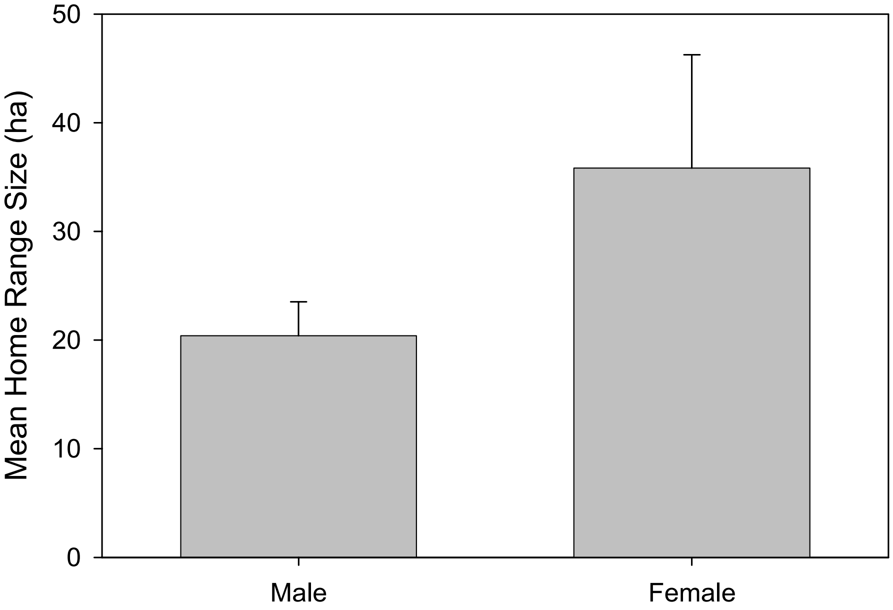

Fig. 20.—Nocturnal movement patterns of northern flying squirrels during 2004-2005. Movement patterns are represented as distance to the nearest known nest tree. Only locations between 18:00 and 06:00 were used.

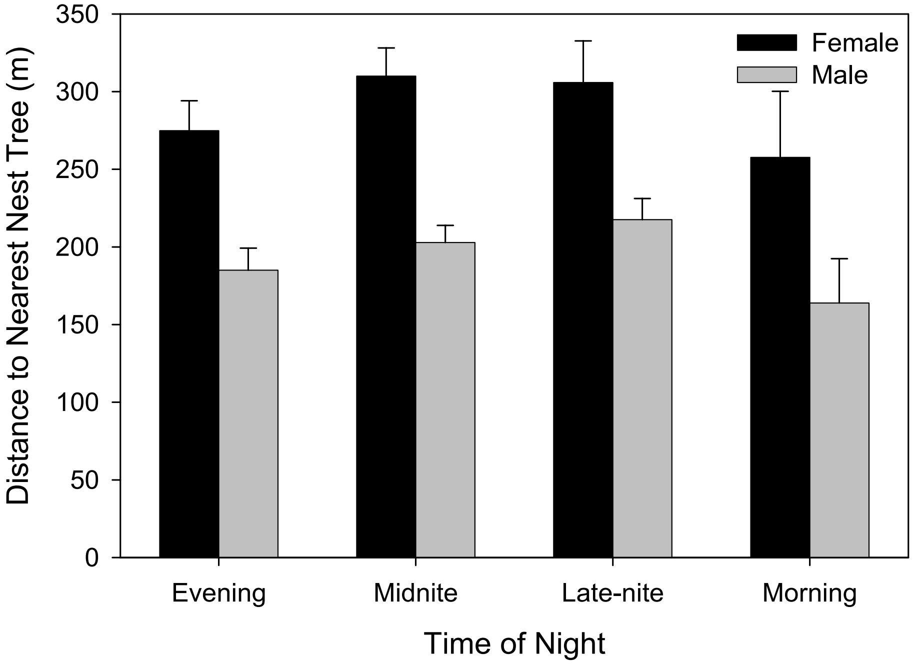

Table 6.—Mean size (cm; dbh) of trees by species available and used by northern flying squirrels at den sites (n = 53) and paired random sites (n = 53) in the northern Sierra Nevada, California, 2006 – 2007. Presence of an asterisk indicates significant differences. Yellow pine includes ponderosa pine (*Pinus ponderosa*) and Jeffrey pine (*P. jeffreyi*).

Tree Type	Mean available tree size	Mean den tree size	N
Abies concolor	26.76	61.07*	15
Abies magnifica	32.42	58.25	4
Calocedrus decurrens	26.38	73.60*	5
Yellow Pine	36.17	121.33*	3
Pseudotsuga menziesii	30.45	89.25*	8
Quercus kelloggii	17.59	29.61*	14
Acer macrophyllum	18.96	19.00	4

Fig. 21.— Total number and percentage (n, %) of trees available (A) and used (B) by northern flying squirrels at den sites (n = 53) and paired random sites (n = 53) in the northern Sierra Nevada, California, 2006 – 2007.

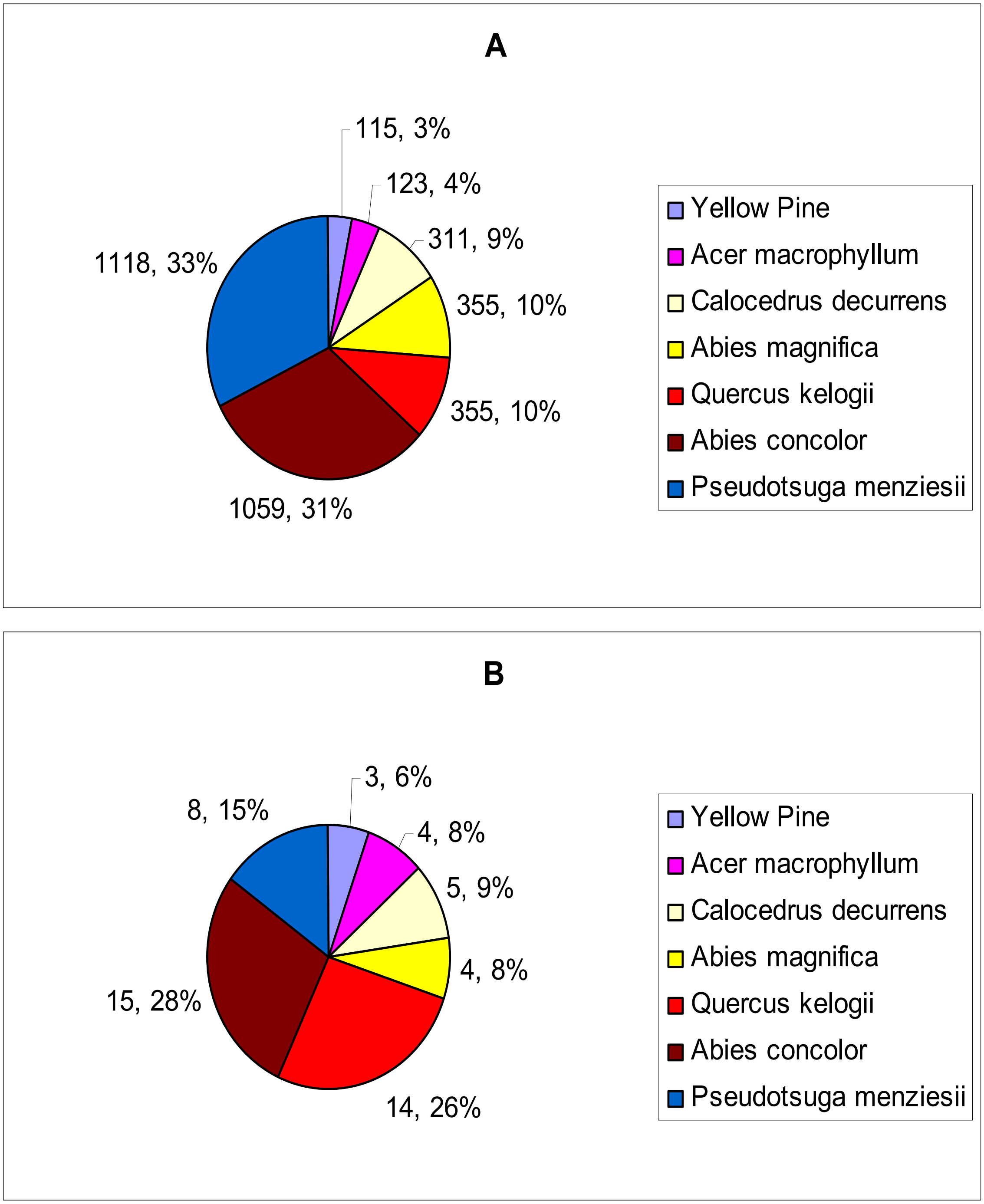

Fig. 22.—Regression of mean adult dusky-footed woodrat density (ha^{-1}) on large (≥33 cm dbh) California black oak density (ha^{-1}) in Plumas National Forest, California, 2004 – 2005.

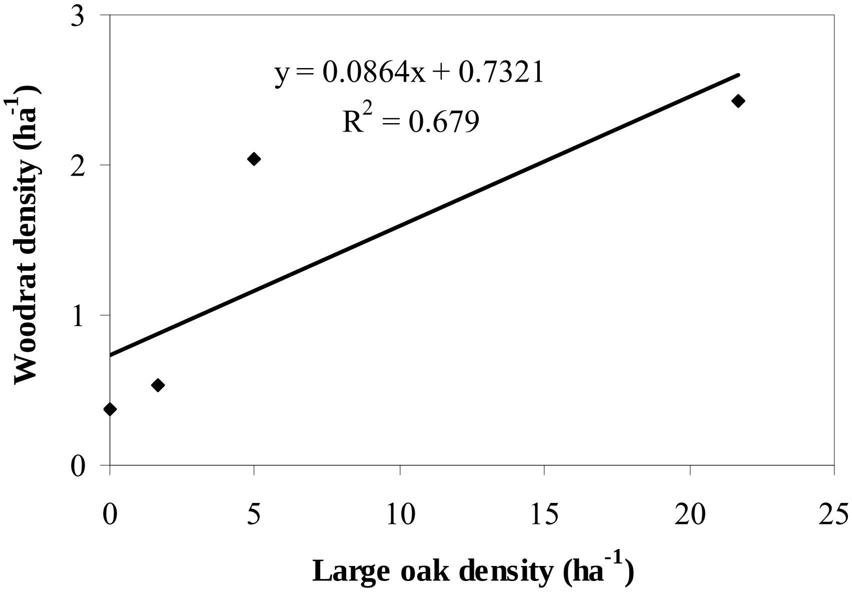

Table 7.— The best habitat model based upon the lowest Akaike Information Criterion used to explain the difference between dusky-footed woodrat house sites (n = 144) and paired random sites (n = 144) in the northern Sierra Nevada, California, 2003 – 2005. Parameter estimates, standard errors (SE), *P*-values for the Wald chi-square statistic, odds ratios, and 95% odds ratio confidence limits are presented from a conditional logistic regression. Odds ratios indicate the increased likelihood of the outcome with each unit increase in the predictor given the covariate pattern.

Variable	**Parameter estimate (SE)**	***P*-value**	**Odds ratio**	**95% Odds ratio confidence limits**	
Large stump presence	1.6051 (0.3779)	<0.001	4.978	2.373	10.442
Degree slope	0.1515 (0.0433)	0.0030	1.164	1.069	1.267
Log volume (m^{3}ha^{-1})	0.0048 (0.0016)	0.0010	1.005	1.002	1.008
Mat-forming shrub (%)	−0.0433 (0.0141)	0.0020	0.958	0.932	0.984
Bare ground (%)	−0.0527 (0.0251)	0.0360	0.949	0.903	0.997

Table 8.— Availability and use of trees for tree house locations by dusky-footed woodrats, by species (%) and by mean size (cm), in the northern Sierra Nevada, 2004 to 2006. Other trees include mountain dogwood (*Cornus nuttallii*), green and white-leaf manzanita (*Arctostaphylos sp.*), and willow (*Salix sp.*). Availability was calculated as the mean proportion of trees and snags.

		Tree houses	
Species	Availability (%)	Cavity (%)	Limb (%)
White fir	30	3	56
Incense cedar	20	0	10
Ponderosa pine	7	0	0
Sugar pine	4	1	0
Douglas-fir	16	3	15
California black oak	13	72	15
Snag	7	21	0
Other trees	4	0	3
Size group	Availability (cm)	Cavity (cm)	Limb (cm)
Tree size	16.7	49.6	18.4
Snag size	10.5	58.2	-

Table 9.— Proportional (%) availability and use of ground and tree houses by dusky-footed woodrats in the northern Sierra Nevada, 2004 to 2006. Numbers in parentheses indicate standard error.

	Ground houses	Tree houses	
		Cavity	Limb
Female (%)	61 (4.7)	37 (4.6)	2 (0.7)
Male (%)	71 (5.2)	24 (5.3)	5 (1.7)
Availability (%)	58	27	15

Fig. 23. —Proportional use of tree houses by dusky-footed woodrats, by month, in the northern Sierra Nevada, 2004 to 2006.

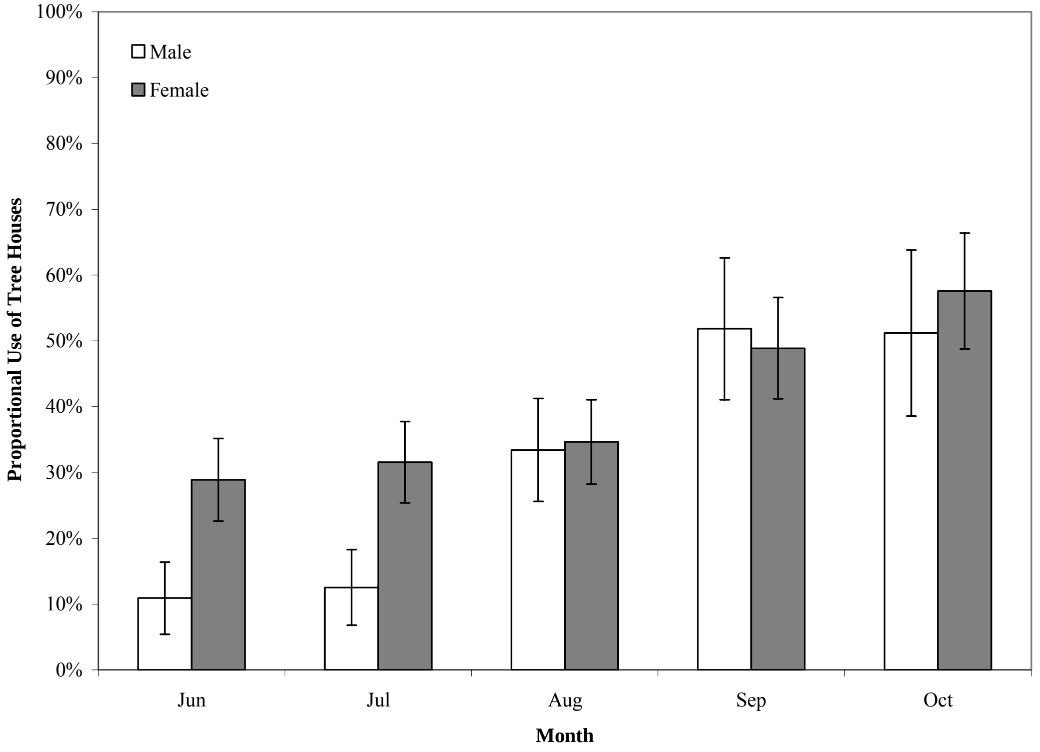

Table 10.— Mean home range (95%) and core area (50%) estimates and associated standard errors (±SE) of dusky-footed woodrats using minimum convex polygon (MCP) and fixed kernel (FK) methods at 2 study sites in the northern Sierra Nevada, California.

			MCP			FK		
Site	Year	Sex	N	Home range	Core area	N	Home range	Core area
1	2004	Male	5	1.2±0.2	0.3±0.1	3	1.1±0.4	0.4±0.2
		Female	9	0.8±0.1	0.2±0.04	6	1.1±0.3	0.4±0.1
	2005	Male	5	1.9±0.6	0.6±0.2	5	1.7±0.7	0.6±0.2
		Female	8	1.2±0.2	0.3±0.1	7	1.4±0.3	0.6±0.1
	2006	Male	3	1.8±0.5	0.4±0.1	1	3.0	0.9
		Female	7	1.2±0.3	0.4±0.1	5	1.2±0.3	0.5±0.1
2	2004	Male	7	3.7±0.3	0.9±0.1	4	3.5±0.4	1.0±0.2
		Female	6	2.8±0.3	0.7±0.1	4	2.9±0.7	1.0±0.3
	2005	Male	2	7.0±0.4	2.6±0.3	2	7.7±0.2	2.8±0.3
		Female	4	5.0±0.5	1.5±0.2	4	6.3±0.7	2.4±0.2
	2006	Male	2	4.6±0.4	1.2±0.6	2	3.6±1.6	1.5±0.9
		Female	5	2.9±0.6	0.7±0.1	3	4.0±1.2	1.3±0.2

Fig. 24.—Core areas (a) and home ranges (b) of dusky-footed woodrats at study site 1 in the northern Sierra Nevada, California, during May-October 2004. The minimum convex polygons for core area (50% MCP) and home range (95% MCP) are shown for graphical simplicity. Solid lines indicate adult females and dashed lined indicate adult males.

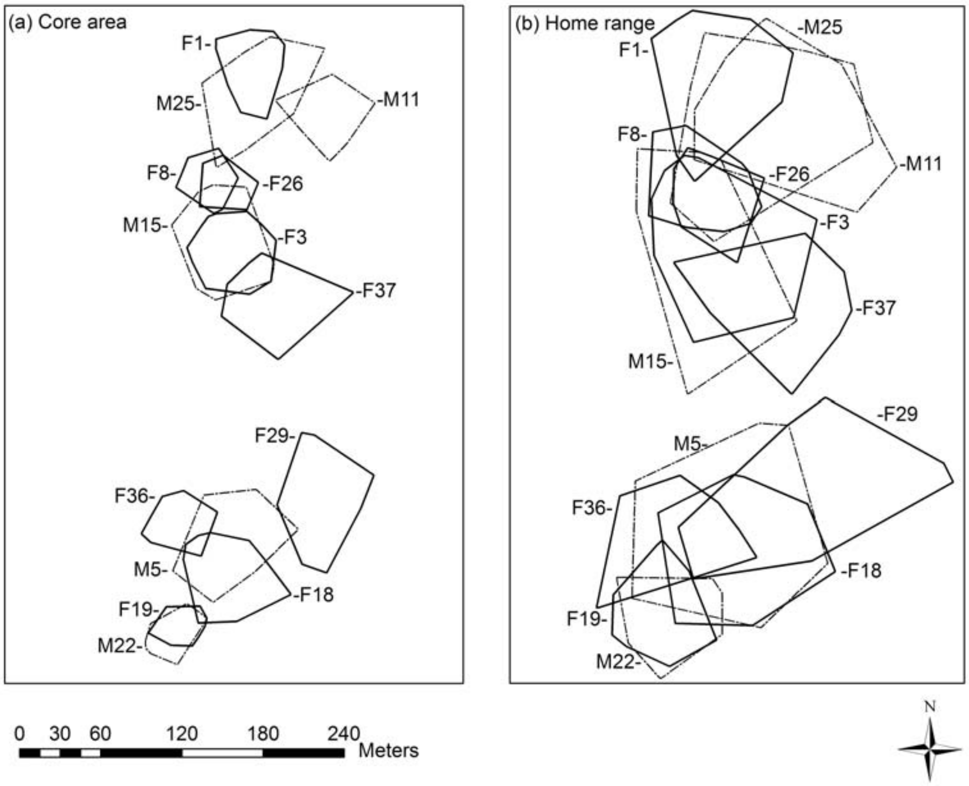

Fig. 25.— Frequency of house sharing (%) by dusky-footed woodrats, by month, in the northern Sierra Nevada, 2004 to 2006.

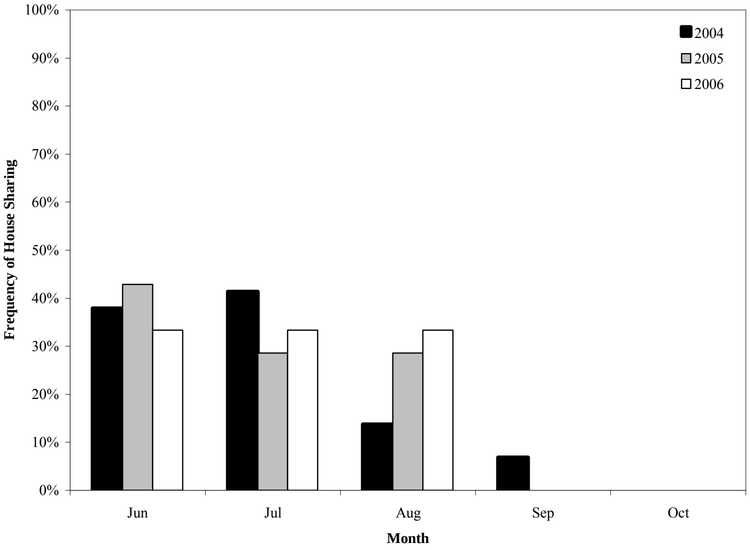

Fig. 26.—Hypothesized model for offspring dispersal in ground dwelling Sciurids (*Spermophilus sp.*). Predicted offspring dispersal distance varies by offspring sex and both offspring and maternal body condition (% fat). Offspring born to mothers in better body condition (i.e., more fat) would begin life higher on the x-axis.

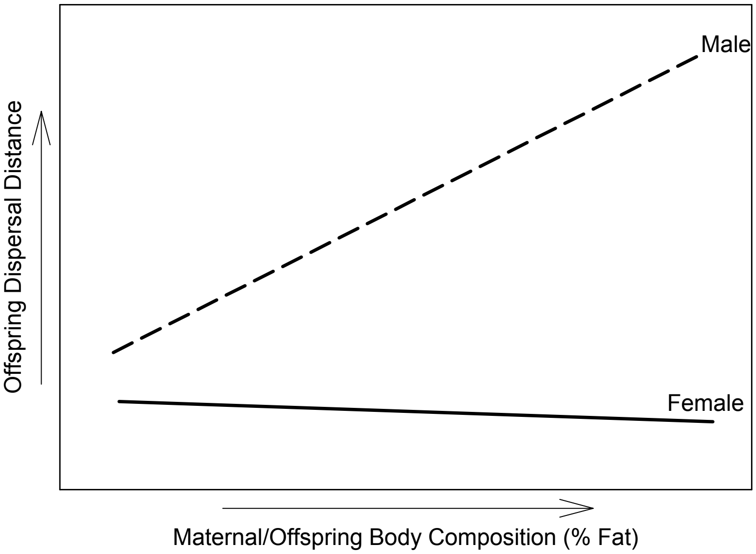

Fig. 27.—Mass of female (mother) golden-mantled ground squirrels and their offspring during 2003 – 2004. All squirrels enter hibernation during early October and emerge following snowmelt in mid May. Significance is indicated by (*).

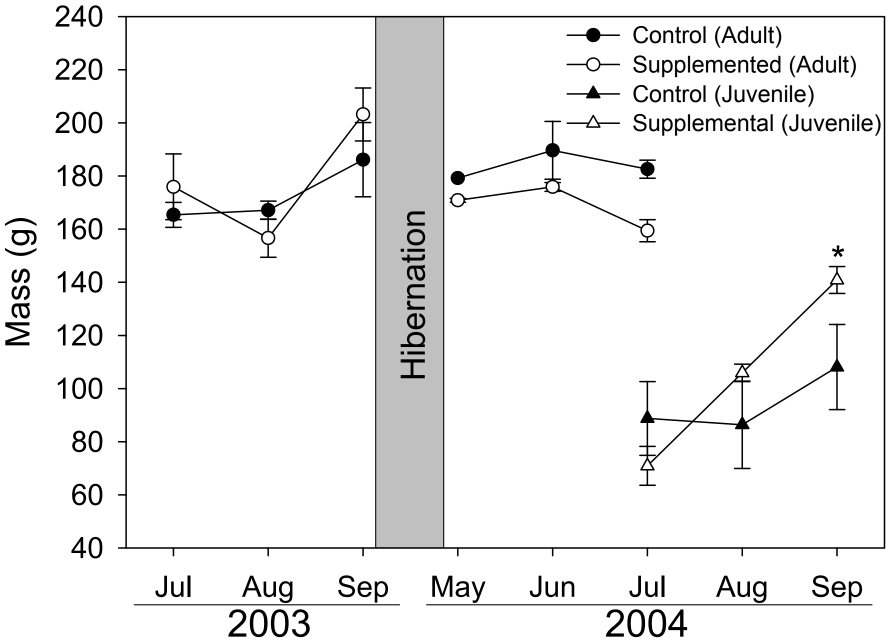

Fig. 28.—Mean exploratory distance (A) and post-natal dispersal (B) distance (m), measured as the distance between location of first capture and location of hibernation, of male (n = 13) and female (n = 10) offspring golden-mantled ground squirrels from each treatment group.

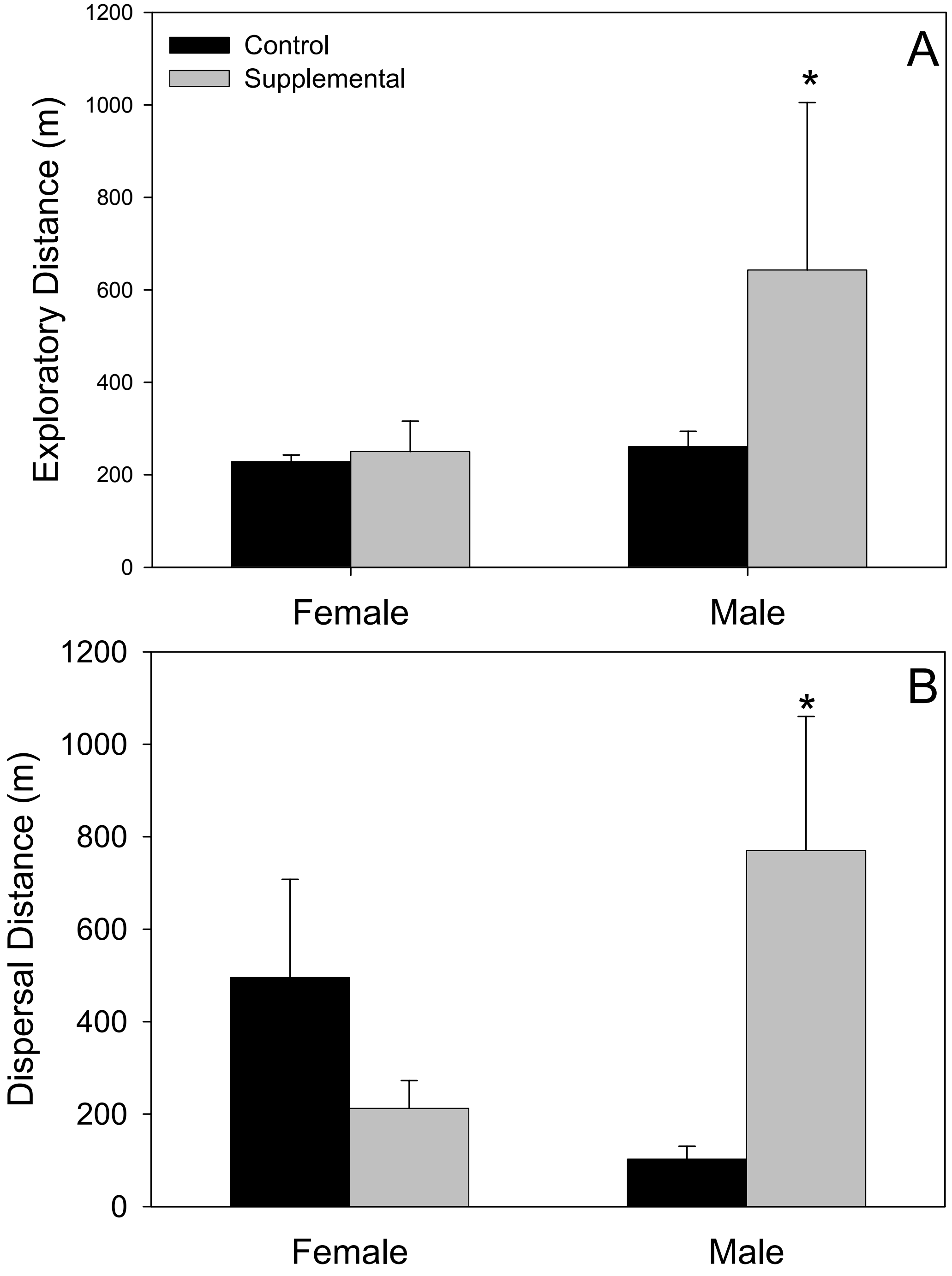

Fig. 29.—Relationship between mean exploratory distance and post-natal dispersal in male (M) and female (F) golden-mantled ground squirrel offspring.

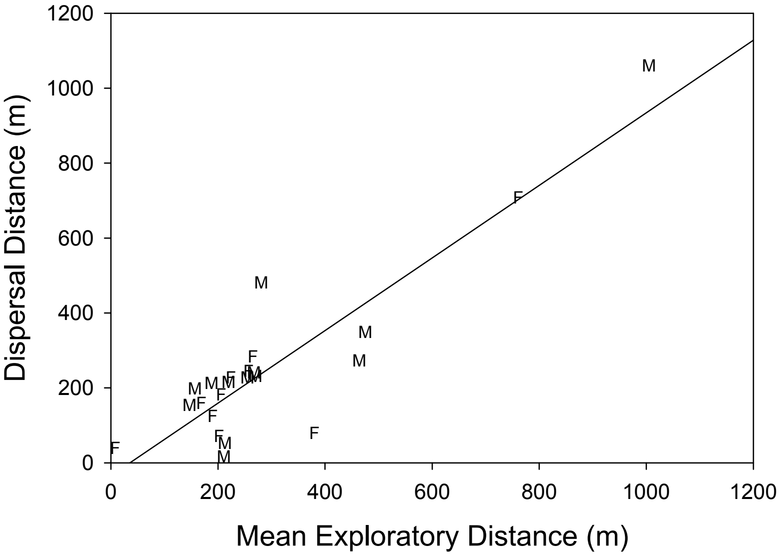

Fig. 30.—Landscape-scale map showing the geographic ranges of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk, and associated habitat, throughout the Sierra Nevada.

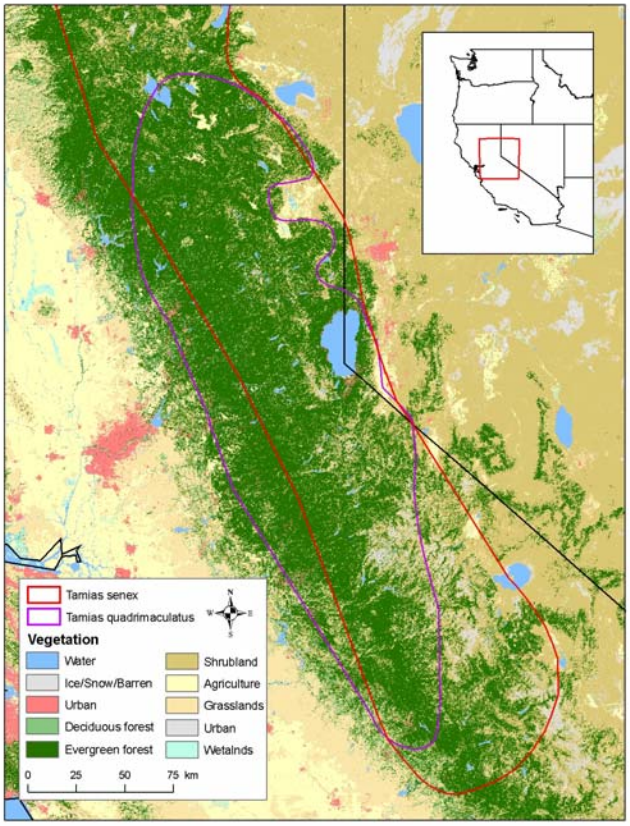

Fig. 31.—Mean abundance (N) of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk among 5 macrohabitat types of Plumas National Forest, CA (2003-2004).

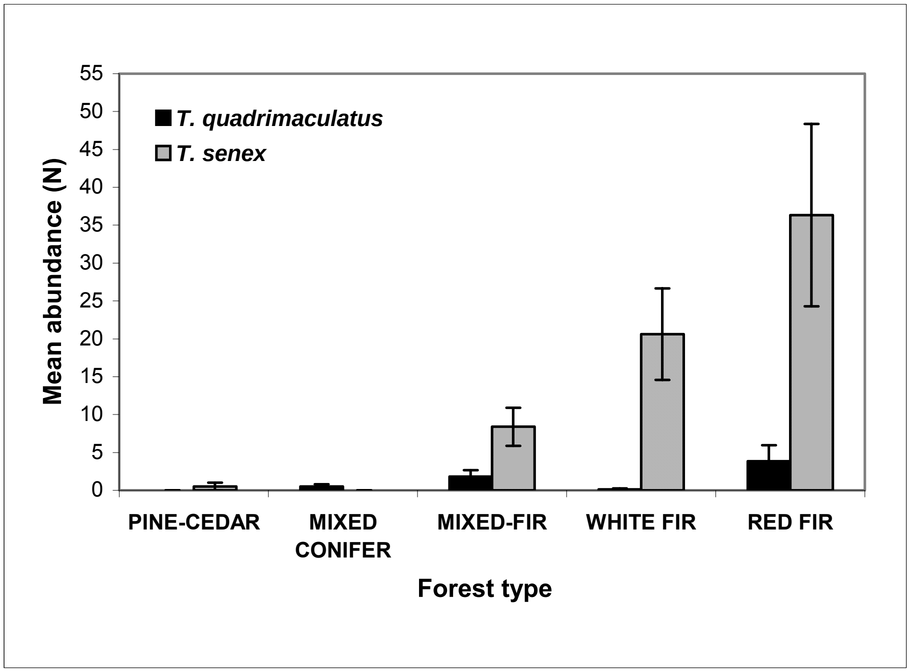

Table 11.—Stepwise logistic regression models of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk microhabitat (trap-scale) associations in Plumas National Forest, CA (2003 and 2004 pooled); variables are ordered by positive parameter estimate.

Model	Variables	Estimate	SE	Wald χ^2	P	Odds ratio	Goodness of Fit
T. quadrimaculatus							
	Canopy Openness	0.030	0.006	22.12	<0.0001	1.030 (1.018-1.043)	*P* = 0.89
	Cover by rocks	0.024	0.009	7.03	0.0080	1.025 (1.006-1.043)	
	Sapling species richness	0.018	0.007	6.00	0.0143	1.018 (1.004-1.033)	
	Slope	-0.045	0.020	4.91	0.0268	0.956 (0.918-0.995)	
	South aspect	-0.013	0.003	25.41	<0.0001	0.987 (0.982-0.992)	
	East aspect	-0.008	0.003	6.85	0.0089	0.992 (0.986-0.998)	
***T*. senex**							
	Shrub species richness	0.623	0.086	52.94	<0.0001	1.865 (1.577-2.206)	*P* = 0.24
	Canopy Openness	0.019	0.004	26.59	<0.0001	1.019 (1.012-1.026)	
	South aspect	0.007	0.001	38.21	<0.0001	1.007 (1.004-1.009)	
	Substrate hardness	-0.460	0.121	14.30	0.0002	0.633 (0.499-0.802)	
	Cover by mats	-0.029	0.010	9.18	0.0025	0.971 (0.953-0.990)	
	Cover by litter	-0.009	0.002	14.47	0.0001	0.991 (0.987-0.996)	

Fig. 32.—Biplot of axes 1 and 2 from canonical correspondence analysis of small mammal trap-scale abundances and microhabitat variables in the Plumas National Forest, California (2003-2004). Vector length indicates the strength of correlation between variables and the canonical axes. *T. quadrimaculatus* is represented by the acronym Taqu and *T. senex* is Tase. The symbol *a* is dead shrubs, *b* is branches, *c* is non-woody vegetation, *d* is small logs, and *e* is large logs. All other species acronyms are as follows: Glsa = *Glaucomys sabrinus*, Misp = *Microtus* species, Nefu = *Neotoma fuscipes*, Pema = *Peromyscus maniculatus*, Spbe = *Spermophilus beecheyi*, Spla = *Spermophilus lateralis*, Tado = *Tamiasciurus douglasi*.

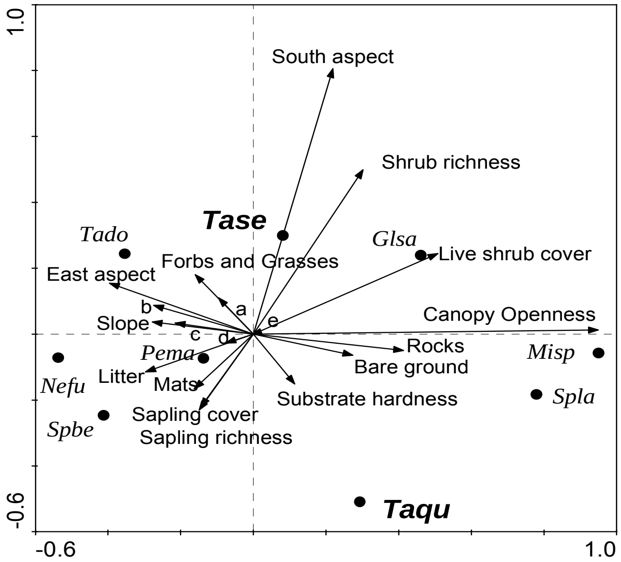

Fig. 33.—Mean abundance (N) of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk, for 2003 and 2004 data separately, among 5 macrohabitat types of Plumas National Forest, CA.

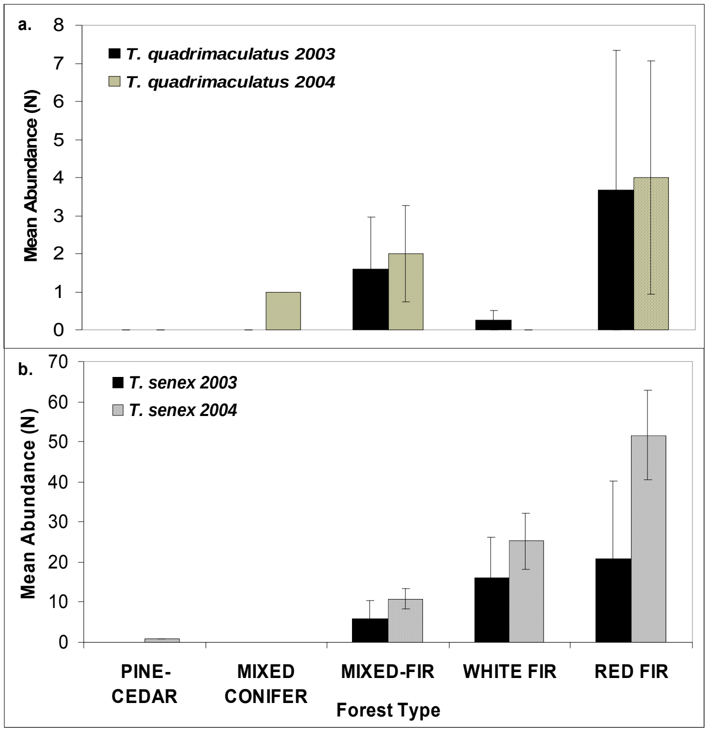

Table 12.—Stepwise logistic regression models of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk microhabitat (trap-scale) associations in Plumas National Forest, CA (2003 and 2004 data separately); variables are ordered by positive parameter estimate. Hosmer Lemeshow goodness of fit values for each of the models include: *T. quadrimaculatus* P > 0.33 (2003), P > 0.09 (2004); *T. senex* P > 0.08 (2003), P > 0.1 (2004).

	2003			**2004**		
Model	**Variables**	**Estimate**	**P**	**Variables**	**Estimate**	**P**
T. quadrimaculatus	Cover by rocks	0.04	<0.0001	Shrub species richness	-1.72	0.0012
	South aspect	-0.02	<0.0001	Cover by live shrubs	0.02	0.0180
	Canopy Openness	0.03	**0.0009**	***Canopy Openness***	0.04	<0.0001
	Cover by large logs	0.02	0.0061	Cover by saplings	0.03	0.0002
	East aspect	-0.01	0.0412	Slope	-0.07	0.0101
T. senex	*South aspect*	0.01	<0.0001	*South aspect*	0.01	<0.0001
	Cover by large logs	0.02	0.0002	Canopy Openness	0.02	<0.0001
	Shrub species richness	*0.48*	*<0.0001*	*Shrub species richness*	*0.62*	*<0.0001*
	Cover by small logs	0.01	0.0213	Cover by Mats	-0.03	0.0060
	Cover by dead shrubs	0.03	0.0066	Cover by litter	-0.01	0.0001
	Sapling species richness	0.27	0.0427	Substrate hardness	-0.39	0.0029
	Cover by non-woody perennials	0.02	0.0085			

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Avian Monitoring in the Lassen and Plumas National Forests

2007 Annual Report

March 2008

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PRBO Contribution Number 1620

Executive Summary

PRBO Conservation Science (PRBO) has been conducting songbird monitoring in the Northern Sierra since 1997. In this report we present results from monitoring efforts of forest management activities within the Herger Feinstein Quincy Library Group project area.

The first chapter discusses results from monitoring aspen habitat on the Lassen National Forest. Results show that treated aspen stands support greater total abundance of birds and abundance of key species such as Mountain Bluebird, Chipping Sparrow, and Red-breasted Sapsucker. Our results also highlight the relative importance of aspen habitat to the avian community compared to coniferous forest.

In Chapter Two we discuss a new project: monitoring Management Indicator woodpecker species in the Lassen National Forest. This project was focused on developing an effective monitoring plan for the rare and elusive Pileated Woodpecker. We used a new landscape modeling technique (MaxEnt) to predict suitable habitat for this species and targeted those areas for sampling with point counts and call back surveys. Results show a far greater detection rate than from previous monitoring in the region and elucidate key habitat components for the species. Pileated Woodpeckers were detected in areas with significantly greater canopy cover, basal area, snags, and downed logs than sites with no detections. We developed an interactive living GIS layer to help managers use up-to-date information on detections of these species on the Lassen National Forest in project planning. Our approach not only provided information about these two species but also, with minimal extra effort, provided information on a whole suite of landbird species. We suggest this approach is a model for implementing effective single- and multi-species monitoring in the region.

In the third chapter we present results from a project designed to reduce fuels while enhancing pine and black oak habitat on the Almanor Ranger District of the Lassen National Forest. We investigated the short-term response of a suite of pine-oak focal species to treatments implemented in 2005 and 2006. Results suggest there was little effect thus far of treatments on a suite of focal bird species, overall avian diversity, or species richness. The only metric that showed an effect was total bird abundance, which

increased after sites were treated. Continued monitoring of this project will be necessary to determine the effects of treatment and successional processes to pine-oak associated bird species.

The fourth chapter discusses result from landscape based habitat modeling of a suite of breeding bird species in the Plumas-Lassen study area. We used maximum entropy (MaxEnt), a powerful new modeling technique that can predict species distributions at a landscape scale. We modeled nine species in this effort and present results and discuss key findings pertinent to land managers. These results suggested the importance of habitat and stand structure heterogeneity to a number of landbird species, including those associated with mature forest. The maps derived from this modeling are ideal tools for use by managers planning projects in the Plumas-Lassen study area.

Acknowledgements

PRBO's work in the Northern Sierra's is a multi-project program with several funding sources. Funding is provided by the regional office of Region Five of the USFS through the Pacific Southwest Research Station, Sierra Nevada Research Center as well as the National Fire Plan. Additional funding is provided by the Lassen National Forest and directly through Herger Feinstein Quincy Library Group Forest Recovery Act monitoring funds. We wish to thank Peter Stine for his leadership and guidance with the Plumas-Lassen Study and staff of the Lassen and Plumas National Forest who support and continue to advocate for our work, especially Mark Williams, Tom Rickman, Coye Robbins, and Bobette Jones of the Lassen National Forest. We are indebted to our hard working field crews who have spent the long hours in the field collecting the massive amount of data required to produce such a report. The 2007 crew included crew leaders Dennis Jongsomjit, Tana Ellis, and Jarred Wolfe and crew members Tim Guida, Paul Taillie, and Lishka Arata.

Management Recommendations

General

- Manage for forest heterogeneity and diversity of habitat types and conditions placing priority on those that exist in small quantities, have been significantly reduced in quality or extent, or are disproportionately important to wildlife and ecosystem function (e.g. aspen, mixed chaparral, pine-hardwood, meadows, late successional forest).

- Restrict all activities that may disturb breeding bird habitat (e.g. timber harvesting, grazing, burning, herbicide treatments, shrub treatments) to the non-breeding season (August - April).

- Maximize snag retention in all projects, including old snags ready to topple. Where priority snags do not occur in high densities save senescing trees and shorter or smaller snags than are currently in snag retention guidelines. Snags as small as eight inches DBH and two meters tall are used by several species of cavity nesting birds (e.g. White-headed Woodpecker). Snags ready to topple are the next generation of down wood, important for many species including Pileated Woodpecker and Oregon Junco.

- Manage coniferous habitat for uneven aged stands with structural diversity including multiple canopy layers and openings that supports shrub and herbaceous understory.

- Focus DFPZ and other forest thinning in dense white fir dominated size class 3 stands to develop more forest heterogeneity that the avian community has evolved to exploit.

- Create more open forests conditions that support shrub and herbaceous understory plant communities. Forests with large trees and 20-30% canopy cover such as the shelter woods on the Swain Experimental forests support an abundant and diverse bird community including declining species such as Olive-sided Flycatcher and Chipping Sparrow.

- Promote the development of forests with old-growth characteristics. Treatments in these areas should focus on ensuring their persistence on the landscape and avoiding impacts that alter their integrity. Manage size class four forest to enhance structural diversity and ensure the full range of old-growth forest conditions will be present on the landscape in the future (e.g. open pine stands, dense close canopy stands).

Aspen

- Aspen habitat enhancement and expansion should be among the highest priorities as aspen is rare on the landscape and the single most species rich avian habitat in the Northern Sierra.

- Promote aspen regeneration to increase overall aspen cover and an understory aspen component. Aspen in the understory size classes were highly correlated with several key bird indices in the ELRD.

- Manage aspen habitat for multiple age and cover classes. Early successional open canopy aspen habitat support a number of bird species of interest (e.g. Mountain Bluebird, Chipping Sparrow).

- Develop strategies for treating Aspen within riparian areas that support, or will support, willows, alders, and other deciduous riparian vegetation. Aspen habitat with these components, harbor a greater diversity and abundance of breeding birds than any other habitat in the Northern Sierra.

- Retain all snags over eight inch DBH in aspen treatments regardless of species, though highest priority should be given to retaining aspen snags.

- Reduce or eliminate over-browsing/grazing in regenerating Aspen stands through fencing or removal of livestock from the area of concern to ensure long-term continued regeneration and structurally diverse aspen stands.

- Consider the potential negative impacts grazing adjacent to aspen treatments has on the abundance of cowbirds and the potential ramifications on open cup nesting birds.

Pine Hardwood

- Prioritize an inventory and delineation of all potential areas for pine-hardwood enhancement at the district level.

- Maximize snag retention focusing on retaining multiple decay classes. Retain all oak and pine snags and where hazard trees are found top them to retain higher densities of snags.

- As both structural diversity and foliage volume are key avian habitat features, restoring both should be a management priority for pine-hardwood enhancement. Suckering of oaks would provide more mid-story foliage volume an important foraging component for many insectivorous birds.

- It is imperative to manage for understory habitat structure - including dense patches of shrubs and herbaceous plant species - in pine-hardwood habitat enhancement projects. Designing treatments that will create a mosaic of varying canopy covers (e.g. 10 – 60%) across stands in combination with prescribed burning should promote the establishment and enhance existing understory plant communities.

- Develop Pine-Oak treatments to create greater mosaics of canopy cover than was implemented at Brown’s Ravine. 40% canopy cover can be achieved across a stand by creating dense clumps of conifers interspersed with semi-open pine-oak patches and open canopies areas dominated by shrubs and regenerating oak and pine.

Montane Shrub

- Consider the ecological value of shrubs within forested habitats and especially where they occur in shrub fields in project planning and design and consider the long-term viability of shrub habitats under the SNFPA.

- Manage a portion (e.g. 50%) of group selections for natural regeneration, including allowing for shrub communities to dominate some sites.

- Allow some areas to regenerate naturally following stand replacing fire events rather than reseeding for quick development of conifers. This should promote greater diversity in habitat structure on the landscape, uneven aged stands, and shrub habitat for numerous avian and other wildlife species.

- Prioritize sites that are, or have the potential to regenerate, mixed species shrub fields (e.g. whitethorn, Manzanita, chinquapin, gooseberry, etc.). Mixed species shrub habitats have higher diversity and abundance of shrub nesting bird species than monotypic stands (e.g. Manzanita fields).

- Retain high snag densities in group selections as snags in open areas are readily used by numerous cavity nesting species, especially woodpeckers. Several shrub study plots support up to five species of woodpecker within a 10 hectare area, including Pileated, Hairy, White-headed, and Red-breasted Sapsucker.

- Replant conifers in group selections not slated for natural regeneration in a clumped design in order to create a mosaic with a semi-open canopy that invigorates shrub development in the openings and reduces the need to re-enter sites for thinning in 20 years.

- Design DFPZ plantation treatments and other thinning projects to create structural diversity by thinning to create some open patches with little canopy cover. In these openings avoid shrub removal to create the attributes of structural diversity that are positively correlated with the bird community.

- Apply prescribed fire treatments in decadent shrub fields where growth and live vegetative cover is now reduced. Manage these areas for regeneration of a newly invigorated shrub community.

- Greatly expand the use of under burns in thinning projects to allow herbaceous and shrub seeds access to mineral soils to allow for regeneration in newly opened canopies.

Chapter 1. Resident and Neotropical Migratory Bird Response to Aspen Enhancement on the Lassen National Forest

Ryan D. Burnett
PRBO Conservation Science

Background and Introduction

Declines in numerous songbird populations throughout North America have been well documented, particularly among Neotropical migrants – those species that breed in the U.S. and Canada and migrate to the Mexico, Central or South America (see Finch and Stangel 1993). The Lassen area supports populations of many of these declining and threatened species, including Warbling Vireo, Swainson's Thrush, Willow Flycatcher, Olive-sided Flycatcher, and Yellow Warbler. The area is home to 9 of the 14 Riparian Focal Species and at least 12 of the 13 Coniferous Forest Focal Species listed by California Partners in Flight (RHJV 2004, CalPIF 2002), as well as all of the species of landbirds identified as declining or likely declining by the Sierra Nevada Ecosystem Project Report (SNEP 1996).

The composition and structure of western North American forests have been altered by fire-suppression, timber harvesting, grazing, and other forest management policies (see Hejl 1994, SNEP 1996, and Siegel & DeSante 1999). Human mediated shifts in the competitive balance of these vast and complex systems can result in permanent loss of habitat types or conditions if steps are not taken to mitigate these impacts.

In the Sierra Nevada, with extensive livestock grazing and the absence of regular fire, aspen are often out-competed by conifers (Mueggler 1985). As a result, the health of aspen has deteriorated and its extent throughout western North America has been reduced by at least 50 and up to 96% (Bartos and Campbell 2001). In 2000, the Eagle Lake Ranger District (ELRD) of the Lassen National Forest (LNF) began an aspen habitat inventory and risk assessment project. This effort documented that nearly 80% of all of the remaining stands had a high or highest risk rating, indicating that without immediate action the future of aspen in the district was endangered. Henceforth, they began a district-wide strategy to enhance and save aspen habitat by implementing conifer removal and erecting grazing exclosures at all remaining stands (Jones et al. 2005). While the study of birds in aspen habitat in the Sierra Nevada has only recently been a focus of ornithological research, evidence from point count data from the nearby Almanor Ranger District of the LNF (Burnett and Humple 2003), the Mono Basin (Heath and Ballard 2003), and the Lake Tahoe Basin (Richardson and Heath 2005), show that aspen habitat supports an extremely rich and abundant avian community that includes several species of conservation concern, such as Warbling Vireo and Red-breasted Sapsucker (Gardali et al. 2000, Rich et al. 2004).

The avian community in the Lassen National Forest occupies a diverse range of niches with its members associated with a broad range of habitat types and features (Siegel and DeSante 1999, Burnett and Geupel 2001). Birds are relatively high on the food chain and have been shown to be sensitive to environmental change. Using one inexpensive standardized method, it is possible to acquire data on an entire community of organisms. Thus, birds are an ideal candidate for use as ecosystem indicators as bird monitoring can provide the necessary feedback at the appropriate breadth and scale (Temple and Wiens 1989, Hutto 1998) to be a valuable tool to land managers.

In 2004, PRBO began monitoring bird response to aspen treatments on the Eagle Lake Ranger District of the Lassen National Forest. With the recent attention the Forest Service has place on monitoring and adaptive management (SNFPA 2004), this project will provide the necessary data to evaluate the efficacy of aspen treatments and provide feedback to support and/or improve future aspen projects in the ELRD and throughout western North America.

Project Area

All avian survey work was conducted on the Lassen National Forest in the Eagle Lake and Almanor Ranger Districts at the junction of the Sierra Nevada and Cascade Mountains of California (Lat 40^0 N, Long 120^0 W). Sites ranged in elevation from approximately 1500 – 2000 meters (Figure 1).

Methods

Aspen Sampling Design

For all aspen sites we used GIS layers containing polygons of known aspen stands based upon aspen inventories conducted by Forest Service staff.

In the Eagle Lake Ranger District we selected sites non-randomly that represent the range of conditions in which aspen are found throughout the District. We limited our selection to areas that contained enough stands or acres to fit a minimum of 4 point count stations with at least 220 meter spacing between points. We attempted to maximize the number of post-treatment sites, which are limited in number, because they could immediately provide us with information on bird response to aspen treatments that were already five to nine years old.

In the Almanor Ranger District we selected sites that were within proposed aspen enhancement projects (e.g., Minnow, Creeks II, Brown's Ravine, and Feather), and one additional site that has been proposed for treatment in the past (Robber's Creek).

On both districts we attempted to maximize the number of points within the delineated aspen stands in an area. In some areas where stands were not in high densities, we limited transect size to allow for completion within the limited morning hours allowed by the standardized protocol. Generally, the first stand chosen was the one closest to the nearest road. Once the first stand was chosen the next closest stand that was at least 200 meters from the previous was selected and so on. All sites were selected without previous knowledge of the local habitat attributes.

Survey Protocol

Standardized five minute fixed radius multiple distance band point count censuses (Ralph et al. 1993, Buckland et al. 1993) were conducted at 181 stations along 18 transects in 2007 (Table 1, Figure 1, and Appendix 1). Detections were placed within one of six categories based on the initial detection distance from observer: less than 10 meters, 10-20 meters, 20-30 meters, 30-50 meters, 50-100 meters, and greater than 100 meters. Birds flying over the study area but not observed landing were recorded separately. The method of initial detection (song, visual or call) for each individual was recorded. Counts began around local sunrise and were completed within four hours. All birds detected at each station during the five-minute survey were recorded. Each transect was surveyed twice between 15 May and 1 July in 2007 (Table 1).

Table 1. Aspen point count transects, ranger district, number of stations, and dates surveyed in 2007.

Site	# of Stations	Ranger District	Date, 1st Survey	Date, 2nd Survey
Ruffa Aspen	12	Almanor	6/8/2007	6/28/2007
Brown's Ravine Aspen	4	Almanor	5/20/2007	6/12 & 6/20/2007
Butte Creek Aspen	8	Eagle Lake	5/23/2007	6/29/2007
Crazy Harry Aspen	7	Eagle Lake	5/24/2007	6/26/2007
Coon Hollow Aspen	14	Almanor	6/4/2007	6/28/2007
Feather Lake Aspen	5	Eagle Lake	5/22/2007	6/24/2007
Harvey Valley Aspen	15	Eagle Lake	6/1/2007	6/21/2007
Lower Pine Creek Aspen	12	Eagle Lake	5/21 & 5/22/2007	6/15/2007
Martin Creek Aspen	11	Eagle Lake	5/25/2007	6/30/2007
Philbrook Aspen	10	Almanor	6/4 & 6/12/2007	6/28/2007
Pine Creek Aspen	14	Eagle Lake	5/21/2007	6/15/2007
Robber's Creek Aspen	16	Almanor	5/22 & 5/23/2007	6/19/2007
Susan River Aspen	12	Eagle Lake	5/24 & 5/31/2007	6/26/2007
West Dusty Aspen 1	10	Almanor	5/29/2007	6/27/2007
West Dusty Aspen 2	6	Almanor	5/27/2007	6/29/2007
West Dusty Aspen 3	8	Almanor	5/29/2007	6/29/2007
West Dusty Aspen 4	8	Almanor	5/30/2007	6/27/2007
Willow Creek Aspen	9	Almanor	5/25/2007	6/24/2007

Habitat Assessment

Habitat characteristics were assessed at all sites using a modified relevé protocol (see Appendix 2 for habitat assessment protocol description). We assessed all sites in the ELRD in 2004 and re-surveyed in 2006 all sites that had been treated since 2004. Habitat assessments were conducted at all aspen sites on the Almanor Ranger District in either 2006 or 2007.

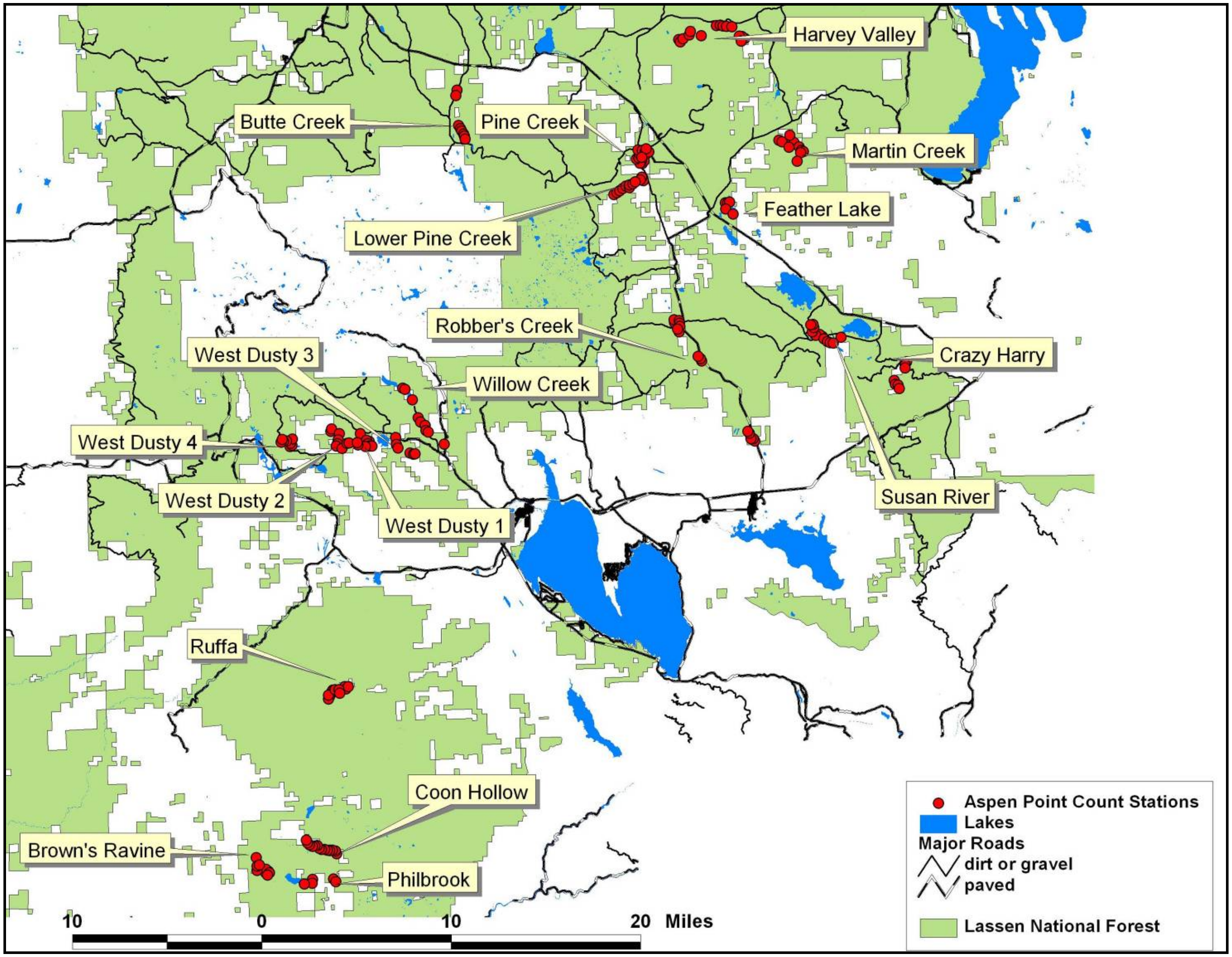
Analyses

Avian community point count analysis was restricted to a subset of the species encountered. We excluded species that do not breed in the study area as well as those that are not adequately sampled using the point count method (e.g., waterfowl, kingfisher, and raptors). We also excluded European Starling and Brown-headed Cowbird from analysis of species richness and total bird abundance because they are invasive species regarded as having a negative influence on the native bird community. We did investigate the abundance of these two species separately and report on them herein.

Species richness

Species richness is the total number of species detected within 50 meters per point across visits within a year.

Figure 1. Location of PRBO Aspen point count stations in the Lassen National Forest surveyed in 2007.



Total Bird Abundance

We define the index of total bird abundance as the mean number of individuals detected per station per visit. This number is obtained by dividing the total number of detections within 50 meters by the number of stations and the number of visits.

Relative Abundance of Species

We define the relative abundance of species as the total detections of that species per point summed across the two visits within a year. We used total detections instead of detections per visit to allow for use of negative binomial regression – which requires raw count data- to compare differences. For analysis that compare multiple years we summed the total detections across years and divided by the number of years. Thus, multiple year analyses are directly comparable to those comparing single years.

Trends in Richness and Abundance

We investigated trends in species richness and total bird abundance at treated and untreated aspen stands in the ELRD from 2004 – 2007. We included all sites surveyed on the ELRD, and since treatment occurred at a number of sites during this four year period, they may have been included in the untreated sample in one or more years and the treated sample in later years.

Statistical Tests

We employed a suite of statistical tests in comparing treated aspen to untreated aspen. Negative binomial regression was used to test for differences in total bird abundance and relative abundance of individual species between treated and untreated aspen stands; while we used linear regression with species richness. We present the p-values from the associated F-test (linear) or Likelihood Ratio Test (negative binomial). For the analysis of trends we used general linear models with year as the independent variable and included transect as a categorical variable for both the treated and untreated samples. We present the test statistic and p-value from the F-test. We then tested to determine if the fitted trend lines between treated and untreated aspen were significantly different from each other. For both species richness and total bird abundance we added a binomial treatment term and an interaction between treatment and year to the model. We then compared the model with the treatment term to the same model but without the interaction using a likelihood ratio test. We present the likelihood ratio χ^2 statistic and p-value from these tests. For all tests we assumed significance at an $\alpha = 0.05$ level, however we considered α levels between 0.05 and 0.10 as marginally significant, and include them in discussion. Stata statistical software was used to conduct all statistical tests (Stata Corp 2005).

Results

Community and Species-specific Indices

Eleven of the 16 aspen transects surveyed in both 2006 and 2007 had greater total bird abundance in 2007, while species richness was higher at nine of 16 sites. In 2007, total bird abundance ranged from a high of 9.50 at Feather Lake to a low of 3.64 at Crazy Harry. Species richness ranged from 8.92 at Ruffa Ranch to 3.67 at West Dusty 2. The mean total bird abundance in 2007 for all sites combined was 5.11 while species richness was 6.67. Seven of the eleven sites showing increases in total bird abundance and five of the nine showing increases in species richness were on the Almanor Ranger District (ARD). Sites on the ELRD showing increases included Feather Lake, Martin Creek, Lower Pine Creek, and Susan River.

We compared the total bird abundance and species richness at untreated aspen sites in the ARD to untreated aspen sites in the ELRD in 2007. Species richness was 6.73 in the ARD and 6.38 in the ELRD. Total bird abundance in the ARD was 4.95 compared to 4.70 in the ELRD (Figure 2); neither of these differences was statistically significant. When sites in the ELRD that have been treated were included, ELRD mean per point species richness increased to 6.70 while total bird abundance increased to 5.19.

Total bird abundance and species richness were higher at treated sites compared to untreated sites in the ELRD across 2006 and 2007, though the difference was only significant with total bird abundance (Table 3, Figures 3, 4, and 5). Total bird abundance was 6.29 at treated sites and 4.70 at untreated sites ($F=8.63$, $p<0.01$). Species richness at treated sites was 7.42 compared to 6.38 at untreated sites ($F=1.64$; $p=0.20$).

Table 2. Mean per point total bird abundance and species richness (within 50 m of observers) at aspen sites surveyed in the Lassen National Forest from 2004 – 2007. Site not surveyed are represented by double dashes.

Station	Total Bird Abundance				Species Richness			
	2004	**2005**	**2006**	**2007**	**2004**	**2005**	**2006**	**2007**
Ruffa Aspen	5.72	7.11	5.92	6.88	7.56	7.33	7.50	8.92
Brown's Ravine Aspen	2.38	3.25	4.13	3.75	2.75	5.25	6.25	5.00
Butte Creek Aspen	4.63	5.81	7.31	5.69	5.75	8.00	9.63	8.38
Coon Hollow Aspen	--	--	--	4.75	--	--	--	6.71
Crazy Harry Aspen	4.50	4.00	5.43	3.64	6.43	5.43	8.00	5.85
Feather Lake Aspen	4.60	7.40	5.30	9.50	6.40	7.20	5.80	7.80
Harvey Valley Aspen	3.47	3.03	5.93	4.17	4.93	4.47	6.93	4.67
Lower Pine Creek	4.00	2.67	4.04	4.67	5.75	4.42	5.92	6.83
Martin Creek Aspen	3.78	4.18	3.91	6.32	5.09	5.45	5.27	8.00
Philbrook Aspen	--	--	--	3.65	--	--	--	5.30
Pine Creek Aspen	4.60	4.57	5.90	5.04	5.93	6.43	7.21	7.00
Robber's Creek Aspen	--	--	5.72	5.78	--	--	7.63	7.31
Susan River Aspen	3.67	3.13	3.09	4.92	4.75	5.00	4.50	6.5
West Dusty Aspen 1	--	--	3.75	4.30	--	--	5.5	6.80
West Dusty Aspen 2	--	--	3.33	3.67	--	--	4.00	3.67
West Dusty Aspen 3	--	--	3.63	3.81	--	--	5.50	5.63
West Dusty Aspen 4	--	--	4.75	5.25	--	--	6.75	7.88
Willow Creek Aspen	--	--	4.28	5.44	--	--	5.33	7.22

Species richness and total bird abundance from 2004 through 2007 were significantly increasing. In treated stands species richness from 2004 to 2007 increased at a rate of 8.9% per year (p=0.01), while untreated stands increased at 5.2% per year (p=0.06). The rate of increase in treated stands was not significantly greater than that in untreated stands (LR χ^2= 1.37, p<0.24). Total bird abundance in treated stands increased at a rate of 8.6% per year (p=0.02) while untreated stands increased at 5.6% per year (p=0.08). The difference in the rate of change between treated and untreated was not significant (LR χ^2= 1.32, p=0.25).

Figure 2. Mean per point species richness and total bird abundance based on detections within 50 meters of observers at Aspen sites in the Almanor and Eagle Lake Ranger Districts in 2007 with standard error bars.

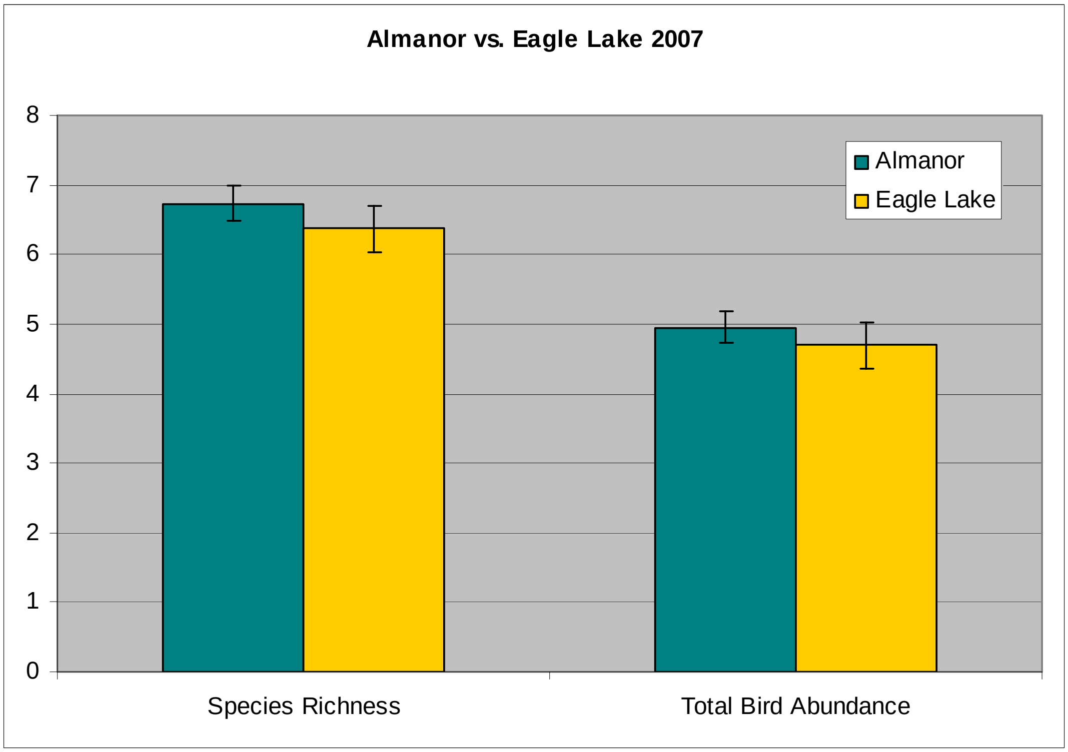


Figure 3. Mean per point species richness and total bird abundance at treated aspen and untreated aspen in the Eagle Lake Ranger District from 2006 – 2007 compared to coniferous forest in the Plumas-Lassen study area from 2003 – 2006.

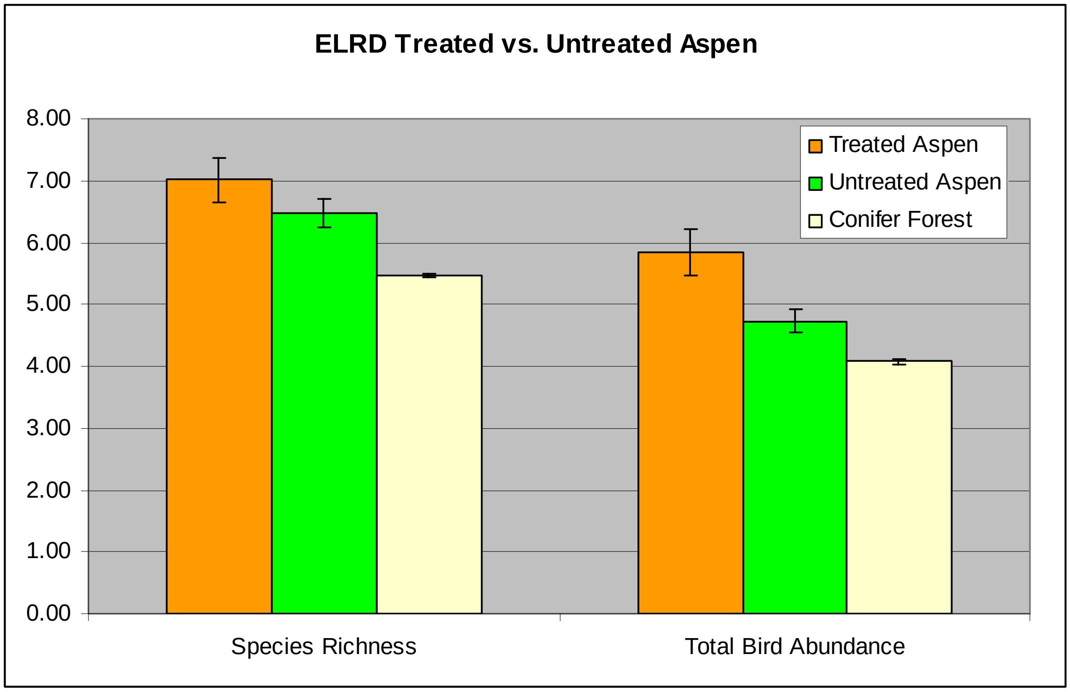


Figure 4. Annual per point species richness (with standard error) at treated and untreated aspen sites from 2004 -2007 in the Lassen National Forest with fitted linear trend.

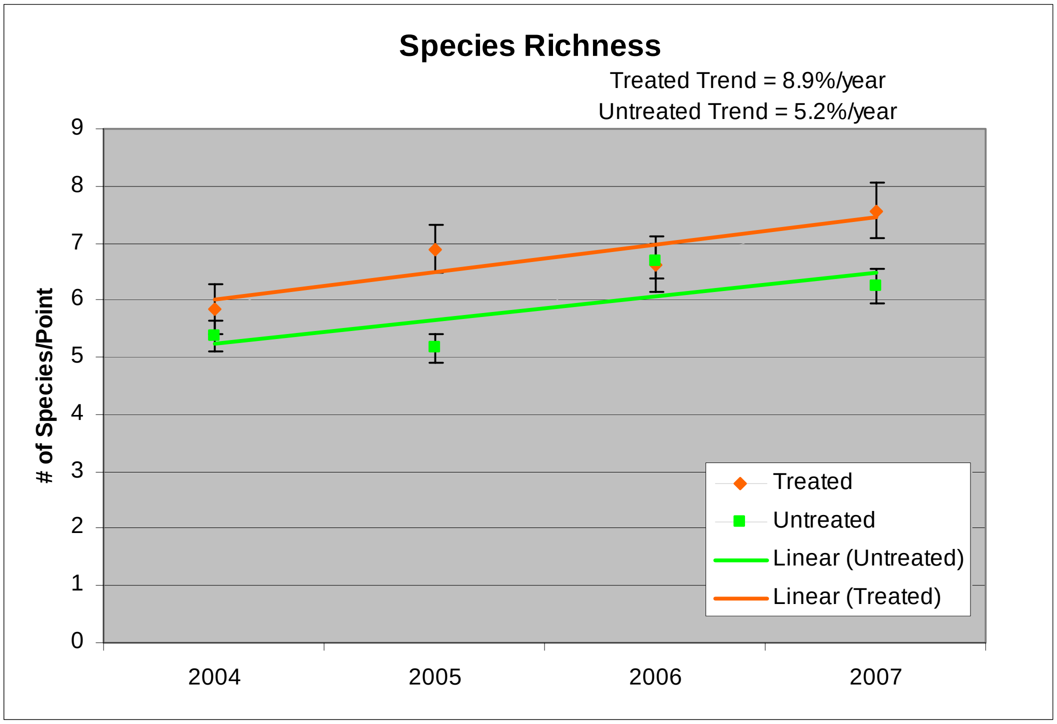
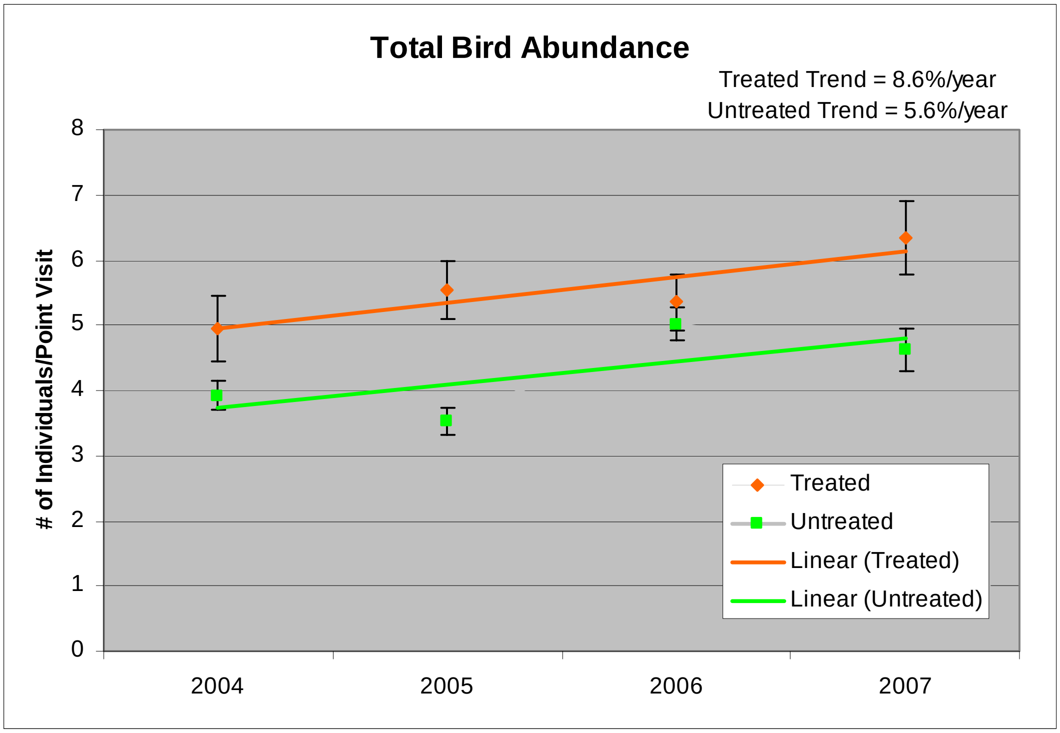


Figure 5. Annual per point visit total bird abundance (with standard error) at treated and untreated aspen sites from 2004 -2007 in the Lassen National Forest with fitted linear trend.



We investigated the relative abundance of ten of the twelve previously identified aspen focal species (Burnett *in press*), at treated aspen, untreated aspen, and conifer forest. There were not adequate detections of Swainson's Thrush and Olive-sided Flycatcher – the remaining two focal species – to include them in the analysis. Olive-sided Flycatcher were detected at 11 of the 18 transects but only one of those detections was within 50 meters of the observer. A total of five Swainson's Thrush were detected, two each at Ruffa Aspen and Coon Hollow, and one at Crazy Harry, the latter is our first detection of this species on the ELRD.

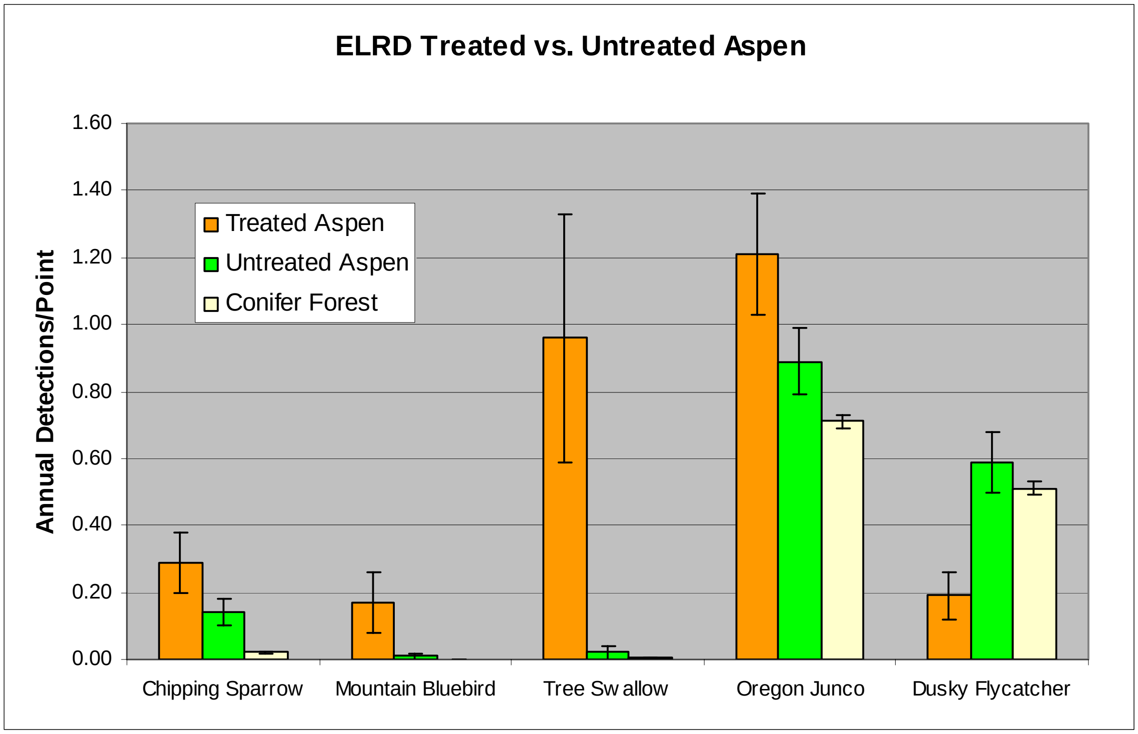
Six of the ten species were more abundant in treated aspen than untreated aspen and coniferous forest (Table 3) with the difference in abundance significant or marginally significant (Figure 6). Red-breasted Sapsucker, Hairy Woodpecker, Mountain Bluebird, Tree Swallow, Oregon Junco and Chipping Sparrow were all significantly or marginally significantly more abundant in treated aspen than untreated aspen. Additionally, total bird abundance was significantly greater in treated stands compared to untreated stands. Of the ten focal species examined, only Dusky Flycatcher was significantly more abundant in untreated aspen than treated aspen.

Table 3. Species Richness, total bird abundance, and the total detections of ten aspen focal species at treated and untreated aspen sites from 2006 and 2007. P-value is from negative binomial regression comparing treated to untreated aspen. Means from conifer forest in the Plumas-Lassen Administrative study area from 2003-2006 are also presented for comparison.

	Treated Aspen	Untreated Aspen	P	Conifer Forest
Species Richness	7.02	6.47	0.20	5.47
Total Bird Abundance	5.85	4.73	<0.01	4.08
Red-breasted Sapsucker	0.50	0.28	0.07	0.05
Hairy Woodpecker	0.40	0.22	0.05	0.06
Western Wood-Pewee	0.35	0.28	0.49	0.03
Dusky Flycatcher	0.19	0.59	0.01	0.51
Warbling Vireo	1.08	1.04	0.86	0.17
Tree Swallow	0.96	0.02	<0.01	0.01
Mountain Bluebird	0.17	0.01	0.00	0.00
Oregon Junco	1.21	0.89	0.10	0.71
Chipping Sparrow	0.29	0.14	0.08	0.02
MacGillivray's Warbler	0.15	0.16	0.99	0.22

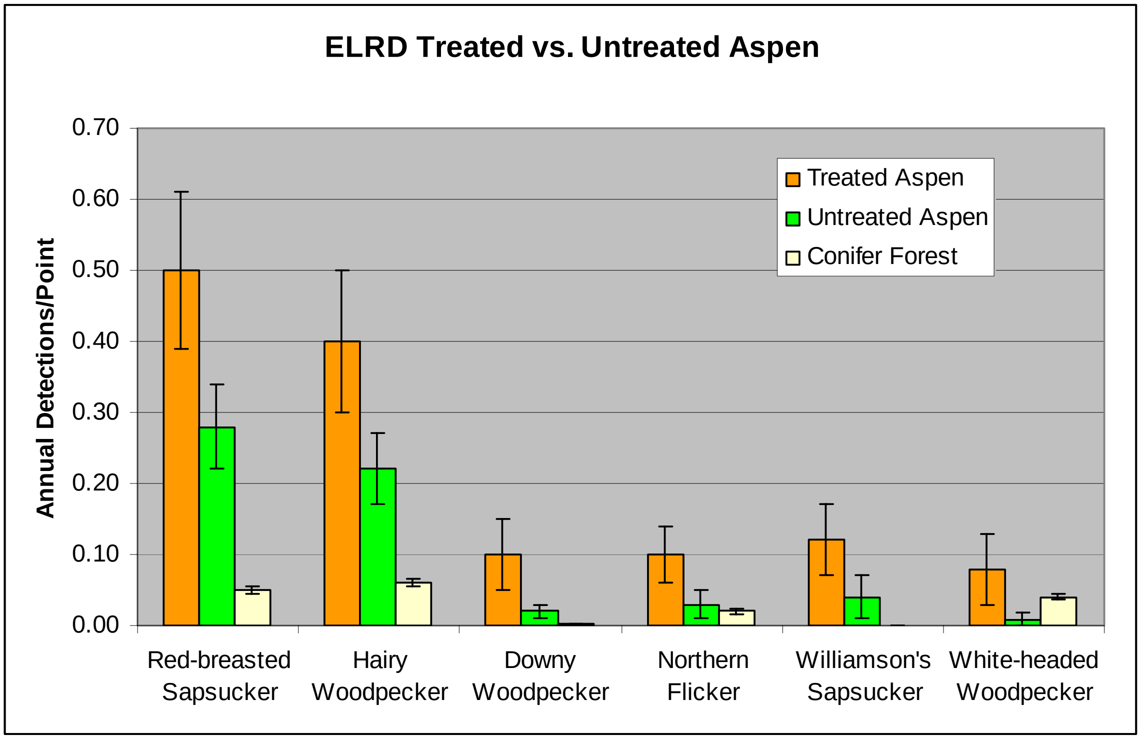
Each of the six species that were more abundant in treated than untreated aspen was also far more abundant in aspen of either type than conifer forest. Two other species, Western Wood-Pewee and Warbling Vireo, were also far more abundant in aspen of either type than conifer forest (Table 3). Of our focal species, only MacGillivray's Warbler and Olive-sided Flycatcher were more abundant in conifer forest than aspen, although Dusky Flycatchers were more abundant in conifer habitat than treated aspen.

Figure 6. Detections per point (with standard error) for seven aspen focal species in treated and untreated aspen in the ELRD from 206-2007 compared to conifer habitat in the Plumas-Lassen Admin Study area from 2003 - 2006.



All six of the most common woodpeckers were more abundant in treated aspen than untreated aspen (Figure 7; Table 3). Hairy Woodpecker relative abundance in treated aspen was 0.40 compared to 0.22 in treated aspen (p=0.06). Red-breasted Sapsucker abundance in treated aspen was 0.50 compared to 0.28 in untreated aspen (p=0.05). Williamson's Sapsucker abundance in treated was 0.12 compared to 0.04 in untreated (p=0.06) and Downy Woodpecker abundance in treated was 0.10 compared to 0.02 in untreated (p=0.05). Compared to coniferous forest, abundance in treated aspen was 6.7 times greater for Hairy Woodpecker, 10 times greater for Red-breasted Sapsucker, and five times greater for Northern Flicker. Furthermore, Downy Woodpecker and Williamson's Sapsucker were not detected within 50 meters of observers from over 4000 point count visits in conifer forest from the Plumas-Lassen study area, while they were fairly common in treated aspen.

Figure 7. Detections per point (with standard error) for the six most abundant woodpeckers at treated and untreated aspen stands in the ELRD from 2006- 2007 compared conifer habitat in the Plumas-Lassen Administrative Study area from 2003 – 2006.



Brown-headed Cowbird and European Starling

In both 2006 and 2007, the European Starling was not detected from point count surveys of Aspen sites in the Lassen National Forest. The mean per point Brown-headed Cowbird abundance was 0.11 for all sites combined. In the ELRD, cowbird abundance at treated sites was 0.08 compared to 0.19 at untreated sites.

Discussion

Overview

In both districts, aspen habitat harbors greater total bird abundance and species richness than conifer forest and far greater abundance of aspen focal species, highlighting the importance of aspen habitat for birds in the region. Untreated aspen habitat on the ELRD and ARD harbor similar abundance and richness of birds, with ARD indices slightly higher. When treated sites are included – which as of 2007 are exclusively on the ELRD – ELRD indices are equal to or higher than those on the ARD. Though we focus the remainder of the discussion on results from treated aspen on the ELRD we believe the results are directly applicable to the ARD and aspen habitat throughout the Northern Sierra.

Treated vs. Untreated Aspen

In the ELRD the short term response to aspen treatments on total bird abundance and species richness has been positive. Total bird abundance was significantly higher at treated sites (24% greater) and species richness, though a lesser effect and not significant, was also higher (9% greater). We would not necessarily have predicted an increase in species richness at sites that had been treated within one to eight years, as treatments remove the vast majority of encroaching conifers. While these conifers are a threat to the health of the aspen community, they do provide suitable conditions for a suite of conifer-associated birds. When these conifers are removed and aspen regeneration has not had the time to develop the structural diversity and habitat complexity lost in the middle story and canopy, one might expect to see a short term drop in species richness. However, the open habitat conditions created through treatment have attracted a new suite of species such as Tree Swallow, Chipping Sparrow, and Mountain Bluebird, which are almost completely absent from untreated aspen. However, it appears that the flush of young aspen shoots three to five years post treatment, as well as a response from the herbaceous layer, more than compensates for any habitat loss from conifer removal. In fact, understory aspen – the first new habitat condition to develop in treated aspen – is the strongest predictor of species richness in aspen habitat on the ELRD (Burnett et al. 2006).

Over the four year period of monitoring bird populations in aspen habitat on the ELRD, there have been significant increases in species richness and total bird abundance in treated and untreated aspen. These same patterns have not been evident from conifer forest over the same time frame (Burnett and Nur 2007). While the difference in the rate of increase between treated and untreated aspen was not significant, the rate is greater in treated aspen for both species richness and total bird abundance. It appears that the initial action of opening up overstocked stands has an immediate benefit to the avian community and that benefit is increasing over time. Thus, there have been significant short term benefits to the avian community from aspen treatments and those benefits appear to be increasing with time. Total aspen cover and especially understory aspen should increase significantly at treated sites in the coming years (Jones et al. 2005). Thus, based on current results already showing significant increases at treated sites, and habitat associations showing the importance of understory aspen, aspen foliage volume, structural diversity, and total aspen cover, we expect these trends will continue if not accelerate in the next five to ten years.

Our aim in selecting focal species to guide and evaluate aspen treatments was to focus on species we know to be far more abundant in aspen than conifer habitat, or that represent key aspen habitat attributes. The vast majority of our focal species were more abundant in treated aspen than untreated aspen, and all but MacGillivray's were indeed more abundant in one form of aspen (treated or untreated) than conifer forest.

MacGillivray's Warbler is an understory species that reaches its greatest abundance in meadow riparian with dense understory foliage (Burnett et al. 2006). As more of these riparian aspen areas are treated and the shade intolerant understory riparian plant community responds, this species should increase at aspen sites.

Dusky Flycatcher is another focal species that nests in the understory in aspen habitat (see cover photo of this chapter for an example of a typical nest location for this species in aspen). This flycatcher was the only species significantly more abundant in untreated aspen than treated aspen. Though they reach their greatest abundance in montane chaparral, we have found them nesting in dense lodgepole pine thickets throughout the Lassen region (pers. obs). This habitat component is largely removed during treatments, thus treated sites are likely to have a short-term negative impact on habitat suitability for this species. However, since treated aspen stands respond with a vigorous flush of new aspen stems (Jones et al. 2005), a dense understory of small trees should develop at most sites 5 to 10 years following treatment. As most treated sites are less than 5 years removed from treatment aspen clones have not had sufficient time to regenerate a dense understory aspen component suitable for nesting by this species. Additionally, a more extensive and vigorous shrub component in riparian aspen systems following conifer release should benefit this species. Regardless, Dusky Flycatcher is a good focal species for evaluating the quality of the understory aspen response following treatment, and we predict they will increase in treated aspen habitat as this study progresses and the number of years since treatment increases.

Aspen treatments appear to be benefiting passerine species that are rare, declining, or both. The four passerines that have shown the greatest positive short-term response to aspen treatments are Tree Swallow, Mountain Bluebird, Chipping Sparrow, and Oregon Junco. Not only are they far more abundant in treated aspen than untreated, they all seem to strongly prefer aspen over conifer habitat. Chipping Sparrow has been significantly declining at a rate of 4.0% per year from 1966-2005 in the Sierra Nevada (Sauer et al. 2007). This species often nests in understory trees in areas with a substantial herbaceous layer where it forages on insects and seeds. They are almost nonexistent in conifer forest in the region, but are among the ten most abundant species in treated aspen. Likewise, Mountain Bluebird and Tree Swallow are all but absent from conifer forest and untreated aspen but are fairly common to abundant (respectively) in treated aspen. Mountain Bluebird has been declining over the past 40 years at a rate of 3.3% per year, though due to their rarity this trend is not significant (Sauer et al. 2007). The abundance of Oregon Junco, one of the most common species in conifer forest, is nearly double in treated aspen. It is another species, though common, that has experienced significant declines (2.4% per year) in the Sierra Nevada (Sauer et al. 2007).

Warbling Vireo, which from 2004-2005 was more abundant in untreated aspen, was slightly more abundant in treated aspen in 2006-2007. A Warbling Vireo nest was found in a two meter tall aspen at Butte Lake point count station 01 this year, anecdotally suggesting sites that have been the longest time since treatment are starting to provide habitat for this species.

Aspen habitat often supports a diverse and abundant guild of cavity nesting species, with many studies showing cavity nesters to disproportionately select aspen trees for nesting (Li and Martin 1991, Dobkin et al. 1995, Martin and Eadie 1999, , Martin et al. 2004). While aspen often contain relatively a high numbers of natural cavities, secondary cavity nesting species have been found to nest predominantly in woodpecker created holes in both live aspen and aspen snags (Li and Martin 1991, Dobkin et al. 1995, Martin and Eadie 1999). Thus, woodpeckers are of vital importance to the cavity nesting birds in aspen habitat.

Woodpeckers continued to be far more abundant in aspen habitat in the Lassen region than non-aspen forest, reaching their greatest abundance in treated aspen sites. Of special note is the case of Downy Woodpecker, a species declining at an alarming rate of 8.8% per year from 1980-2006 in the Sierra Nevada. As with all the other woodpeckers it was significantly more abundant in aspen than conifer forest and showed a preference for treated aspen. It is a riparian associated species, thus treatment of riparian aspen and cottonwood-dominated sites that have been encroached by conifers should benefit this species. The habitat conditions that result following treating aspen stands likely mimic natural disturbances such as fire and blow-down that woodpeckers often associated with. However, the ecological benefits of fire may not be fully realized by just treating aspen stands. It would be necessary to monitor demographic parameters. As it is possible that they are "tricked" by the treatment as food availability may not be any greater. However, we have no solid reason to believe treated aspen are not providing high quality habitat for woodpeckers.

At numerous treated aspen - including those at Feather Lake, Butte Creek, Pine Creek, and Martin Creek - we confirmed active woodpecker nest cavities within treated stands, and a myriad of previously excavated cavities. Removing encroaching conifers from within and surrounding aspen stands, resulting in the expansion of stands and increased density of large diameter aspen stems over time, should increase habitat for woodpeckers. There is little doubt that aspen supports far greater abundance of woodpeckers than coniferous forest and that treating aspen results in even greater increases in these species of management interest. In turn, woodpeckers are a critical component of the aspen community as the source of cavities for an abundant and diverse group of secondary cavity nesting birds, many of which use these aspen areas in relatively high numbers (e.g., Mountain Bluebird, Tree Swallow, Mountain Chickadee).

Brown-headed Cowbird

Brown-headed Cowbirds were present at a number of aspen sites, especially in the ELRD. However, treated aspen sites contained less than half the number of cowbirds than untreated sites. The distribution and abundance of cowbirds is most likely tied to the proximity of grazing allotments and the number of cows, and possibly less to treatment effect. Nineteen of the 33 cowbird detections in 2006 and 2007 were at Harvey Valley, an actively grazed area. As Harvey Valley is to be treated in 2008, measures beyond just fencing aspen may be necessary to alleviate the negative impacts of grazing on the aspen bird community here. In addition, permanent exclusion of grazing from aspen stands may be necessary to avoid significant detrimental impacts to a number of aspen-associated species (Earnst et al. 2005).

Conclusions

Our results from 2006 and 2007 continue to suggest that aspen treatments employed on the ELRD are having a positive effect on the aspen breeding bird community. Key species such as Red-breasted Sapsucker, Mountain Bluebird, and Chipping Sparrow all appear to have had a short-term positive response to treatment. Based on these and previous results we believe that treatments that increase the size and health of aspen stands will be highly beneficial to key breeding bird species in the Lassen National Forest and should be a top priority of land managers here. We also recognize the value of continuing the monitoring of landbird communities in treated aspen habitat in order to determine how they change as time since treatment progresses.

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Appendix 1. GPS (UTM NAD 27) coordinates for all aspen point count locations surveyed in the Lassen National Forest in 2007.

STATION	CODE	SITE	X_COORDINATE	Y_COORDINATE
Ruffa Aspen	ASPN	1	634087	4447622
Ruffa Aspen	ASPN	2	633993	4447459
Ruffa Aspen	ASPN	3	633909	4447283
Ruffa Aspen	ASPN	4	633842	4447102
Ruffa Aspen	ASPN	5	633746	4446885
Ruffa Aspen	ASPN	6	633746	4447193
Ruffa Aspen	ASPN	7	635118	4447923
Ruffa Aspen	ASPN	8	635203	4447725
Ruffa Aspen	ASPN	9	635411	4447925
Ruffa Aspen	ASPN	10	634306	4447661
Ruffa Aspen	ASPN	11	634612	4447680
Ruffa Aspen	ASPN	12	634683	4447371
Butte Creek Aspen	BCA	1	644638	4498553
Butte Creek Aspen	BCA	2	644550	4498065
Butte Creek Aspen	BCA	3	644760	4495527
Butte Creek Aspen	BCA	4	644952	4495285
Butte Creek Aspen	BCA	5	645027	4495074
Butte Creek Aspen	BCA	6	645194	4494831
Butte Creek Aspen	BCA	7	645272	4494654
Butte Creek Aspen	BCA	8	645346	4494398
Brown’s Ravine Aspen	BRAS	1	628386	4432142
Brown’s Ravine Aspen	BRAS	2	628624	4432262
Brown’s Ravine Aspen	BRAS	3	627589	4433429
Brown’s Ravine Aspen	BRAS	4	628428	4432429
Crazy Harry Aspen	CHA	1	682820	4475480
Crazy Harry Aspen	CHA	2	682688	4475240
Crazy Harry Aspen	CHA	3	682703	4474972
Crazy Harry Aspen	CHA	4	681773	4473900
Crazy Harry Aspen	CHA	5	681857	4473575
Crazy Harry Aspen	CHA	6	682098	4473532
Crazy Harry Aspen	CHA	7	682189	4473220
Feather Lake Aspen	FLA	1	667437	4488993
Feather Lake Aspen	FLA	2	667620	4488996
Feather Lake Aspen	FLA	3	667803	4489035
Feather Lake Aspen	FLA	4	667477	4488439
Feather Lake Aspen	FLA	5	668080	4488016
Harvey Valley Aspen	HVA	1	663482	4502834
Harvey Valley Aspen	HVA	2	663608	4502617
Harvey Valley Aspen	HVA	3	663820	4502901
Harvey Valley Aspen	HVA	4	664353	4503212
Harvey Valley Aspen	HVA	5	664447	4503537
Harvey Valley Aspen	HVA	6	665382	4503145
Harvey Valley Aspen	HVA	7	666678	4504026
Harvey Valley Aspen	HVA	8	666994	4504055
Harvey Valley Aspen	HVA	9	667246	4503973
Harvey Valley Aspen	HVA	10	667540	4503942
Harvey Valley Aspen	HVA	11	667974	4503901

Harvey Valley Aspen	HVA	12	669088	4502928
Harvey Valley Aspen	HVA	13	668861	4503100
Harvey Valley Aspen	HVA	14	668631	4503130
Harvey Valley Aspen	HVA	15	668785	4502703
Lower Pine Creek Aspen	LPA	1	660456	4490845
Lower Pine Creek Aspen	LPA	2	660334	4491146
Lower Pine Creek Aspen	LPA	3	660216	4490936
Lower Pine Creek Aspen	LPA	4	657955	4489672
Lower Pine Creek Aspen	LPA	5	658237	4489822
Lower Pine Creek Aspen	LPA	6	658449	4489995
Lower Pine Creek Aspen	LPA	7	658711	4490186
Lower Pine Creek Aspen	LPA	8	658995	4490395
Lower Pine Creek Aspen	LPA	9	659287	4490252
Lower Pine Creek Aspen	LPA	10	659286	4490494
Lower Pine Creek Aspen	LPA	11	659595	4490602
Lower Pine Creek Aspen	LPA	12	659793	4490770
Martin Creek Aspen	MCA	1	672919	4494467
Martin Creek Aspen	MCA	2	673274	4494078
Martin Creek Aspen	MCA	3	673697	4493728
Martin Creek Aspen	MCA	4	673905	4493440
Martin Creek Aspen	MCA	5	674067	4493319
Martin Creek Aspen	MCA	6	673832	4493247
Martin Creek Aspen	MCA	7	671981	4494288
Martin Creek Aspen	MCA	8	672235	4494142
Martin Creek Aspen	MCA	9	673517	4492496
Martin Creek Aspen	MCA	10	672833	4493680
Martin Creek Aspen	MCA	11	672888	4494725
Pine Creek Aspen	PCA	1	660374	4492311
Pine Creek Aspen	PCA	2	660524	4492546
Pine Creek Aspen	PCA	3	660297	4492538
Pine Creek Aspen	PCA	4	660175	4492348
Pine Creek Aspen	PCA	5	659873	4492702
Pine Creek Aspen	PCA	6	660075	4492809
Pine Creek Aspen	PCA	7	660132	4493134
Pine Creek Aspen	PCA	8	659993	4493476
Pine Creek Aspen	PCA	9	660365	4493446
Pine Creek Aspen	PCA	10	660627	4493377
Pine Creek Aspen	PCA	11	660746	4493133
Pine Creek Aspen	PCA	12	660931	4493315
Pine Creek Aspen	PCA	13	660698	4493566
Pine Creek Aspen	PCA	14	660328	4492835
Robber’s Creek Aspen	ROCA	1	669942	4468779
Robber’s Creek Aspen	ROCA	2	669793	4468956
Robber’s Creek Aspen	ROCA	3	669593	4468975
Robber’s Creek Aspen	ROCA	4	669486	4469442
Robber’s Creek Aspen	ROCA	5	669344	4469591
Robber’s Creek Aspen	ROCA	6	665405	4475553
Robber’s Creek Aspen	ROCA	7	665306	4475774
Robber’s Creek Aspen	ROCA	8	665115	4475967
Robber’s Creek Aspen	ROCA	9	663507	4478021

Robber’s Creek Aspen	ROCA	10	663373	4478266
Robber’s Creek Aspen	ROCA	11	663310	4478598
Robber’s Creek Aspen	ROCA	12	663106	4478822
Robber’s Creek Aspen	ROCA	13	663091	4479042
Robber’s Creek Aspen	ROCA	14	663513	4478985
Robber’s Creek Aspen	ROCA	15	663540	4478747
Robber’s Creek Aspen	ROCA	16	663579	4478488
Susan River Aspen	SRA	1	677245	4477578
Susan River Aspen	SRA	2	675682	4477640
Susan River Aspen	SRA	3	675445	4477816
Susan River Aspen	SRA	4	675110	4477746
Susan River Aspen	SRA	5	674827	4478047
Susan River Aspen	SRA	6	674932	4478384
Susan River Aspen	SRA	7	674883	4478663
Susan River Aspen	SRA	8	674697	4478626
Susan River Aspen	SRA	9	675795	4477426
Susan River Aspen	SRA	10	676097	4477220
Susan River Aspen	SRA	11	676339	4477123
Susan River Aspen	SRA	12	676609	4477077
West Dusty Aspen 1	WDA1	1	634004	4469806
West Dusty Aspen 1	WDA1	2	633923	4469600
West Dusty Aspen 1	WDA1	3	634639	4469394
West Dusty Aspen 1	WDA1	4	634539	4468874
West Dusty Aspen 1	WDA1	5	634497	4468542
West Dusty Aspen 1	WDA1	6	634387	4468347
West Dusty Aspen 1	WDA1	7	634873	4468129
West Dusty Aspen 1	WDA1	8	635297	4468584
West Dusty Aspen 1	WDA1	9	635469	4468617
West Dusty Aspen 1	WDA1	10	636174	4468629
West Dusty Aspen 2	WDA2	1	639420	4469076
West Dusty Aspen 2	WDA2	2	639502	4468483
West Dusty Aspen 2	WDA2	3	639619	4468179
West Dusty Aspen 2	WDA2	4	640654	4467742
West Dusty Aspen 2	WDA2	5	640951	4467632
West Dusty Aspen 2	WDA2	6	641089	4467671
West Dusty Aspen 3	WDA3	1	636449	4469388
West Dusty Aspen 3	WDA3	2	637197	4468745
West Dusty Aspen 3	WDA3	3	636961	4468828
West Dusty Aspen 3	WDA3	4	637049	4468527
West Dusty Aspen 3	WDA3	5	637181	4468351
West Dusty Aspen 3	WDA3	6	637412	4468346
West Dusty Aspen 3	WDA3	7	636864	4468309
West Dusty Aspen 3	WDA3	8	636248	4468425
West Dusty Aspen 4	WDA4	1	630461	4468307
West Dusty Aspen 4	WDA4	2	630615	4468421
West Dusty Aspen 4	WDA4	3	630501	4468560
West Dusty Aspen 4	WDA4	4	630663	4468939
West Dusty Aspen 4	WDA4	5	630154	4468780
West Dusty Aspen 4	WDA4	6	629921	4468724
West Dusty Aspen 4	WDA4	7	629708	4468657

West Dusty Aspen 4	WDA4	8	629797	4468887
Willow Creek Aspen	WICA	1	640030	4473252
Willow Creek Aspen	WICA	2	640219	4473149
Willow Creek Aspen	WICA	3	640837	4472266
Willow Creek Aspen	WICA	4	641354	4470754
Willow Creek Aspen	WICA	5	641541	4470368
Willow Creek Aspen	WICA	6	641956	4470077
Willow Creek Aspen	WICA	7	641999	4469674
Willow Creek Aspen	WICA	8	642215	4469538
Willow Creek Aspen	WICA	9	643562	4468519

Appendix 2. PRBO Northern Sierra Aspen Habitat assessment protocol.

All data is collected within a 50 meter radius circle centered on the point count station.

1st Section General Information:

Station = 3 or 4 letter code (e.g. PCA)

Point # = the actual point number of the PC.

Habitat 1 = general classifications (MCF, MCP, MCEA, ASP)

Habitat 2 = only record this if there is a distinct habitat edge (i.e. point is bisected by a clear cut/forest edge)

Date = the date you are collecting this data.

Aspect = the direction of the slope given in degrees (the direction a drop water would flow if poured onto the point). Collect magnetic direction.

Slope = the average slope of the plot with 90 degrees being vertical and 0 degrees being flat, from the highest point to the lowest (i.e., if it drops 10 meters over the 100 meter plot, slope is 10 %.)

Water = true or false is there any water in the plot running or standing.

Snags<10 = total number of the snags in the plot less than 10cm DBH (this includes things that still have dead branches on it but it must be appear to be completely dead, leaning snags that are uprooted but not on the ground or almost on the ground count).

Snags30>10 = the number of snags greater than 10 cm DBH but less than 30 cm DBH (see above for more details).

Snags >30 = the total number of snags greater than 30 cm DBH.

Logs = any downed trees or limbs greater than 8cm DBH and greater than 2m long. Must still have shape of log, rotted decomposed stuff that is really falling apart should not be counted.
Cover Layers
These are divided up into 6 layers (Tree, Tree Shrub, Real Shrub, Total Shrub, and Herbaceous)

Tree – this is defined by height category alone. Any plant species whose upper bounds (highest point) is greater than 5 meters tall is included in this category (a 6 m tall Manzanita would be included in this category, however a 4m tall White Fir would not be).

Tree Shrub – this is all tree species that are less than 5 meters tall regardless of height, this means a 25cm tall White Fir counts in this category. Tree species are the conifers, black oak, maple, white alder, canyon oak, etc. Do not count aspen in this category.

Real Shrub - this is the true shrub species as well as a few shrubby trees that rarely get above 5 meters tall (Dogwood, Mountain Alder, ARPA, CHCA, CECO, CEIN, etc.), record the total cover of these species regardless of height.

Total Shrub - this is the total cover of all vegetation whose maximum height is between 0.5 and 5 meters (the original relevé way of doing it). It may be just the sum of real shrub and true shrub but overlap and tall real shrubs may lead to differences.

Aspen – record the cover of all aspen and the low and high heights regardless of height category.

Herbaceous Layer – this is the total cover of all non-woody vegetation, regardless of height.

Note: the maximum cover theoretically is 100% for all of these categories but practically that would be impossible to achieve.

Height Bounds
High - estimate is to the nearest ½ to 1 meter of the average height of the upper bounds of the vegetation layer (tree, tree shrub, real shrub). This is not the tallest outlier it is the average high of the tallest plants in that layer (e.g., of the tallest trees in the plot what is the average high height).

Low – the average (as defined in the high) of the lowest living branches of the tree and tree shrub and real shrub do not record this for total shrub or herbaceous.

Lower and Upper Species – record the plant species that dominates the lower and upper bounds for all of the categories you collected low and high height data for, if you think there is absolute equal representation of these than good for you! Flip and coin and stop wasting your time and my money and move on to the next measurement.

DBH = estimate the minimum and maximum DBH of any tree within 50 meters, and record what species it is. Do not record this for the shrub layers.

Species List
Record these as T1 (tree layer), TS (true shrub), RS (real shrub), S1 (total shrub) and H1 (herbaceous)

Record for each of these layers the % each species comprises of the total (this number should add up to 100% regardless of the % total cover). List as many species as can easily be recorded in a timely manner. Chasing down that lone shrub off in the corner of the plot is not worth the effort. However, we are interested in hardwood species so if they are present in small numbers recording them even if they are less than 5% is worth the effort, also recording a single large tree as 5% or less is probably also worth it.

DBH Classes
Place each tree in the plot with a DBH (i.e. greater than 1.5 meters tall) into the four DBH classes on the bottom of the page. Note that the DBH tape may be in inches so you need to divide by 2.54. If there are more several hundred trees by all means make a good estimate do not go around taping every tree.

Aspen Density Transects
Using permanently (orange rebar) marked transects lay 50 meter tape out from center of point to one end point (transects are east and south unless an un-crossable barrier is met then chose the bearing 180 degrees from the un-crossable). Record all aspen stems that are within 3 feet of the tape (either side). For each Aspen hit place it within one of 4 categories as listed on the bottom of the sheet (0-1.5’, 1.5’-4.5’, 4.5-1” DBH, and >1” DBH). Subtotal all of these at the 100 ft mark (30.5 meters) and then a grand total for the entire 50 meters. Conduct this for both 50 meter transects.

Canopy Cover
Using same transect as Aspen density above record the hit/no hit along the transect every 10 feet (~3 meters) using the densitometer. For each hit record the species and subtotal these at 100 feet (30.5 meters) and then a grand total for all 50 meters. Repeat for the second transect. Note: It is vital that time is spent to lay out the tape accurately and taught so that transects are as repeatable as possible.

Chapter 2. Management Indicator Species Woodpecker Monitoring in the Lassen National Forest

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Background and Introduction

In order to help guide management of National Forest lands in the United States, the National Forest Management Act (NFMA) was passed in 1976. In 1982 planning regulations were implemented that guided the establishment of Management Indicator Species (MIS) under NFMA. The MIS approach was adopted in order to use a suite of species that can elucidate the most appropriate management approaches by guiding resource management plan revisions and forest plan project implementation. As part of this process the Lassen National Forest identified Pileated and Hairy Woodpeckers (among other species) as MIS (LRMP 1992).

Pileated Woodpecker is the largest extant woodpecker in United States (Bull and Jackson 1995). While its distribution includes a variety of forested habitats across the eastern United States, in the west it is associated almost exclusively with mid- to late seral conifer-dominated forests (Mellen et al. 1992, Bull and Holthausen 1993). Their home range size is large and extremely variable compared to other North American woodpeckers with the literature reporting a range in western populations from 660 – 2600 acres (Bull and Jackson 1995). In Oregon, average home range size was between 1000 and 1200 acres (Bull and Holthausen 1993, Mellen et al. 1992). Due to their retiring nature, habitat specialization, and large territory sizes, standard bird monitoring techniques (e.g. point counts) are unlikely to detect sufficient numbers of this species for meaningful analysis of population trends. Thus, in order to adequately sample this species we developed a GIS-based predictive model of suitable habitat in the Lassen National Forest and followed up point count surveys with broadcasting of drumming and calls.

Hairy Woodpecker is a habitat generalist that occurs throughout a wide range of habitats in North America (Jackson et al. 2002). It is the most abundant (based on point count detections) woodpecker on National Forest land in the northern Sierra Nevada (PRBO unpublished data) and occurs across a range of elevations and habitat conditions here. Due to its generalist nature, it is difficult to determine key habitat attributes for this species, though based on its natural history we know that snags are important for foraging, roost, and nest sites. We have found this species reaches its greatest abundance in burned coniferous forest with large quantities of standing burned trees and in treated aspen stands (see chapter 1). We present information from detections of this species on the new MIS transects but also guide those interested to other chapters of this report or reports from previous years results for more discussion of this species in the Lassen National Forest (e.g. Burnett et al. 2006, Burnett and Nur 2007).

PRBO has been monitoring landbirds in the Lassen National Forest since 1997, focused primarily on the Almanor Ranger District. In 2007 PRBO began a comprehensive forest wide monitoring program for these two woodpecker species. We identified four objectives for our MIS woodpecker monitoring project:

1. Determine the distribution of these species across the forest
2. Provide baseline data for determining long-term trends of these species
3. Identify key habitat features for Pileated Woodpecker
4. Determine a valid approach to monitoring Pileated Woodpecker in the Sierra Nevada.

As a companion to this chapter we created two GIS layers, one is the output from the model predicting suitable Pileated Woodpecker habitat and the second is the detections of all woodpeckers from all sites surveyed by PRBO since 1997 in the Northern Sierra.

Methods

Predictive Model

In order to maximize detections of Pileated Woodpeckers we developed a model to predict areas most likely to support this species. We used a powerful machine learning algorithm called Maxent (Phillips et al. 2006) to predict Pileated Woodpecker distributions based on occurrence data and GIS-based environmental data layers. Maxent is based on the principle of maximum entropy, and uses information about a known set of species occurrence points, compared with environmental "background" data, to develop parsimonious models of species occurrence. The method accommodates several different types of non-linear relationships and is similar to generalized additive models (Hastie and Tibshirani 1990) in its outputs and interpretation.

Species occurrence data came from PRBO's Northern Sierra projects point count survey database, which spanned from 1997-2006 and included over 2600 locations. PRBO point count survey data also contains species absence information, which was used for the Maxent modeling. Any location at which the species was detected at least once at any distance was considered a presence location.

Predictors of species distributions were GIS-based environmental data layers (50-m by 50-m pixels, Table 1). A variety of vegetation, climate, hydrology, and land use data layers were manipulated to create input data layers of hypothesized importance for Pileated Woodpecker (Table 2). Manipulation of input data was performed using ArcGIS 9.2 (ESRI 2006) and Fragstats 3.3 (McGarigal and Marks 1995). Resulting metrics included moving window averages (average pixel value within a circle of a given radius), linear densities (i.e., stream density), and Euclidean distances (i.e., distance to nearest stream or lake). Climate parameters were obtained from PRISM 800-m grid cell climate datasets (http://prism.oregonstate.edu/); vegetation parameters were based on USDA Forest Service CALVEG vegetation tiles converted to grid format at a 50m resolution (http://www.fs.fed.us/r5/rsl/clearinghouse/gettiles.shtml); topographic and hydrologic parameters were derived from the USGS's national elevation dataset (http://ned.usgs.gov/) and national hydrographic dataset (http://nhd.usgs.gov/), respectively.

Model predictions were cross-validated using a subset of the data points (25%) selected at random by the Maxent program. Model performance was assessed using the area under the curve (AUC) of receiver operating characteristic (ROC) plots (Fielding and Bell 1997).

Model validation statistics (ROC AUC) indicated good model performance. AUC values represent the predictive ability of a distribution model and are derived from a plot of true positive against false positive fractions for a given model. Higher values (up to 1.0) characterize higher accuracy models. An AUC value of 0.5 is the equivalent of a random prediction. As a general guideline, AUC values of 0.6 – 0.7 indicate poor accuracy, 0.7 – 0.8 is fair, 0.8 - 0.9 is good, and values greater than 0.9 represent excellent accuracy (Swets 1988).

Table 1. GIS-based environmental predictors of species distribution

Environmental Variable	Description	Original Source
Habitat		
Wildlife habitat types	Categorical and combined vegetation types derived from CALVEG types using the California Wildlife Habitat Relationships (CWHR) classification scheme.	U.S. Forest Service CALVEG Eveg tiles (2000 or 2004)
WHR size classes	Tree size classifications on a 1-6 scale. Classes 5 and 6 were combined (6 being a combination of large and mid size trees)	U.S. Forest Service CALVEG Eveg tiles (2000 or 2004)
WHR density classes	Canopy cover ranging from sparse to dense.	U.S. Forest Service CALVEG Eveg tiles (2000 or 2004)
Weather		
Temperature monthly minimum/maximum	Average monthly minimum and maximum temperatures for Jan, March, June, Oct.	Oregon State University (PRISM climate mapping system)
Precipitation monthly average	Average monthly precipitation for Jan, March, June, Oct.	Oregon State University (PRISM climate mapping system)
Bioclimatic variables	Climate variables derived from monthly min, max, and average temperature and precipitation values	Derived from Oregon State University (PRISM climate mapping system) after Nix (1986)
Topography		
Elevation	Elevation at point in meters.	U.S. Geological Survey (Teale GIS Solutions Group)
Slope	Slope at point derived from elevation data.	U.S. Geological Survey (Teale GIS Solutions Group)
Perennial and intermittent stream density	Stream density (km/km^2) within 1 km radius.	U.S. Geological Survey (National Hydrography Dataset)

Table 2. Habitat variables selected for input into Pileated Woodpecker habitat model.

Variable	Description
Red fir	Percent shrub habitat within a 1km radius
Sierran Mixed Conifer	Percent mixed conifer forest within a 1km radius
White fir	Percent white fir vegetation within a 1km radius
All vegetation types	Vegetation type at point count location
Precipitation	Average precipitation in Jan, Mar, Jun, Oct
Temperature	Minimum and maximum temperatures in Jan, Mar, Jun, Oct
Size class 4 and 5	Vegetation size classes within a 1 km radius
Density class 1 and 2	Tree density within a 1km radius (cwhr class O & M+D)
Slope	Slope at point count location
Elevation	Elevation at point count location

Site Selection

In a GIS environment we clipped model outputs to the Lassen Forest boundary. We then queried the data to show only those sites considered to have greater than 40% likelihood that the habitat conditions that best predict this species occurrence were present. We then used a random point generator to select 70 potential starting points, which was double the number of transects we intended to establish. We then randomly selected among the starting points and attempted to establish transects within the polygons or several adjacent polygons. We attempted to place at least eleven transects in each district regardless of the amount of habitat the model suggested the district had (Table 3). If a random point fell within a polygon where an existing transect was located we used that transect (1 on ELRD and 7 on ARD).

Each transect was six points long with 500 meters between each point. We doubled the normal distance between point count stations in order to survey more area and to limit multiple surveys within the same woodpecker's territory.

Survey Protocol

At each station upon arrival we conducted a standardized five minute – multiple distance band fixed radius point count. The same survey technique used at all other PRBO northern Sierra point count stations. If a Pileated Woodpecker was detected during the point count census after the five minute survey we moved on to the next station.

If a Pileated Woodpecker was not detected during the five minute point count we conducted a playback survey that was up to three minutes in duration. We used a digital audio recording of a series of Pileated Woodpecker calls and drumming broadcast over a Radioshack® "Power Horn" blaster at full volume. Based on several field tests our callback could be detected from between 150 and 250 meters by our observers based on field conditions (e.g. slope, tree density). The callback survey consisted of three 30 second callback surveys each separated by a 30 second listening period. The direction the blaster was directed was rotated 120 degrees from the previous broadcast position for each subsequent playback. If at any point during the survey a Pileated Woodpecker was detected we ceased the playback, recorded the type of detection (drumming, visual, or call) and distance from the observer, and moved on to the next survey location.

Table 3. MIS point count/Pileated Woodpecker callback survey transects, transect codes, Ranger District, and dates surveyed in the Lassen National Forest in 2007.

Transect Name	Transect Code	Ranger District	1st Survey	2nd Survey
114	114	Almanor	5/23/2007	6/7/2007
Cottonwood Creek	COCR	Almanor	6/7/2007	6/23/2007
D102	D102	Almanor	5/24/2007	6/11/2007
D108	D108	Almanor	5/24/2007	6/11/2007
D111	D111	Almanor	5/22/2007	6/10/2007
D112	D112	Almanor	5/23/2007	6/7/2007
Louse Creek	LOCR	Almanor	6/5/2007	6/30/2007
Peacock Point	PEPO	Almanor	6/4/2007	6/23/2007
Rattle Snake	RASN	Almanor	5/25/2007	6/12/2007
Rocky Point	ROPO	Almanor	5/25/2007	6/10/2007
Snag Lake	SNLA	Almanor	6/4/2007	6/21/2007
Upper Mill Creek Trail	UMCT	Almanor	5/26/2007	6/13/2007
Bear	BEAR	Eagle Lake	6/12/2007	7/1/2007
Crater Mountain	CRMO	Eagle Lake	5/26/2007	6/14/2007
Dixie Springs	DISP	Eagle Lake	5/29/2007	6/15/2007
Dow Flat	DOFL	Eagle Lake	5/30/2007	6/16/2007
Harvey Valley DFPZ	HVD	Eagle Lake	6/2/2007	6/21/2007
Harvey Valley Reference	HVR	Eagle Lake	6/2/2007	6/21/2007
Lodgepole	LODG	Eagle Lake	5/31/2007	6/13/2007
Logan Mountain	LOMO	Eagle Lake	5/31/2007	6/29/2007
Pine Creek	PINE	Eagle Lake	5/28/2007	6/14/2007
Squaw Valley	SQVA	Eagle Lake	5/29/2007	6/15/2007
Swain's Hole	SWHO	Eagle Lake	6/1/2007	6/18/2007
Ashpan Butte	ASBU	Hat Creek	6/6/2007	6/27/2007
Bald Mountain	BALD	Hat Creek	6/8/2007	6/25/2007
Crag	CRAG	Hat Creek	6/9/2007	6/30/2007
Devil's Rock	DERO	Hat Creek	6/8/2007	6/27/2007
Freaner Peak	FRPE	Hat Creek	6/9/2007	6/28/2007
Horse Heaven	HOHE	Hat Creek	6/9/2007	6/28/2007
Ice Cave	ICCA	Hat Creek	5/30/2007	6/16/2007
Lost Creek	LOST	Hat Creek	6/5/2007	6/19/2007
Moon Springs	MOON	Hat Creek	6/8/2007	6/25/2007
Plum Valley	PLUM	Hat Creek	6/2/2007	6/19/2007
Potato Butte	POBU	Hat Creek	6/9/2007	6/29/2007
Signal Butte	SIBU	Hat Creek	6/1/2007	6/18/2007

Vegetation sampling protocol

At each survey station a modified relevé protocol was used to asses habitat conditions (Ralph et al. 1993). A detailed description of the data collected and methods are presented in Appendix 1. Key information collected included: basal area, canopy closure, number of snags by size category, tree richness, average canopy height, and absolute cover of each tree and shrub species.

Analysis

Avian community point count analysis was restricted to a subset of the species encountered. We excluded species that do not breed in the study area as well as those that are not adequately sampled using the point count method (e.g., waterfowl, kingfisher, and raptors). We also excluded European Starling, an invasive species that is generally regarded as having a negative influence on the native bird community.

Species Richness and Total Bird Abundance

Species richness is defined as the total number of species detected within 50 meters. Presenting the mean species richness, as we do herein, allows for comparisons between transects or habitats consisting of different numbers of point count stations. We define total bird abundance as the mean number of individuals detected per station per visit. This number is obtained by dividing the total number of detections within 50 meters by the number of stations and the number of visits.

For comparison of total bird abundance and species richness at Pileated Woodpecker sites compared to sites where they were not detected we tested for significant using logistic regression. For all analyses we present untransformed arithmetic means along with standard error of that mean.

Habitat Comparisons

We chose seven habitat variables that we believed may be important to Pileated Woodpeckers and compared them at sites where we detected Pileated Woodpecker and at sites where they were not detected in 2007. We considered site to have a positive detection if the species was detected at any distance and by any means (e.g. point count, call back, and incidental). We tested for significance using two-tailed student t-tests and considered significance at the $\alpha = 0.05$ level. We then entered each of the variables found to be significantly different into a reverse stepwise logistic regression model, with the level of significance set at $\alpha = 0.10$. We repeated this for Hairy Woodpecker, but we only used detections from point counts, as we did not conduct playbacks for this species. We also included all seven habitat variables (see Table 6) we believed were potentially important for the species into the stepwise model. All statistical analysis was conducted using Stata statistical software (Stata Corp 2006).

Results

Pileated Woodpecker

Pileated Woodpecker were detected on 21 of the 35 transects and within 100 meters of observers at 15 of the 21 transects in 2007. They were detected at nine of the twelve transects in the ARD, six of the eleven transects in the ELRD, and six of the twelve transects on the HCRD. Pileated Woodpecker were detected at 82 of the 234 stations (35% of sites) by way of point count or call back survey, 22% from point count surveys and 13% from call backs. Of the sites where they were confirmed, 63% were by way of point count surveys while 37% were from callbacks. Pileated Woodpecker were detected within 100 meters of observers at 9% of the stations (n=22), with all but three of those detections from call back surveys. They were detected at an additional nine stations from incidental observations before or after the surveys were conducted.

Figure 1. Locations of MIS survey transects in the Lassen National Forest in 2007 with detections of Pileated Woodpecker and areas predicted to have high suitability for Pileated Woodpecker from Maximum entropy landscape based model.

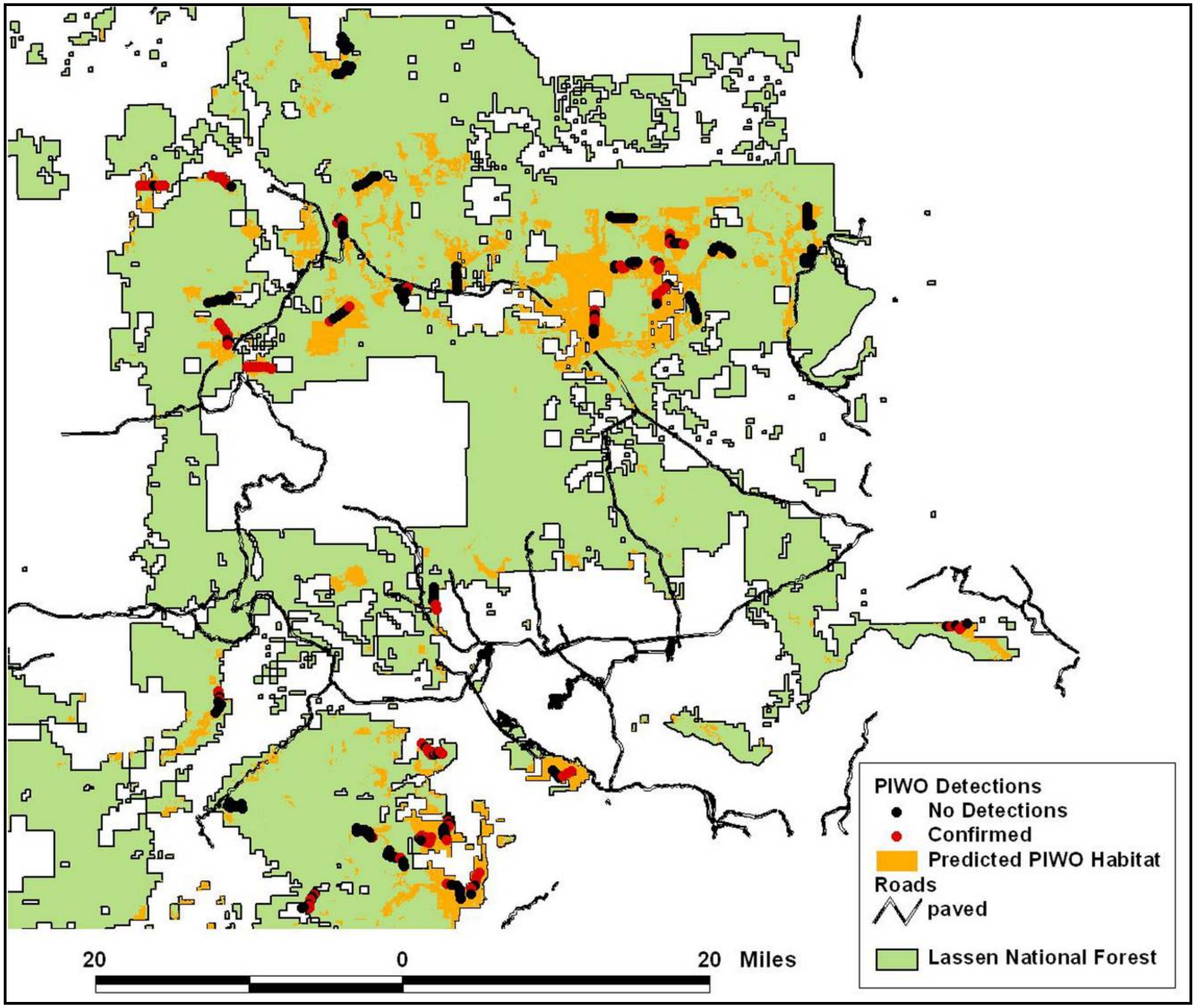


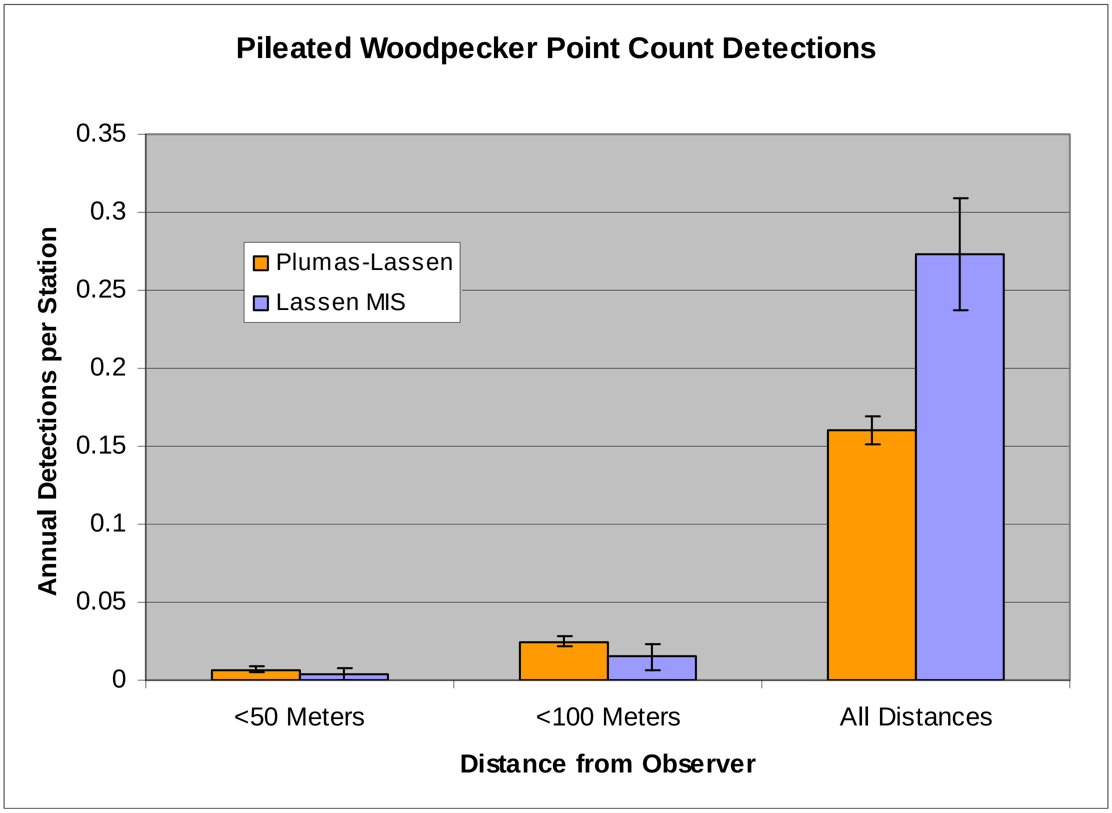
Table 4. MIS transects where Pileated Woodpecker were encountered in the Lassen National Forest in 2007 based on all detections from point counts, call back surveys, and incidental detections before or after surveys.

Transect Name	Ranger District	Pileated Detected	Pileated < 100 meters from survey point
114	Almanor	X	X
Cottonwood Creek	Almanor	X	X
D102	Almanor		
D108	Almanor	X	
D111	Almanor	X	X
D112	Almanor	X	X
Louse Creek	Almanor	X	X
Peacock Point	Almanor		
Rattlesnake	Almanor		
Rocky Point	Almanor	X	
Snag Lake	Almanor	X	X
Upper Mill Creek Trail	Almanor	X	
Bear	Eagle Lake	X	X
Crater Mountain	Eagle Lake	X	X
Dixie Springs	Eagle Lake		
Dow Flat	Eagle Lake		
Harvey Valley DFPZ	Eagle Lake	X	
Harvey Valley Reference	Eagle Lake	X	
Lodgepole	Eagle Lake	X	X
Logan Mountain	Eagle Lake		
Pine Creek	Eagle Lake		
Squaw Valley	Eagle Lake	X	X
Swain's Hole	Eagle Lake		
Ashpan Butte	Hat Creek	X	X
Bald Mountain	Hat Creek		
Crag	Hat Creek	X	X
Devil's Rock	Hat Creek		
Freaner Peak	Hat Creek	X	X
Horse Heaven	Hat Creek	X	X
Ice Cave	Hat Creek		
Lost Creek	Hat Creek		
Moon Springs	Hat Creek		
Plum Valley	Hat Creek	X	X
Potato Butte	Hat Creek	X	
Signal Butte	Hat Creek		

We compared detection rates of Pileated Woodpeckers at point count surveys on the Lassen MIS transects to those from the Plumas Lassen study area (Figure 2). Mean detections per point within 50 meters of observers was 0.004 for MIS and 0.007 for Plumas-Lassen. For detections within 100 meters of observers it was 0.015 for MIS and

0.025 for Plumas-Lassen; for all detections MIS was 0.27 compared to 0.16 for Plumas-Lassen.

Figure 2. Pileated Woodpecker total detections per point count station, with standard error, by distance from observer at MIS woodpecker point count stations in the Lassen National Forest in 2007 compared to point count stations in the Plumas Lassen study area in 2005 and 2006.



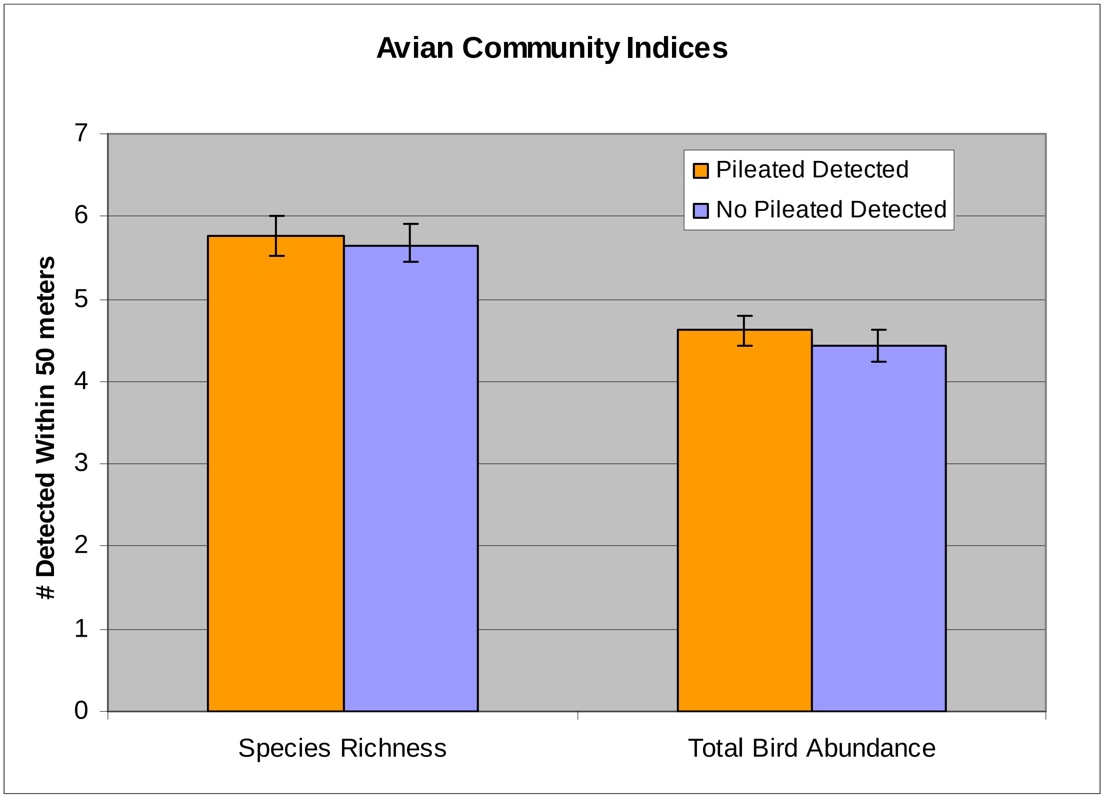
Species richness and total bird abundance for all sites combined in 2007 was 5.70 and 4.46 respectively in 2007 (Table 5). Species richness ranged from a high of 8.50 at Dixie Springs to a low of 3.17 at Moon Springs. Total bird abundance ranged from a high of 8.25 at Dixie Springs to a low of 2.25 at Moon Springs. In comparison, the average from 2003 – 2006 in the Plumas Lassen study was 5.68 for species richness and 4.31 for total bird abundance (Burnett and Nur 2007).

Species richness at sites where Pileated Woodpecker were detected was 5.76 compared to 5.65 at sites were they were not detected (Figure 3). Total bird abundance was 4.61 at detected sites compared to 4.44 at sites they were not detected; neither difference was statistically significant.

Table 5. Avian community indices at Pileated Woodpecker survey sites in 2007 in the Lassen National Forest.

Station	Species Richness	Total Bird Abundance
114	7.83	7.71
Ashpan Butte	4.33	3.00
Bald Mountain	7.33	7.50
Bear	7.00	6.33
Cottonwood Creek	6.50	4.25
Crag	4.17	3.25
Crater Mountain	6.17	5.08
D102	5.67	4.00
D108	7.58	6.33
D111	4.83	3.46
D112	5.75	4.42
Devil's Rock	4.83	3.50
Dixie Springs	8.50	8.25
Dow Flat	5.67	4.08
Freaner Peak	6.33	4.50
Horse Heaven	7.50	5.83
Harvey Valley DFPZ	5.14	3.36
Harvey Valley Reference	4.29	3.14
Ice Cave	5.50	3.58
Louse Creek	5.17	4.25
Lodgepole	4.33	3.83
Logan Mountain	6.17	4.25
Lost Creek	5.67	4.25
Moon Springs	3.17	2.25
Peacock Point	4.83	3.58
Pine Creek	6.67	5.50
Plum Valley	5.33	3.92
Potato Butte	6.17	3.75
Rattle Snake	5.08	3.83
Rocky Point	5.67	5.08
Signal Butte	3.83	2.50
Snag Lake	5.17	3.54
Squaw Valley	5.83	4.50
Swain's Hole	5.67	4.83
Upper Mill Creek Trail	5.92	4.67
Average	**5.70**	**4.46**

Figure 3. Avian community indices at sites where Pileated Woodpecker were detected compared to sites where they were not detected in the Lassen National Forest in 2007.



Habitat Variables at Pileated Woodpecker Sites

We chose seven habitat variables we predicted might be important for Pileated Woodpeckers (Table 6). We then compared these variables at sites were Pileated were detected and at sites were there were no detections. As described in the methods, this included only sites where Pileated Woodpeckers were predicted to occur, so differences might be greater if compared to all forest sites where they did not occur. We tested for significance using a one tailed t-test as our hypothesis was that each of these variables would be greater at Pileated Woodpecker occupied sites. Six of the seven variables were significantly or marginally significantly greater at occupied sites. Only maximum tree diameter (the diameter of the largest tree in the plot) was not significantly different. There were significantly greater basal area, canopy closure, canopy height, snags, and logs at sites were Pileated were detected compared to sites were they were not (Table 6, Figures 4 – 6). Basal area averaged 170.40 sq. ft at occupied sites compared to 117.40 at unoccupied sites, and canopy closure was 49% compared to 37%.

Table 6. Comparison of seven key habitat variables at sites were Pileated Woodpecker were detected and sites where they were not detected (including only sites where they were predicted to occur; not forest-wide), with standard error (SE) and p-value from one-tailed t-tests (Stata Corp 2005).

Habitat Variable	Pileated Detected	SE	No Pileated Detected	SE	P
Snags > 60 cm DBH	2.06	0.31	1.03	0.17	<0.01
Snags >30 cm DBH	8.03	0.96	4.83	0.62	<0.01
Logs	45.88	3.07	37.45	3.33	0.04
Canopy Height (m)	28.66	0.71	25.63	0.82	<0.01
Maximum Tree DBH (cm)	99.78	3.09	91.72	7.04	0.19
Basal Area (sq.ft./acre)	170.40	2.0	117.40	8.0	<0.01
Canopy Closure	0.49	0.02	0.37	0.02	<0.01

The average canopy height was 28.66 meters at occupied sites compared to 25.63 at unoccupied sites. There were 2.06 large snags at occupied sites compared to 1.03 at unoccupied sites. Likewise, there were 8.03 snags over 30 cm (11.81 inches) compared to 4.83 at unoccupied sites. There were 45.88 logs at occupied sites and 37.45 and unoccupied sites.

Figure 4. Mean canopy closure (with standard error) at sites where Pileated Woodpecker were detected compared to sites where they were not in the Lassen National Forest in 2007. Canopy closure was measured at 16 points along four transects within 50 meters of survey point.

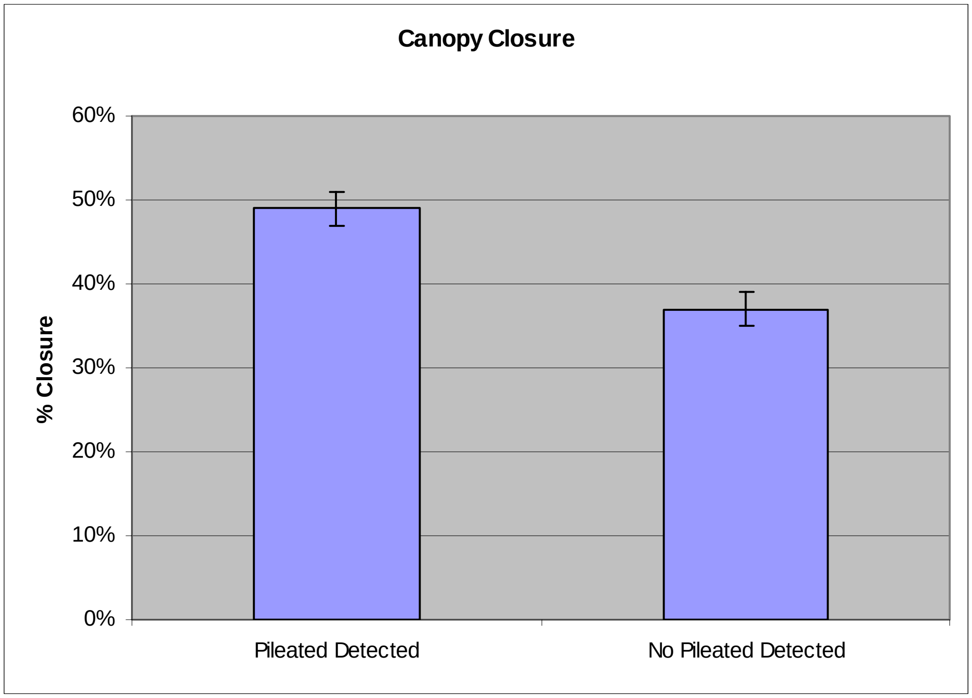


Figure 5. Mean canopy height (with standard error) at sites where Pileated Woodpecker were detected compared to sites where they were not in the Lassen National Forest in 2007. Canopy height is the average height of the tallest trees within a 50 meter radius circle around the survey point.

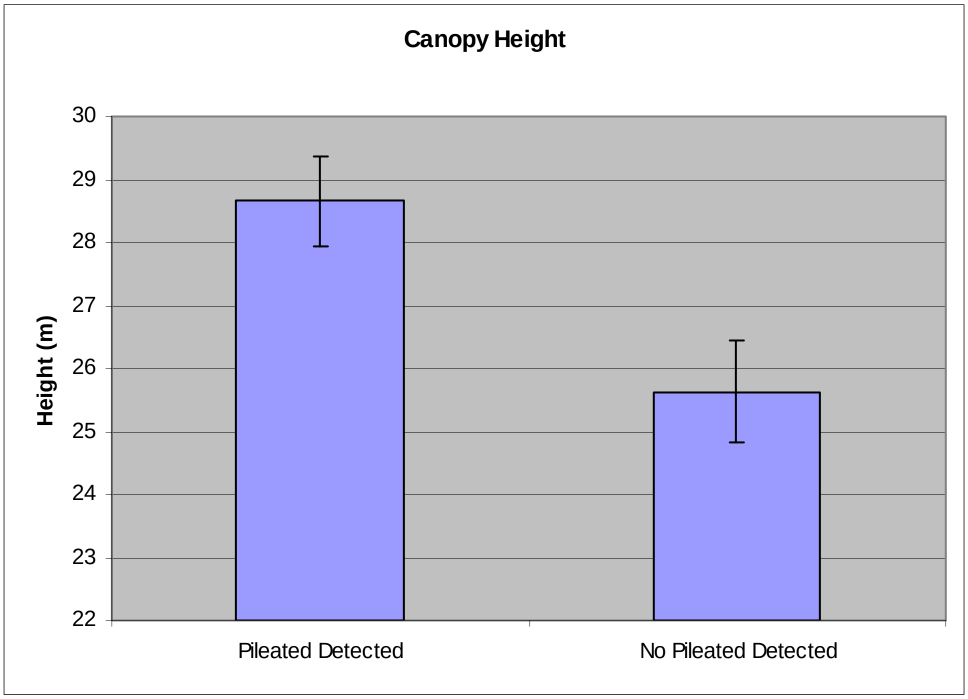
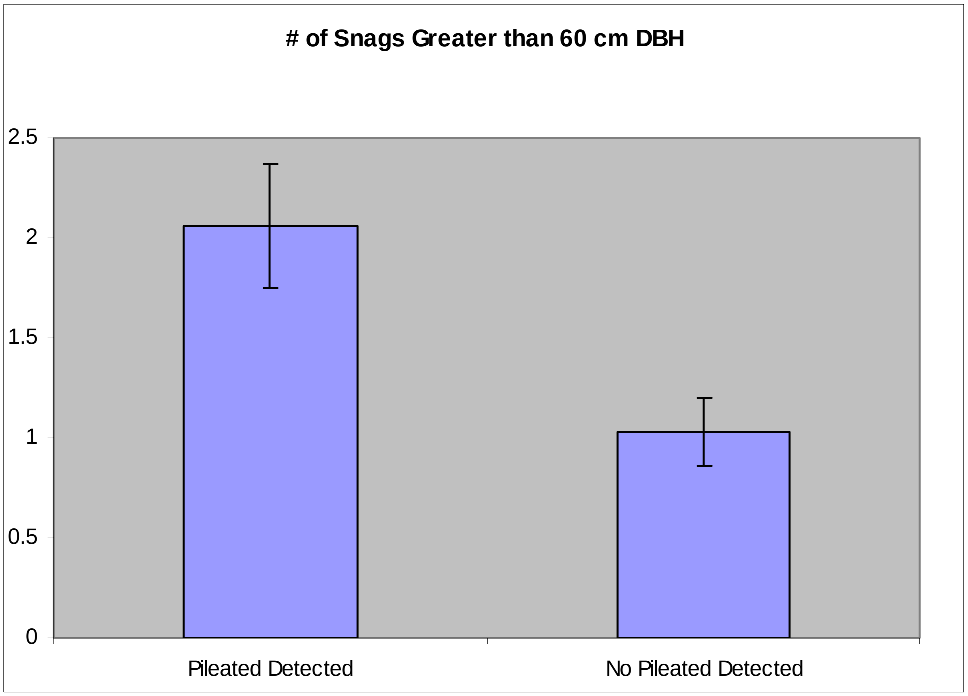


Figure 6. Mean number of snags greater than 60 cm DBH (with standard error) at sites where Pileated Woodpecker were detected compared to sites where they were not in the Lassen National Forest in 2007. Snags were counted within a 50 meter radius circle around the survey point center.



Of these habitat variables the single best predictor of the presence of Pileated Woodpecker, and the only variable to remain in the stepwise logistic regression model, was canopy closure ($r^2 = 0.08$, $p<0.001$).

Hairy Woodpecker

Hairy Woodpecker were detected by way of point count survey (no callbacks were done for this species) at 28 of the 35 transects. There were a total of 83 Hairy detections, 44 of which were within 100 meters of observers. The mean per point Hairy Woodpecker abundance within 100 meters of observers was 0.17. Using the same seven variables listed above for Pileated Woodpecker (Table 6), canopy closure was the only significant predictor of Hairy Woodpecker abundance; and it was a negative association ($r^2= 0.05$, $p=0.02$).

Discussion

Pileated Woodpecker

Survey Approach

Pileated Woodpeckers were detected at far greater percentage of points and transects from the Lassen MIS surveys in 2007 than from the random sampling conducted in the Plumas-Lassen study from 2003 -2006. There were two primary differences between these two sampling schemes. The Lassen MIS surveys employed habitat modeling outputs to help select survey sites, and used call back surveys broadcast following each point count; this resulted in 37% increase in sites with detections over point counts alone. It is important to remember that call back surveys were only conducted after a point count survey failed to detect them, thus the 37% increase is the true increase over conducting point counts alone.

Using the maximum entropy model to predict sites that were likely to support habitat for Pileated Woodpecker appears to have increased the rate of Pileated detections as well. The total detections per point count station were 69% higher from the Lassen MIS than the Plumas-Lassen. However, this result was not consistent across detections at all distances, with detection rates within 50 and 100 meters of observers greater at Plumas-Lassen sites. Additionally, our call back surveys at previous points may have resulted in birds following observers to the next point or increasing their likelihood of vocalizing after being aroused up by previous call backs. However, on other transects we only detected them from a single point. Due to large territory size of Pileated's it is difficult to determine absolute numbers from point count and call back type surveys. We spaced points twice the normal point count spacing of 250 meters to limit multiple detections of the same birds but we have little doubt that we detected the same birds at multiple points within a transect.

Though it is not totally clear the value of using the model to target areas to survey, in order to increase detection rates, errors of omission, and reduce costs, we suggest sampling targeted areas with moderate to high habitat suitability be used along with call back surveys to monitor this species. The most prudent metric for measuring change over time for this species is probably detections at the transect level.

District Level Differences

We hypothesized prior to implementing this monitoring program that the majority of Pileated Woodpecker habitat and detections would be from the ARD, which contains large amounts of mixed conifer and fir forest. The amount of habitat predicted to support Pileated Woodpecker was similar among the districts with the greatest on the ELRD. However, Pileated were detected from a greatest portion of transects in the ARD. This may be due to a true difference, or may be an artifact of the majority of data used to build the model coming from the ARD and our sampling including some of those sites. The results do show that the species occurs across the entire forest and suitable habitat exists in relatively large quantities compared to our predictions. However, when one considers that the species was detected at a little more than half of the areas predicted, the amount of suitable habitat may be considerably less than our model output suggest. Though, these errors of commission may be ameliorated by errors of omission. We have developed a new Pileated Woodpecker model for the Plumas-Lassen study area (see Chapter 4).

Pileated Woodpeckers and the Avian Community

Comparing species richness and total bird abundance, we found no statistical difference between sites where Pileated Woodpecker were or were not detected. However, it is important to note that the sampling area is not the forest as a whole, but areas where the model predicted they would occur. For example, the sample did not include habitat such as meadows or shrub fields. Pileated Woodpecker were found to be significantly more abundant in Spotted Owl Core areas than outside these areas, while species richness and total bird abundance were both significantly lower in Core areas (Burnett and Nur 2007).

Habitat Conditions

Though our model limited the habitat we were sampling to those areas believed to have the conditions suitable for Pileated Woodpecker, we still found significant differences in a number of habitat measures between sites with and without detections. The differences would likely be considerably more marked if we compared sites with detections to the forest as a whole. Regardless, these results still paint a picture of the fairly specialized habitat conditions that this species occupies in the Northern Sierra: areas that contain large number of snags, high canopy closure and height, and relatively high basal area with downed woody debris.

Canopy Closure

The closure of the canopy – as measured by densitometer – was the single best predictor of Pileated Woodpecker presence in the Lassen National Forest. High canopy cover – a different but correlated measurement to canopy closure – has been identified as an important habitat condition for this species. In Oregon, roost trees were located in unlogged forest with greater than 60% canopy cover (Bull et al. 1992). The average canopy closure at sites Pileated Woodpecker were detected in our study was 49%. However, they may require or at least prefer higher canopy closure in nest and roost stands than foraging areas (Mellen et al. 1992), so this result does not necessarily suggest that they are occupying areas with less canopy cover in the Northern Sierras than in Oregon. Habitat preferences appear closely aligned with other late seral species of management concern in the region such as Pine Marten, Spotted Owl, and Northern Goshawk. In fact, Pileated Woodpeckers were significantly more abundant inside of 1000 acre California Spotted Owl Core areas than outside of Core areas (Burnett and Nur 2007).

Snags and Cavities

Large snags, as well as large trees that will be the next generation of large snags, are critical to managing habitat for this species. They are used for foraging, nesting, and roosting. A number of studies from the Pacific Northwest have shown that the majority of nests are in large snags. Based on four studies in Washington and Oregon, the average nest tree DBH was 94 cm and mean tree height was 33 meters (reviewed in Bull and Jackson 1995). The need for a large supply of suitable substrate for cavities is accentuated by the fact that cavities are rarely re-used between years and upwards of eleven roost cavities are used within a year by individual birds (Bull et al. 1992). Rotting snags and live trees, which are most likely to be removed as hazards during timber harvest, appear crucial; one study showed 95% of roost cavities had a hollow interior created by decay rather than excavation (Bull et al. 1992).

Of note, is a report of this species using large aspen for nesting (Grinnell and Miller 1944). We have documented this species in Aspen habitat along Pine Creek in the ELRD and Ruffa Ranch on the ARD. In both circumstances the canopy cover was well below 50%, though there were large conifers and snags and higher canopy cover in the vicinity.

Downed Wood Debris

There were more logs at sites we detected Pileated Woodpecker than sites where we did not, though the difference was only marginally significant. However, the way we defined and counted logs may not be totally appropriate to capture the needs of this species. Logs were sampled in the standardized point count releve method with any downed wood over two meters in length with a DBH over eight cm counted. Thus a ten meter long log with a 60cm DBH would be counted as equal to one that was two meters long and ten centimeter DBH. In future years we will modify our log sampling technique to more adequately quantify differences at a scale more likely to be meaningful to this species as it appears to be an important habitat component. A study in Oregon found that 38% of foraging was on logs and that they selected for logs with a diameter greater than 38cm with extensive decay (Bull and Holthausen 1993, Torgersen and Bull 1995). This species is known to forage extensively on carpenter ants *(Camponotus spp.*), which are prevalent in decaying downed woody material in coniferous forests of the west (Bull and Jackson 1995).

Canopy Height

Another key habitat component found to be significantly greater at sites where Pileated Woodpeckers were detected was canopy height. Though little information exists in the literature on canopy height within territories, at roost and nest sites trees averaged between 27 and 41 meters. Multiple studies also identified old-growth or late seral forest as being important for the species (reviewed in Bull and Jackson 1995).

Prescribed Fire and Pileated Woodpecker

Prescribed fire may have negative short-term impacts on Pileated Woodpecker. Prescribed has been shown to reduce down wood and may directly kill the ants that Pileated Woodpecker forage on (Bull et al. 2005). While prescribed fire is an important tool for land managers its potential negative impacts to Pileated Woodpecker habitat should be considered when determining the most prudent locations for introducing fire. In this same study they found mechanical treatments also significantly reduced snags and down wood but still resulted in significantly more Pileated Woodpecker foraging activity than areas that were mechanically treated and then burned. Fuel treatments in Pileated Woodpecker habitat should concentrate on making stands more resilient to high intensity fire while maintaining large down wood, snags, and relatively high tree density.

Hairy Woodpecker

In contrast to Pileated's, Hairy Woodpeckers were fairly common in the areas we surveyed – and occupied a wide range of sites. They were detected on the majority of sites we surveyed as well as from our other monitoring in the region (Burnett et al. 2006).

They appear to reach their greatest abundance in disturbance-associated habitats, especially burned forest and treated aspen (see Chapter 1). The single best predictor of their abundance in the 2007 MIS monitoring was a negative association with canopy closure. Based on these results, we believe that the majority of fuel treatments, aspen and oak restoration project that maximize snag retention and maintain a large downed woody debris component should provide habitat that supports relatively high densities of this species. Leaving large patches of areas that stand-replaced in fire as open snag fields should also benefit this and many other woodpecker species such as Black-backed Woodpecker, Lewis' Woodpecker, Northern Flicker, and both sapsucker species (Red-breasted and Williamson's).

Management Recommendations for Pileated Woodpecker

For the majority of these recommendations, we suggest they only be prescribed in areas that our model predicts to have high habitat suitability (>40%) for the species our are otherwise considered suitable habitat for this species. However, we recommend the snag retention guidelines be employed in all projects across all habitats.

Basal Area Retention:

- **Monitoring Results:** 10 factor basal area averaged 142 sq. ft. at occupied sites and 104 at unoccupied sites. 20 factor basal area averaged 170 sq. ft at occupied sites and 117 at unoccupied sites. Both statistically significant. Averaging the results from these two factor calculations the average basal area at occupied sites is 156 sq. ft. compared to 111 at unoccupied.

- **Management Recommendation:** Retain basal area of approximately150 sq.ft.

Retention of Snags:

- **Monitoring Result:** There were 2 snags over 60cm dbh (24 inches), and 8 snags over 30cm dbh(12 inches) per 2 acre plot at Pileated Woodpecker occupied sites compared to 1 and 4 respectively in unoccupied sites - these differences were statistically significant.

- **Management Recommendation:** All snags over 18 inches should all be retained. Operations should be adjusted if any large snags are deemed hazards as every effort should be made to ensure there retention. These are the most likely nest and roost trees for this species. Retention of snags 12 – 18 inches may be important as foraging substrate and should be retained. If snags are deemed a hazard they should be felled and left as large woody debris; or, if they are tall snags, topping them to a reasonable height to reduce the hazard (15 – 25 feet tall) and leaving the topped portion as downed woody material is another preferred option.

Downed Woody Debris Retention:

- **Monitoring Result:** The number of logs (over 8 inch diameter and at least 2 meters long) at occupied sites was 46 compared to 37 at unoccupied sites (marginally significant).

- **Management Recommendation:** Retain all large downed logs – Pileated's forage on carpenter ants in downed wood. Retain as much downed wood over 15 inches diameter as is feasible while meeting fuel reduction objectives. Priority should be given to the largest diameter material in a range of decay classes.

Canopy Closure:

- **Monitoring Result:** Canopy closure - based on densitometer measurements - at Pileated Woodpecker occupied sites was 49% compared to 37% at unoccupied sites. This difference was statistically significant.

- **Management Recommendation:** Retain canopy closure at approximately 50%.

Limiting Disturbance:

- **Monitoring Result:** this species is shy and retiring and may be more sensitive than most species to chronic disturbance during the breeding season.

- **Limited Operating Periods:** Consider limiting timber harvest operations near known nesting sites or high concentrations of this species during the peak of the breeding season (April – June).

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Appendix 1. PRBO MIS Habitat Assessment Protocol.

All data is collected within a 50 meter radius circle centered on the point count station.

1st Section General Information:

Station = 4 letter code (e.g. MOON)

Point # = the actual point number of the station.

Habitat 1 = general classifications (MCF, MCP, MCO, Shrub)

Habitat 2 = only record this if there is a distinct habitat edge (i.e. point is bisected by a clear cut/forest edge)

Date = the date you are collecting this data.

Aspect = the direction of the slope given in degrees (the direction a drop water would flow if poured onto the point). Collect magnetic direction.

Slope = the average slope of the plot with 90 degrees being vertical and 0 degrees being flat, from the highest point to the lowest.

Water = true or false is there any water in the plot running or standing.

Snags30>10 = the number of snags greater than 10 cm DBH but less than 30 cm DBH (see above for more details).

Snags >30 -60 = the total number of snags greater than 30 cm and less than 61 cm DBH.

Snags > 60 = the total number of snags greater than 60cm DBH.

Logs = any downed trees or limbs greater than 8cm DBH and greater than 2m long. Must still have shape of log, rotted decomposed stuff that is really falling apart should not be counted.

Cover Layers
These are divided up into 6 layers (Tree, Tree Shrub, Real Shrub, Total Shrub, and Herbaceous)

Tree – this is defined by height category alone. Any plant species whose upper bounds (highest point) is greater than 5 meters tall is included in this category (a 6 m tall Manzanita would be included in this category, however a 4m tall White Fir would not be).

Tree Shrub – this is all tree species that are less than 5 meters tall regardless of height, this means a 25cm tall White Fir counts in this category. Tree species are the conifers, black oak, maple, white alder, canyon oak, etc.

Real Shrub - this is the true shrub species as well as a few shrubby trees that rarely get above 5 meters tall (Dogwood, Mountain Alder, ARPA, CHCA, CECO, CEIN, etc.), record the total cover of these species regardless of height.

Total Shrub - this is the total cover of all vegetation whose maximum height is between 0.5 and 5 meters (the original Relevé way of doing it). It may be just the sum of real shrub and true shrub but overlap and tall real shrubs may lead to differences.

Herbaceous Layer – this is the total cover of all non-woody vegetation, regardless of height.

Note: the maximum cover theoretically is 100% for all of these categories but practically that would be impossible to achieve.

Height Bounds
High - estimate is to the nearest ½ to 1 meter of the average height of the upper bounds of the vegetation layer (tree, tree shrub, real shrub). This is not the tallest outlier it is the average high of the tallest plants in that layer. (E.g. of the tallest trees in the plot what is the average high height).

Low – the average (as defined in the high) of the lowest living branches of the tree and tree shrub and real shrub do not record this for total shrub or herbaceous.

Lower and Upper Species – record the plant species that dominates the lower and upper bounds for all of the categories you collected low and high height data for, if you think there is absolute equal representation of these than good for you! Flip and coin and stop wasting your time and my money and move on to the next measurement.

Max Tree DBH = record the DBH of the largest single trees in the plot and record what species it is.

Species List
Record these as T1 (tree layer), TS (true shrub), RS (real shrub), S1 (total shrub) and H1 (herbaceous)

Record for each of these layers the % each species comprises of the total (this number should add up to 100% regardless of the % total cover). List as many species as can easily be recorded in a timely manner. Chasing down that lone shrub off in the corner of the plot is not worth the effort. However, we are interested in hardwood species so if they are present in small numbers recording them even if they are less than 5% is worth the effort, also recording a single large tree as 5% or less is probably also worth it.

Basal Area
Standing in the center of the plot using the Cruz-All place the end of the chain at your mouth and look through the key and record the number of trees by species that fill the opening (ie no light can be seen on either side of the cruz-all opening. Record this for the 5, 10, and 20 factor slots on the cruz all and record separately in the provided space on the form.

Canopy Closure
Canoy closure is measured every three meters at 16 points along each of four 48meter long transects (each of the cardinal directions). Starting at the 3 meter mark facing north record canopy hits using the densitometer. For each hit record the species. For each direction there will be total of 16 readings and thus 64 total readings for the plot. All hits above 5 meters height are counted.

Chapter 3. Resident and Neotropical Migratory Bird Response to Fuel Treatments in Pine-Oak Habitat in the Almanor Ranger District

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PRBO Conservation Science

Background and Introduction

The species composition and structure of forests in western North America have been altered in the last century. The primary forces behind these changes are believed to be fire suppression and timber harvest practices (Minnich et al. 1995, Chang 1996, Stephenson 1999, Taylor 2000). Human-mediated shifts in the competitive balance of these vast and complex forest ecosystems can result in the widespread loss of unique and ecologically valuable habitat attributes upon which wildlife depend (Hejl 1994). In the mixed conifer forests that dominate the Sierra Nevada Mountains of California, these management practices have led to an increase in shade tolerant white fir (*Abies concolor*) and incense cedar (*Calocedrus deccurrens*), and to declines in shade intolerant pines (*Pinus ponderosa* and *Pinus lambertiana*) and hardwoods such as California black oak (*Quercus kelloggii*) (Vankat and Major 1978, Parsons and Benedetti 1979, Minnich et al. 1995).

In the Northern Sierra Nevada, pine-hardwood and mixed conifer hardwood plant communities are the dominant forest types in a confined elevation belt between roughly 3,500 and 5,500 feet on the western slope. The dominant hardwood in this habitat is California black oak with ponderosa pine the dominant conifer, at least historically (MacDonald 1990). Both Black Oak and Ponderosa Pine are shade intolerant species that require disturbances that open up forest canopies to ensure their health and long-term viability on the landscape (McDonald 1990, McDonald and Tappeiner 1996). Black Oak, with its limited maximum growth, is particularly susceptible to encroachment of conifers in a disturbance-limited ecological condition that exists as a result of fire suppression. As a result, without management intervention the health, extent, and eventually the long-term viability of the pine-oak forest in this region are threatened.

PRBO monitoring in the Almanor Ranger District (ARD) from 1997 – 2002 identified mixed conifer hardwood forest as among the most species rich avian habitats in the region. Many Neotropical migrant birds were positively associated with attributes of mixed conifer hardwood habitat (Burnett and Geupel 2001). In 2003, PRBO assisted the ARD in designing a pilot pine-oak enhancement project intended to promote the health and long-term viability of Pine-Hardwood habitat, based on the best available knowledge at the time. Specifically, the project was designed to reduce the overall amount of white fir, where feasible to establish pines as the dominant conifers, and to provide conditions that enhance existing black oak and increase its presence in the treated stands. The objective was to maintain a minimum cover of 30% oak and 30% conifer (averaged across the stand) with a maximum 10% overlap of canopies.

The U.S. Forest Service is emphasizing monitoring as part of an adaptive management ecological-based approach to forest management in the Sierra Nevada (SNFPA 2004). As pine-oak enhancement is a relatively new management practices in the region, monitoring and an adaptive management strategy are critical to providing managers with scientific results to help guide and evaluate such projects.

Avian monitoring is considered an excellent tool for providing feedback on the effects of land management actions (Temple and Wiens 1989, Hutto 1998, Burnett et al. 2005). Numerous avian species of management interest are associated with hardwood habitats in the Sierra Nevada and can provide information on the structure and function of ecological systems. These factors, along with concerns over widespread declines of Neotropical migratory birds (Finch and Stangel 1993), ensure that bird monitoring of forest management is exceedingly relevant.

Project Area

The project area is located west of Philbrook Lake in the vicinity of Fish Creek in the ARD of the Lassen National Forest. The Lassen National Forest is located in the Northern Sierra Nevada mountains of California (Lat 40^0 00’N, Long 120^0 22’W). Study sites range from 1400 – 1650 meters elevation. The total area being treated in this project is approximately 900 acres (Figure 1).

Methods

Sampling Design

Our adaptive management based monitoring plan is designed to investigate the effects of treatment on avian secondary population parameters of abundance, species richness, ecological diversity, and the abundance of individual species. Additionally, by collecting vegetation data at each point we will determine the factors influencing these metrics at pre-treatment sites and link observed changes in bird abundance to changes in habitat conditions following treatment.

Because this study is part of an adaptive management experiment employed on actively managed National Forest lands, our study design had to take into consideration limitations imposed by conducting such an experiment. The treatment implemented in each of the different units is based on pre-existing conditions in the unit and the stands are not of equal size; thus, the nine treatment units are not true replicates of each other. Once we have collected post-treatment data we will determine the most appropriate scale at which to analyze our data, based on plot effects and other potential interactions. We may then be able to reassign individual point counts into different strata based on pre-existing condition to create the most biologically appropriate replicates. For example, since the goal of treatment is to create one desired condition (30% oak, 30% conifer canopy cover), it may be appropriate to assign replicates at the treatment unit level by placing units and reference points into two or three mutually exclusive strata based on pre-existing condition (e.g., low oak high conifer, high oak low conifer, and high oak high conifer). This would give us between three and five replicates – depending on number of subgroups selected – in each pre-existing condition class.

In order to achieve this design, we placed point counts in each of 9 units scheduled for treatment and placed an equal number of points in adjacent reference stands (Table 1, Figure 1, Appendix 1). Points were laid out in a manner as to maximize sample size within treatment units using GIS coverage of the treatment boundaries provided by the Almanor Ranger District. Layout of treatment points was then conducted in an Arc View GIS environment (ESRI 2000). Point count stations were spaced at approximately 225 meter intervals throughout the treatment units and were a minimum of 100 meters from unit boundaries. However, due to changes in unit boundaries made by the Forest Service following the 2004 field season, a few points are now as close at 10 meters from treatment boundaries. For analysis of treatment effects we dropped all points within 25 meters of unit edges.

Reference sites were chosen that met two requirements: they were within 4 km of the nearest treated unit (almost all were within 2 km) and the site contained evidence of black oak (living oaks, oak snags, or oak logs). Since the presence of forest with a black oak component was limited in the surrounding forest and GIS vegetation layers did not adequately delineate mixed conifer forest with or without black oak, it was not possible to randomly select appropriate replicates for our treatment sites using GIS. Since we believed that habitat structure and composition were the primary factors influencing the avian community, we wanted to ensure our reference sites were a proportional representation of the habitat conditions in the treated stand sample. Thus, all reference sites were laid out in the field and were established after all treatment unit points had been established and classified into general habitat condition (Appendix 2). Reference point count stations are all a minimum of 100 meters from treatment boundaries and spaced at approximately 225 meter intervals.

Table 1. Point Count transects, number of stations, and dates surveyed in 2007 in the Brown's Ravine project area of the Almanor Ranger District of the Lassen National Forest.

Site	# of Stations	Dates, 1st Survey	Dates, 2nd Survey
LOKR	32	5/16 , 5/17/2007	6/18, 6/22, 6/25
MOKR	6	5/17, 5/20/2007	6/17, 6/22/2007
OAK1	7	5/16, 5/17/2007	6/18, 6/25/2007
OAK2	14	5/16/2007	6/25/2007
OAK3	10	5/17/2007	6/18/2007
OAK4	10	5/20/2007	6/17/2007
OAK5	7	5/17/2007	6/22/2007
OAK6	4	5/19/2007	6/12/2007
OAK7	8	5/19, 5/20/2007	6/12, 6/21/2007
OAK8	7	5/19/2007	6/21/2007
OAK9	6	5/16/2007	6/18/2007
UOKR	38	5/19, 5/20/2007	6/11, 6/12, 6/20, 6/21/2007

Survey Protocol

Standardized five minute fixed radius-multiple distance point count censuses (Ralph et al. 1993, Buckland et al. 1993) were conducted at 149 stations, 73 in stands that have or will be treated, and 76 in adjacent reference stands. Sites Oak 1, 2, and 3 were treated in the fall of 2005, while Oak4, 5, and 9 were treated in the fall of 2006. Oak 6, 7, and 8 had not been treated as of 2007. Point count detections were placed within one of six categories based on the initial detection distance from observer: less than 10 meters, 10-20 meters, 20-30 meters, 30-50 meters, 50-100 meters, and greater than 100 meters. Birds flying over the study area but not observed landing were recorded separately. The method of initial detection (song, visual or call) for each individual was also recorded.

All birds detected at each station during the five-minute survey were recorded. Sites were surveyed from sunrise to 3.5 hours later. Each station was surveyed twice during the peak of the breeding season (May 15 – August 1).

Habitat Assessment

Habitat attributes were assessed over a 50 meter radius at all points in 2005 using a modified relevé protocol (Appendix 3). Additionally, vegetation was assessed more intensively at a subset of treatment points by the ARD staff in 2004 and 2005 using an 11.3 meter radius plot (C. Robbins pers. comm.). We will investigate the relationship of relevé measures of habitat characteristics to those collected in the more intensive 11 meter radius plots. Based on the results of this analysis we may use measures from both sampling scales to correlate with bird indices in 2006.

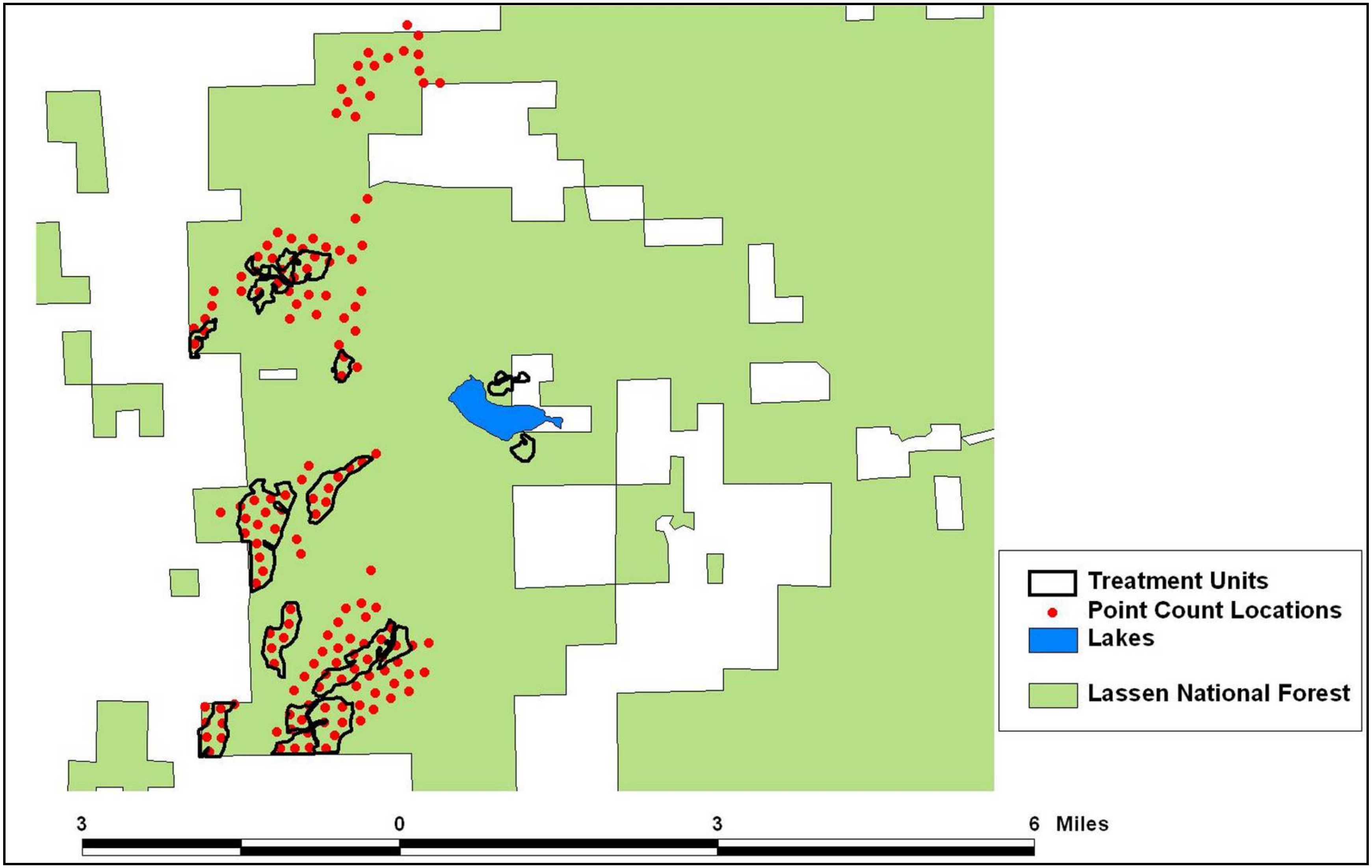
Analyses

Avian community point count analysis was restricted to a subset of the species encountered. We excluded species that do not breed in the study area as well as those species that are not adequately sampled using the point count method (e.g., waterfowl, kingfisher, and raptors). We also excluded European Starling, an invasive species that is generally regarded as having a negative influence on the native bird community. For community index analysis we present data based on treatment unit (Figure 1). For reference sites we used the general location of the points within the project area (Upper, Middle, or Lower).

Species richness

Species richness is defined as the total number of species detected within 50 meters of the observer. Richness can be presented as cumulative species richness (total number of species detected within a habitat or along a transect) or as mean species richness (average number of species detected per point within a habitat or transect). Presenting the mean species richness, as we do herein, allows for comparisons between transects or habitats consisting of different numbers of point count stations.

Figure 1. Location of PRBO Pine-Oak point count stations in the Almanor Ranger District and designation of treatment units in 2004.



Total Bird Abundance

We define total bird abundance as the mean number of individuals detected per station per visit. This number is obtained by dividing the total number of detections within 50 meters by the number of stations and the number of visits.

Species Abundance

The abundance of individual species is defined as the total number of individuals detected within 50 meters across both visits.

Statistical Analysis

We used generalized linear mixed models with a negative binomial distribution with the "lmer" procedure in R, to analyze the effects of treatments on the relative abundance of focal species and community indices (RDCT 2008). We considered multiple hypotheses and tested them using an information theoretical approach with transect and site included as random effects (Burnham and Anderson 2002). We started with a year hypothesis – testing if the effect of year as a continuous variable was a predictor of each metric. We then created a variable for year since treatment and coded untreated sites as 0, sites treated the previous fall as one, and two for sites treated the year before. Additionally, we tested to see if there was an inherent difference in our control and treated sites by including a categorical variable which could be coded as control, treated 2005, or treated 2006. We also investigated the interaction of year and control impact to discern if any differences were found with these variables over time which would suggest the treatment resulted in difference (Table 2). Thus, we had two hypotheses, one which looked at treated sites before and after treatment and the other which looked to see if there were difference between control and impact over time.

For each species we developed predicted index of abundance using model averaged estimates from the final set of models with Akaike Information Criteria (AIC) scores within five points of the top model. We present AIC scores, ΔAIC, and model weights for each candidate model.

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Table 2. Variable codes and descriptions used in Akaike's Informaiton Criteria model selection for 12 focal species and three community indices assessing the effects of pine-hardwood enhancement fuel reduction project.

Variable Code	Variable Name
Intercept	Represents the null model where no effects were found
CI	Control/Impact (Possible categories = control, treated2005, treated 2006)
Year	Year, continuous from 2004- 2007
Yr.post.treat	Years since treatment 0 = untreated, 1 and 2 years post treatment
CI*Year	Interaction between Control/Impact and year

Results

We examined species richness and total bird abundance across nine treatment units and three groupings of reference points across all years surveyed (Table 3, Figure 2). In 2007 species richness ranged from 5.29 in Unit 4 to 7.57 in Unit 1. Total bird abundance ranged from 3.61 in Unit 4 to 5.64 in Unit 8. Species richness and total bird abundance were higher in 2007 than all other years at seven of the nine treatment stands but only one of the three reference areas. Relative abundance was also higher at seven of the nine treatment stands and all three of the reference areas in 2007.

Table 3. Mean (per point) ecological diversity, mean number of individuals detected (within 50m), and species richness at each sites surveyed in the Brown's Ravine Project area of the Almanor Ranger District, 2004-2007. NS = not surveyed.

Stand	Number of Points	Species Richness				Total Bird Abundance			
		2004	2005	2006	2007	2004	2005	2006	2007
1	7	4.29	4.86	5.86	7.57	3.36	3.5	4.14	5.36
2	14	4.07	4.77	5.71	5.79	2.79	3.35	4.14	4.25
3	10	2.6	4.8	5.50	6.70	1.60	3.10	3.75	4.65
4	10	3.2	5.00	5.86	5.29	2.35	3.39	4.64	3.61
5	7	4.43	5.57	4.57	6.71	3.64	4.43	3.14	4.86
6	4	4.75	4.50	5.33	6.00	3.88	3.08	3.83	3.83
7	8	4.89	3.88	4.38	6.25	3.69	3.06	3.00	4.31
8	7	3.71	3.00	5.14	6.43	2.86	1.93	3.79	5.64
9	6	NS	5.50	4.50	5.67	NS	4.25	3.75	4.83
LOKR	31	3.38	4.75	5.63	5.41	2.44	3.23	3.97	4.83
MOKR	6	3.00	7.00	4.67	6.67	1.83	5.08	4.00	4.67
UOKR	37	4.09	5.00	5.94	6.72	3.21	4.44	4.44	5.26

Investigating the effects of treatment, the model with the most support for each of the13 focal species was one with the intercept only. In other words we were unable to reject the null hypothesis that treatment had no effect on these metrics. However, for most species there was some support for other models (Table 4). Species for which the analysis suggested a positive effect of treatment include Audubon's Warbler, White-headed Woodpecker, Oregon Junco, and the community index of total bird abundance. The species with a possible negative effect of treatment were Cassin's Vireo and Hermit Warbler.

Table 4. List of models in order of their level of support for 12 pine-hardwood focal bird species with Akaike Information Criteria (AIC), the difference in AIC between a given model and the top model (ΔAIC$_)$, and model weights. Models with weights closest to 1 have the most support. A list of the variable codes included under model are presented in Table 2.

Species	Model	AIC	ΔAIC	Weight
Band-tailed Pigeon	Intercept only	62.41	0.00	0.48
	year	64.41	1.99	0.18
	yr.post.treat	65.19	2.78	0.12
	CI	65.25	2.84	0.12
	year + yr.post.treat	66.29	3.88	0.07
	CI + year	67.18	4.76	0.04
Hairy Woodpecker	Intercept only	157.57	0.00	0.24
	year	158.66	1.09	0.14
	yr.post.treat	158.69	1.12	0.14
	Control/Impact	159.63	2.06	0.09
	year + yr.post.treat	159.71	2.14	0.08
	CI + year	160.62	3.05	0.05
	CI + yr.post.treat	160.63	3.06	0.05
	CI*year	160.65	3.08	0.05
	year + CI *year	160.65	3.08	0.05
	CI*year + yr.post.treat	161.63	4.06	0.03
	year + CI*year + yr.post.treat	161.63	4.06	0.03
	CI + year + yr.post.treat	161.64	4.08	0.03
White-headed Woodpecker	Intercept only	116.96	0.00	0.43
	yr.post.treat	118.37	1.42	0.21
	year	118.86	1.90	0.17
	year + yr.post.treat	119.87	2.92	0.10
	CI	120.20	3.24	0.09

Table 4 continued.

Species	Model	AIC	ΔAIC	Weight
Dusky Flycatcher	Intercept only	493.03	0.00	0.35
	year	493.50	0.47	0.28
	yr.post.treat	495.03	2.00	0.13
	year + yr.post.treat	495.47	2.44	0.10
	CI*year + yr.post.treat	496.30	3.27	0.07
	year + CI*year + yr.post.treat	496.30	3.27	0.07
Warbling Vireo	Intercept only	360.18	0.00	0.25
	year	360.23	0.05	0.24
	yr.post.treat	361.75	1.57	0.11
	year + yr.post.treat	361.75	1.57	0.11
	year + CI*year	363.48	3.30	0.05
	CI*year	363.48	3.30	0.05
	CI	363.88	3.70	0.04
	CI + year	363.93	3.75	0.04
	CI*year + yr.post.treat	364.50	4.32	0.03
	year + CI*year + yr.post.treat	364.50	4.32	0.03
	CI + yr.post.treat	364.56	4.38	0.03
	CI + year + yr.post.treat	364.97	4.79	0.02
Cassin’s Vireo	Intercept only	293.00	0.00	0.29
	yr.post.treat	293.33	0.33	0.24
	year	294.74	1.74	0.12
	year + yr.post.treat	295.12	2.12	0.10
	CI	295.46	2.46	0.08
	CI + yr.post.treat	296.75	3.74	0.04
	year + CI*year	296.89	3.89	0.04
	CI*year	296.89	3.89	0.04
	CI + year	297.06	4.06	0.04
Red-breasted Nuthatch	Intercept only	557.42	0.00	0.73
	CI	560.22	2.79	0.18
	yr.post.tr	561.71	4.29	0.09
Nashville Warbler	Intercept only	449.94	0.00	0.63
	year	451.00	1.06	0.37
Hermit Warbler	Intercept only	442.55	0.00	0.51
	yr.post.treat	443.89	1.34	0.26
	year	444.91	2.35	0.16
	year + yr.post.treat	446.39	3.84	0.07

Table 4. continued

Species	Model	AIC	∆AIC	Weight
Audubon's Warbler	Intercept only	654.18	0.00	0.48
	yr.post.treat	655.56	1.39	0.24
	CI	657.33	3.16	0.10
	CI + yr.post.treat	658.06	3.89	0.07
	CI + year	658.37	4.19	0.06
	year	658.40	4.22	0.06
MacGillivray's Warbler	Intercept only	310.36	0.00	0.50
	year	311.38	1.02	0.30
	yr.post.treat	313.13	2.77	0.13
	year + yr.post.treat	314.15	3.79	0.08
Western Tanager	Intercept only	316.20	0.00	0.64
	year	317.31	1.11	0.36
Oregon Junco	Intercept only	564.45	0.00	0.28
	yr.post.treat	565.63	1.18	0.16
	year	566.07	1.62	0.12
	CI	566.61	2.16	0.10
	year + yr.post.treat	567.01	2.55	0.08
	CI + yr.post.treat	568.07	3.62	0.05
	year + CI:year	568.08	3.63	0.05
	CI*year	568.08	3.63	0.05
	CI + year	568.11	3.65	0.05
	year + CI*year + yr.post.treat	569.00	4.54	0.03
	CI*year + yr.post.treat	569.00	4.54	0.03
	CI + year + yr.post.treat	569.14	4.69	0.03

The model weight for the White-headed Woodpecker intercept only model was 0.43, followed by years post-treatment at 0.21, year only at 0.17, and a model with both year and years post-treatment at 0.10. The intercept only model for Cassin's Vireo had a model weight of 0.29, followed closely by the year post-treatment model at 0.24. The next most supported model was the year only with a weight of 0.12. The intercept only model for Hermit Warbler had a model weight of 0.51, followed by years post-treatment at 0.26, and year only at 0.16. The intercept only model for Audubon's Warbler had a model weight of 0.48, followed by years post-treatment at 0.24, and control/impact at 0.10. As with all of the other species the top model for Oregon Junco was the intercept only with a weight of 0.28, followed by the years post-treatment and year only models with weights of 0.16 and 0.12, respectively.

Table 5. List of models for community indices of species richness, ecological diversity, and total bird abundance with Akaike Information Criteria (AIC), the difference in AIC between a given model and the top model (ΔAIC), and model weights. Models with weights closest to 1 have the most support. A list of the variable codes included under model are presented in Table 2.

Index	Model	AIC	ΔAIC	Weight
Species Richness	Intercept only	498.66	0.00	0.18
	year + yr.post.treat	499.66	1.00	0.11
	year + CI*year	499.95	1.29	0.09
	CI*year	499.95	1.29	0.09
	CI*year + yr.post.tr	500.46	1.80	0.07
	year + CI*year + yr.post.treat	500.46	1.80	0.07
	CI + year	500.54	1.88	0.07
	CI + year + CI*year	500.54	1.88	0.07
	CI + CI*year	500.54	1.88	0.07
	CI + year + CI*year + yr.post.treat	500.58	1.92	0.07
	CI + CI*year + yr.post.treat	500.58	1.92	0.07
	CI + year + yr.post.treat	501.49	2.83	0.04
Ecological Diversity	year	437.84	0.00	0.21
	year + yr.post.treat	438.84	1.00	0.13
	year + CI*year	439.49	1.65	0.09
	CI*year	439.50	1.66	0.09
	CI + year	439.74	1.90	0.08
	year + CI*year + yr.post.treat	440.02	2.18	0.07
	CI*year + yr.post.treat	440.02	2.18	0.07
	CI + year + yr.post.treat	440.70	2.86	0.05
	CI + CI*year + yr.post.treat	440.72	2.89	0.05
	CI + year + CI*year + yr.post.treat	440.73	2.89	0.05
	CI + year + CI*year	440.79	2.96	0.05
	CI + CI*year	440.79	2.96	0.05
Total Bird Abundance	yr.post.treat	619.71	0.00	0.39
	year	620.04	0.33	0.33
	year + yr.post.treat	622.23	2.52	0.11
	CI + year	624.02	4.31	0.05
	CI*year	624.12	4.41	0.04
	year + CI*year	624.12	4.41	0.04
	Intercept only	624.40	4.69	0.04

Community index model results are shown in Table 5. For species richness the intercept only model had the strongest support with a model weight of 0.18, followed by the model with both year and years post-treatment at 0.11. The model with the greatest support for the Shannon Wiener index of diversity was the year only model with a weight of 0.21, followed by the model with both year and years post-treatment at 0.13. The top model for total bird abundance was years post-treatment with a model weight of 0.39, followed by the year only model at 0.33, and the model with both year and years post-treatment at 0.11.

Predicted annual indices of abundance for the five species that showed some evidence of an effect of treatment are shown in Figures 3-7. For each of these species the predicted value at treated sites changed trajectory following implementation of treatment while controls did not.

Figure 2. Predicted annual index of abundance for White-headed Woodpecker from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.

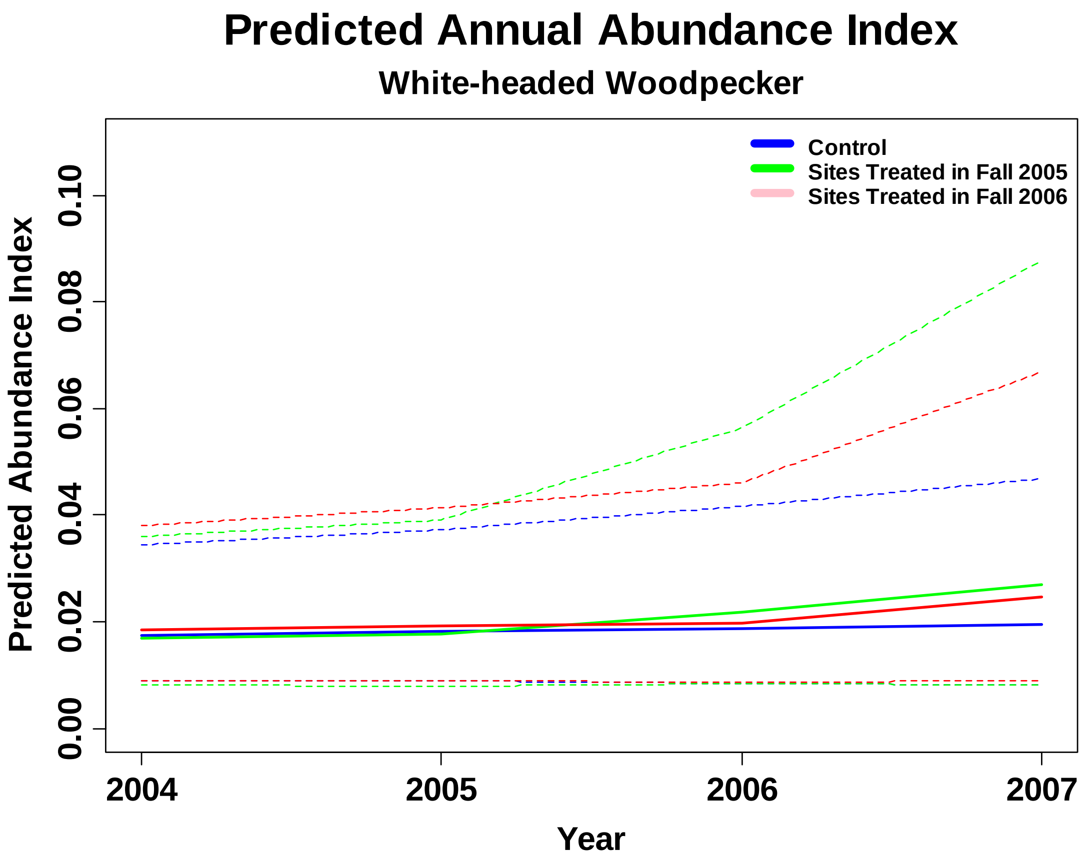


Figure 3. Predicted annual index of abundance for Audubon's Warbler from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.

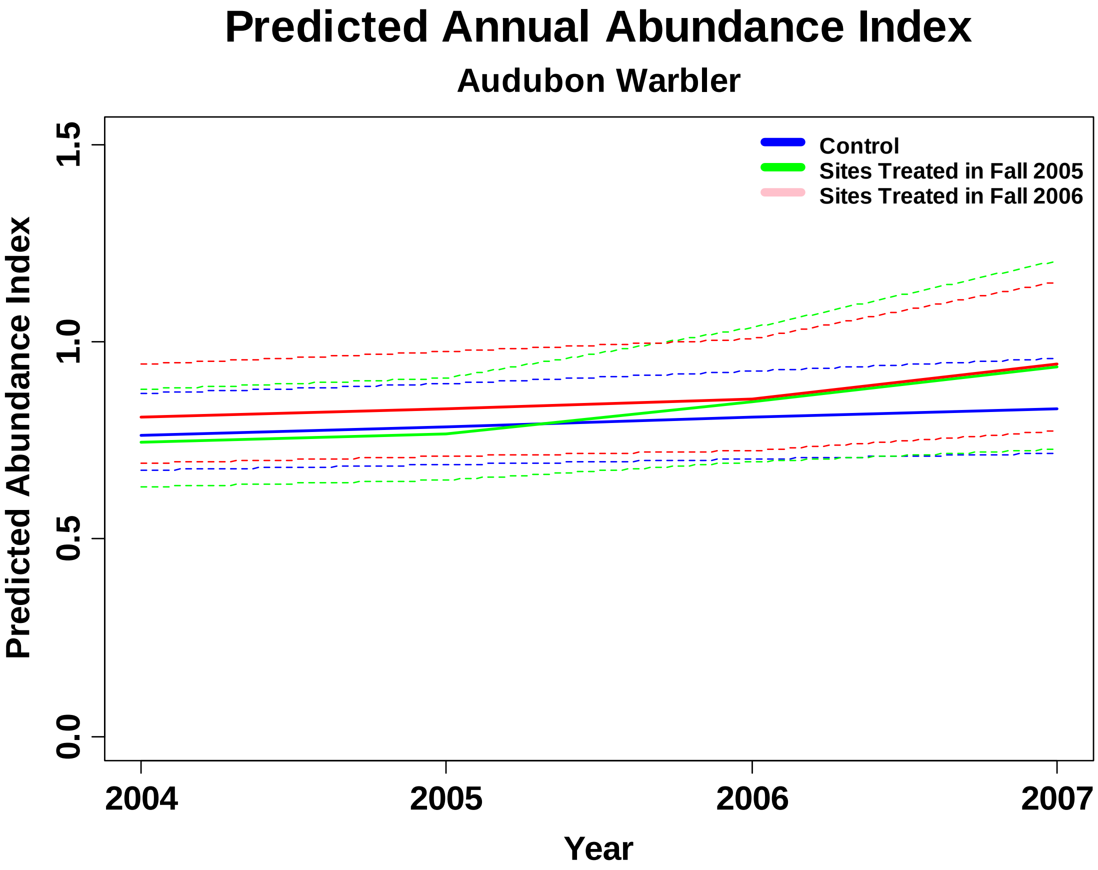


Figure 4. Predicted annual index of abundance for Oregon Junco from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.

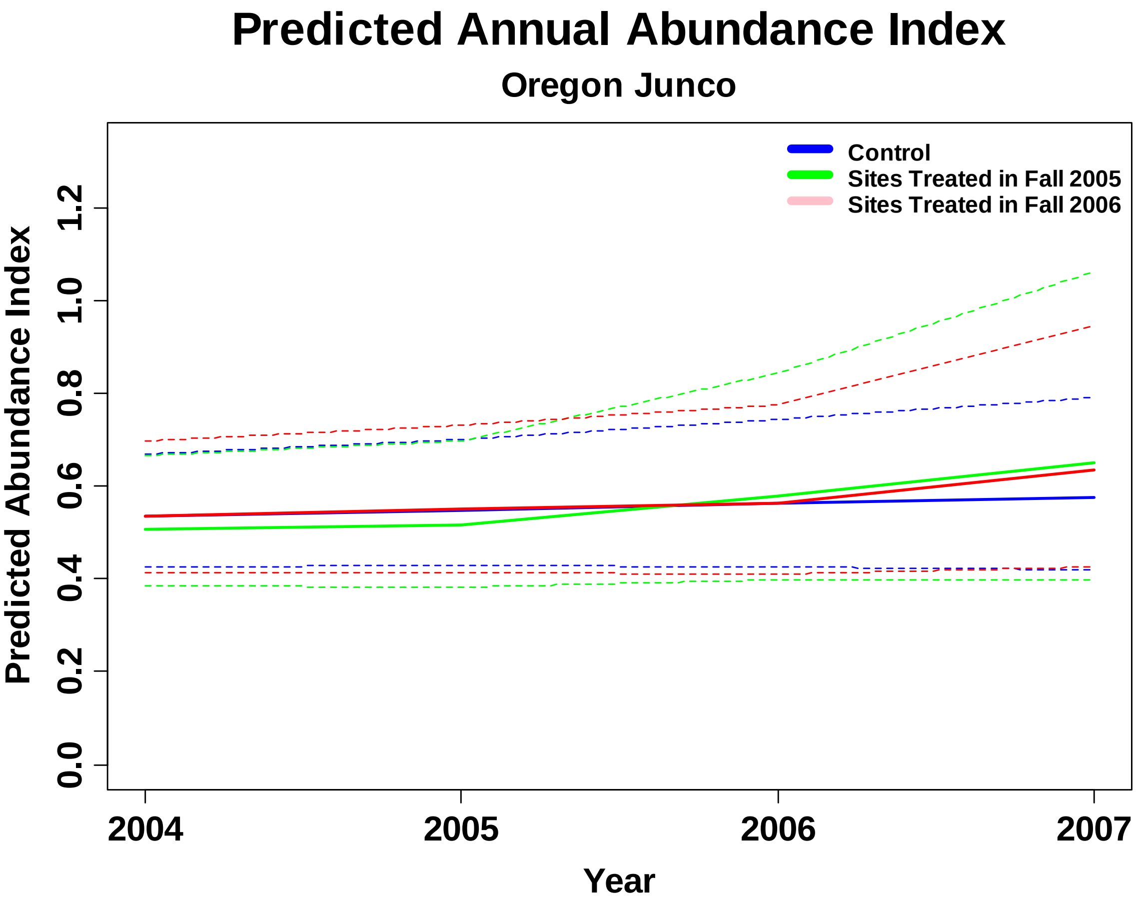


Figure 5. Predicted annual index of abundance for Cassin's Vireo from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.

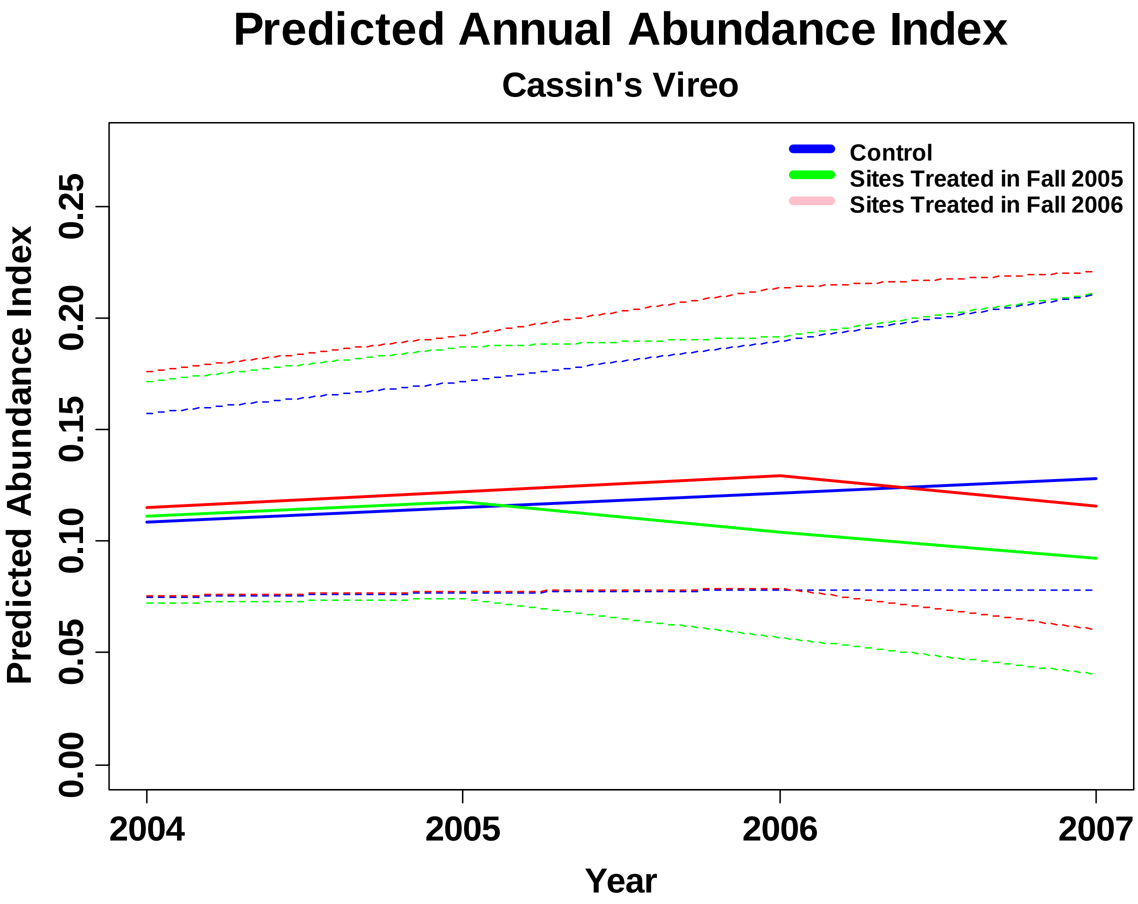


Figure 6. Predicted annual index of abundance for Hermit Warbler from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.

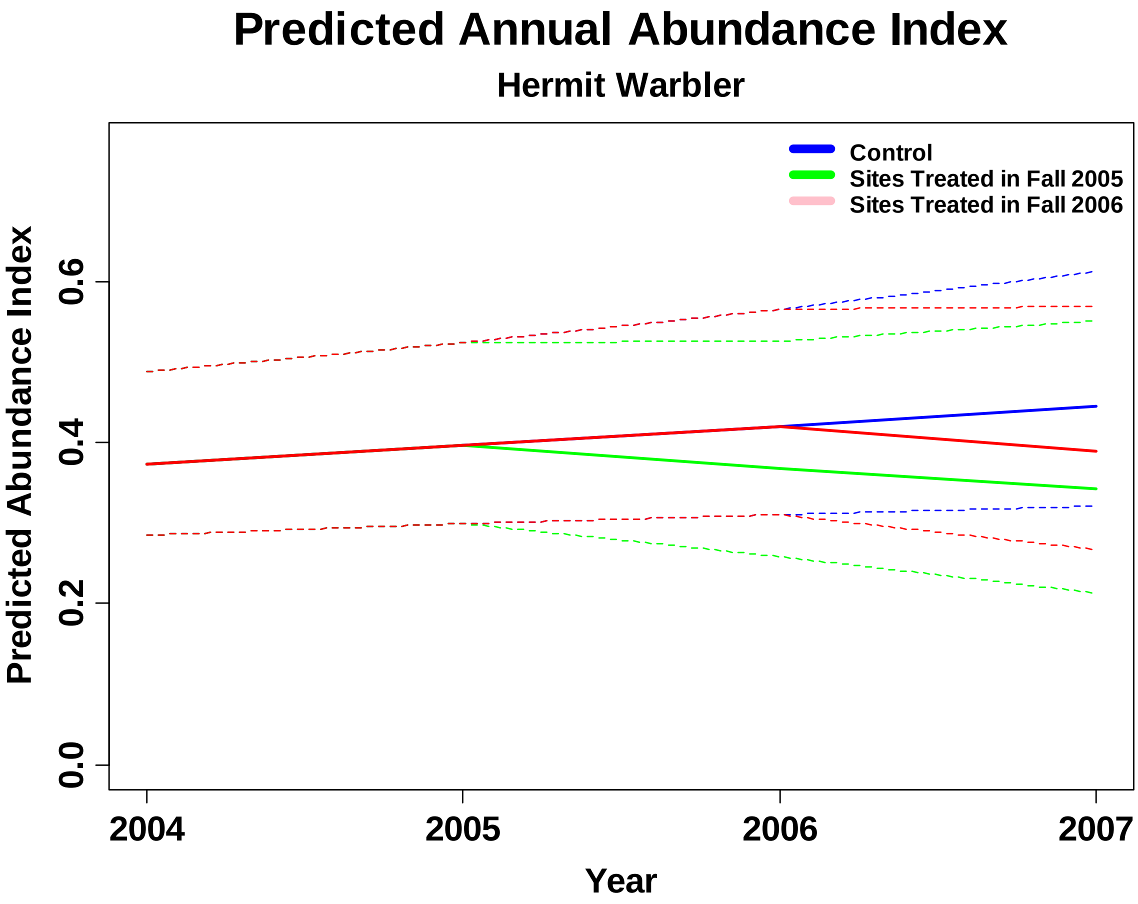
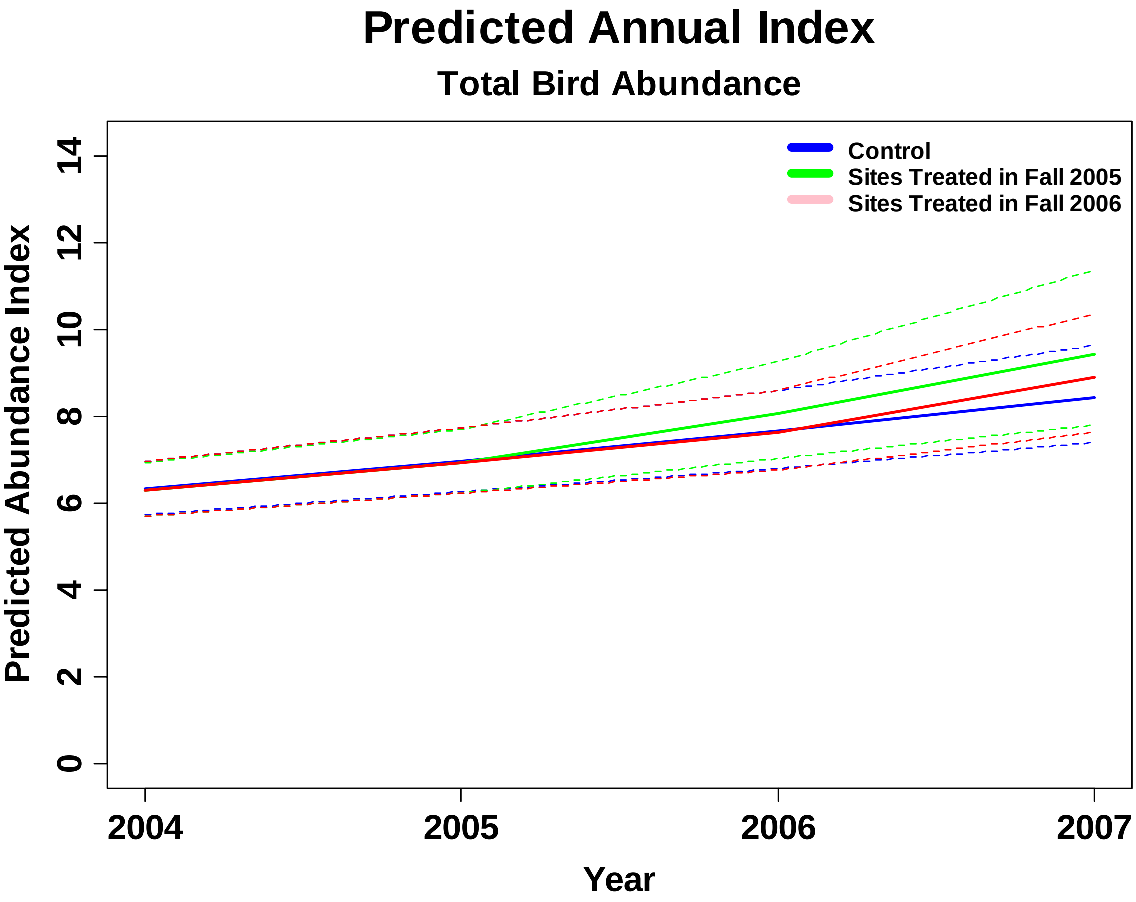


Figure 7. Predicted annual index for total bird abundance from generalized linear mixed effect model. Predictions are model averaged estimates using all models within five AIC points of the top model. Dashed lines represent the 95% confidence interval surrounding the estimate.



Discussion

Overview

Our top model for each species led us to the conclusion that we failed to reject the null hypothesis that there was no discernible effect of treatment. The variability within our dataset was equal to or greater than the variation that could be attributed to any treatments, and may have overwhelmed any true impact of treatment on these sites. A larger sample of treated sites and several more years of post-treatment data in the coming years should increase the ability to detect effects. Though data power was likely an issue in detecting effects, the relatively small differences in species abundance at sites before and after treatment does suggest the treatments have yet to have any major effects on the abundance of the majority of focal species. However, for several species there was fairly good support for the hypothesis that treatment did have an effect (Figures 2 – 7). Several species showed signs of a modest positive response, while several others showed a modest negative response.

Species Response to Treatments

Cassin's Vireo and Hermit Warbler were the two species that showed the most support for a negative effect of treatment. Cassin's Vireo has a strong preference for foraging in black oak in the Sierra Nevada and they most often forage within ten meters of the ground (Airola and Barret 1985). The project removed a number of black oak stems and favored retention of the largest oaks with the fullest crowns. This reduction, coupled with the removal of dense understory white fir, may have reduced the middlestory foliage volume which is not only used by this species for foraging but also nesting (Goguen and Curson 2002, Siegel and DeSante 2003). In our opinion, immediately following treatment the stands were less structural diverse than prior to treatment. In the long term, the reduction of canopy cover, removal of dense pockets of young white fir, and cutting of oaks may result in an increase in under and middle-story oak foliage volume as oaks re-sprout and respond to increased sunlight. Thus, the long-term effects of treatment may have a net benefit to Cassin's Vireo and other species with similar foraging niches such as Western Tanager and Nashville Warbler. The other species that may have been negatively affected by treatments is Hermit Warbler. This species is associated with stands of relatively large trees in mixed conifer forest in the Lassen region. The reduction in canopy cover coupled with a lack of structural diversity may have resulted in short-term negative effect to this species. However, they seem to show a preference for true mixed conifer forest with a diversity of tree species (Burnett and Humple 2003; also see Chapter 4). If treated sites respond with an increase in oak, pine, and increased structural diversity, the long-term effects of treatment may be neutral to beneficial to this species. Future treatments that use more of a mosaic design, instead of the relatively even spacing of these treatments, may reduce any negative short-term effects to Hermit Warbler and increase the long-term benefits.

Audubon's Warbler and Oregon Junco are among the most common breeding birds in the Lassen region (Burnett et al. 2005). There was some support for treatments having a positive effect on both of them. Oregon Junco, though still common, has been experiencing a significant population decline in the Sierra Nevada of 2.4% per year ($p = 0.03$), over the past 40 years (Sauer et al. 2006). They nest on the ground in a wide range of habitat conditions, including relatively dense stands of conifer. However, they also eat seeds and may benefit from increased herbaceous cover of grasses and forbs. In general they seem to prefer open habitats and habitat edges, which is the likely explanation for their positive response immediately following treatments. Audubon's Warbler also occur across a relatively broad range of habitats though they seem to prefer more open conifer conditions. They show a preference for pine dominated conifer forest over the dense white fir encroached stands that existed in the project area prior to treatments. While they are foliage gleaners, like the other warblers, they are also accomplished at fly catching. The more open spaces created through thinning may provide better conditions for aerial foraging.

Structural Diversity

Much of the white fir encroached pine-hardwood habitat in the ARD is lacking both under and middle story foliage volume and overall structural diversity. As canopy closure increases in the absence of natural disturbance, suitable conditions for vigor and reproduction of understory plant assemblages is lost. Shrubs, herbs, and grasses are replaced with seedling and sapling white fir and incense cedar (*Calocedrus decurrens*).

Tree species, especially black oak, drop understory branches, and without fire little oak sprouting occurs. As both structural diversity and foliage volume are key avian habitat features, restoring both should be a management priority for pine-hardwood enhancement.

Species such as Dusky Flycatcher, Nashville Warbler and MacGillivray's Warbler are all strongly associated with shrub habitat (Burnett and Humple 2003, Siegel and DeSante 2003). In the Lassen region shrub nesting species are more abundant in thinned forest that supports greater shrub cover than unthinned forest (Siegel and DeSante 2003). A vigorous understory – including dense patches of shrubs and herbaceous plant species – should be a desired condition in pine-hardwood habitat enhancement projects. Designing treatments that will create a mosaic of varying canopy covers (e.g. 10 – 70%) across stands in combination with prescribed burning and wildland fire use, should promote the establishment and enhance existing understory plant communities.

Snags

Though the effects of treatments were opposite and inconclusive for Hairy and White-headed Woodpeckers, the value of snags to birds and other wildlife is well established (e.g., Laudenslayer et al. 2002). Five of the twenty-one most abundant species in the project area are obligate cavity nesters (Burnett et al. 2006). While the woodpeckers excavate their own cavities, species such as Red-breasted Nuthatch rely to some degree on abandoned woodpecker cavities or natural cavities for nest sites. Furthermore, dead and dying trees are an important food source for many avian species, especially bark gleaners such as woodpeckers and nuthatches. Timber harvest operations can result in unintended loss of snags and dying trees due to logistical issues during harvest operations. A group selection Black Oak enhancement project in the El Dorado National Forest resulted in a significant decrease in snag density following treatment (Garrison et al. 2005). Snag retention and ensuring long-term healthy snag dynamics are important management considerations for pine-hardwood enhancement. Topping hazard trees and some dead and dying trees to a maximum allowable height (to meet safety needs) – even as low as two meters above ground – would maintain or increase this important habitat component.

Band-tailed Pigeon

Band-tailed Pigeon, another species occurring in low numbers in the project area, has been declining in the Sierra Nevada (-3.0%/year, p=0.17), over the past 40 years (Sauer et al. 2006). Our results suggest they have shown a slight increase in treated stands while their numbers have remained stable in untreated stands. As they occur at low densities and are highly nomadic, it is difficult to monitor this species that is so closely tied to black oak in the study area. Little is known about the specific habitat features influencing its abundance and productivity in the Sierra Nevada. One of its primary food sources is acorns; thus, increasing oak health and habitat extent on the landscape, including mast production and reliability, should benefit this declining species.

Conclusions

The results of our analysis of the effects of pine-oak habitat enhancement are inconclusive. Due to large annual variation in bird abundance across the study area and relatively small sample and number of years of post-treatment data for most species, there has been no strong effect of treatments.

Based on the results from this analysis, our previously developed habitat associations, and information gleaned from the literature, we have developed specific recommendations for managing key habitat attributes in pine-hardwood forest in the Lassen region (listed in the beginning of this report following the executive summary). We suggest that the Lassen National Forest continues to design pine-hardwood enhancement projects that incorporate these recommendations within an adaptive management framework. They then can then be tested and refined in order to maximize the ecological benefit of projects to birds and other wildlife.

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Appendix 1. GPS coordinates (UTM Zone 10 NAD 27) for all point count locations surveyed in the Brown's Ravine Pine-Hardwood Enhancement Project in the ARD, 2005.

Station Name	Latitude	Longitude	Station Name	Latitude	Longitude
LOKR00	4427104.89	626315.74	MOKR01	4430559.57	627788.29
LOKR01	4427350.45	627671.53	MOKR02	4430768.63	627884.31
LOKR02	4427566.64	627820.95	MOKR04	4430953.99	628909.56
LOKR03	4427760.19	627968.16	MOKR05	4429652.72	627708.98
LOKR04	4427944.69	628104.98	MOKR06	4429426.03	627774.42
LOKR05	4428187.47	628174.90	MOKR07	4430059.68	626552.66
LOKR06	4428388.57	628339.10	OAK101	4426869.71	626325.54
LOKR07	4428593.41	628454.72	OAK102	4427090.71	628135.31
LOKR08	4428678.79	628692.18	OAK103	4426414.03	626371.27
LOKR09	4429174.91	628841.49	OAK104	4426629.62	626567.25
LOKR10	4428609.05	628919.34	OAK105	4426856.65	626575.43
LOKR11	4428474.07	628755.61	OAK106	4427078.77	626546.03
LOKR12	4426718.16	627406.67	OAK107	4427135.94	626763.25
LOKR13	4428078.12	629718.88	OAK208	4426464.68	627453.45
LOKR14	4428032.04	629471.53	OAK209	4426476.64	627680.74
LOKR15	4427790.85	629247.45	OAK210	4426480.63	627900.04
LOKR16	4427654.03	629046.27	OAK211	4426707.92	627872.14
LOKR17	4427576.40	628808.08	OAK212	4426755.77	627628.90
LOKR18	4427413.92	628609.02	OAK213	4426987.04	627600.99
LOKR19	4426896.08	628672.78	OAK214	4427126.60	627888.09
LOKR20	4427132.55	628669.42	OAK215	4426899.32	627788.39
LOKR21	4427058.77	628876.58	OAK216	4426476.64	628151.26
LOKR22	4427313.82	628895.53	OAK217	4426664.05	628286.84
LOKR23	4427227.42	629134.62	OAK218	4426859.44	628402.48
LOKR24	4427457.57	629194.23	OAK219	4427102.68	628402.47
LOKR25	4427596.22	629412.55	OAK220	4426637.79	626335.32
LOKR26	4427333.03	629410.88	OAK221	4426859.44	628127.33
LOKR27	4427633.64	629654.87	OAK322	4427400.99	628042.85
LOKR28	4427767.40	628312.91	OAK323	4427597.51	628157.37
LOKR29	4427997.12	628339.24	OAK324	4427525.72	628382.31
LOKR30	4428138.30	628516.32	OAK329	4427899.01	628568.95

Station Name	Latitude	Longitude	Station Name	Latitude	Longitude
LOKR31	4428061.73	628729.28	OAK330	4427681.26	628590.50
OAK331	4427824.83	628777.14	OAK768	4433916.95	627337.91
OAK332	4427865.53	629011.07	OAK869	4433752.48	627475.92
OAK333	4428131.13	628992.49	OAK870	4433637.16	627663.08
OAK334	4428293.84	629148.04	OAK871	4433769.50	627869.15
OAK335	4428033.01	629219.81	OAK872	4433898.05	627670.63
OAK437	4429869.26	627110.74	OAK873	4433868.63	628197.99
OAK438	4429737.29	626922.20	UOKR01	4433007.48	627593.71
OAK439	4429803.28	627378.45	UOKR02	4433221.68	627699.54
OAK440	4430155.84	626852.44	UOKR03	4433955.81	627979.38
OAK441	4430244.45	627061.71	UOKR04	4434069.51	627798.15
OAK442	4430274.61	627304.92	UOKR05	4434222.78	627626.97
OAK443	4430327.40	627529.28	UOKR06	4434313.31	627415.23
OAK444	4430095.51	627476.49	UOKR07	4434231.55	627949.64
OAK445	4430065.34	627227.62	UOKR08	4434088.60	628147.42
OAK446	4429965.42	626931.63	UOKR09	4434041.80	628359.00
OAK547	4430032.16	628000.44	UOKR10	4433916.57	628548.30
OAK548	4430273.79	627948.20	UOKR11	4434114.48	628701.57
OAK549	4430210.12	628157.17	UOKR12	4434533.79	628597.95
OAK550	4430425.62	628193.09	UOKR13	4434834.55	628777.88
OAK551	4430592.14	628331.86	UOKR14	4432825.69	628596.86
OAK552	4430747.24	628501.64	UOKR15	4433010.78	628430.81
OAK553	4430818.85	628709.55	UOKR16	4433185.72	628604.22
OAK656	4432859.46	626140.28	UOKR17	4433420.53	628692.53
OAK657	4432998.50	626315.20	UOKR18	4433063.74	628011.14
OAK658	4433206.32	626416.87	UOKR19	4433352.05	628147.90
OAK659	4433427.59	626446.77	UOKR20	4433369.88	627893.04
OAK760	4433415.97	627143.18	UOKR21	4436397.39	628815.70
OAK762	4433548.31	627419.20	UOKR22	4436857.27	628890.04
OAK763	4433417.86	626859.61	UOKR23	4436968.80	629099.00
OAK764	4433650.39	626865.27	UOKR24	4437048.81	628793.99
OAK765	4433727.90	627080.80	UOKR25	4436857.80	628643.00
OAK766	4433952.88	627112.94	UOKR26	4436619.79	628679.00

Station Name	**Latitude**	**Longitude**	**Station Name**	**Latitude**	**Longitude**
OAK767	4434123.03	627264.18	UOKR27	4436494.80	628389.00
UOKR28	4436299.80	628485.00			
UOKR29	4436084.80	628593.00			
UOKR30	4436129.80	628312.00			
UOKR31	4436587.80	629634.99			
UOKR32	4436590.80	629884.99			
UOKR33	4436777.80	629566.00			
UOKR34	4437028.80	629555.00			
UOKR35	4437308.79	629555.00			
UOKR36	4437073.81	629331.99			
UOKR37	4437476.80	629389.00			

Appendix 2. PRBO Pine-Oak habitat assessment protocol.

All data is collected within a 50 meter radius circle centered on the point count station.

1st Section General Information:

Station = 3 letter code (e.g. OAK1)

Point # = the actual point number of the station.

Habitat 1 = general classifications (MCF, MCP, MCO, Shrub)

Habitat 2 = only record this if there is a distinct habitat edge (i.e. point is bisected by a clear cut/forest edge)

Date = the date you are collecting this data.

Aspect = the direction of the slope given in degrees (the direction a drop water would flow if poured onto the point). Collect magnetic direction.

Slope = the average slope of the plot with 90 degrees being vertical and 0 degrees being flat, from the highest point to the lowest. (If it drops 10 meters over the 100 meter plot slope is 10 %.)

Water = true or false is there any water in the plot running or standing.

Snags<10 = total number of the snags in the plot less than 10cm DBH (this includes things that still have dead branches on it but it must be appear to be completely dead, leaning snags that are uprooted but not on the ground or almost on the ground count).

Snags30>10 = the number of snags greater than 10 cm DBH but less than 30 cm DBH (see above for more details).

Snags >30 = the total number of snags greater than 30 cm DBH.

Logs = any downed trees or limbs greater than 8cm DBH and greater than 2m long. Must still have shape of log, rotted decomposed stuff that is really falling apart should not be counted.

Cover Layers
These are divided up into 6 layers (Tree, Tree Shrub, Real Shrub, Total Shrub, and Herbaceous)

Tree – this is defined by height category alone. Any plant species whose upper bounds (highest point) is greater than 5 meters tall is included in this category (a 6 m tall Manzanita would be included in this category, however a 4m tall White Fir would not be).

Tree Shrub – this is all tree species that are less than 5 meters tall regardless of height, this means a 25cm tall White Fir counts in this category. Tree species are the conifers, black oak, maple, white alder, canyon oak, etc.

Real Shrub - this is the true shrub species as well as a few shrubby trees that rarely get above 5 meters tall (Dogwood, Mountain Alder, ARPA, CHCA, CECO, CEIN, etc.), record the total cover of these species regardless of height.

Total Shrub - this is the total cover of all vegetation whose maximum height is between 0.5 and 5 meters (the original Relevé way of doing it). It may be just the sum of real shrub and true shrub but overlap and tall real shrubs may lead to differences.

Black Oak – record the cover of all Black Oak regardless of height in the plot.

Herbaceous Layer – this is the total cover of all non-woody vegetation, regardless of height.

Note: the maximum cover theoretically is 100% for all of these categories but practically that would be impossible to achieve.

Height Bounds

High - estimate is to the nearest ½ to 1 meter of the average height of the upper bounds of the vegetation layer (tree, tree shrub, real shrub). This is not the tallest outlier it is the average high of the tallest plants in that layer. (E.g. of the tallest trees in the plot what is the average high height).

Low – the average (as defined in the high) of the lowest living branches of the tree and tree shrub and real shrub do not record this for total shrub or herbaceous.

Lower and Upper Species – record the plant species that dominates the lower and upper bounds for all of the categories you collected low and high height data for, if you think there is absolute equal representation of these than good for you! Flip and coin and stop wasting your time and my money and move on to the next measurement.

DBH = estimate the minimum and maximum DBH of any tree within 50 meters, and record what species it is. Do not record this for the shrub layers.

Species List

Record these as T1 (tree layer), TS (true shrub), RS (real shrub), S1 (total shrub) and H1 (herbaceous)

Record for each of these layers the % each species comprises of the total (this number should add up to 100% regardless of the % total cover). List as many species as can easily be recorded in a timely manner. Chasing down that lone shrub off in the corner of the plot is not worth the effort. However, we are interested in hardwood species so if they are present in small numbers recording them even if they are less than 5% is worth the effort, also recording a single large tree as 5% or less is probably also worth it.

DBH Classes

Place each tree in the plot with a DBH (i.e. greater than 1.5 meters tall) into the four DBH classes on the bottom of the page. Note that the DBH tape may be in inches so you need to divide by 2.54. If there are more several hundred trees by all means make a good estimate do not go around taping every tree.

Oak Density Transects

Using permanently (orange rebar) marked transects lay 50 meter tape out from center of point to one end point (transects are east and south unless an un-crossable barrier is met then chose the bearing 180 degrees from the un-crossable). Record all black oak stems that are within 3 feet of the tape (either side). For each hit place it within one of 4 categories as listed on the bottom of the sheet (0-3', 3'-6', 6-12" DBH, and >1' DBH). Subtotal all of these at the 100 ft mark (30.5 meters) and then a grand total for the entire 50 meters. Conduct this for both 50 meter transects.

Canopy Cover

Using same transect as the Oak density above record the hit/no hit along the transect every 10 feet (~3 meters) using the densitometer. For each hit record the species and subtotal these at 100 feet (30.5 meters) and then a grand total for all 50 meters. Repeat for the second transect. Note: It is vital that time is spent to lay out the tape accurately and taught so that transects are as repeatable as possible.

Chapter 4. Landscape-scale Predictive Models for Northern Sierra Landbirds

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Introduction

Forest Service mangers are tasked with making important decisions, often with limited scientific information. These decisions are often complex and involve consideration of multiple potentially competing objectives at various spatial scales. In order to be successful, managers need decision support tools in the form of scientifically-based, appropriately scaled syntheses of available information.

There are currently several such tools available to National Forest land managers in the Sierra Nevada, including the California Department of Fish & Game's (DFG) Wildlife Habitat Relationship (WHR) system (http://www.dfg.ca.gov/whdab/html/cwhr.html). The WHR allows the user to select general habitat types including some characteristics of those habitats (e.g., small trees) within various predefined areas (e.g., USDA Ecoregions) with an output of predicted species occurrence lists. With appropriate GIS-based habitat layers, WHR predictions can also be made spatially explicit, and can provide reasonably accurate predictions for conservation planning at the ecoregional scale (Edwards et al. 1996). For North American birds, the U. S. Geological Survey (USGS) has developed an online tool (http://umesc-ims01.er.usgs.gov/website/new_bird/viewer.htm) that summarizes both land cover and bird survey data at a variety of spatial scales. California Partners in Flight (CalPIF) also has a tool available online that provides site-specific bird lists (http://cain.nbii.gov/prbo/calpifmap/livemaps/). While these are all good systems, they do not provide the kind of detailed information at the appropriate spatial scales for project, ranger district, or even Forest level decision making. WHR is based on expert opinion compiled across species' ranges; the USGS system is based on Breeding Bird Survey (BBS) routes, of which there are only twenty nine across the entire Sierra Nevada; and the CalPIF system is only site-specific for where monitoring has occurred and is not extrapolated out to a regional scale.

When adequate survey data are available, spatial models of species habitat associations and spatial predictions of species occurrence ("species distribution models" or "habitat occupancy models") can serve as useful decision support tools for managers to identify and rank potential habitat areas in order to guide management decisions. While GIS-based, empirical species distribution models have been developed at broad spatial scales for over a decade (Lindenmayer et al. 1991, Pereira and Itami 1991, Aspinall and Veitch 1993), the recent availability of high-resolution aerial photography and satellite imagery, and resulting detailed vegetation classification maps, have improved our ability to develop fine-scale models of species occurrence for local and regional conservation purposes (Ozesmi and Mitsch 1997, Loyn et al. 2001, Gibson et al. 2004). At the landscape scale, species distribution models are generally based on habitat variables such as vegetation cover type/structure, and local topographic and climatic variations, rather than general land cover classes and broad-scale climate. Thus they can provide significant improvements in predictive power over a simple habitat suitability index (HSI) or wildlife habitat relationship (WHR) model.

The objective of this analysis was to provide the necessary tools to help managers make informed decisions using landbirds as indicators for ecologically based management. In order to do so we developed spatially explicit landscape based predictive models for nine bird species across the Plumas-Lassen study area using our existing avian survey data and existing vegetation and climatic landscape based datasets.

Methods

Study Area

The Plumas-Lassen study area is located in the extreme Northern Sierra Nevada and Southern Cascade Mountains in Plumas, Butte, and Tehama counties of California (Figure 1). We used the area encompassed by the 2002 GIS based vegetation maps developed as part of the Plumas-Lassen Administrative Study (PLAS) to define our study area boundary. The study area encompasses approximately 1,100,000 acres ranging in elevation from 600 to 2500 meters and encompassing a broad range of habitat types, size and canopy cover classes.

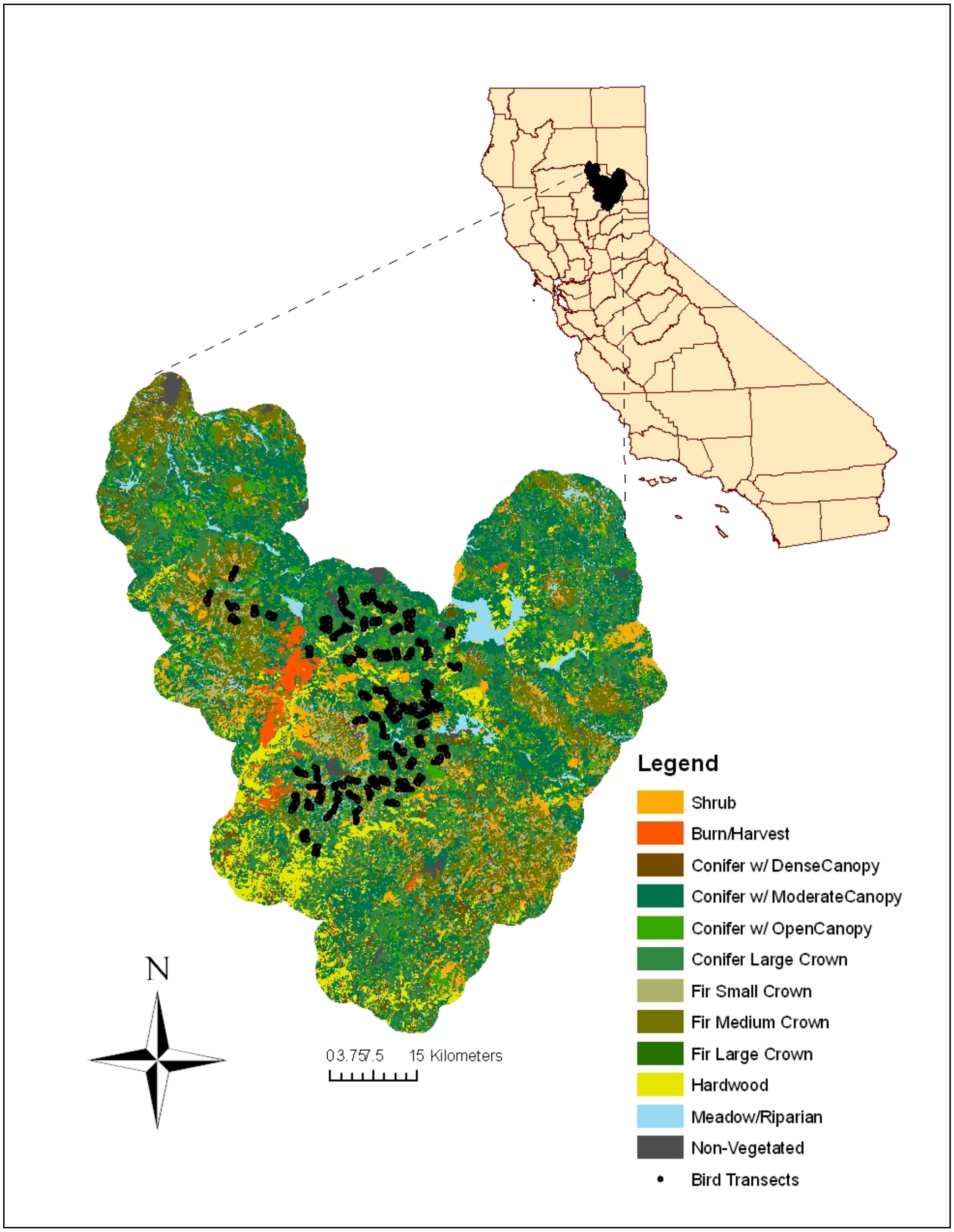
Point Count Methods

We used variable radius point counts to sample landbirds (Buckland et al. 1993, Ralph et al. 1993, Thomas et al. 2003). Point counts at each point within a transect were conducted for 5 minutes, with each individual bird recorded. Each transect was visited twice in each year it was surveyed. Surveys were conducted by observers well versed in the identification of species encountered. Counts were conducted starting just after local sunrise up to four hours and were not conducted in inclement weather (e.g. wind over 10mph, rain, dense fog). We used all detections from all distances from observers to input into the models. We included point count data from all untreated sites in our study area from 2003-2006, which included between six to eight visits at each of over 1000 points across all years. Treated sites were not included in these models.

Site Selection

Point count transect selection was carried out from 2002-2004, using slightly different techniques employed 2003 and 2004 than in 2002. In 2002, a set of randomly selected transect starting points were generated in ArcView GIS (ESRI 2000) for each of the proposed eleven treatment units (roughly 50,000 in size) on the basis of accessibility from roads and stratification by forest stand characteristics (average crown closure and tree size). There were 3 tree size categories based on crown diameter (<12’, 12-24’, and >24’ or two-storied) and 2 tree crown closure categories (30-50% and 60-80%), resulting in 6 combinations by which to stratify sampling. These classes were derived from the complete Forest Service classifications. Starting points placed in these categories were also constrained to be at least 100 m, but not more than 250 m, from a road; and at least 50 m from a planned or proposed Defensible Fire Protection Zones (DFPZs). In ArcView GIS (ESRI 2000), points were placed randomly within polygons that met these requirements, on the basis of information in data layers provided by the US Forest Service. Ten potential starting points were generated for each of the 6 strata, resulting in 60 points per treatment unit, even though only one starting point per stratum was needed.

Figure 1. Location of the Plumas-Lassen study area within California, major vegetation types within study area, and avian sampling transects.



Using GIS layers representing ownership, slope, and habitat we attempted to fit U-shaped transects using a random heading determined by spinning a compass. If a transect could not be established after four compass spins – due to topography (slopes >30%), bodies of water, or other constraints (e.g. private property) – the next point in the list was attempted, and so on until a satisfactory location was found for that particular stratum. The transect was then established by placing 6 points along the random compass bearing at 250 m intervals, turning 90 degrees from original bearing 500 meters to point 7, then returning 180 degrees from original bearing back towards starting point until 12 points were established.

Analysis from GIS layers and field classification of all points established in 2002 revealed that points were distributed across the six different structural strata proportionate to their frequency across the entire study area (Burnett et al. 2003). We believe this was due to the amount of area a transect covers combined with the extreme heterogeneity (in size and canopy closure) across the study area. Since only the first point was stratified; the remaining eleven points were laid out in a U-shape across the landscape and thus allowed to fall into any structural category.

In 2003 and 2004, following changes to the study plan mandated by changes in direction from the Plumas and Lassen National Forests, it was necessary to reassess our original study design. Thus, we modified our design to place three transects in each individual CalWater Planning Watershed (CalWater 1999) within the previously defined treatment units 2, 3, 4, and 5. Based on our finding that stratifying points by habitat structure resulted in a distribution of points no different than would have been expected by non-stratified random points, and the logistical difficulties in placing transects in 2002 using this method, we decided not to stratify random starting points in 2003 or 2004 by structural class. Other than not stratifying points by cover and size class, in 2003 and 2004 our site selection methodology was very similar.

Species Selection

We developed spatial models for nine avian species (Table 1). We included all species proposed as Management Indicator Species (MIS) by the Forest Service (MIS DEIS 2007), as well as those currently identified as focal species in the Lassen National Forest (the Plumas National Forest does not specifically list any landbird species). Additionally, we included several focal species identified by the California Partner's in Flight Coniferous Forest Bird Conservation Plan (CalPIF 2002). We also chose Hermit Warbler as it was the most abundant songbird detected in our study area, though it is not on either the MIS or focal species lists. Together we believe these species represent the range of habitat requirements utilized by birds in the study areas.

Table 1. Species selected for modeling in the Plumas-Lassen study area, status as a current or proposed Management Indicator Species (MIS DEIS 2007), and status on the California Partner's in Flight Coniferous Forest Bird Conservation Plan focal species list (CalPIF 2002).

Species	MIS	CalPIF Focal Species
Hairy Woodpecker	X	
Pileated Woodpecker	X	X
Olive-sided flycatcher	X	X
Dusky Flycatcher		
Brown Creeper	X	X
Nashville Warbler	X	
Hermit Warbler		
MacGillivray's Warbler		X
Fox Sparrow	X	X

Modeling Approach

We employed a powerful machine learning algorithm called Maxent (Phillips et al. 2006) to predict species distributions based on species occurrence locations and GIS-based environmental data layers in the PLAS. Maxent is based on the principle of maximum entropy, and uses information about a known set of species occurrence points, compared with environmental "background" data, to develop parsimonious models of species occurrence. The method accommodates several different types of non-linear relationships and is similar to generalized additive models (Hastie and Tibshirani 1990) in its outputs and interpretation. Because point count surveys produce absence as well as presence data, we used this information in our models. We used environmental data from just our survey locations, rather than the entire study area, as "background" for the models. Spatial predictions (maps) of species occurrence were generated for each management indicator species.

Model predictions were cross-validated using a subset of the data points (25%) selected at random by the Maxent program. Model performance was assessed using the area under the curve (AUC) of receiver operating characteristic (ROC) plots (Fielding and Bell 1997), a threshold-independent measure of model accuracy (i.e., a measure of model accuracy that does not depend on a particular probability cut-off to distinguish between presence and absence). AUC values represent the predictive ability of a distribution model and are derived from a plot of true positive against false positive fractions for a given model. The larger the area under the curve (AUC), the higher the rate of correct classification for both presence and absence values, across a range of cut-off probabilities (because predictions are expressed as probabilities of occurrence, rather than strict presence or absence). The value of the AUC is always between 0.5 and 1.0. A value of 0.5 indicates a chance model performance while a value of 1.0 indicates perfect performance. A value of 0.8 means that 80% of the time a random selection from the presence group will have a higher probability of occurrence than a random selection from the absence group. As a general guideline, AUC values of 0.6 – 0.7 indicate poor accuracy, 0.7 – 0.8 is fair, 0.8 - 0.9 is good, and values greater than 0.9 represent excellent accuracy (Swets 1988).

We also evaluated the importance of each variable in the final model, as well as by itself, by assessing the difference in model performance (training gain) as measured by the Maxent program. For final model variables, we evaluated partial response curves produced by Maxent to interpret relationships between the occurrence of each species and each environmental variable. Because these curves were based on models containing other, potentially correlated, variables, they may differ from univariate relationships, and may not accurately reflect the functional response of a species to a particular environmental variable. Furthermore, these relationships should only be considered relevant for the area surveyed.

We reclassified habitat types in the Vestra vegetation map by combining similar habitats in order to limit the total possible variables (Table 2). For each species we selected a suite of variables that we believed might be important in explaining its distribution at the landscape scale (Appendix B). Additionally, we selected eight climatic variables that were included in each species' model (Table 3).

Table 2. Habitat types, size classes, and canopy density classes used in Maxent landscape models with CWHR classes and codes included in each type or classification.

Vegetation Type	CWHR Classes	CWHR Codes
Shrub	Brush, Plantation, Burned-Harvested	CX, FBX, FXC
Riparian or Meadow	Meadow, Riparian, Aspen, Pasture	GM, HA, RIP, GP
Hardwoods	Black Oak, Live Oak, Tanoak	HB, HL, HT
Ponderosa Pine Forest	Ponderosa Pine	PP
Mixed Conifer Forest	Douglas Fir & Ponderosa Pine Mixed Conifer and Mixed Conifer	DMC, PMC, MC
White Fir Forest	White Fir Mixed Conifer & True Fir	WMC, TF
Red Fir Forest	Red Fir	RF
Unvegetated	Water, Urban, Rock, Bare	NW, NU, NR, NB
Tree Size Classes		**CWHR Size Class**
Saplings	Saplings	Size 2
Poles	Less than 12 ft. crown diameter	Size 3
Small Trees	12 – 24 ft. crown diameter	Size 4
Medium/Large Trees	>24 ft. crown diameter	Size 5 & 6
Canopy Densities Classes		**CWHR Density Classes**
Open Canopy	Sparse and Open	S & P
Mostly Closed Canopy	Moderate	M
Closed Canopy	Dense	D

Table 3. Variable codes and descriptions for variables used in maximum entropy modeling of nine landbird species in the Plumas-Lassen study area. Metrics were calculated using moving window averages within the given radius. Temperature is expressed in degrees Celsius multiplied by 10 and precipitation is expressed in centimeters.

Variable codes	Description
an_mn_temp	Annual mean temperature
an_precip	Annual precipitation
precip_dry_qtr	Total precipitation in the driest quarter of the year
mn_diurn_range	Mean diurnal temperature range (Mean of (monthly maximum temperature - minimum temperature))
isotherm	Isothermality ((Mean diurnal range/Annual temperature range)*100)
temp_seasonality	Temperature seasonality (Standard deviation of mean temperature)*100
mx_temp_wm_mnth	Maximum temperature of the warmest month
mn_tmp_wm_qtr	Mean temperature of the warmest quarter

Results

Model validation statistics (ROC AUC) indicated fair to excellent model performance for the nine species investigated, with scores ranging from 0.70 to 0.93 (Table 4). Graphs depicting the nature of the relationship between each species and the chosen environmental variable, as well as graphs showing the relative importance of the most influential variables for each species, are presented (Figures 2 - 10). The species with the best performing models were Hermit Warbler at 0.93, Nashville Warbler at 0.90, and Dusky Flycatcher at 0.87. The species with the poorest performing models were Hairy Woodpecker at 0.70 followed by Brown Creeper at 0.74. Maps of predicted species distributions for the PLAS study area are presented in Appendix A.

Table 4. Area under the curve (AUC) receiver operating characteristics (ROC) and qualitative model performance for each of nine species in the Plumas-Lassen Study area from Maxent landscape based habitat modeling.

Species	ROC AUC	Model Performance
Hairy Woodpecker	0.70	Fair
Pileated Woodpecker	0.80	Good
Olive-sided Flycatcher	0.82	Good
Dusky Flycatcher	0.87	Good
Brown Creeper	0.74	Fair
Nashville Warbler	0.90	Excellent
Hermit Warbler	0.93	Excellent
MacGillivray's Warbler	0.78	Fair
Fox Sparrow	0.85	Good

Hairy Woodpecker

Model performance was fair for Hairy Woodpecker with an AUC of 0.70 (Table 4). The percent of white fir-dominated forest contributed most to the model. The response to this variable was curvilinear, peaking at approximately 25%. There was a negative relationship with the amount of size class four forest, and a mostly positive, though complex, response to the percent of open canopy forest (Figure 2). Vegetation at the point count location was also among the most influential habitat variables as positive associations with burn and red fir forest were of note. Annual precipitation and annual mean temperature were among the most influential climatic variables, both positive associations.

Pileated Woodpecker

Model performance for Pileated Woodpecker was good, with an AUC of 0.80 (Table 4). A relatively large number of variables were important contributors to explaining this species presence in the study area (Figure 3). The habitat variables with the strongest influence were the amount of mixed conifer, red fir, white fir forest, and size class two forest. The effect of red fir and size class two forest was negative, while white fir was positive. The effect of mixed conifer forest was more complex. Among the most influential climatic variables were the mean diurnal range in temperature, precipitation in the driest quarter, and mean annual temperature. The effect of precipitation in the driest quarter was negative while the other two had a positive effect.

Olive-sided Flycatcher

Model performance for Olive-sided Flycatcher was good with an AUC of 0.82 (Table 4). The habitat variables with the greatest contribution to the model were the amount of white fir forest, open canopy forest, edge between forest and non-forested habitats, and shrub habitat (Figure 4). Each of these four variables had a positive effect on the likelihood of this species being present at a site. However, the relationship with white fir forest appears to have a threshold; around 90% at which point the relationship turned negative. The climatic variables with the greatest influence were mean diurnal temperature range and temperature seasonality. The effect of diurnal temperature range was negative while that of temperature seasonality was more complex, being moderately positive at lower values but strongly negative at the highest levels.

Dusky Flycatcher

The overall model performance for Dusky Flycatcher was good, with an AUC of 0.87 (Table 4). The habitat variables with the greatest model contribution were the percent of hardwood forest, percent of ponderosa pine forest, and habitat conditions at the point count station (Figure 5). The relationship with both hardwoods and ponderosa pine was negative. The habitat conditions at the point with the greatest influence were negative associations with hardwoods and burn. The two most influential climatic variables were mean diurnal temperature range, which had a positive effect, and annual precipitation, which showed a complicated pattern.

Brown Creeper

The model performance for Brown Creeper was fair with an AUC of 0.74 (Table 4). By far the most influential habitat variables was a negative relationship with the percent of the 500 meter radius circle comprised of size class two forest (Figure 6). Though substantially less influential than the amount of size class 2 forest, the cohesion of high density forest and the amount of mixed conifer forest were the next most important habitat variables for this species. Cohesion of dense forest had a curvilinear effect: positive at lower levels and negative as it increased. The habitat at the point count station was also among the most influential habitat variables for this species with a strong negative influence of size class 2.

Nashville Warbler

Model performance for Nashville Warbler was excellent with an AUC of 0.90 (Table 4). The percent of mixed conifer forest contributed far more to the model than any other habitat variable, with its effect strongly positive (Figure 7). A number of climatic variables appeared important including dry quarter precipitation, mean temperature in the warmest quarter of the year, and mean annual temperature. Annual mean temperature was positive while the other two showed more complex non-linear effects.

Hermit Warbler

Model performance for Hermit Warbler was excellent with an AUC of 0.93, the best performing of the nine models (Table 4). The habitat variables that contributed the most to the model were the percent of hardwood, followed by the percent of size class two and percent of moderate density forest (Figure 8). The effect of hardwood habitat and size class two forest were negative while the response to moderate density forest was curvilinear (positive at lower levels and then turning negative as moderate density forest became dominant). Overall climatic variables were less predictive for this species than for others. The most influential ones were mean annual temperature and mean warm quarter temperature, both of which had a positive effects.

MacGillivray's Warbler

Model performance for MacGillivray's Warbler was fair with an AUC of 0.78 (Table 4). The habitat variables that contributed the most to the model were the amount of size class five forest, followed by the percent of ponderosa pine and mixed conifer forest (Figure 9). The effect of size class five forest was positive while those of ponderosa pine and mixed conifer forests were negative. The most predictive climatic variables included mean diurnal range, mean warm quarter temperature, and dry quarter precipitation. The effects of all three were generally negative, though for both dry quarter precipitation and mean warm quarter temperature the effects were more complex.

Fox Sparrow

Model performance for Fox Sparrow was good with an AUC of 0.85 (Table 4). The habitat variables that contributed the most to the model were the percents of size class five forest, shrub habitat, and open canopy forest (Figure 10). The relationship with each of these variables was non-linear, showing positive effects at lower levels and as each increased they reached a threshold where the effect turned negative. The three most influential climatic variables were mean diurnal range, dry quarter precipitation, and annual precipitation. The effect of annual precipitation was positive and near linear while mean diurnal range was mostly negative and dry quarter precipitation was curvilinear, with a peak in the middle.

Figure 2. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Hairy Woodpecker. Variable codes are defined in Appendix C and D.

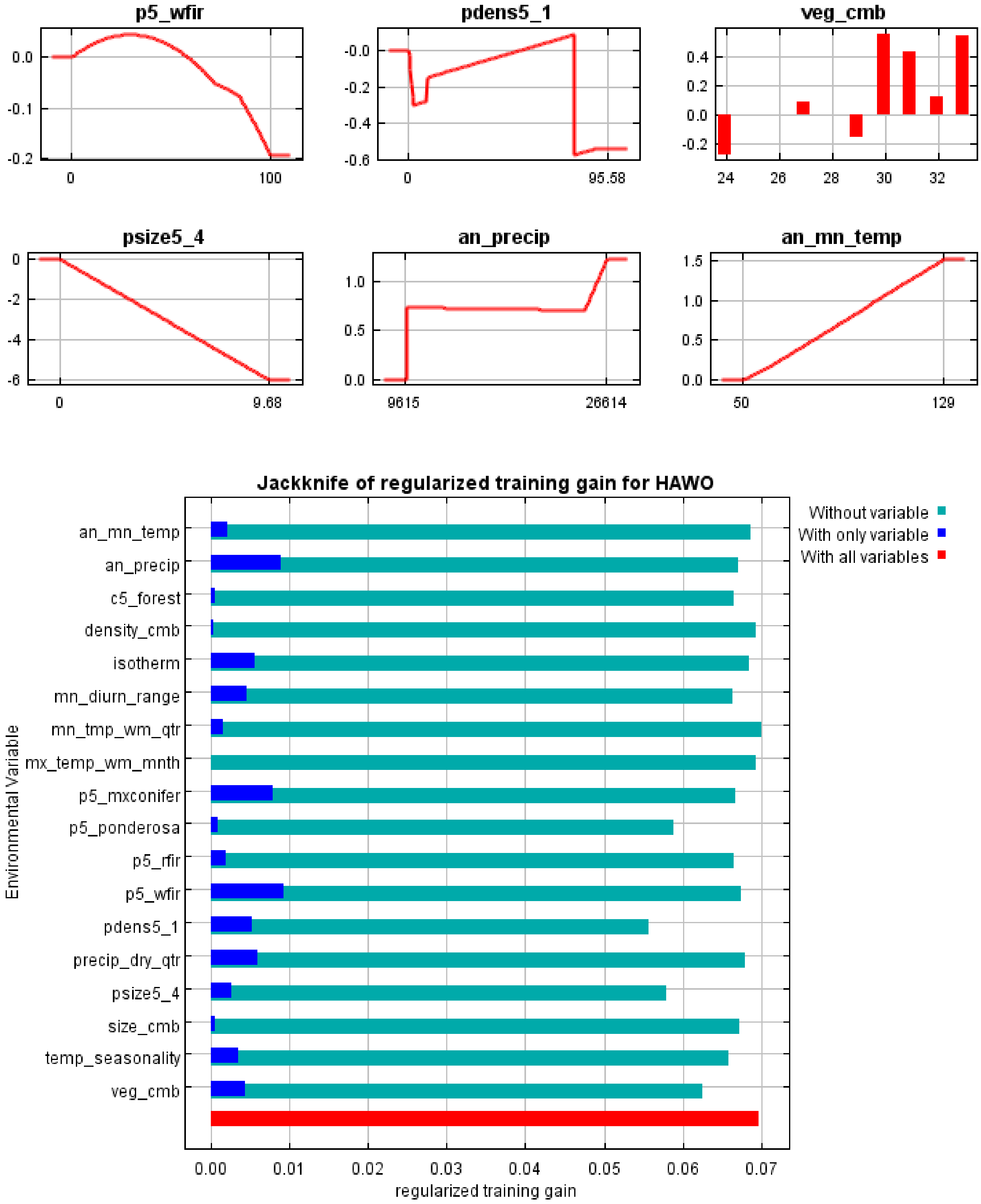


Figure 3. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Pileated Woodpecker. Variable codes are defined in Appendix C and D.

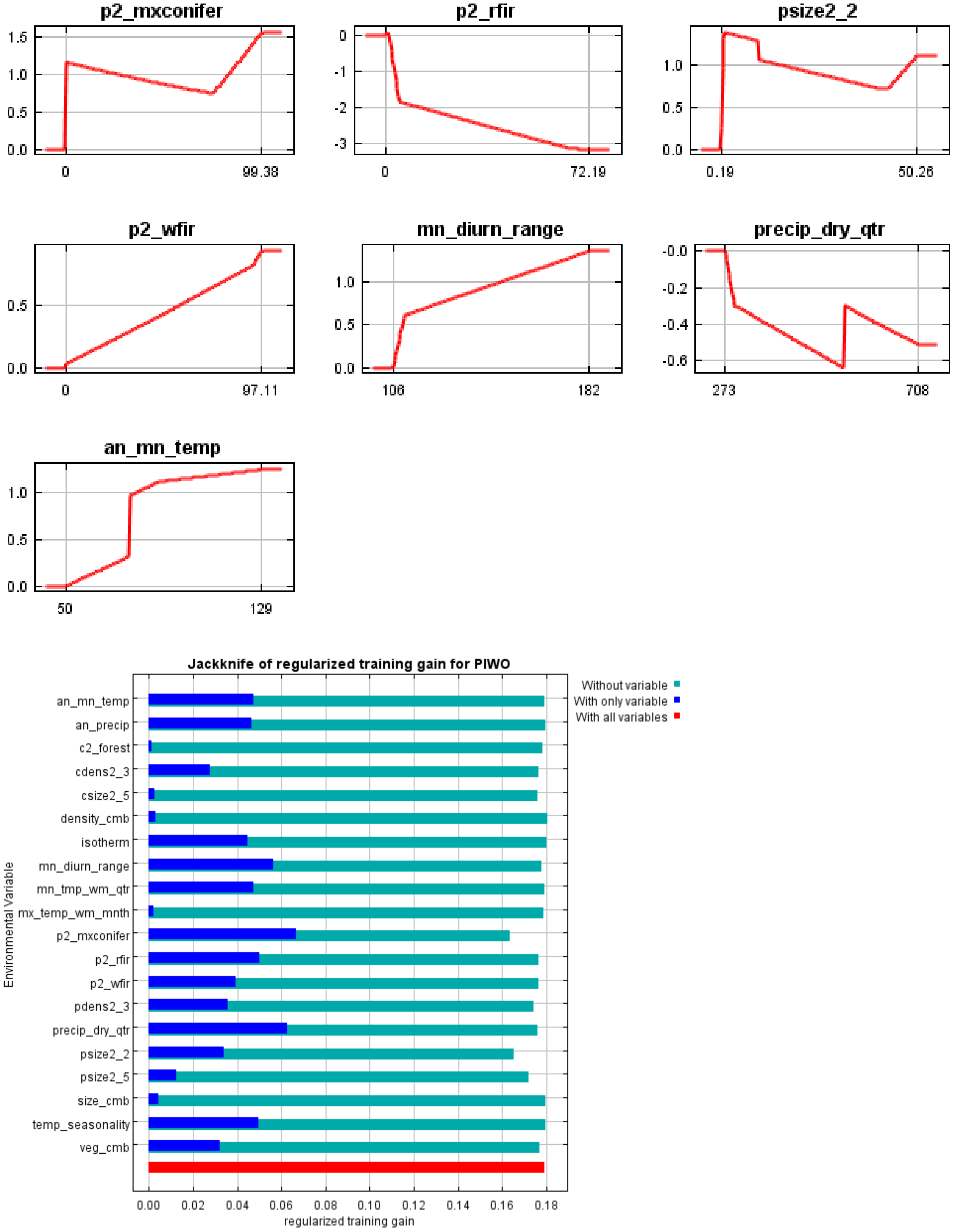


Figure 4. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Olive-sided Flycatcher. Variable codes are defined in Appendix C and D.

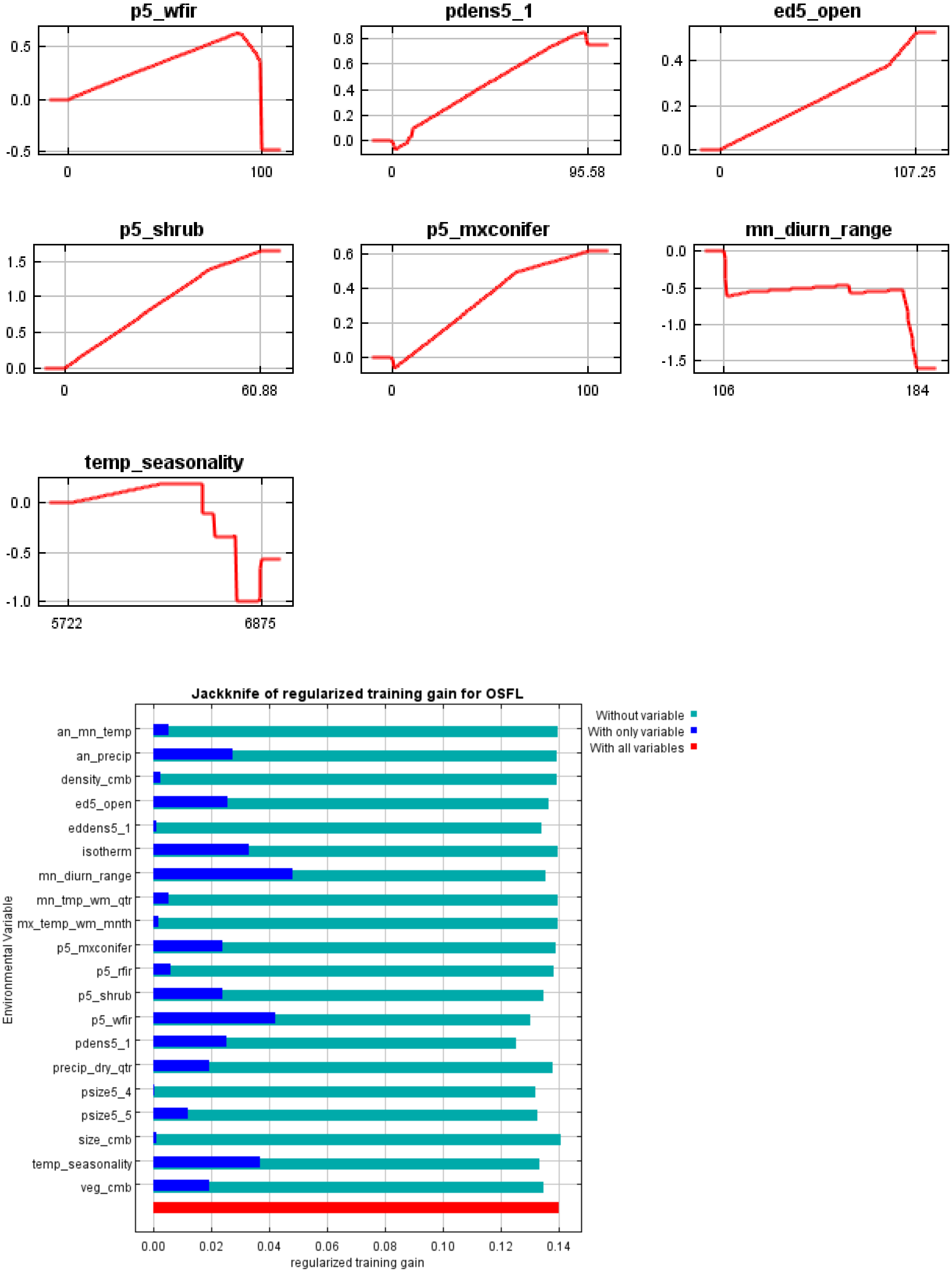


Figure 5. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Dusky Flycatcher. Variable codes are defined in Appendix C and D.

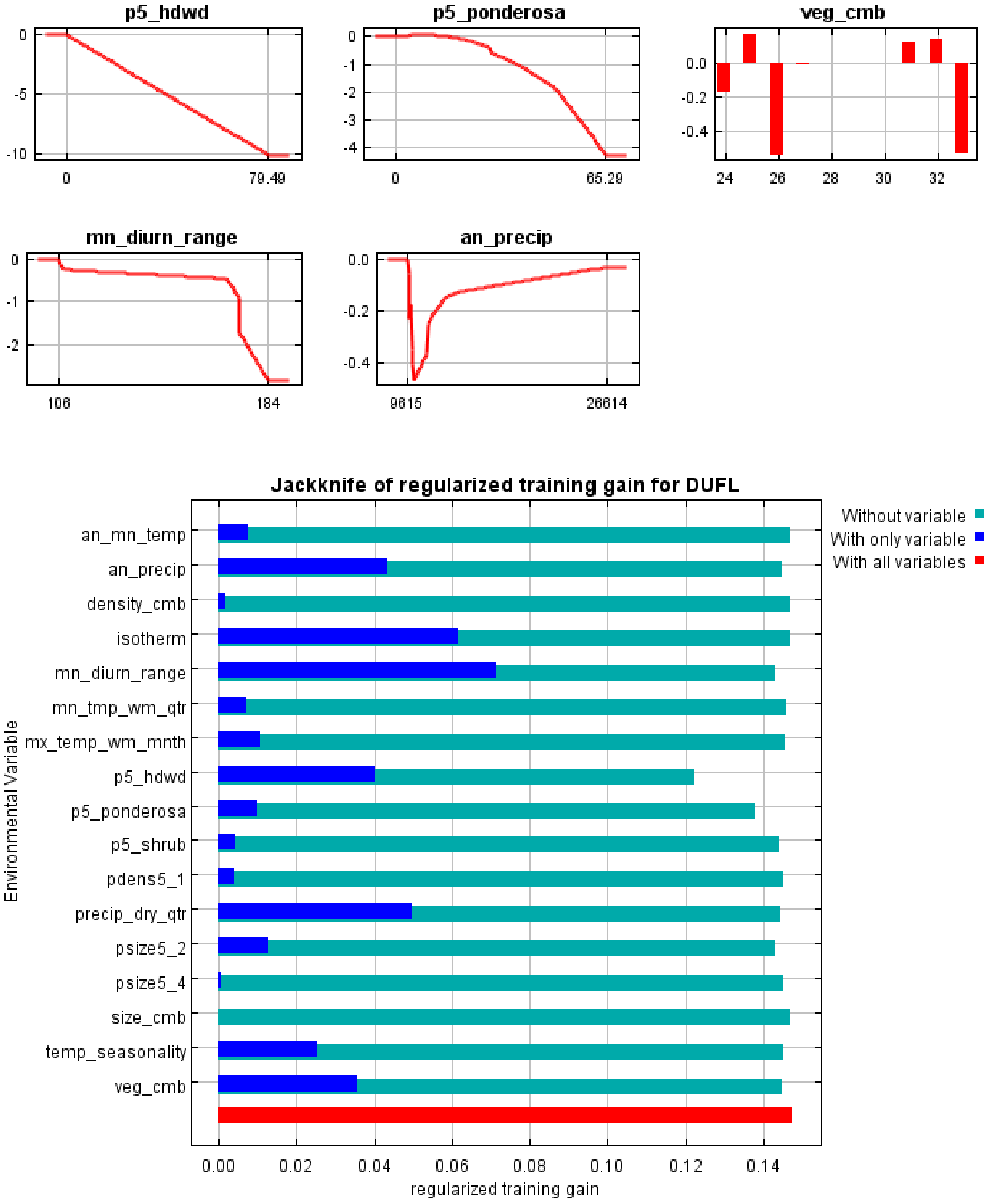


Figure 6. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Brown Creeper. Variable codes are defined in Appendix C and D.

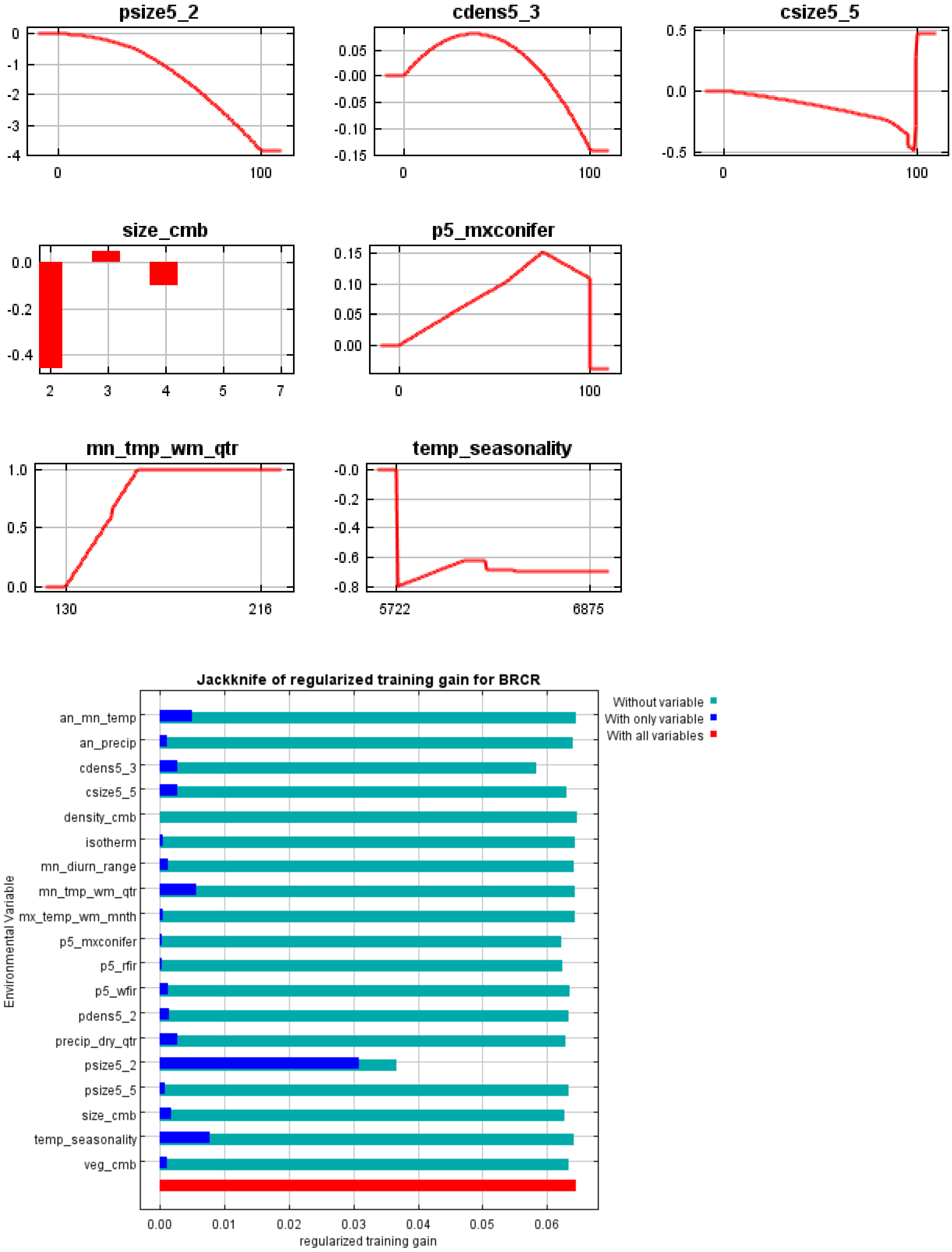


Figure 7. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Nashville Warbler. Variable codes are defined in Appendix C and D.

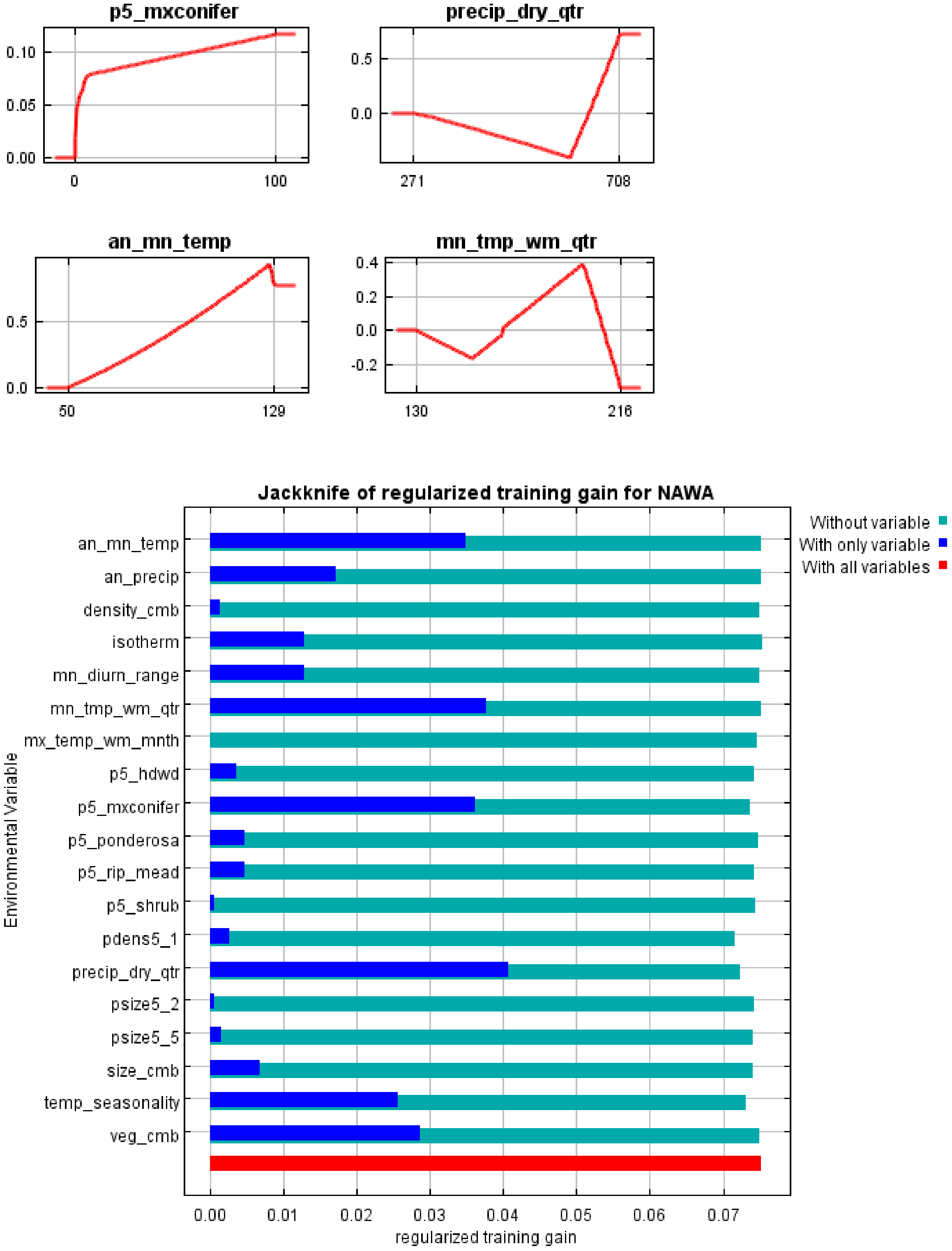


Figure 8. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Hermit Warbler. Variable codes are defined in Appendix C and D.

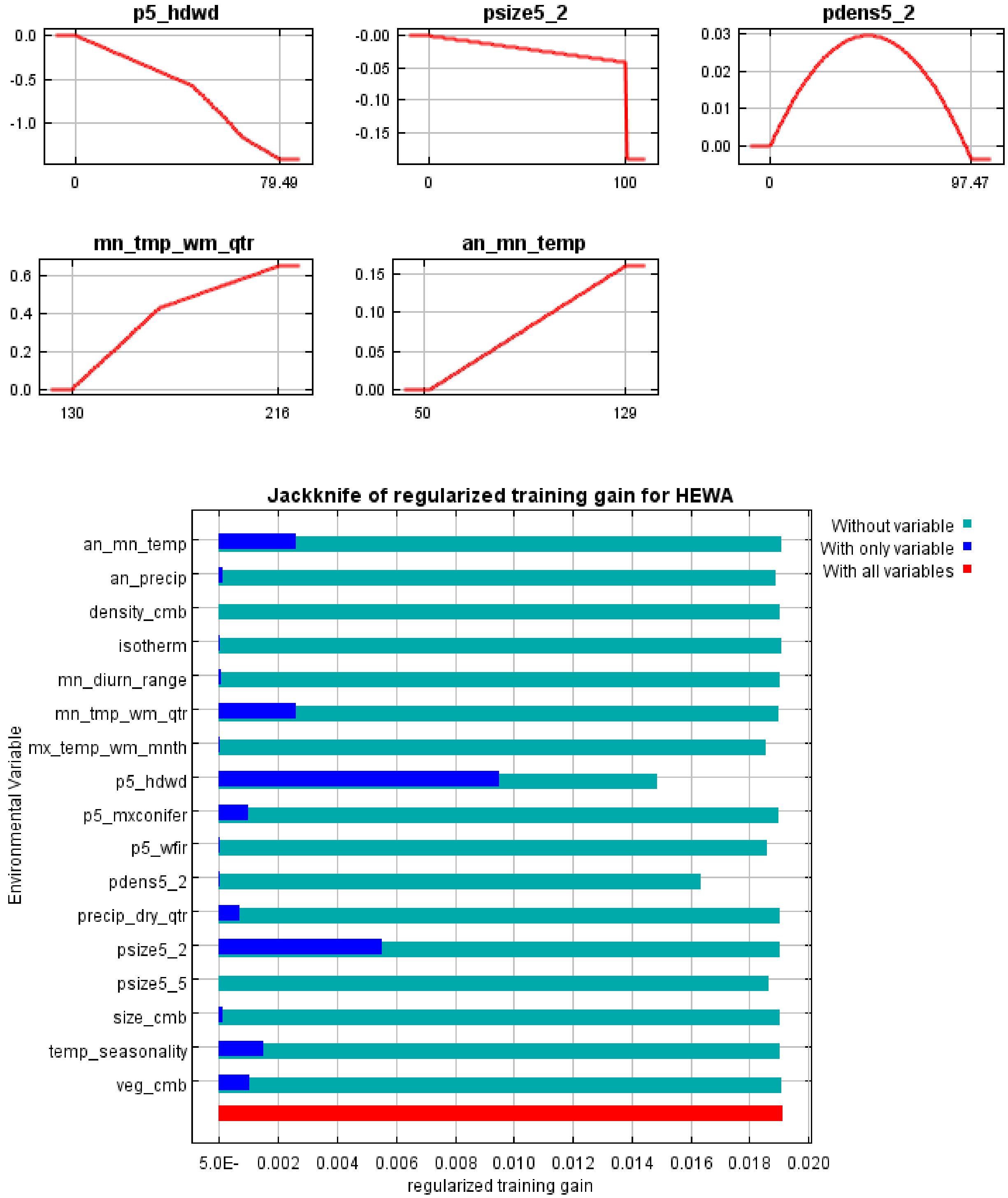


Figure 9. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for MacGillivray's Warbler. Variable codes are defined in Appendix C and D.

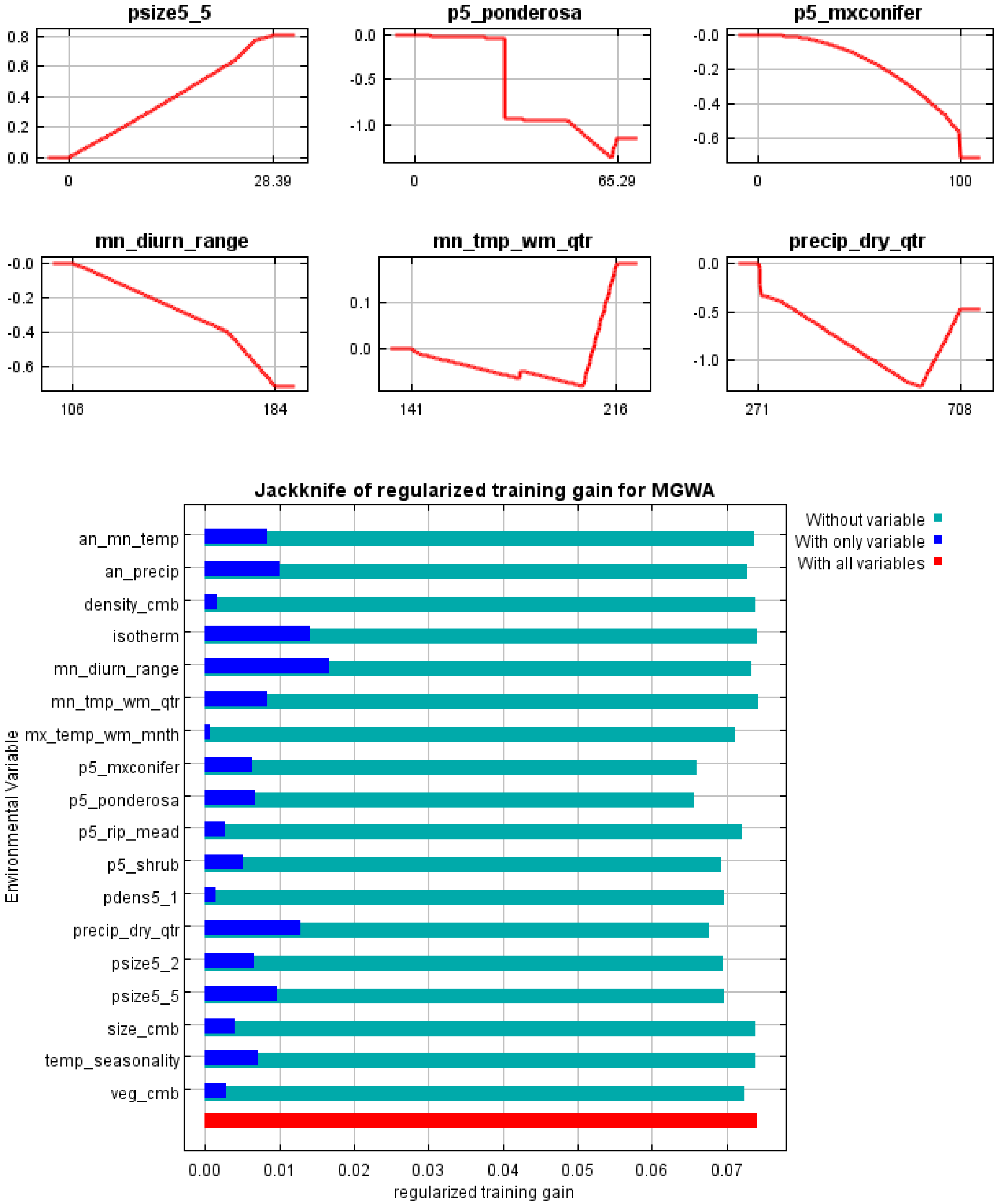
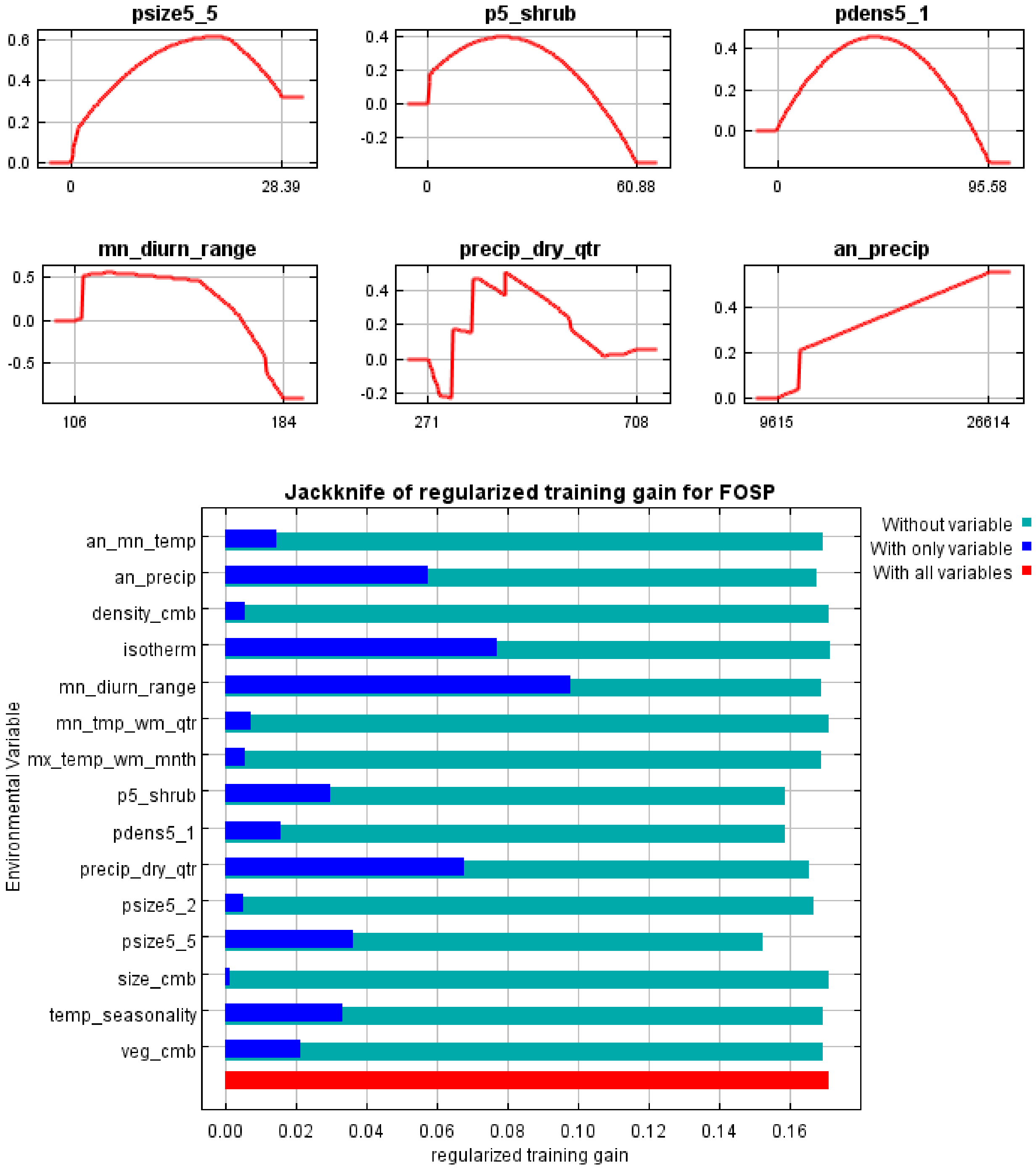


Figure 10. Partial response curves and jacknife estimates of individual variable contribution from Maxent landscape model for Fox Sparrow. Variable codes are defined in Appendix C and D.



Discussion

Models as Planning Tools

The spatially explicit distribution maps developed from this analysis can readily be used in land management and planning decisions. They should, however, be used with an understanding of their limitations. Models are simplifications of complex ecological systems and, as a result, no prediction is perfect. They are best estimates based on the best available data. Distribution models do not tell us about the processes that drive population change, and hence simply prioritizing specific areas may not lead to the project's desired outcome. Furthermore, we did not equally sample the entire area for which the predictions were made. Thus, model performance may be poorer in areas where the habitat and climate vary considerably from the areas that were sampled; such as in east side pine and the highest elevations.

The model predictions presented herein may be used to address management questions at a variety of different spatial scales. However, because the models do not include site-specific habitat characteristics, they should be used primarily as a coarse filter to help guide project planning. Thus said, they have a number of useful applications. Models may be used to evaluate potential landbird impacts of small-scale projects such as plantation management or a larger scale network of DFPZ's and group selections. Additionally, these models can be used to analyze the potential impacts of a proposed action to a species in the context of the surrounding landscape. Another key benefit of using landbird models is that planning can be based on multiple species that represent a diverse array of habitats, life history strategies, and ecosystem processes. Further, many of the metrics presented here are based on common species; thus their use in management decisions constitutes a proactive ecosystem approach to management and preservation of biodiversity.

Habitat Variables

Across the species and metrics examined, we found that landscape-level vegetation characteristics (within a 500-m radius, or 2000-m radius for Pileated Woodpecker) were generally more important predictors than vegetation type at the survey location. Furthermore, the landscape metrics of edge density and cohesion were important for Olive-sided Flycatcher, and Brown Creeper suggesting habitat configuration and pattern are key components influencing the distribution of species across the landscape. It is important to note that this analysis only investigated broad habitat types at the local level and did not consider the influence of more detailed quantifications of local habitat conditions that clearly are important for determining habitat suitability for landbirds in the Sierra Nevada.

We intentionally selected species that we felt occupied a broad range of habitat types and conditions in the study area. Thus, it is not surprising to find that cumulatively these species are associated with a diverse and often contrasting set of variables. However, within this variation we did find a few consistent patterns.

Canopy cover and Tree density

Open canopy forest was among the most important variables for three species: Hairy Woodpecker, Olive-sided Flycatcher, and Fox Sparrow. All of which had a positive association with this condition. Open canopy forest exists in the study area as a climax condition where spacing is created by competition, often in areas with poor soil and moisture conditions. It also exists throughout the forest in areas that burn often enough to regularly eliminate understory trees and in early successional stands following more intense fire. However, fire intervals have been lengthened (Taylor and Skinner 2003), and acreage affected by wildfire today in California is only a fraction of what it was historically (Stephens et al. 2007). Though the total number of acres affected by high severity fire are surely fewer, within individual fires the percent of the area that burns at high intensity has increased in the last 50 years (H. Safford pers. comm.). As a result, fire's role in creating and maintaining early successional shrub dominated habitats has been altered as well as its role in creating structural diverse mature forest. The lack of pyrodiversity is likely resulting in a loss of structural and floristic diversity at a landscape scale. These factors are likely to manifest in loss of habitat for a large number of disturbance-dependent species including Olive-sided Flycatcher, Dusky Flycatcher, MacGillivray's Warbler, and Fox Sparrow.

Heterogeneity

The Maxent modeling approach that we used provided insight regarding the non-linear relationships between the indicator species and landscape habitat patterns. Most modeled bird responses to landscape variables were not linear or even monotonic. In many cases, the optimal condition was an intermediate one, even among forest-associated species, suggesting that landscape heterogeneity is important.

The Olive-sided Flycatcher, more than any other bird species, requires heterogeneity in the form of edges at the union of distinctly different habitat types (McGarigal and McComb 1995, Howell and Burnett *in prep*). They occur most often where mature forest meets high intensity burn, shrub fields, and meadows (Altman and Sallabanks 2000). It is one of the fastest declining species over the past 40 years in the Sierra Nevada, and the rate of decline appears to be accelerating in recent years (Sauer et al. 2006). Though some of the reasons for its decline may be due to issues on its wintering grounds (Siegel and Desante 1999), there is little doubt that current trends towards a more homogenous fire-suppressed forest will negatively impact this species (Hutto 1995).

Presence of mixed conifer forest had a positive effect on four species: Pileated Woodpecker, Olive-sided Flycatcher, Nashville Warbler, and Hermit Warbler. For this habitat designation we did not include white fir dominated mixed conifer, as under current conditions this habitat type often reaches near homogenous stands of white fir in the study area. Thus, this association is with what may have historically been the more common mixed conifer forest types dominated by either pine, Douglas fir, or an equal representation of multiple species. It is our experience that within these heterogeneous mixed conifer types, hardwoods are more likely to be present than in ones dominated by white fir. In fact, Nashville Warbler is rarely found away from hardwoods, especially Black Oak, and Hermit Warbler is associated with arboreally diverse mixed conifer forest in the study area (Burnett and Humple 2003). The conversion of true mixed conifer forest to more homogenous white fir dominated forest may result in negative impacts to these species. In contrast, Pileated Woodpecker and Olive-sided Flycatcher were both positively associated with both mixed conifer and white fir forest types, and lack the association with hardwood trees found in the above species.

MacGillivray's Warbler, a shrub nesting species, was positively associated with size class five forest. Unlike Fox Sparrow, MacGillivray's Warbler can occur in relatively small forest gaps dominated by shrub cover. Within size class five forests there may be more natural gaps and increased heights to live crowns, allowing more sunlight to reach the forest floor. These conditions are more likely to support a shrub understory resulting in habitat suitable for this species. However, forest dominated by larger trees may directly benefit this species as well.

The importance of forest gaps should be considered key to this and other species. Management actions that increase the amount of structurally diverse size class five forest on the landscape will likely benefit a number of bird species: mechanical treatments that significantly reduce canopy cover or create forest gaps have been shown to benefit MacGillivray's Warbler and other open forest and shrub associated species (Siegel and DeSante 2003, Hagar et al. 2004). Additionally, many forest associated birds are likely to benefit from small gaps in mature forest as they utilize the unique resources available therein (Vitz and Rodewald 2006).

Heterogeneity in the Sierra Nevada is not only important for providing diverse habitat types occupied by a diverse range of birds, but the heterogeneity itself – the juxtaposition of distinct habitat types and structures – appears key to maintenance of avian diversity (McGarigal and McComb 1995). With the role of wildfire greatly reduced in shaping forest structure, mechanical treatments, wildland fire use, prescribed burning, and most importantly a re-evaluation of the importance of stand replacing fire and management thereafter will be necessary to ensure structural diversity and the full range of forest types and conditions are represented on the landscape.

Mature Forest Patch Size

Hermit Warbler, Pileated Woodpecker, and Brown Creeper all showed a negative response to the amount of the surrounding landscape in the smallest size class forest, suggesting there are benefits to limiting the fragmentation of habitat dominated by large trees. These results are in contrast to those for many of the other species and highlight the importance of a balanced approach to ecosystem management that ensures patches of mature forest are available for these species. With management focused on providing relatively large patches of intact mature forest for species such as Spotted Owl and Pine Marten, the needs of these forest-dwelling birds are likely to be met. In fact, Hermit Warbler is currently the most abundant bird in the Plumas-Lassen study area.

Using Birds a Management Indicators

Pileated and Hairy Woodpeckers are management indicator species on the Lassen National Forest. Pileated Woodpeckers show a strong aversion to red fir forest and appear to avoid higher elevations all together (see Chapter 2). The habitat needs of this species should be managed for in the mixed conifer and white fir dominated forest of the middle elevations. The habitat associations of Hairy Woodpecker were in direct contrast to those of Pileated Woodpecker. Hairy Woodpeckers were negatively associated with white fir, were associated with burn and red fir at the local level, and were more likely to occur as the amount of open canopy forest increased. Thus, management actions that benefit one of these species is likely to negatively impact the other. These species illustrate the need to avoid treating management indicators as if they are endangered species but use them as tools to help inform a more balanced approach that ensures the needs of all species are being met. Using tools such as these models, it is possible to prioritize planned treatments or other actions in the most effective locations to ensure both species needs are being met.

Climate and Sierra Birds

Climate variables are likely correlated with vegetation variables, but at a large landscape scale they provide more insight to help refine models as they incorporate additional information that is not represented by vegetation types alone. However, when interpreting the relative contribution of different variables to the final models it is important to consider these variables are all interacting, which can confound the importance or change the direction of their effect.

For a number of species, climate variables were among the most important variables even when habitat was included in the model, suggesting that climactic factors – beyond their role in defining and shaping habitats – play an important role in determining the distribution of avian species in the Sierra. Indeed, other studies have highlighted the importance of climate to bird distributions (Root 1988). Climate may be important to birds in numerous ways including its influence on the timing and intensity of insect outbreaks, thermoregulation of eggs and nestlings, and adult overwinter survival. At a smaller microhabitat scale, climate has also been shown to affect bird distribution and even abundance through its effect on nest site selection (Martin 2001). The climate variables that were included in the models represent both extremes and averages that may likely define the physiological boundaries and requirements of birds. As we continue into an era of increased climatic variability it will be critical to better understand its potential role in shaping habitat types as well as ecosystem processes.

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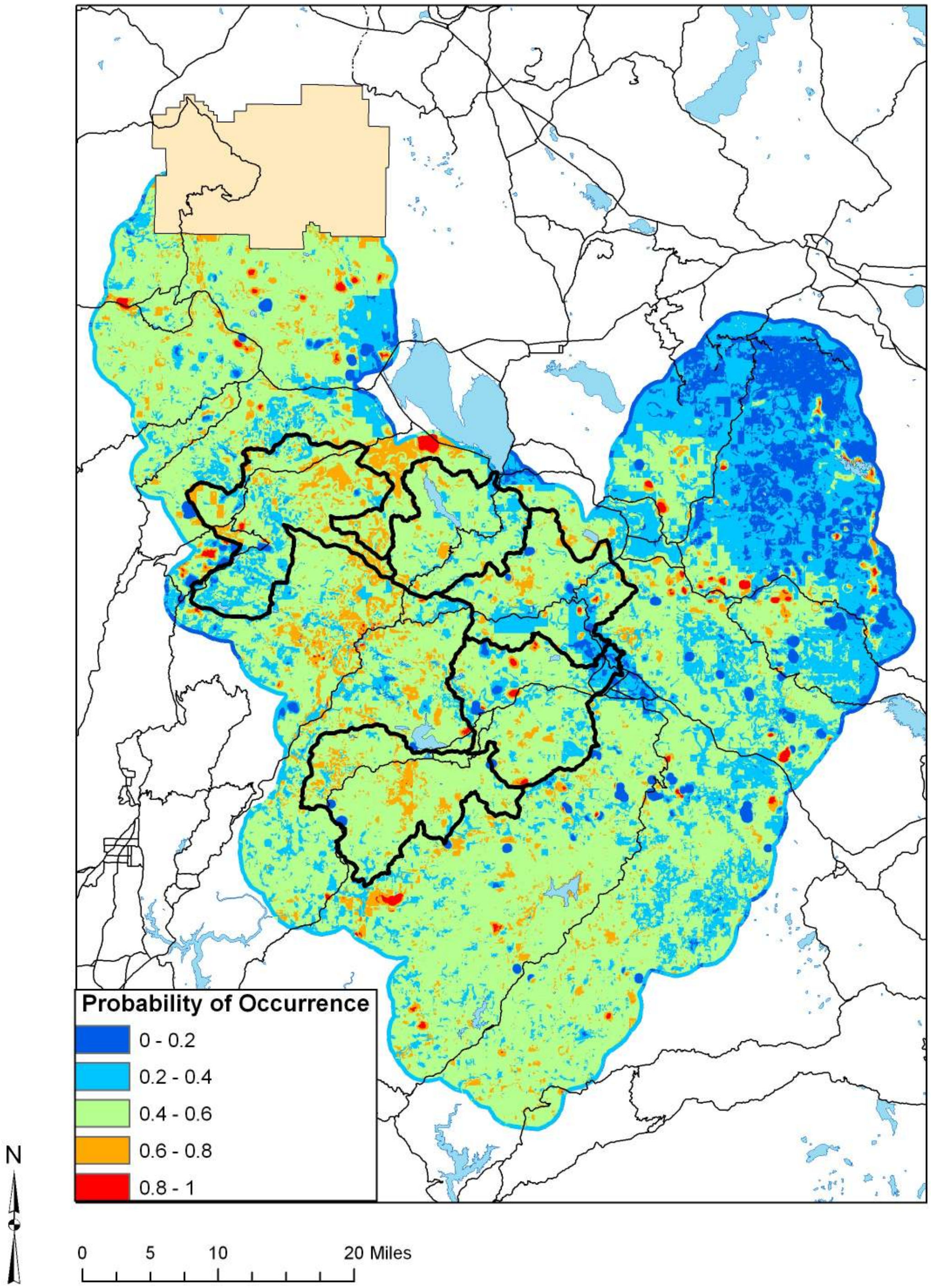
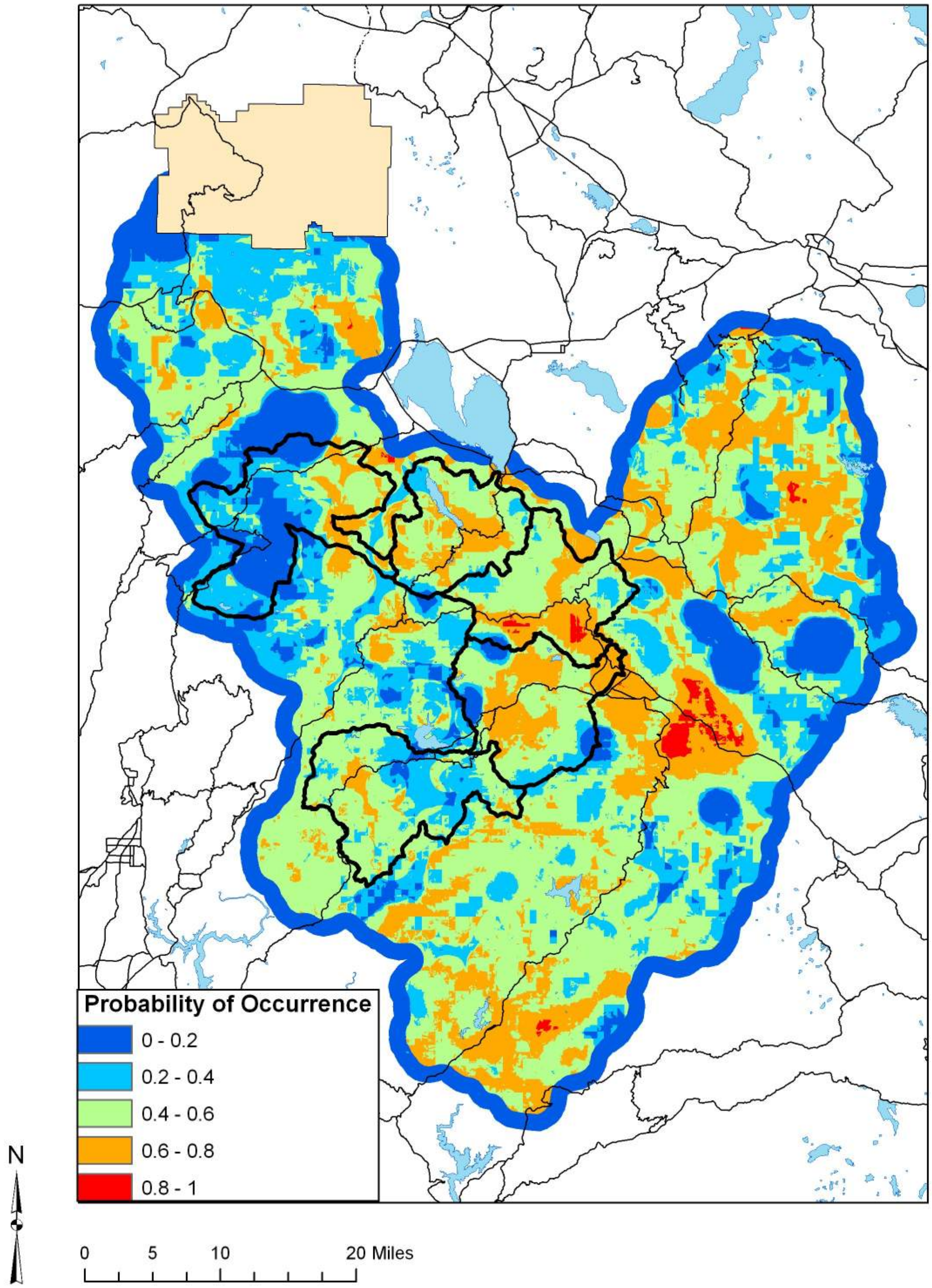
Appendix A. Predicted probabilities of occurrence for nine species in the Plumas-Lassen study area based on MaxEnt landscape habitat modeling. The black outlined polygons in the center of the map are the former administrative study treatment units. Lassen National Park is depicted in beige in the north portion of the maps.

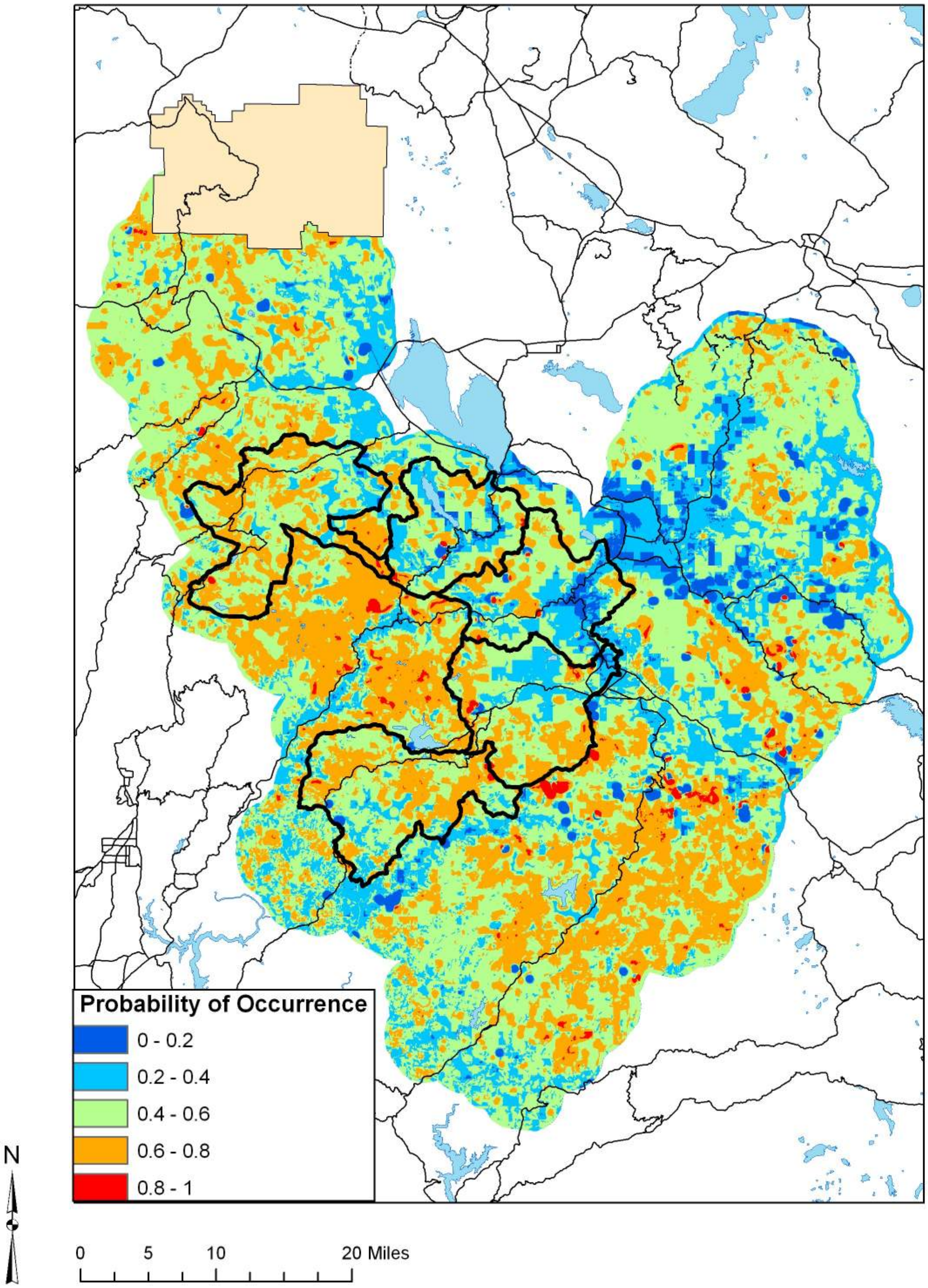
Hairy Woodpecker



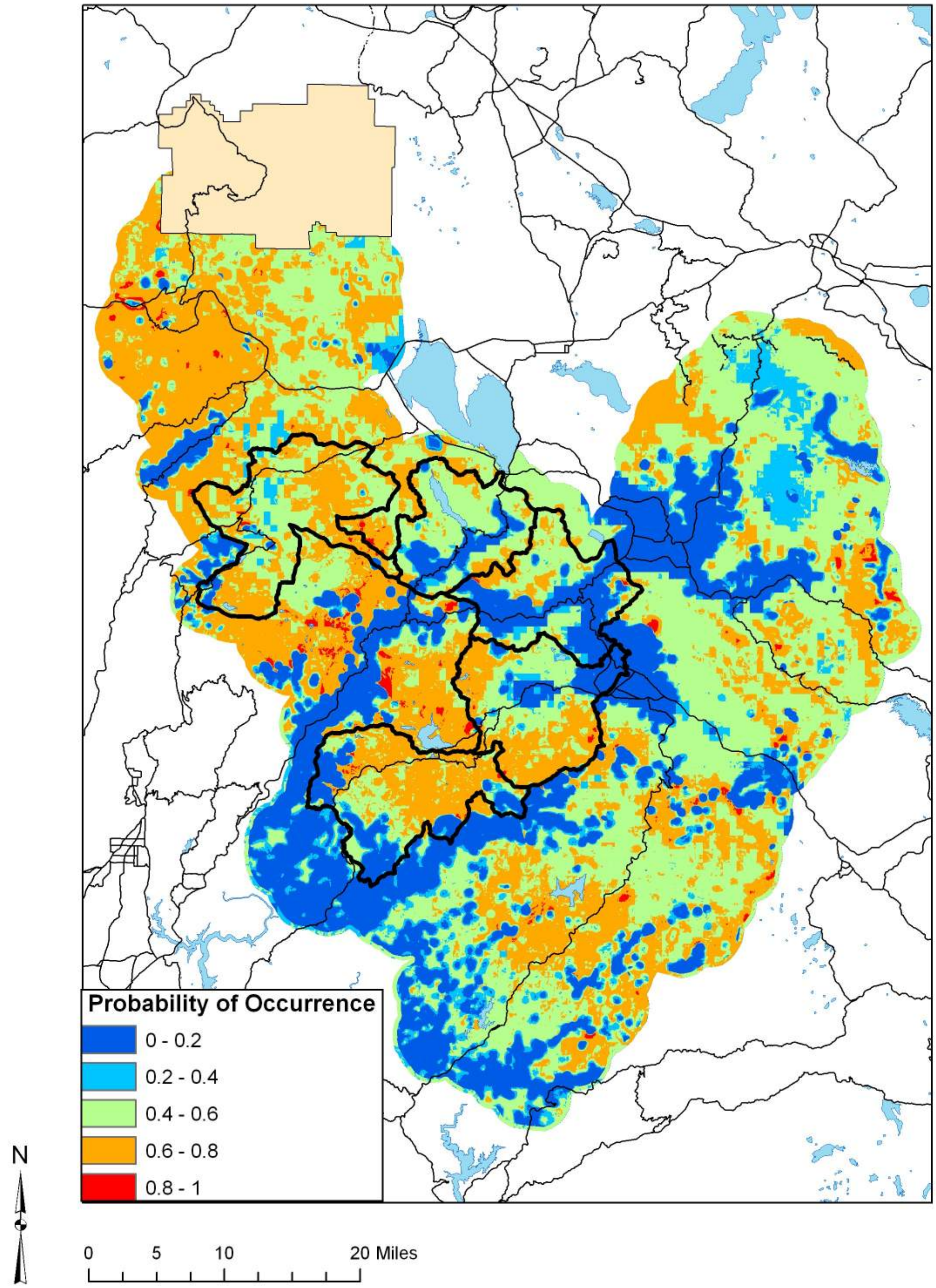
Pileated Woodpecker



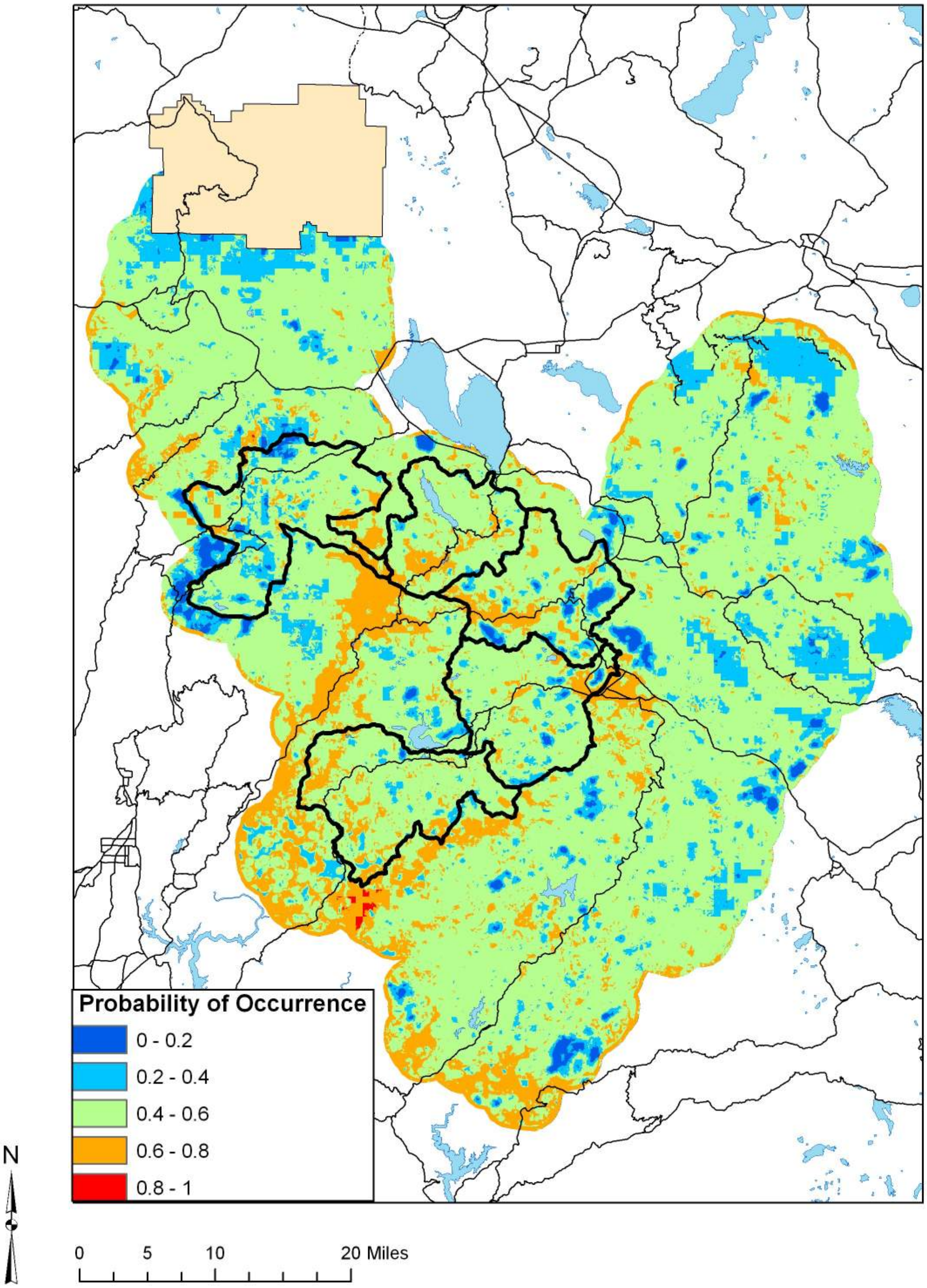
Olive-sided Flycatcher



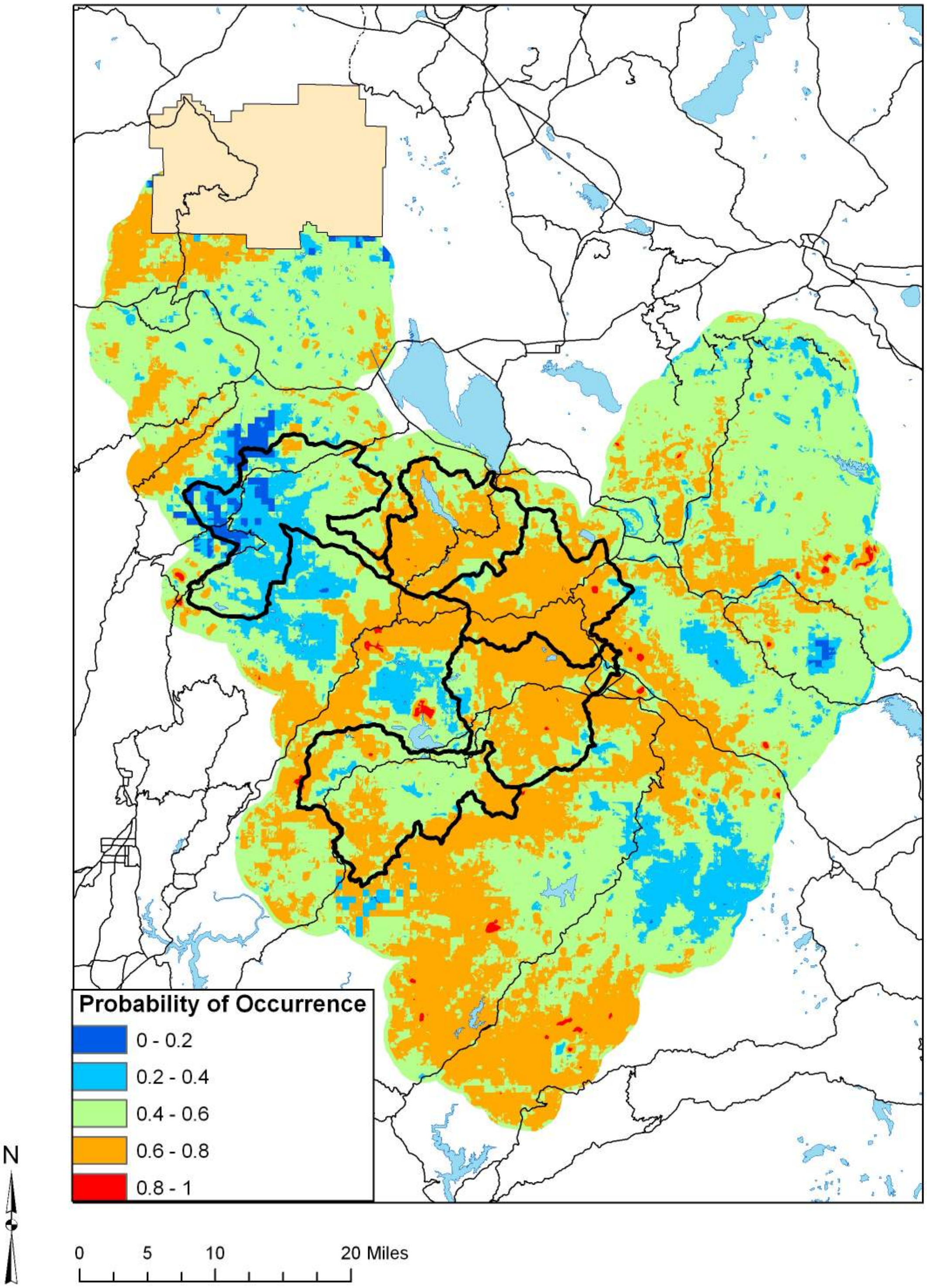
Dusky Flycatcher



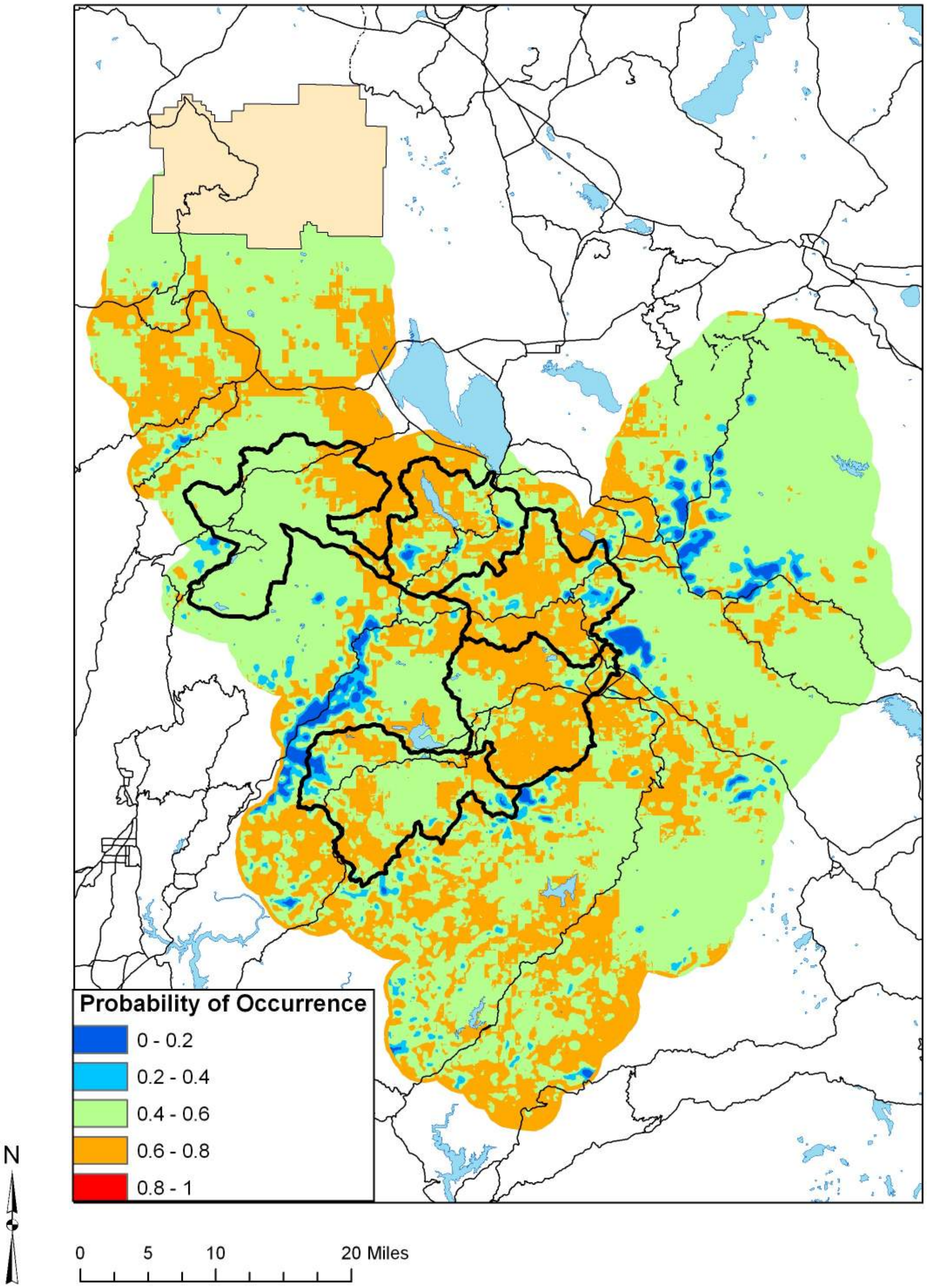
Brown Creeper



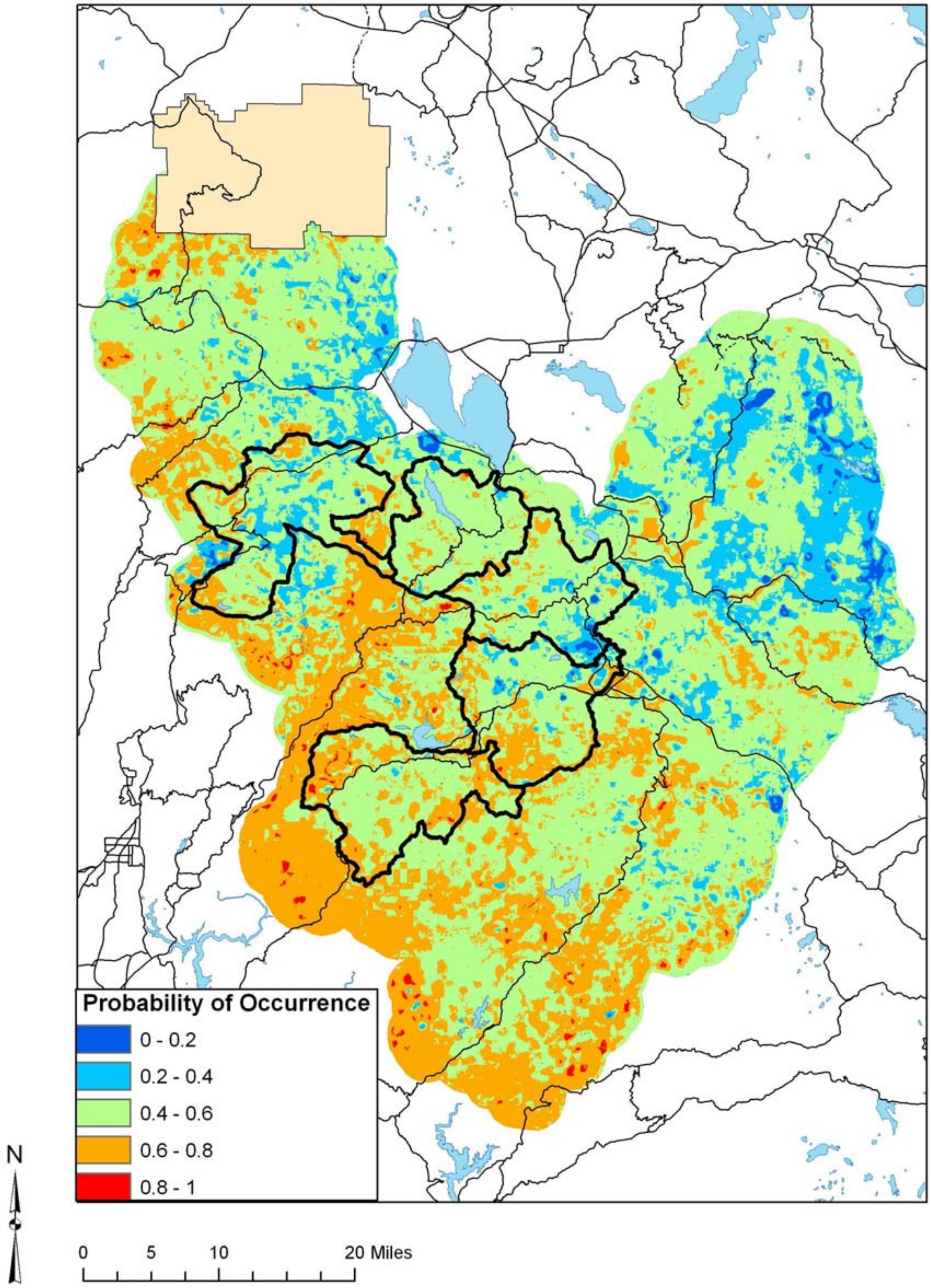
Nashville Warbler



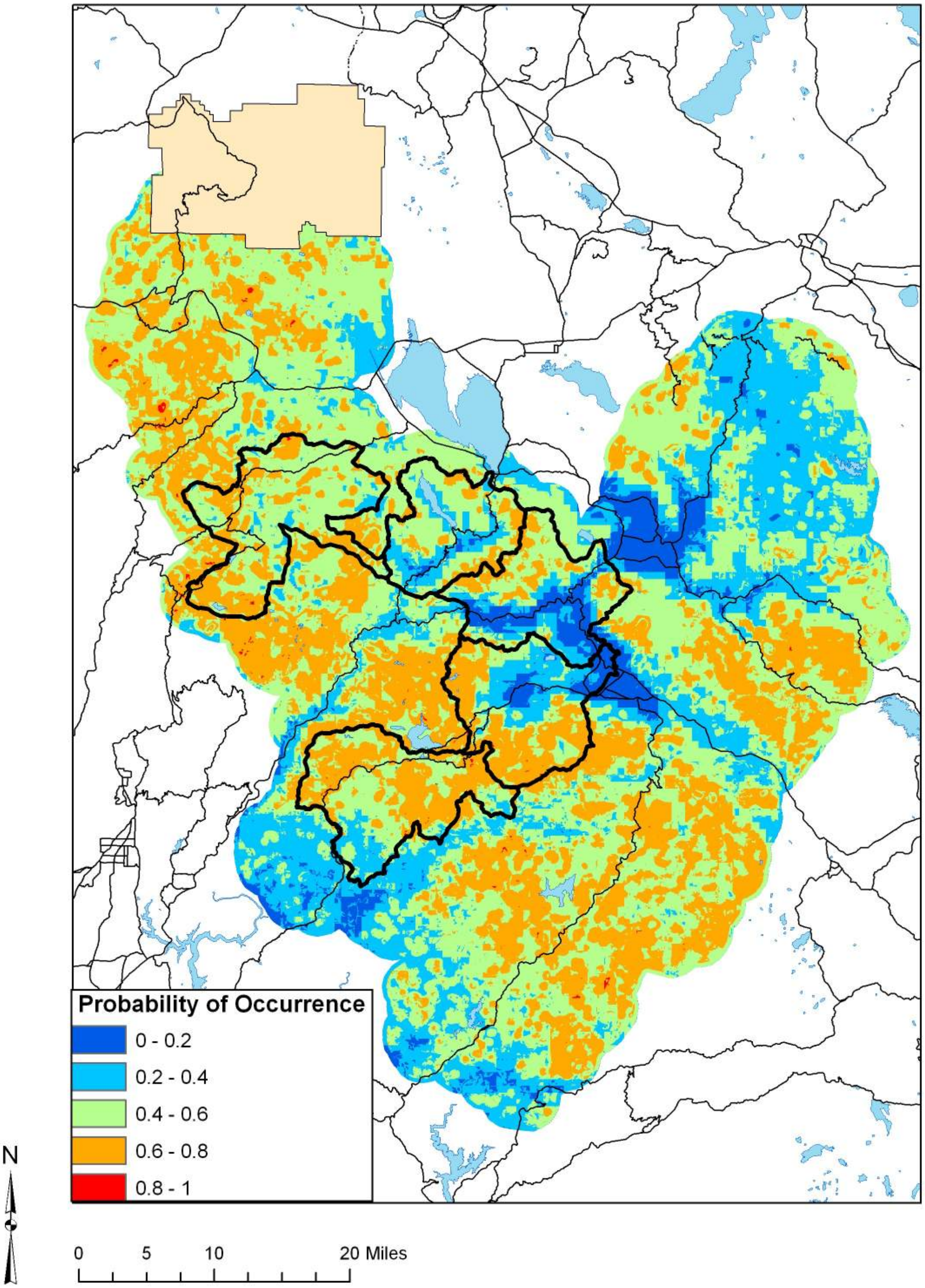
Hermit Warbler



MacGillivray's Warbler



Fox Sparrow


Probability of Occurrence
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
N
0
5
10
20 Miles

Appendix B. Habitat variables used as input for modeling the presence of each species in the Plumas-Lassen Study area. Codes are defined in Tables 2 – 5 in this report.

Species	**Variables at 500m and 2km**	**Density class**	**Size class**	**Cohesion**	**Edge Density**
PIWO	cover class D, size classes 2 and 5, RF, WFD, MC	3	2 & 5	fortype35, dens3 & size5	
HAWO	Burn, cover class P, MC, WFD, PPD, RF, size class 4	1	4		
OSFL	cover class P, size class 4 and 5, RF, MC, WFD, Burned, SHB	1	4 & 5		fortype36 & dens1
DUFL	SHB, HDWD, PPD, density class P, size class 2 and 4	1	2 & 4		
BRCR	size classes 2 and 5, cover class M, MC, WFD, RF	2	2 & 5	dens3 & size5	
NAWA	HDWD, SHB, PPD, MC, RIP/MDW, size 2, size 5, cover class P	1	2 & 5		
HEWA	HDWD, MC, WFD, size class 4 and 5, density class M	2	2 & 5		
MGWA	SHB, RIP/MDW, PPD, MCD, density class P, Size 2 and 5	1	2 & 5		
FOSP	Shrub, size class 2 and 5, cover class P, Burn	1	2 & 5		

Appendix C. Variable codes and descriptions of habitat metrics used in maximum entropy modeling of nine landbird species in the Plumas-Lassen study area. Metrics were calculated using moving window averages within the given radiusf (2000 meters for Pileated Woodpecker and 500 meters for all other species).

Habitat Variable Code	**Description**
Shrub	Percent shrub vegetation class within the given radius
rip_mead	Percent riparian and meadow vegetation class within given radius
Hdwd	Percent hardwood vegetation class within the given radius
Ponderosa	Percent ponderosa pine vegetation class within the given radius
Mxconifer	Percent mixed conifer vegetation class within the given radius
Wfir	Percent white fir vegetation class within the given radius
Rfir	Percent red fir vegetation class within the given radius
Unveg	Percent unvegetated class within the given radius
veg_cmb	Vegetation class at the point count station
size_cmb	Size class at the point count station
density_cmb	Density class at the point count station
pdens (classes 1, 2, or 3)	Percent of CWHR forest density class within the given radius.
psize (classes 2, 3, 4, or 5)	Percent CWHR forest size class within the given radius.
cdens class 2 or 3	Cohesion index for given density class within the given radius
csize class 4 or 5	Cohesion index for given size class within the given radius
cforest	Cohesion index for combined forest types (red fir, white fir, mixed conifer, ponderosa pine dominated) within the given radius
ed5_open	Edge density of combined open vegetation types (shrub, riparian/meadow, burn, unvegetated) within 500 meters
eddens5_1	Edge density of CWHR density class 1 within 500 meters

Appendix D. PRBO codes, habitat types, and CHWR types by code used for defining habitat at the location of each point count station. Habitat at the point was derived from the Vestra GIS vegetation map.

Vegetation Codes	**Habitat Type**	**CWHR Types Included**
24	Shrub & Plantation	CX, FBX, FXC
25	Riparian or Meadow	GM, HA, RIP, GP
26	Hardwoods	HB, HL, HT
27	Ponderosa Pine Dominated	PP
28	Mixed Conifer Dominated	DMC, MC, PMC
29	White Fir Dominated	WMC, TF
30	Red Fir Dominated	RF
31	Unvegetated	NW, NU, NR, NB
33	Burned	FBX
36	Combined Open types	GM, HA, RIP, GP
35	Combined Forest types	RF,WFD,MC,PPD
32	other	LP, GP
Size Codes		**Size Types**
2	Small	Size 2
3	Medium-Small	Size 3
4	Medium- Large	Size 4
5	Large	Size 5 - 6
Density Codes		**Density Classes**
1	Open	P
2	Moderate	M
3	Dense	D

OUTREACH AND PUBLICATIONS

Publications in Prep

Landscape effects on songbird abundance in the Northern Sierra – submitted March 2008 – Journal of Wildlife Management.

Avian community composition in the context of Spotted Owl management in the Sierra Nevada – submitted April 2008 – Forest Ecology and Management.

Habitat use and productivity of two shrub dependent bird species in clear cut plantations in the Sierra Nevada – submitted spring 2008 – The Condor.

Short-term response of the avian community to Aspen enhancement timber harvest treatments – submitted summer 2008 – Restoration Ecology.

Presentations

Using Birds to Guide National Forest Management in the Sierra Nevada – oral presentation – International Partner's in Flight Conference – 2/16/08 – McAllen, TX.

Managing Disturbance Associated Habitats for Birds in the Sierra Nevada – invited oral presentation – Region 5 Forest Management Conference – 2/6/08 – Reno, NV.

Managing Aspen Habitat for Birds in the Sierra Nevada– invited oral presentation at: Aspen Delineation Project – Aspen Workshop – 9/12/2007 – Lassen National Forest.

Ecological Significance of Lake Almanor Meadows to Birds – oral presentation at Almanor Basin Watershed Advisory Committee Workshop on meadow management – 8/7/07 - Chester, CA.

Using Birds to Guide Forest Management in the HFQLG Area: Results from 2002 – 2006 – invited oral presentation – USFS Region 5 biologist conference – 5/23/07 - Sacramento, CA & PLAS symposium 3/2007.

Other Outreach

"Birds in the Park" – presentation on managing coniferous forest for birds and bird banding demonstration in collaboration with Lassen Volcanic National Park – over 200 park visitors participated 7/22/07.

Sierra Nevada Conservancy Field Trip – 5/1/2007 – Westwood, CA.

Aspen Workshop – invited to participate in the event co-sponsored by the Lassen National Forest, Aspen Delineation Project, and Sierra Forest Legacy – 9/13/2007.

Led Plumas Audubon Society Field Trip – 10/3/2007 – Chester, CA.

Bird Banding Field Trip – coordinated outreach field trips with the Lassen National Forest to view bird banding and discuss the use of birds as indicators in forest management, PLAS study, and PRBO – 7/25/2007, 8/8/2007.

Integration with Management

We provided input to several important Forest Service projects in 2007 in an effort to integrate our results to help guide forest management in the Sierra Nevada. In addition we:

1. Updated the "Interactive GIS Project" with 2007 avian monitoring data. This product can be used by forest planners in the region to determine the presence/absence or abundance of all species detected in the study area.

2. Updated the Lassen National Forest interactive GIS CD with presence/absence data of each woodpecker species at every point count station ever surveyed by PRBO in the district. We also conducted a tutorial of its application and use with ARD biologist Mark Williams.

3. Continued distribution with positive feedback for our white papers integrating avian monitoring data into science based recommendations for managing four important Sierra habitat types for birds.

Chapter 5:
California Spotted Owl Module

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Introduction

Knowledge regarding the effects of fuels and vegetation management on California spotted owls (***Strix occidentalis occidentalis;*** CSOs) and their habitat is a primary information need for addressing conservation and management objectives in Sierra Nevada forests. The specific research objectives of the California spotted owl module as identified and described in the Plumas-Lassen Study (PLS) Plan are:

1) What are the associations among landscape fuels treatments and CSO density, distribution, population trends and habitat suitability at the landscape-scale?

2) What are the associations among landscape fuels treatments and CSO reproduction, survival, and habitat fitness potential at the core area/home range scales?

3) What are the associations among landscape fuels treatments and CSO habitat use and home range configuration at the core area/home range scale?

4) What is the population trend of CSO in the northern Sierra Nevada and which factors account for variation in population trend?

5) Are barred owls increasing in the northern Sierra Nevada, what factors are associated with their distribution and abundance, and are they associated with reduced CSO territory occupancy?

6) Does West Nile Virus affect the survival, distribution and abundance of California spotted owls in the study area?

Current information on the distribution and density of CSOs across the HFQLG study area is required to provide the data necessary to build predictive habitat models and provide baseline population information against which we will assess post-treatment changes in CSO populations and habitat. Continued monitoring on the Lassen Demographic Study Area is critical for estimating CSO population trends and status. Our focus in 2007 was to conduct landscape inventories of CSO distribution and abundance, and continue banding to provide the required data and baseline information to meet the objectives of Research Questions 1-4 identified above. Complete landscape inventory surveys were conducted across 9 of 11 survey areas in 2007 (Figure 1). Surveys were not conducted in 2 survey areas in 2006 or 2007 (SA-5, SA-7, Figure 1). Surveys were not conducted in these 2 study areas in 2006 or 2007 because sufficient data for determining the number and distribution of CSO sites for initial habitat modeling efforts was collected in 2004-2005. Details on survey methods are described in the study plan. Efforts were made to monitor the pair and reproductive status of each owl, and to capture, uniquely color-mark, and collect blood samples from each individual owl across the study area. Capture and color-marking is necessary to estimate survival and population trend, and to assess exposure to West Nile Virus (WNV)(Research Question #5). We also recorded all barred and hybrid barred-spotted owls encountered in the study area and synthesized all existing barred owl records for the northern Sierra Nevada to address Research Question #6. Additionally, we initiated radio-telemetry studies on CSOs within SA-4 in the Meadow Valley project area to document home range size and configuration, and to assess habitat selection relative to the recently implemented treatments.

Results

CSO Numbers, Reproductive Success, Density and Population Trends:

A total of 71 territorial CSO sites were documented in 2007 across the study area (Figure 2). This total consisted of 62 confirmed pairs, 3 unconfirmed pairs (i.e., one member of pair confirmed as territorial single plus single detection of opposite sex bird), and 6 territorial single CSOs (single owl detected multiple times with no pair-mate detected). Thirty-six pairs successfully reproduced in 2007 (55% of confirmed/unconfirmed pairs). A total of 65 fledged young were documented in 2007 (1.81 young per successful nest) (Table 1). Across the recent four years of the study, CSO reproduction has been highest in 2004 and 2007 in terms of the percent of CSO pairs that successfully reproduced, and to lesser degrees in terms of the number of young fledged per successful nest. Approximately 50% of CSO pairs successfully reproduced in 2004 and 2007 while only 14% and 18% were successful in 2005 and 2006, respectively. CSO reproduction is known to vary with spring weather. Precipitation patterns were more similar in 2004 and

2007, with total precipitation relatively low during March-April of 2004 and 2007 as compared to 2005 and 2006 (Figure 3).

Table 1. California spotted owl reproduction on the Plumas and Lassen National Forests 2004-2007.

Year	**Percent of confirmed/unconfirmed pairs with successful nests**	**Young fledged per successful nest**
2004	49.4%	1.68
2005	17.7%	1.47
2006	13.8%	1.50
2007	55.4%	1.81

The Lassen Demographic Study Area (SA-1A, SA-11, SA-12, SA-13, SA-14, SA-15) and Plumas NF Survey Areas (SA-2, SA-3, SA-4, SA-5, SA-7) were fully integrated in 2005 to define the overall Plumas-Lassen Study project area and provide consistent CSO survey effort across the project area. (Figures 1 & 2). The crude density estimates in this report differ from those reported in the 2006 Annual Report for the same year because of updates and corrections to the GIS base survey maps and CSO survey results databases that were conducted in winter 2007-2008 to correct the original survey area boundaries and survey results to make them congruent with the actual watershed boundaries of each survey area. We estimated the crude density of CSOs based on the number of territorial owls detected across 9 survey areas during 2007 surveys at the Survey Area spatial scales (Tables 2 and 3). The estimated crude density across the overall study area in 2007 was 0.066 territorial owls/km^2. Overall study area crude densities are not directly comparable across years because different total areas were surveyed in each year. However, crude density estimates within individual survey areas indicate similar densities and number of territorial sites (pair sites plus territorial single sites) between 2004-2007 for the survey areas on the Plumas NF (SA-2, SA-3, SA-4), while numbers appear to have declined on the Lassen survey areas (SA-1A, SA-11, SA-12, SA-13, SA-14, SA-15) between 2005-2007 (Tables 2 and 3).

Table 2. Crude density of territorial California spotted owls across survey areas on the Plumas and Lassen National Forests 2004-2007. Locations of survey areas are identified in Figure 1.

		Crude Density of Territorial Owls (#/km^2)			
Survey Area	**Size (km^2)**	**2004***	**2005***	**2006***	**2007***
SA-2	182.4	0.126	0.143	0.115	0.115
SA-3	214.4	0.075	0.093	0.089	0.103
SA-4	238.2	0.059	0.050	0.046	0.071
SA-5	260.2	0.069	0.069	NS****	NS****
SA-7	210.3	0.071	0.062	NS	NS
SA-1A	190.4	NI***	0.042	0.042	0.053
SA-1B**	130.3	NI	0.023	NS	NS
SA-11	179.4	NI	0.045	0.033	0.033
SA-12	215.8	NI	0.097	0.070	0.074
SA-13	152.9	NI	0.105	0.085	0.065
SA-14	318.7	NI	0.053	0.044	0.035
SA-15	196.8	NI	0.086	0.036	0.056
Total Study Area	2489.8	0.078	0.073	0.060	0.066

*Total Area surveyed each year: 2004 = 1,106 km^2; 2005 = 2,490 km^2; 2006 = 1,889 km^2; 2007 = 1,889 km^2

**NI = not included. Project level area surveyed only in 2005. Included for comparative purposes.

***Lassen Demographic Study Area – incorporated into the overall study in 2005.

****Survey areas not surveyed in 2006 and 2007.

Table 3. Number of pairs (confirmed and unconfirmed) and territorial single California spotted owls across the Plumas-Lassen Study survey areas on the Plumas and Lassen National Forests, California, 2004-2007.

	2004		**2005**		**2006**		**2007**	
Survey Area	**Pairs**	**Singles**	**Pairs**	**Singles**	**Pairs**	**Singles**	**Pairs**	**Singles**
SA-2	11	1	12	2	10	1	10	1
SA-3	7	2	10	0	9	1	11	0
SA-4	7	0	5	2	4	3	8	1
SA-5	8	2	9	0	NS***	--	NS***	--
SA-7	7	1	6	1	NS	--	NS	--
SA-1A	NI**	--	4	0	4	0	5	0
SA-1B*	NI	--	3	0	NS	--	NS	--
SA-11	NI	--	4	0	3	0	3	0
SA-12	NI	--	10	1	1	7	8	0
SA-13	NI	--	8	0	6	1	5	0
SA-14	NI	--	8	1	7	0	5	1
SA-15	NI	--	8	1	3	1	4	3

*NI = not included. Project level area surveyed only in 2005. Included for comparative purposes.
**Lassen Demographic Study Area – incorporated into the overall study in 2005.
***Survey areas not surveyed in 2006 and 2007.

The most recent information on CSO population trends is included in the January 2006 meta-analysis, conducted to estimate CSO population trends and to assess population status in response to a petition to list the CSO under the Endangered Species Act (Blakesley et al. 2006). These data continue to provide the best estimates of CSO population trends. Data collected between 1990-2005 from four CSO demographic studies across the Sierra Nevada and southern Cascades, including the Lassen Demographic Study Area, were analyzed as part of the meta-analysis workshop. The Lassen Demographic Study Area is contained within the overall PLS study area and consists of survey areas SA-1A, SA-11, SA-12, SA-13, SA-14 and SA-15 in Figure 1. Full details on meta-analysis methods and results are provided in Blakesley et al. (2006). In synopsis, across the four study areas, results indicated that the Lassen Study CSO population exhibited the strongest evidence for a population decline between 1990-2005. Mean lambda for the Lassen Demographic Study was 0.973, with 95% confidence limits ranging from 0.946-1.001 (Table 4).

Table 4. Mean estimated population lambda (population change) for California spotted owls on four study areas in the southern cascades and Sierra Nevada, 1990-2005 (Blakesley et al. 2006)

Study Area	**Lambda**	**Standard Error**	**95% Confidence Interval**
Lassen National Forest	0.973	0.014	0.946-1.001
Sierra National Forest	0.992	0.013	0.966-1.018
Sequoia-King Canyon National Park	1.006	0.031	0.947-1.068
Eldorado National Forest	1.007	0.029	0.952-1.066

Radio-Telemetry – Meadow Valley Project Area

Eight adult territorial CSOs were radio-tagged during April-June of 2007 within SA-4 in the Meadow Valley Project Area. CSOs were fitted with 12g backpack-mounted transmitters from Holohill Systems with projected radio life expectancy of 1.5 years. We attempted to locate each radio-tagged CSO 5 times over each 2-week sample period between April and September 2007. CSOs were tracked from the ground using vehicles and hand-held H-antennas. Approximately 30 locations were recorded for each individual. Data from the breeding period are currently being proofed and edited for analysis. These data will be used to investigate CSO home ranges sizes and configurations, as well as habitat selection within home ranges relative to available vegetation and fuels treatments. Radio-tagged birds are currently being followed at reduced effort during the nonbreeding period to determine wintering locations and post-breeding movements.

Habitat Assessment – Nest/Roost Plot Scale

We documented a total of 103 CSO territorial sites between 2004-2006. We overlayed the nest/primary roost site for each of the 103 CSO sites with the CWHR vegetation classes available within the VESTRA photo-interpreted vegetation map for the PLS to examine nest-site habitat association patterns. Approximately 53% of the nest sites were located within CWHR 5M, 5D and 6 size classes (Table 5, Figure 4). An additional 37% of the sites were located within CWHR size class 4M and 4D polygons. CWHR size class 4 is defined as stands with average tree sizes of 12-24 inch diameter-at-breast-height (dbh) trees. Of the 38 sites located in size class 4 polygons, 25 (66%) were in size class 4 polygons with a large tree component (i.e., presence of >24 inch dbh trees). Overall, about 90% of the site were located within CWHR 4M, 4D, 5M, 5D, and 6 size classes. The remaining 10 sites were located in more open, smaller-tree size polygons, with nests or roost located within remnant, scattered larger trees (Table 5, Figure 4).

Table 5. Distribution of California spotted owl nest/primary roost sites (n = 103) across CWHR tree size classes within the Plumas-Lassen Study on the Plumas and Lassen National Forests, 2004-2006.

CWHR Size Class*	**CWHR Size Class Description**	**Number of Nests**	**Percent**
Barren	Open, sparse tree coverage	1	1.0
3S	6-12 inch dbh, ,20% CC	1	1.0
3M-LT	6-12 inch dbh, 40-60% CC, large trees recorded	1	1.0
3D	6-12 inch dbh, >60% CC	4	3.9
4P	12-24 inch dbh, 20-40% CC	3	2.9
4M	12-24 inch dbh, 40-60% CC	3	2.9
4M-LT	12-24 inch dbh, 40-60% CC, large trees recorded	12	11.7
4D	12-24 inch dbh, >60% CC	10	9.7
4D-LT	12-24 inch dbh, >60% CC, large trees recorded	13	12.6
5M	>24 inch dbh, 40-60% CC	25	24.3
5D	>24 inch dbh, >60% CC	9	8.7
6	>24 inch dbh, >60% CC, multi-layer canopy	21	20.1

*defined by average tree size (dbh = diameter at breast-height) and average percent canopy cover (CC).

While the distribution of nest site locations relative to broad vegetation classes provides insight into patterns of nest-site habitat, we also conducted vegetation sampling at nest or primary roost sites to describe vegetation structure and composition. Vegetation plot sampling was conducted at 80 CSO territories across 2005-2007. Vegetation plots were centered on CSO nest trees, or on a primary roost tree for sites where no nest has been documented, and were measured using the national Forest and Inventory Assessment (FIA) protocol. The FIA protocol is used nationally by the USDA Forest Service for inventorying and monitoring vegetation. FIA sampling consists of measuring vegetation structural and compositional variables within a 1-ha plot centered on a CSO nest or roost tree. Only one plot was collected from each CSO territory, with the most frequently used nest tree serving as the plot center location, or the most recent nest tree used at sites where no nest tree was used more frequently than another. CSO nest sites were characterized by mean total basal areas of 260.8 ft^2/acre, 7.4 snags (>15 inch dbh)/acre, and 10.7 trees (>30 inch dbh)/acre (Table 6). Under the FIA protocol, canopy cover is modeled based on the tree list. The modeled canopy cover for these plots averaged 64.1%. Shrub cover averaged 7.7%. Fuel loads averaged 0.75 tons/acre for 1-hr fuels, 4.0 tons/acre for 10-hr fuels and 4.44 tons/acre for 100-hr fuels (Table 6). Use of the FIA sampling protocol will facilitate monitoring of vegetation and development of CSO habitat models that can be used as adaptive management planning tools. Habitat models are currently being evaluated that can be used to assess projected changes in CSO nesting habitat suitability under varying fuels and vegetation treatment scenarios.

Table 6. Nest-site (1 ha (2.47 acres)) habitat characteristics collected using the Forest Inventory and Analysis sampling protocol at California spotted owl nest sites (n = 80) on the Plumas and Lassen National Forests, California, 2005-2006.

Variable	Mean	SE
Total Basal Area (ft^2/acre)	260.8	6.47
# Trees >= 30 inch dbh (#/acre)	10.7	0.58
Basal Area Trees >= 30 inch dbh (ft^2/acre)	96.0	5.70
# Trees >= 24 inch dbh (#/acre)	19.9	0.90
Basal Area Trees >= 24 inch dbh (ft^2/acre)	131.7	6.29
# Trees <12 inch dbh (#/acre)	383.5	26.36
Basal Area Trees , <12 inch dbh (ft^2/acre)	50.1	2.71
# Snags >=15 inch dbh (#/acre)	7.4	0.80
Mean Duff Depth (inches)	3.0	0.16
Duff (tons/acre)	67.4	3.64
Mean Litter Depth (inches)	2.3	0.18
Litter (tons/acre)	23.7	1.81
1 Hour Fuels (tons/acre)	0.75	0.03
10 Hour Fuels (tons/acre)	4.0	0.21
100 Hour Fuels (tons/acre)	4.4	0.28
Shrub Cover (%)	7.7	1.16
Canopy Cover (%)*	64.1	1.24

* estimated through Forest Vegetation Simulator modeling of plot-based tree lists.

Habitat Assessment – Core Area/Home Range Scale

Core area habitat associations around 102 CSO sites was assessed by using a Geographic Information System (GIS) and the VESTRA photo-interpreted vegetation map to determine the vegetation patterns within a 500 acre (201 ha) circle centered on each of the CSO territory sites. To compare the CSO sites with the general availability of habitat across the study area we also assessed the same vegetation patterns around 130 points determined by placing a systematic grid across the study area. For this summary we assessed vegetation using the USDA Forest Service Region 5 classification system. Overall, CSO core areas averaged 75.7% suitable habitat (classes 3N, 3G, 4N, 4G) whereas the grid points averaged 61.9% (Table 7, Figure 5). Approximately 32% of CSO core areas was composed of large tree polygons (>24inch dbh, >=40% canopy cover) compared to 19.6% of the grid points (Table 7, Figure 6).

Table 7. Distribution of USDA Region 5 vegetation classes (Mean (SE)) within 500 acre (201 ha) circles centered on California spotted owl (CSO) territories (n = 102) and systematic grid (Grid) points (n = 130) within the Plumas-Lassen Study on the Plumas and Lassen National Forests, 2004-2006.

R5 Size Class*	**R5 Size Class Description**	**CSO**	**Grid**
Non-forest	Sum of non-forest land types	4.4 (1.0)	8.4 (1.2)
Total Size 1	Sum of 1G,1N, 1P, 1S: <6 inch dbh, all %CC classes	1.7 (0.3)	1.6 (0.3)
2P & 2S	6-12 inch dbh, 10-39% CC	3.4 (0.4)	4.1 (0.5)
2N	6-12 inch dbh, 40-69% CC	3.8 (0.6)	4.4 (0.9)
2G	6-12-24 inch dbh, >=70% CC	1.6 (0.5)	0.5 (0.1)
3P&3S	12-24 inch dbh, >10-39% CC	9.2 (0.8)	16.1 (1.3)
3N	12-24 inch dbh, 40-69% CC	37.2 (2.4)	38.5 (1.8)
3G	12-24 inch dbh, >=70% CC	6.2 (1.0)	3.8 (0.7)
4P&4S	>24 inch dbh, >10-39% CC	1.0 (0.3)	2.1 (0.4)
4N	>24 inch dbh, 40-69% CC	25.8 (2.0)	17.3 (1.6)
4G	>24 inch dbh, >=70% CC	6.5 (0.1)	2.4 (0.8)
Total 4N & 4G	Sum of 4N & 4G: >24 inch dbh, >= 40% CC	32.4 (2.3)	19.6 (1.8)
Total Suitable habitat	Sum of classes 3N, 3G, 4N, 4G = >12 inch dbh, >40% CC	75.7 (2.19)	61.9 (1.75)

*defined by average tree size (dbh = diameter at breast-height) and average percent canopy cover (CC).

Banding, Blood Sampling, West Nile Virus Monitoring

Sixty-six owls were captured and banded in 2007. Blood samples were collected from 38 individuals and screened at the University of California, Davis for West Nile Virus antibodies. None of the 120 individual samples collected from 2004-2006 have tested positive for WNV antibodies. The 2007 samples have not been analyzed to date.

Barred and Sparred (spotted/barred hybrid) Distributional Records:

We detected the presence of 4 barred owl and 4 sparred owls during 2007 surveys within our intensive study area. Our synthesis and update of barred-sparred owl records through 2007 based on Forest Service and California Department of Fish and Game databases indicates that there are a minimum of 41 individual site records across the northern Sierra Nevada (Figure 7). This includes a total of 19 records that have been documented within our intensively surveyed study area. The first barred owl in the region was reported in 1989. The pattern of records suggests that barred/sparred owls have been increasing in the northern Sierra Nevada between 1989-2007.

California Spotted Owl Diet:

A single survey plot was established at a CSO nest or roost location at each CSO territory on the Plumas National Forest in 2003-2007. Systematic searches for pellets and prey remains were conducted in each plot during each year. During 2007, 552 pellets were collected. An additional 2767 pellets have been collected 2003-2006 (2003 = 606; 2004 = 807; 2005 = 838; 2006 = 516) bringing the project total to 3319 pellets. To date 1418 pellets have been sorted and all prey items identified to species or taxonomic group when species identification could not be ascertained. Mammals comprised the dominant taxonomic group identified in the diet. The three most frequently detected species were the dusky-footed woodrat (detected in 43% of pellets), northern flying squirrel (detected in 39% of pellets), and *Peromyscus* species (detected in 27% of pellets)(Table 5). The 838 pellets collected in 2005 have been sorted and identification of all prey species has been completed while the 2006 sample is currently being sorted.

Summary 2004-2007

Our efforts to date have focused on collecting the initial data to address our primary research objectives and provide the baseline data for monitoring HFQLG implementation. In conjunction with the now fully integrated Lassen Demographic Study we have collected landscape-scale information on the distribution and abundance of CSOs across approximately 650,000 acres of land. Determining the accurate number and distribution of CSO sites requires multiple years of survey and marking of individual CSOs to delineate separate territories and identify individual birds that move among multiple sites within and across years. These baseline data are fundamental for developing empirically based habitat models for understanding CSO habitat associations and developing adaptive management tools and models. The near completion of the Meadow Valley area projects in 2007 marks the first landscape series of HFQLG treatments to be implemented within the study area, providing the first opportunity to address treatment effects within a case study framework. Our baseline information on CSO distribution and habitat associations, coupled with our 2007 radio-telemetry work, will allow us to assess associations between CSOs and vegetation changes.

Dedicated monitoring of CSOs on the Lassen Demographic study continues to provide critically valuable demographic and population trend information for determining the status of CSOs. The declining population trend estimated through the meta-analysis of the Lassen Demographic Study data and the apparent decline in numbers of CSOs observed between 2005-2007 within the Lassen NF survey areas warrant close continued monitoring of the status of CSOs within the study area, along with continued management focus on providing high-quality CSO habitat during the planning and implementation of HFQLG treatments. We lack similar long-term demographic data for the Plumas NF study areas, but our baseline information on CSO distribution and abundance suggests that numbers of territorial CSOs and sites have been similar across 2004-2007.

Our focused diet analyses have broadened and deepened our understanding of CSO diets and sources of variation in CSO diets among pairs and across environmental gradients.

Monitoring of WNV exposure coupled with demographic monitoring has provided an opportunity to assess if WNV may ultimately be a factor influencing CSO viability. To date we have not had a positive detection for WNV within CSOs. Finally, through our research into historical and current occurrence records, in conjunction with our field surveys, we have been able to document the colonization of the northern Sierra Nevada by barred owls. Our results indicate that barred owls are increasing in the northern Sierra Nevada and may become an increasing risk factor to CSOs.

Current Research: 2008

In 2008 we will continue monitoring owl distribution, abundance, demography, and population trend across the Study Area. We will also continue our radio-telemetry investigation of habitat use within the Meadow Valley project area. Beginning in March 2008 we will initiate surveys and follow-up visits to determine CSO distribution, abundance and habitat associations within the Antelope Complex and Moonlight fire areas. This work will provide an opportunity to assess the effects of wildfire on CSOs and their habitat and will provide a valuable complement to our current research investigating CSO habitat associations and response to fuel treatments. In addition to continuing field surveys in 2008 designed to address our six research questions, we have broadened our emphasis on the development of predictive habitat relationship models as described in the module study plan. We have continued to work closely with biologists on the Plumas and Lassen National Forests, and the R5 Regional Office, to identify and define the types of analyses and tools that would best address management needs. Baseline information collected during this study forms the foundation for this phase of the research. The combination of broad-scale landscape CSO distribution data, in conjunction with detailed demographic information available from the Lassen Demographic Study, will facilitate exploration and development of predictive habitat models for use in an adaptive management framework and to directly monitor implementation of the HFQLG project.

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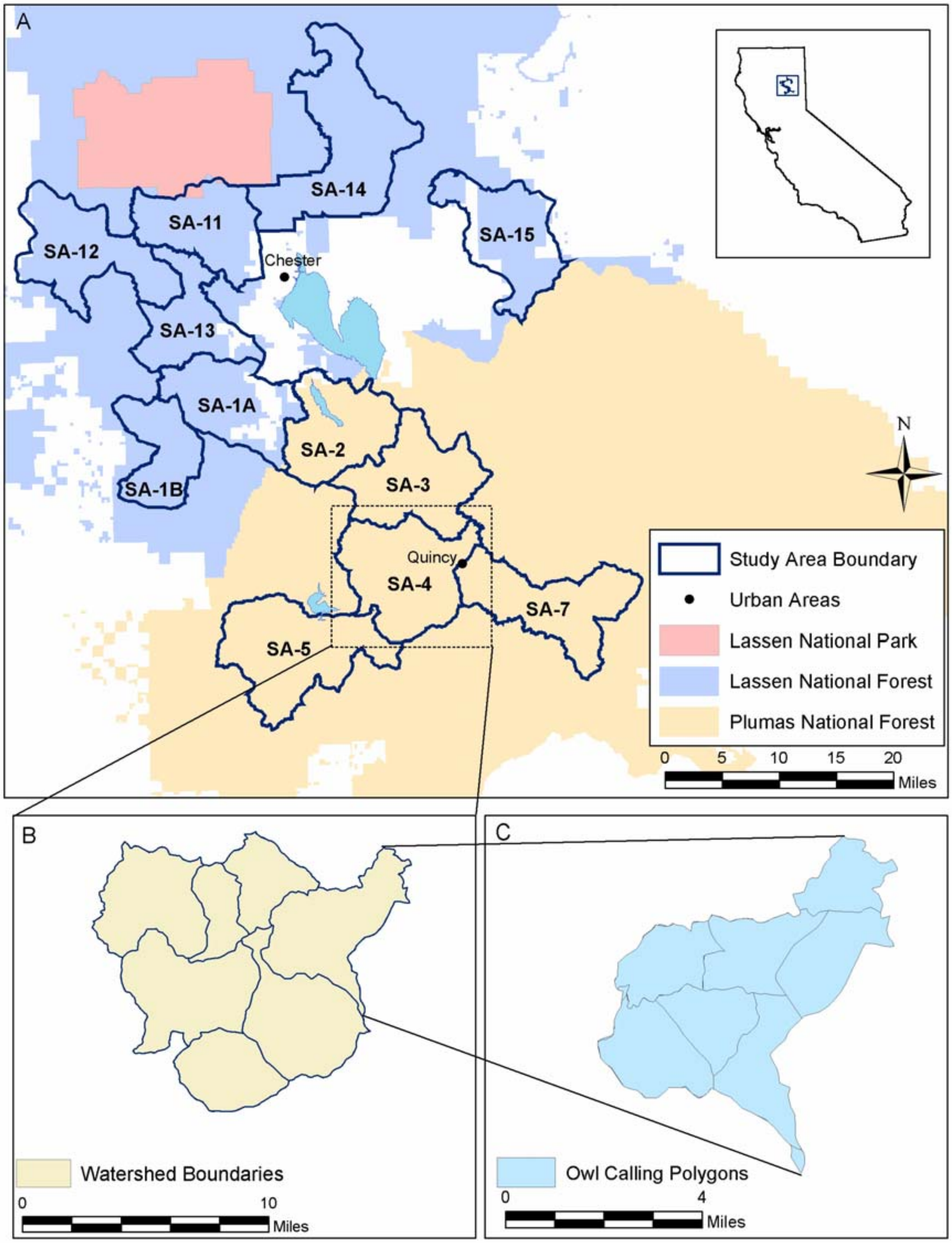

Figure 1. (A) Location of CSO Survey Areas surveyed in 2004-2007. (B) Example of original survey plot consisting of multiple Cal-Planning watersheds. (C) Example of Primary Sampling Units for surveying for CSOs. See text and study plan for further details .

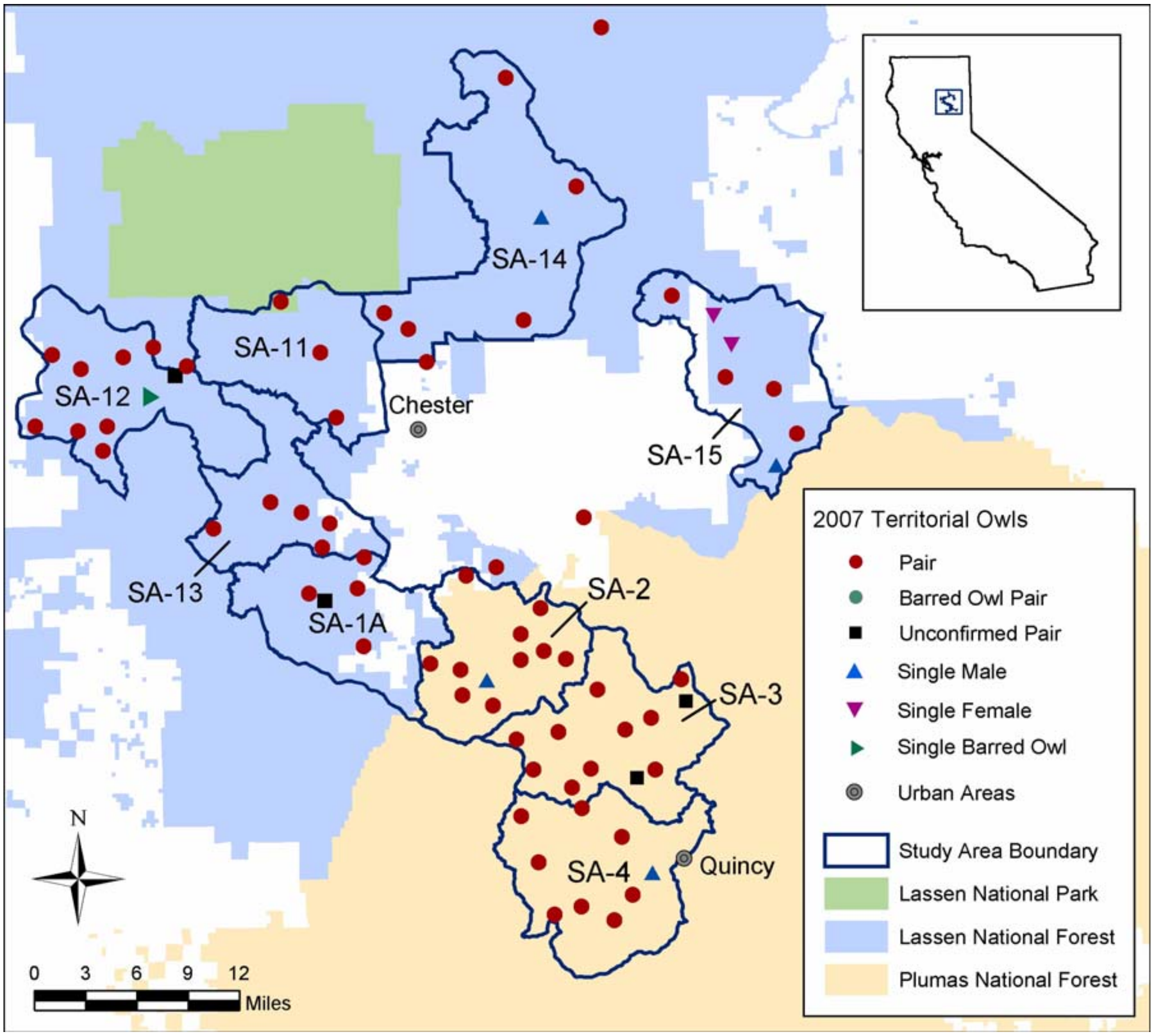

Figure 2. Distribution of California spotted owl territories within CSO survey plots across the Plumas and Lassen National Forests, 2007.

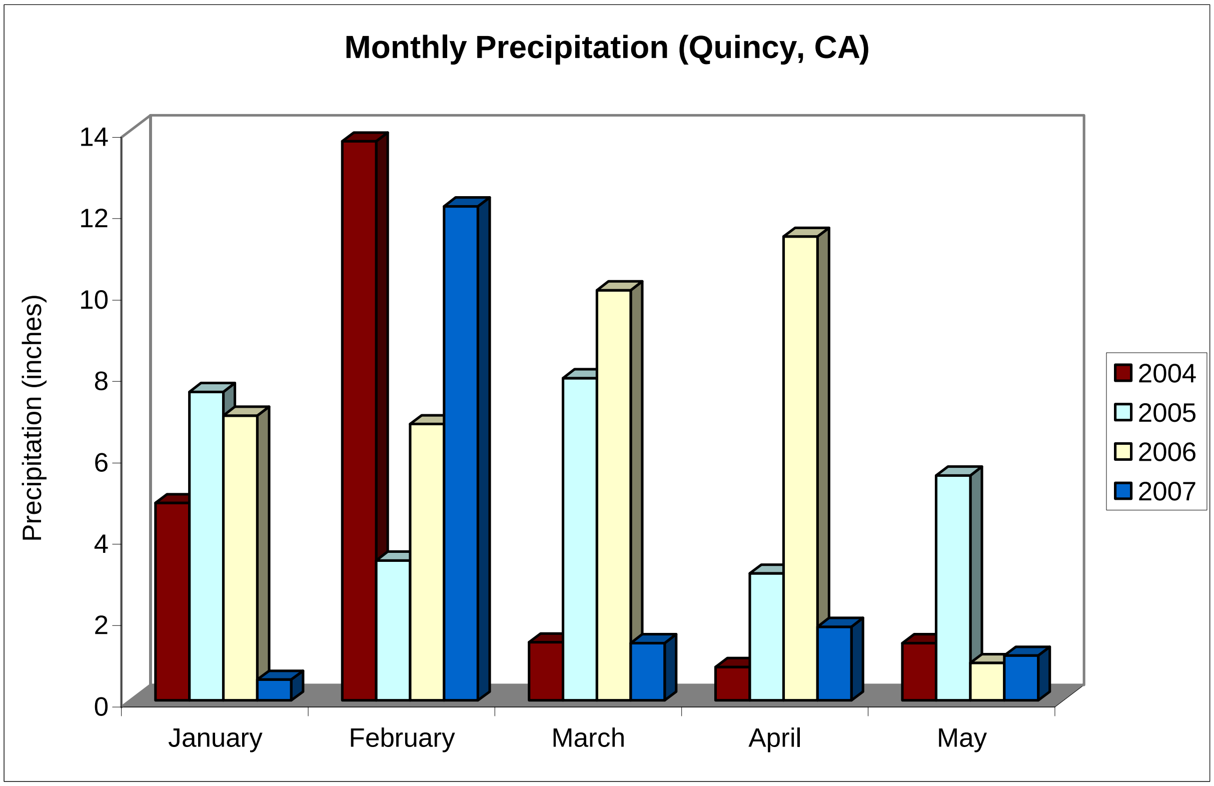

Figure 3. Monthly precipitation totals for Quincy, California, during January-May, 2004-2007 (data from Western regional Climate Center).

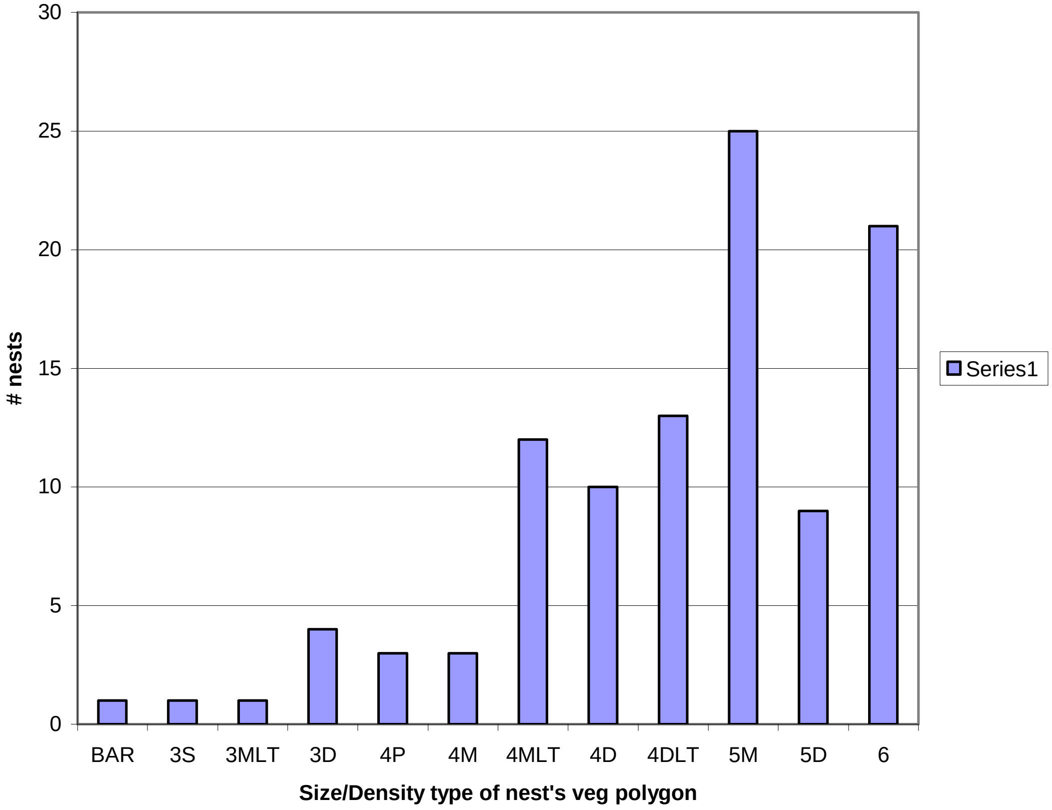

Figure 4. Distribution of California spotted owl (n = 103) nest sites by California Wildlife Habitat Relationship (CWHR) database vegetation classes on the Plumas and Lassen national Forests, California, 2004-2007. Descriptions of the CWHR classes are provided in Table 5 within the text of this document.

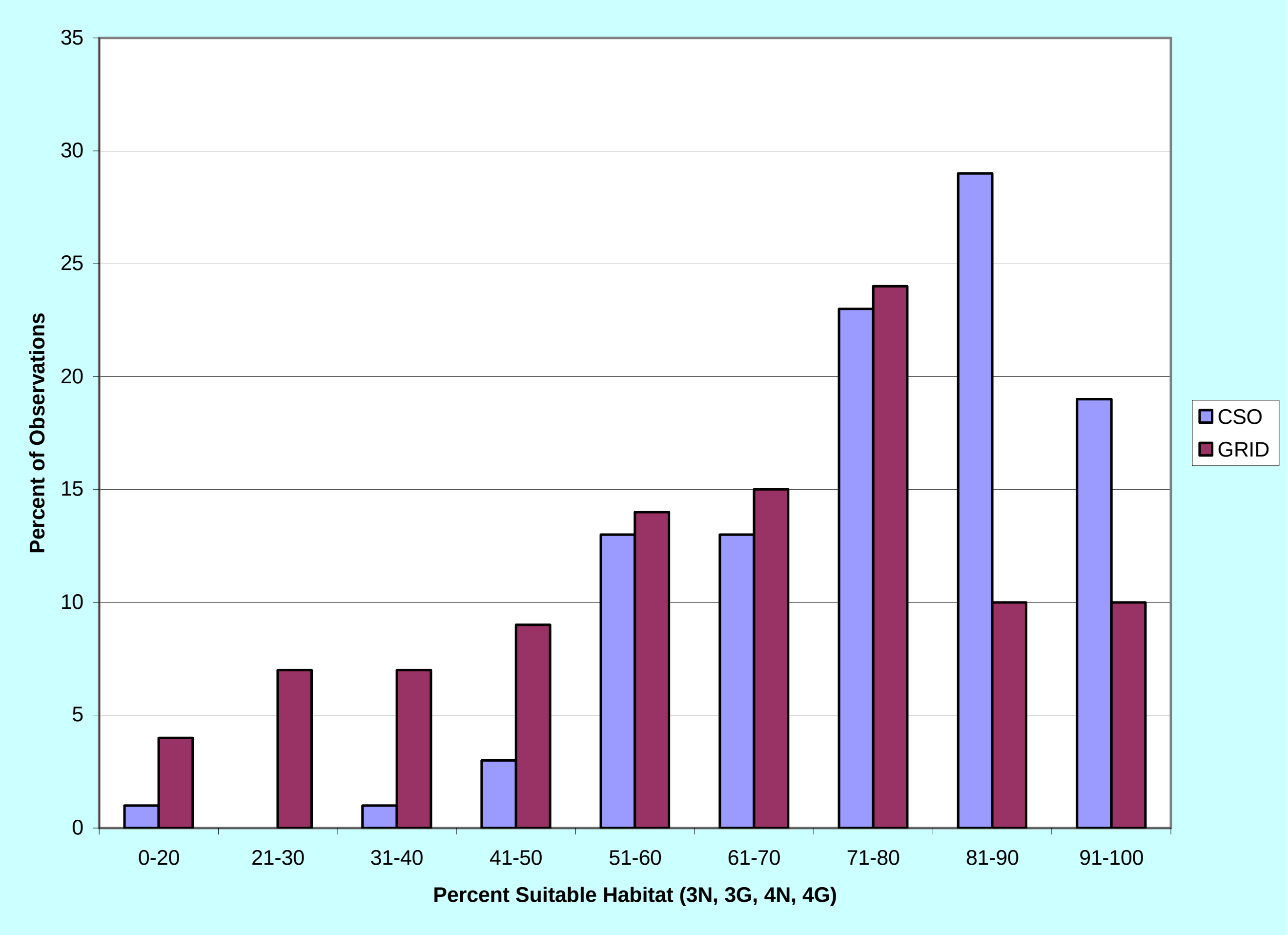

Figure 5. Percent suitable habitat (>=12 inch dbh trees with >=40% canopy cover) within 500 acre (201 ha) circles centered on California spotted owl (CSO, n = 102) and systematic grid points (Grid, n = 130) on the Plumas and Lassen National Forests, California, 2004-2007.

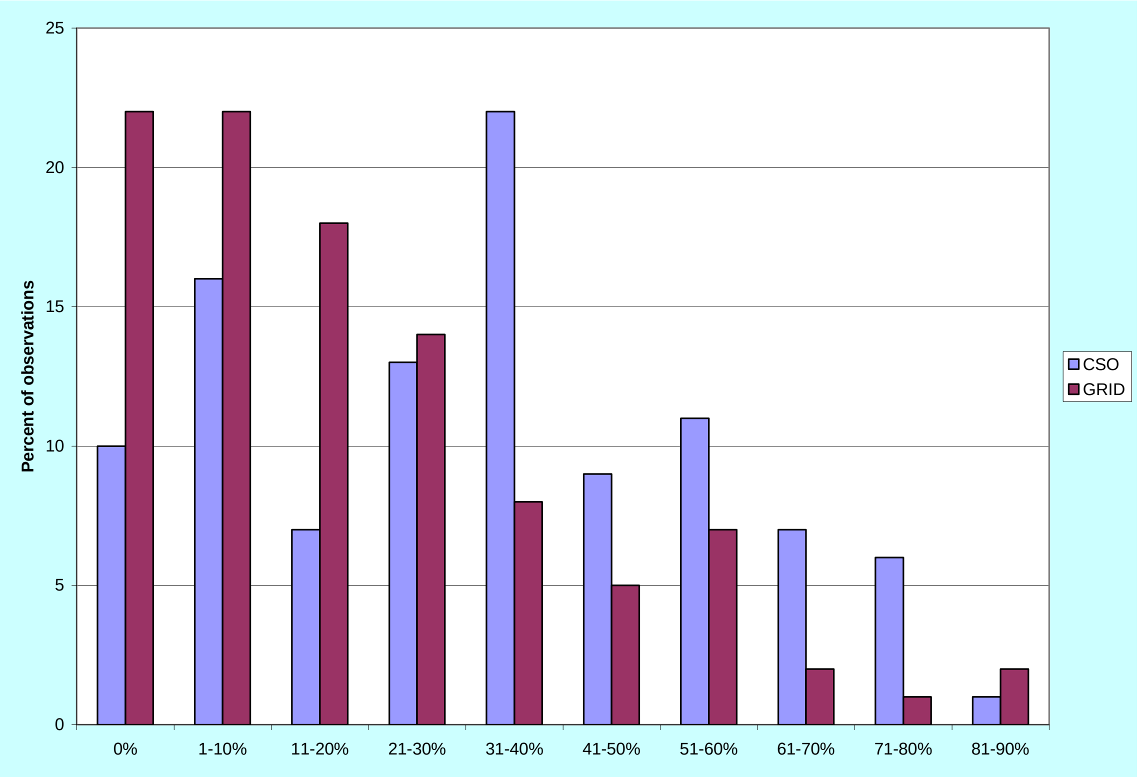

Figure 6. Percent large tree habitat (R5 classes 4N &4G: >=24 inch dbh trees with >=40% canopy cover) within 500 acre (201 ha) circles centered on California spotted owl (CSO, n = 102) and systematic grid points (Grid, n = 130) on the Plumas and Lassen National Forests, California, 2004-2007. Descriptions of R5 classes are provided in Table 7 within the text of this document.

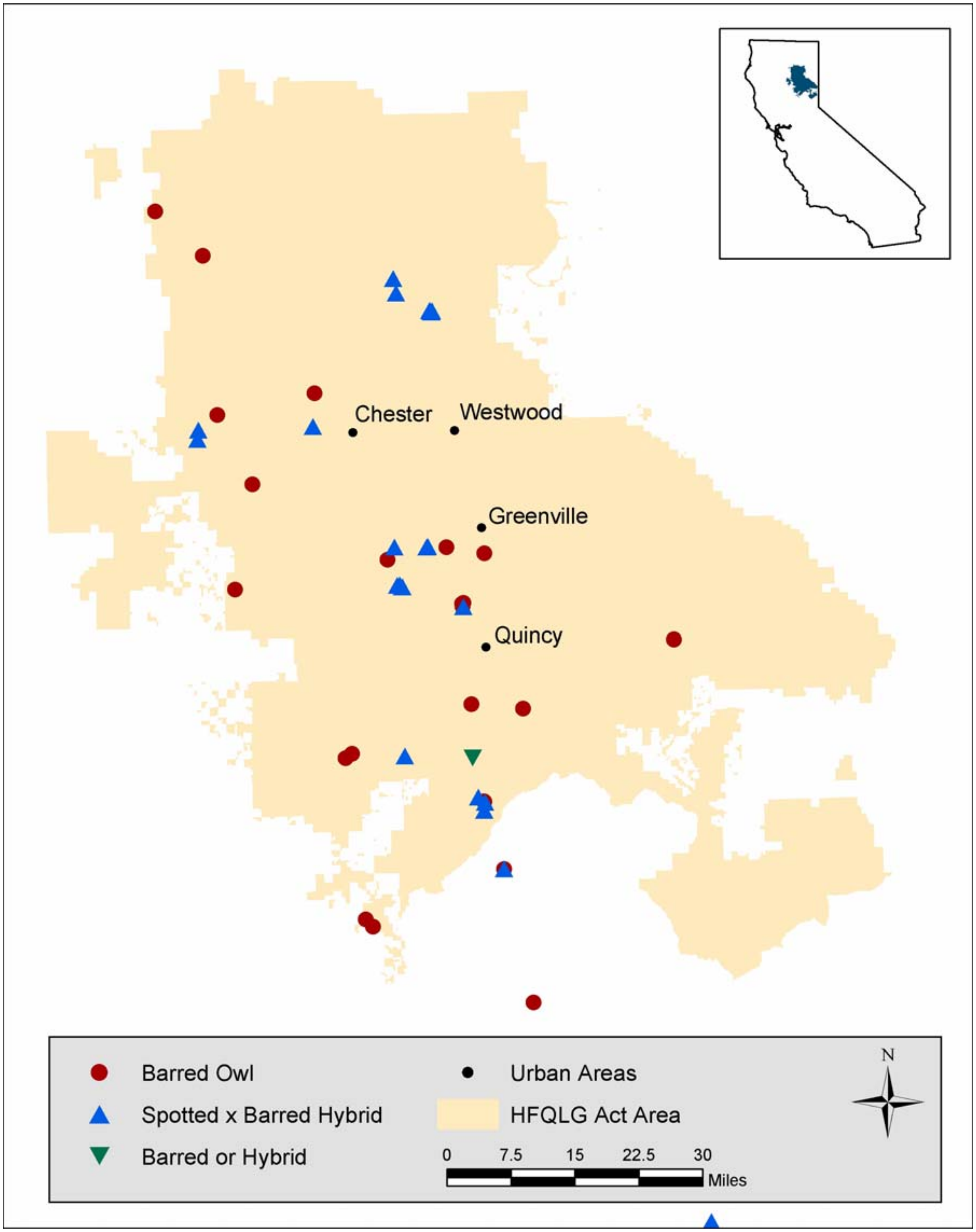

Figure 7. Distribution of Barred and Sparred (Spotted-Barred hybrids) Owls between 1989-2007 within the HFQLG Project area.

Table 5. Prey species occurrences in California spotted owl pellets collected on the Plumas National Forest 2003-2004.

Prey Species	Number of 2003 Pellets Containing Taxon (n=606)	Percentage of 2003 Pellets Containing Taxon	Number of 2004 Pellets Containing Taxon (n=812)	Percentage of 2004 Pellets Containing Taxon	Total Number of Pellets Containing Taxon (n=1418)	Total Percentage of Pellets Containing Taxon
Mammals	**581**	**95.87**	**797**	**98.15**	**1378**	**97.18**
Dusky-footed woodrat (*Neotoma fuscipes*)	287	47.36	318	39.16	605	42.67
Northern flying squirrel (*Glaucomys sabrinus*)	254	41.91	298	36.70	552	38.93
Deer mouse (*Peromyscus* spp.)	145	23.93	237	29.19	382	26.94
Unidentified mouse (*Peromyscus* spp. or *Mus musculus*)	16	2.64	32	3.94	48	3.39
California red-backed vole (*Clethrionomys californicus*)	11	1.82	11	1.35	22	1.55
Meadow voles (*Microtus* spp.)	12	1.98	32	3.94	44	3.10
Unidentified vole	6	0.99	6	0.74	12	0.85
Pocket gopher (*Thomomys bottae*)	26	4.29	73	8.99	99	6.98
Chipmunk (*Tamias* spp.)	6	0.99	32	3.94	38	2.68
Western harvest mouse (*Reithrodontomys magalotis*)	0	0.00	1	0.12	1	0.07
Shrew (*Sorex* spp.)	22	3.63	40	4.93	62	4.37
Broad-footed mole (*Scapanus latimanus*)	23	3.80	89	10.96	112	7.90
Large bat (e.g., *Eptesicus* spp.)	8	1.32	13	1.60	21	1.48
Small bat (e.g., *Myotis* spp.)	10	1.65	8	0.99	18	1.27

Table 5. (Continued)

Prey Species	**Number of 2003 Pellets Containing Taxon (n=606)**	**Percentage of 2003 Pellets Containing Taxon**	**Number of 2004 Pellets Containing Taxon (n=812)**	**Percentage of 2004 Pellets Containing Taxon**	**Total Number of Pellets Containing Taxon (n=1418)**	**Total Percentage of Pellets Containing Taxon**
Unidentified rabbit or hare (family *Leporidae*)	1	0.17	11	1.35	12	0.85
Unidentified large rodent (comparable to a woodrat)	15	2.48	28	3.45	43	3.03
Unidentified small rodent (comparable to a mouse)	30	4.95	56	6.90	86	6.06
Unidentified mammal	3	0.50	2	0.25	5	0.35
Unidentified vertebrate (may include non-mammals)	8	1.32	15	1.85	23	1.62
Birds	**59**	**9.74**	**104**	**12.81**	**163**	**11.50**
Unidentified bird (unknown size)	4	0.66	4	0.49	8	0.56
Unidentified large bird (e.g., American robin)	23	3.80	38	4.68	61	4.30
Unidentified medium bird (e.g., western tanager)	15	2.48	31	3.82	46	3.24
Unidentified small bird (e.g., pine siskin)	12	1.98	20	2.46	32	2.26
Steller's jay (*Cyanocitta stelleri*)	2	0.33	5	0.62	7	0.49
Northern flicker (*Colaptes auratus*)	3	0.50	6	0.74	9	0.63
Insects	**82**	**13.53**	**145**	**17.86**	**231**	**16.29**
Long-horned beetle (*Ergates* spp.)	46	7.59	61	7.51	107	7.55
Giant lacewing (*Polystoechotes lineata*)	11	1.82	25	3.08	36	2.54
Jerusalem cricket (*Stenopelmatus* spp.)	25	4.13	45	5.54	70	4.94
Carpenter ant (*Camponotus* spp.)	1	0.17	11	1.35	12	0.85
Cicada	2	0.33	25	3.08	27	1.90
Unidentified insect	3	0.50	14	1.72	17	1.20