Spotted Owl Home Range and Foraging Patterns Following Fuels-Reduction Treatments in the Northern Sierra Nevada, California

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CLAIRE VIRGINIA GALLAGHER
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Approved:

Deborah L. Elliott-Fisk, Chair

John J. Keane

Douglas A. Kelt

Committee in Charge
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Spotted owl home range and foraging patterns following fuels treatments in the northern Sierra Nevada, California

CLAIRE V. GALLAGHER, Graduate Group in Ecology, University of California, Davis, CA 95616

ABSTRACT

To evaluate spotted owl foraging and home range characteristics in a landscape recently modified by fuels-reduction treatments, we radio-marked and tracked 10 spotted owls (*Strix occidentalis*) in the northern Sierra Nevada from April 2007- October 2008. Spotted owl foraging patterns following fuels treatment have not been well-documented prior to this study. We gathered 436 owl foraging locations across 2 breeding seasons, and categorized fuels treatments into 4 types: Defensible Fuel Profile Zones (DFPZs), landscape-scale thins designed as fire breaks; understory thin, removal of trees <10-inches diameter; group selection, removal of all trees <30-inches diameter in <0.8-ha patches; and understory thin followed by underburn. We evaluated spotted owl home range size and composition using repeated measures analysis of variance and resource selection functions. To analyze owl foraging patterns within home ranges, we evaluated a priori hypotheses using an information-theoretic approach and Akaike's Information Criterion corrected for small sample sizes. Although we found considerable variation between owl home ranges and foraging preferences, owls consistently foraged closer to site centers than expected at random. Spotted owls avoided DFPZs during both survey years; evidence for owl use of group selections and understory thin was inconclusive. One owl strongly selected underburn areas for foraging, although inter-owl variation and limited area of underburn within the study area prevent extrapolating this observation further. Spatial orientation of all treatment types relative to owl core areas and home ranges complicated interpretation of results. Conclusions from this study are exploratory and are intended to provide a baseline for further research.

KEY WORDS spotted owl, fuels treatments, fuels management, silvicultural treatments, forest restoration, habitat use, home range, foraging, *Strix occidentalis*, Sierra Nevada

The ecological, economic, and political effects of wildfire are of current and acute concern for the Sierra Nevada bioregion (McKelvey et al. 1996, North et al. 2009, Safford 2009). Decades of fire suppression have increased the risk of catastrophic wildfire, transitioning the historic fire regime to more frequent, extreme, and forest stand-replacing fire events (Miller et al. 2009). Additionally, based on current trajectories of climate change, the frequency of fire events is projected to further increase significantly (McKenzie et al. 2004). Methods to mediate these catastrophic fire events are fiercely debated (Noss et al. 2006), but fire and fuels treatments (e.g., forest thinning) have been broadly proposed, implemented, and litigated as a primary management strategy (U.S. Forest Service [USFS] 2004, Stephens and Moghaddas 2005, North et al. 2009, Safford 2009).

Fire and fuels treatments (hereafter 'fuels treatments') are designed, proposed, and implemented at the landscape scale, and currently are the primary management activities affecting forest ecosystems and species of concern, such as spotted owls (*Strix occidentalis*), on federal lands in the Sierra Nevada (USFS 2004). Management strategies for federal lands have historically incorporated spotted owl population viability across the species' range, but the efficacy and impacts of fire and fuels treatments to spotted owls remain largely unknown, and are hotly contested based on limited available information (USFS 2004, Hanson et al. 2009a, 2009b, Spies et al. 2009). The need for scientific research regarding the impacts of fire and fuels treatments to spotted owls is critical, particularly in current ecological and political climates.

While it is possible that fuels management activities may affect spotted owls, the risk of the loss of untreated forest to catastrophic fire may also pose significant impacts (Miller et al. 2009). The Recovery Plan for the Northern Spotted Owl (*S.o. caurina*; U.S. Department of the Interior 2008) listed the "ongoing loss of suitable habitat as a result of timber harvest and catastrophic fire" as one of the top threats to the viability of this subspecies. The plan proposed the implementation of a no-reserve strategy for the owl, with fuels treatments installed in up to 70% of forests in fire-prone provinces, in an effort mitigate the threat of wildfire.

The current population status of the California spotted owl (*Strix occidentalis occidentalis*) in the Sierra Nevada is uncertain; recent demographic analyses suggest populations are stable or slightly declining (Franklin et al. 2004, Blakesley et al. 2006, 2010). This uncertainty warrants caution in spotted owl conservation and management efforts (Franklin et al. 2004, Anthony et al. 2006).

Although spotted owls have been studied for more than 2 decades (Verner et al. 1992, Noon 2002), the effects of fuels treatments on the species remains largely unknown. Most research has focused on habitat associations and the estimation of population parameters and trends (Blakesley et al. 2001, 2006, Franklin et al. 2004). As an associate of economically valuable old-growth forests, spotted owl habitat selection at nest and roost sites is well-documented as favoring multi-layered understories with high canopy closure, dominated by large-diameter trees (Bias and Gutiérrez 1992, Gutiérrez et al. 1995, LaHaye et al. 1997, Moen and Gutiérrez 1997, Bond et al. 2004, Chatfield 2005). Spotted owl foraging site selection has received less research attention, but several recent studies report more heterogeneity in foraging sites, including late seral forest, broadleaf forest, riparian forest, and post-burn areas (Call et al. 1992, Glenn et al. 2004, Clark 2007, Williams 2008, Bond et al. 2009). Spotted owl habitat and foraging site selection have not been characterized for areas that have been recently modified by fuels treatments.

Current management guidelines for the Sierra Nevada advocate implementation of landscape-scale fuels treatments such as Defensible Fuel Profile Zones (DFPZs), and Strategically Placed Area Treatments (SPLATS), as approaches to modify fire behavior, facilitate suppression, and protect civic and economic interests. The general prescription of fuels treatments is a reduction of forest canopy cover to ≤40%, retention of trees ≥30-inches diameter, and a reduction of tree density, ladder fuels, and surface fuels (USFS 2004). The effects of these forest stand modifications on California spotted owls remain undescribed, which has contributed to the controversy and litigation surrounding ecological management directions in the Sierra Nevada (Noon 2002, USFS 2004, North et al. 2009).

Research reported here was designed to assess the effects of fuels treatments on California spotted owls, by characterizing home range configuration and foraging site selection immediately following treatment installation. For central-place foragers such as spotted owls, selection for the central place and foraging locations may differ strongly, and become confounded in resulting patterns. Research attention solely given to nest and roost site selection may result in limited interpretations of site selection (Rosenberg and McKelvey 1999, Ganey et al. 2003, Glenn et al. 2004). Thorough examination of the effects of fire-reduction treatments on California spotted owls requires study of population dynamics and habitat selection at multiple spatial scales across multiple years; the present contribution is intended to establish initial behavioral responses and to establish a baseline against which further research can be compared.

STUDY AREA

Fuels management in the Sierra Nevada is guided by the 2004 Forest Plan Amendment (USFS); fire and fuels management on the Lassen, Plumas, and the Tahoe National Forests is superceded by direction outlined in the federal Herger-Feinstein Quincy Library Group Forest Recovery Act of 1998 (HFQLG Act). HFQLG Act forest management is characterized by suites of 1) Defensible Fuel Profile Zones (DFPZs), landscape-scale forest thins that are designed to function as a fuel break by reducing canopy cover and ladder fuels, and 2) group selections, <0.8-ha harvests of all trees less than 30-inches in diameter, both prescribed according to site criteria. The HFQLG Act prohibits fuels and timber harvest treatments within spotted owl Protected Activity Centers (PACs), 300-acre units of late seral forest delineated by forest biologists around spotted owl nests and roosts; other areas of spotted owl home ranges may be treated.

The Meadow Valley Project (MVP), on the Plumas National Forest, is the first and only HFQLG Act forest treatment suite to reach full implementation; additional HFQLG Act projects are in progress or under litigation. MVP harvest operations were initiated in

2003, and 80% of prescribed harvests were completed by January 2007; remaining treatments and harvests were completed by October 2008. Under HFQLG Act guidelines, contracting parties have up to 5 years from the date of sale to complete fuels treatments; treatments may also be modified by the contractor for logistical reasons. Without research control over spatial or temporal installation of treatments within the HFQLG Act area, this research uses a passive adaptive management framework (Kendall 2001).

We identified the MVP area as the location for this study, as it is the only HFQLG Act project to date to achieve full installation. We created a biologically-relevant perimeter for the study area by overlaying the MVP area with the California Watershed Map (CALWATER version 2.2, California Interagency Watershed Mapping Committee) in a Geographic Information System (GIS). Eight watersheds completely contained the MVP area; 7 of these watersheds were surveyed for spotted owls from 2002-2009, while 1 watershed was surveyed from 2002-2005. The perimeter of the 7 most-recently surveyed watersheds was delineated as the perimeter of this study (Fig. 1); the remaining watershed was excluded due to lack of recent spotted owl information. The resulting 23,823 ha study area encompassed 4,160 ha of fuels treatments.

Territorial owl sites within the study area boundary were identified by annual surveys conducted (2002-2009) by the Pacific Southwest Research Station (PSW), U.S. Forest Service. For site selection, these sites were constrained to those that had been occupied for more than 1 year and were currently occupied by pairs. This limited our site selection to 6 sites in 2007 and a different configuration of 6 sites in 2008 (Fig. 2).

PSW personnel radio-marked owls at these sites with backpack radio-transmitters (Holohil Systems Ltd. Model RI-2C, Ontario, Canada) fitted to each owl with Teflon®-coated Kevlar® ribbon (Bally Ribbon Mills, Bally, PA). Total mass of the radio-transmitters was 14 g, or 2.5% of the body weight of an average spotted owl male (554g, ± 0.6%) and 2.2% of the body weight of an average female (644g ± 0.7%) on the Plumas National Forest (PSW, unpublished data). Females were radio-tagged in June, after young fledged from the nest.

METHODS

All analyses were conducted for the breeding season only. Breeding season was defined as April 1- September 30, based upon the expected return of territorial birds from wintering grounds, and the juvenile fledging period extending into August and September (Gutiérrez et al. 1995). The non-breeding season was defined as October 1- March 31. These a priori dates were later supported by winter habits of the radio-tagged owls, which were on territory in 2007 through early November, and returned to territories in mid-March 2008. The full tracking period extended through the 2007 and 2008 breeding seasons (Fig. 3). Several radio-transmitters began to fail in late September 2008, and we removed all radio-transmitters in October 2008.

Radiotelemetry

Two observers, working together, derived owl locations using standard radiotelemetry triangulation techniques (White and Garrott 1990, Kenward 2001, Millspaugh and Marzluff 2001). We separated sequential locations for each owl by ≥24 hours to reduce temporal autocorrelation; this resulted in a maximum sampling regime of 5 locations per bird every 2 weeks, or 10 locations per bird per month. We continuously varied the order of owl tracking to sample across the full activity period for each owl, and gathered all owl locations between 1 hour after sunset and 1 hour before sunrise.

We installed permanent telemetry stations within owl core areas, and marked their position using a Trimble GeoExplorer3 Geographic Positioning System (GPS) unit with ≤5 m accuracy. Where it was not possible to use a permanent telemetry station, observers recorded their position with a Trimble GeoExplorer3 or Garmin 60Cx GPS with ≤10m accuracy; observers used the Garmin unit only when a GeoExplorer3 was unable to obtain a position. Observers analyzed signals using handheld directional 2-element H-type antennae (RA-14, Telonics Inc., Mesa, AZ) and TR-2 handheld receivers (Telonics Inc.), and immediately plotted bearings on 1:12,000 scale topographic maps. After observers estimated the first 2 bearings simultaneously, one observer moved to take a third bearing while the second observer monitored the signal for any changes indicating bird movement. Observers gathered bearings as close together in time as possible to reduce the probability of bird movement, balancing desired angle change with accessibility and elapsed time. Once in the vicinity of the owl, mean elapsed time of the triangulation process was 16 minutes (SE = 0.5 minutes, *n* = 465).

After collecting ≥3 bearings and drawing the triangulation on the map, observers checked data in the field using Palm LOCATE (Pacer Computing, Nova Scotia, Canada). Recent spotted owl telemetry studies have used a 95% confidence ellipse of 2 ha (Clark 2007) or 5 ha (Glenn et al. 2004, Williams 2008) to ensure location precision; we employed a more conservative limit and accepted locations when the 95% confidence ellipse was <1.5 ha. If the ellipse was ≥1.5 ha, the surveyors repeated the triangulation process. If, after an hour of repeated efforts, the error ellipse remained large, the surveyors noted the approximate location and moved on to the next owl. Locations with large ellipses were analyzed for spatial sample bias.

If the owl was ≤200 m from the surveyors, an effort was made to observe the bird and verify location. Surveyors abandoned this effort if they detected a change in signal indicating bird movement. Conversely, if surveyors were unable to locate an owl for 4 days, an exhaustive search by vehicle was initiated. If still unable to locate an owl after ≥2 weeks, surveyors searched for the owl by fixed-wing aircraft.

We analyzed the spatial data for each location using the software LOAS 4.0b (Ecological Software Solutions, Urnäsch, Switzerland). We used bearing error, distance between surveyor and owl, and the angular arrangement of surveyor positions to calculate the 95% confidence ellipse of each location with the maximum likelihood estimator. Accuracy of triangulation estimates was assessed using daytime owl location information: working individually while owls were roosting, observers triangulated on the owl and then moved in on the signal to directly observe the bird. Surveyors recorded the owl's true location with a Trimble GeoExplorer3 GPS unit, and noted the difference between the estimated location and true location. The datum was rejected if, upon observing the owl, the owl appeared disturbed or awake, or if changes in the radio signal indicating bird movement were detected while the observer approached. Mean bearing error between estimated and true locations was 7.25 degrees (SE = 0.85), and mean distance error was 68.5 m (SE = 38 m). Similar studies on spotted owls report accuracy estimates of 8.25-9.6 degrees bearing error and mean distance errors of 68-164 m (Carey et al. 1992, Glenn et al. 2004, Forsman et al. 2005).

Home Range Analysis

We estimated spotted owl home ranges using the 100% Minimum Convex Polygon (MCP) and fixed kernel density estimator methods. MCP has been criticized for its sensitivity to sample size, outliers, and sampling duration (White and Garrott 1990, Seaman et al. 1999, Laver and Kelly 2008), but is included here for purposes of comparison, because of its prevalent inclusion in other spotted owl home range studies.

We chose fixed kernel density estimators as the primary home range model for this dataset, as adaptive kernel estimators tend to undersmooth data at outer contour levels and overemphasize outliers (Seaman et al. 1999). To objectively assess the choice of estimator, we tested the fit of the fixed-kernel density estimator against the fit of adaptive-kernel density estimator by applying information-theoretic model selection (Horne and Garton 2006b). We evaluated the relative Kullback-Leibler [KL] distance of the 2 home range models by applying the likelihood cross-validation criterion to the owl location data, using Animal Space Use 1.2 (Horne and Garton 2006b). The relative KL distances supported fixed kernel density estimators as the appropriate choice for this dataset.

We chose the likelihood-cross-validation (CVh) smoothing parameter to calculate bandwidth for fixed kernel estimators. CVh has been shown to provide home range estimations of better fit than other methods (e.g. least-squares cross-validation [LSCV]) with simulated data and sample sizes <50 (Horne and Garton 2006a). We calculated breeding season home ranges for owls with a minimum of 30 locations, following Seaman et. al (1999). Owl locations with 95% confidence ellipses ≤1.5-ha were used for home range derivation.

We examined potential correlates of home range size using mixed-model analysis of variance (ANOVA) with repeated measures in SAS 9.2 (SAS Institute Inc., Cary, NC, USA). The area contained within the 95% fixed kernel volume contour defined home range size. We included year, reproductive status, and sex in models, because other studies have reported differences in home range size between sexes, and between breeding and non-breeding seasons (Forsman et al. 1984, Zabel et al. 1992). As fuels treatments occur as large spatial patches, we hypothesized that selection or avoidance of fuels treatments would influence home range size. We were not able to compare paired and unpaired owls in analyses because only one owl was unpaired. Owl identity was modeled as a random effect; all other parameters were modeled as fixed effects.

We also evaluated factors potentially associated with the cumulative area of fuels treatment within home ranges, using mixed-model ANOVA with repeated measures in SAS 9.2. Reproductive status, sex, and year were modeled as fixed effects, while owl identity was modeled as a random effect. We defined the area of fuels treatments within the home range as the treated area contained within the 95% fixed kernel volume contour.

Owl Use of Treatment Areas: Home Range Placement

We analyzed owl use of fuels treatments at second- and third- order spatial scales, following Johnson (1980). For second-order analysis, we used a simplified resource selection function (Manly et al. 2002) to evaluate the spatial composition of owl home ranges relative to the study area. Owl home ranges defined use areas, while the study area described the available area.

We used the 2009 Region 5 Remote Sensing Laboratory map for the Meadow Valley Project area (MVP09 Map) to analyze the presence and distribution of fire and fuels treatments within the study area and owl home ranges. Derived from aerial photographs and satellite data captured in August 2009, the MVP09 Map describes all harvested and treated areas within the MVP area. Although treatment areas are clearly delineated, habitat attributes are not currently available for the full study area and preclude paired habitat analysis of treated and non-treated forest.

We created a treatment map of the study area by overlaying the study area boundary with the MVP09 Map in GIS. We also created fuels treatment maps for each owl's home range by overlaying the 95% fixed kernel contour with the MVP09 Map. To analyze owl use of fuels treatments, we compared the proportion of fuels treatments in each home range with the total proportion available in the study area using resource selection ratios ($\hat{w}_i$). We estimated selection ratios, variances, and confidence limits, following Design II Sampling Protocol A in Manly (2002). We used Bonferroni-corrected 90% confidence limits to define selection ($\hat{w}_i > 1$), use equal to availability ($\hat{w}_i = 1$), or avoidance ($\hat{w}_i < 1$) for each treatment type.

The Sierra Nevada has a complex history of land use and management (Verner et al. 1992, Chatfield 2005), and the study area reflected this history. For analyses, we limited fuels treatments to those that had been implemented since the HFQLG Act took effect in 1998. We grouped fuels treatments into 4 broad categories: 1) DFPZs, landscape-scale forest thins designed to function as fire breaks by a reduction in canopy cover, tree density, and ladder fuels; 2) understory thin, prescribed as removal of shrubs and trees <10-inches diameter; 3) understory thin followed by underburn; and 4) group selection, a removal of all trees <30-inches diameter in <0.8-ha patches, designed as a forest health treatment to mimic natural gaps while generating revenue. DFPZs and group selections are features of the HFQLG Act and were distributed throughout all owl home ranges within the study area. The MVP area contains 1,784 ha of DFPZ treatments and 272 ha of group selections, which are typically located near or embedded within DFPZs. The MVP area also contains 1,440 ha of understory thin and 665 ha of underburn. Separation of treatment types into finer categories was not justified due to limited data.

In contrast to DFPZs and group selections, understory thins and underburns were not uniformly distributed throughout the study area; understory thins were only implemented in the southern half of the study area, while underburns were conducted only in the north. Therefore, we restricted underburn and understory thin analyses to owls whose site centers were within 1 mile of the treatment of interest, to reduce the confounding factors of non-uniform treatment distribution, long travel distances, and territoriality of resident birds near these treatments. We chose a 1 mile distance because it is the approximate mean foraging distance from site center across all 420 owl locations included in home range analyses ($\bar{x}$= 1770 m, SE = 241 m).

Owl Use of Treatment Areas: Foraging

We analyzed owl use of fuels treatments at the third-order scale using mixed-model logistic regression with repeated measures in SAS 9.2. To further explore factors that may be associated with owl foraging in treated areas, we evaluated sets of a priori models using mixed-model regression with repeated measures, Akaike's Information Criterion corrected for small sample sizes (AIC_c), and Akaike weights (w_i) in SAS 9.2 (Burnham and Anderson 2002). For all third-order analyses, owl foraging locations quantified used habitat, while randomly-generated points within each home range approximated the habitat available to each owl.

We created a map of treatments, classified by treatment type, for each owl's home range by overlaying the 95% fixed kernel home range contour with the MVP09 Map in GIS. We then used GIS to generate 500 random points within the 95% contour of each owl's home range. We considered owl and random locations to be within treatment if the location fell within a treatment polygon in the MVP09 Map, or within 5 m of the treatment polygon boundary. This buffer for within-treatment consideration derives from the inherent error of the boundary lines of the map (5 m; Ramirez, USFS Remote Sensing Laboratory, personal communication). Additionally, we visited all owl locations that were potentially within treatment during daytime hours to ground-truth the treatment status indicated by the map. Owl locations 5-50m from a treatment boundary likely were associated with treatment but were not considered to be within treatment for analyses, as it is unclear if the animals were interested in the treatment, the area adjacent to treatment, or the edge habitat between the two; our dataset included 12 such locations.

We compared owl use locations with random locations for each fuels treatment type and PACs using mixed-model logistic regression (Keating and Cherry 2004). We also used mixed-model ANOVA to assess if owl use locations were associated with proximity to the nearest fuels treatment, distance to the owl's site center, and second- and third - order polynomial derivatives of the site center distance (distance + distance^2 and distance

+ distance^2 + distance^3, respectively), which are metrics for central-place foragers (Rosenberg and McKelvey 1999, Glenn et al. 2004). We defined site center as the current nest tree for breeding birds, and the primary roost site for non-breeding birds. We chose a repeated measures design with compound symmetry for all analyses, to control for individual owl differences.

To further explore factors that may be important to owl use of fuels treatments for foraging, we developed a priori models comparing owl locations within and outside of fuels treatments. We evaluated these models using mixed-model logistic regression with repeated measures, AIC$_c$, and Akaike weights (w_i) in SAS 9.2 (Burnham and Anderson 2002). We hypothesized that owls would not travel further than necessary to forage, thus distance between the foraging location and the site center (expressed as linear, second-, and third- order polynomial terms) would affect owl use of treatment areas, as treatments are not typically located near owl site centers. Because spotted owls are associated with large size-class trees and high canopy cover (Verner et al. 1992, Gutiérrez et al. 1995), we included distance to the nearest PAC in models, hypothesizing that owls are more likely to forage near PACs. As spotted owls have been documented to make larger movements during the non-breeding season (Forsman et al., 1984) and owl reproduction rates for 2008 were the lowest in 5 years across adjacent demography study areas (PSW, unpublished data), we also hypothesized that year would be correlated with owl foraging differences. As the amount of fuels treatment within each owl's home range is expected to vary widely, we chose a null model of owl identity for this model set.

We examined parameters that may influence the distance of owl foraging locations to the nearest fuels treatment using a priori mixed-model ANOVA with repeated measures.

We hypothesized that owl distance from treatment would be correlated with distance to the nearest PAC, because spotted owls have been documented to forage in high canopy cover (Call et al. 1992) and may forage closer to PACs than fuels treatments. We also hypothesized that distance to the nearest fuels treatment would be associated with distance from the owl's site center, expressed either as linear, second-order polynomial, or third-order polynomial terms. Of the distance metrics, we anticipated that the third-order polynomial distance to site center would be most strongly associated with distance to fuels treatment, because treatments are not typically located near the center of the home range. We included year in models, reasoning that owls would have less incentive to forage near the site center in a poor breeding year such as 2008. Expecting wide variation amongst owls, we chose the independent variable of owl identity as the null model for this set.

We also analyzed the proportion of each owl's locations within fuels treatments, using a priori mixed-model ANOVA with repeated measures. By simple probability, we hypothesized that the area of each fuels treatment type available within the home range, as well as the cumulative total area of available treatments, would influence the proportion of owl locations within treatment. As spotted owls have been documented to forage in high canopy cover (Call et al. 1992), we hypothesized that understory thin and underburn treatments would be associated with greater owl foraging than DFPZs and group selections, which affect the overstory. We also hypothesized that total PAC area within the home range would be negatively associated with the proportion of locations within treatment, as increased PAC area mutually excludes fuels treatments as available foraging habitat. As with other model sets, we hypothesized that owl use of fuels treatments would be influenced by the distance between foraging locations and the owl's site center, the distance from the owl's location to the nearest fuels treatment, and the distance from the owl location to the nearest PAC. Because this model set is based upon summary metrics for each owl's locations and home range, all distances were expressed as a mean, minimum, and maximum distance (3 total variables per distance metric). We expected that distance to the nearest PAC would affect the proportion of locations in treatment more than distance to fuels treatments, believing that owls would be more likely to visit PACs for nesting and roosting activities, and thus forage more closely to the PACs. Last, we hypothesized that the proportion of owl locations within fuels treatments would increase with decreasing minimum distances from each treatment type to the site center. The null model of this set is the independent variable of owl identity, as a wide range between individuals is expected.

We used AIC_c to rank all model sets, and calculated ΔAIC_c as the difference between each model and the most parsimonious model. The model with the lowest AIC_c value was assumed to be the most parsimonious, and models with a $\Delta AIC_c \leq 2$ of the top model were considered competitive (Burnham and Anderson 2002, Arnold 2006). We also calculated the Akaike weight (w_i) to evaluate model likelihood (Burnham and Anderson 2002). Because the post-fuels treatment nature of this study area differs from other spotted owl studies, and because landscape-scale habitat information is not yet available for this study area, these model sets are considered exploratory.

Vegetation Analysis: Foraging Locations

We gathered vegetation metrics at 30% of owl use locations, to further quantify owl foraging locations in both treated and untreated areas. Forest Inventory and Analysis (FIA) plots are a standardized 1-ha vegetation inventory protocol utilized nationwide to monitor public and private forests (U.S. Forest Service, Arlington, VA). FIA plot design is nested, with a measurement-intensive microplot contained within a circular subplot, which is then nested within a circular annular plot; 4 replicates of the nested plots are all located within a single 1-ha circular plot. We followed standard FIA protocol to gather vegetation metrics at owl foraging sites; in addition, we measured 2 fuels transects (Brown's Lines) per subplot.

We randomly selected 9 locations from each owl's nocturnal use locations as FIA plot centers (i.e., 30% of the minimum number of foraging locations per bird). Post-randomization, we extended the list of FIA plot centers to include all locations within fuels treatments that had not already been selected, such that all owl locations within a treatment were measured. During site selection, we excluded sites that had been modified, by fuels treatments or other processes, between the date of owl use and the date of vegetation measurement. We also excluded from selection any owl locations that had an error ellipse equal to or greater than the radius of the FIA plot. We tested site selection for spatial bias prior to initiating measurements.

Measurements within each FIA plot included: 1) tree species, diameter, and height within each nested plot; 2) shrub species, height, and width along fuels transects within subplots; 3) litter and duff depth, as well as 1-hour (small twigs <0.25 inch diameter), 10-hr (0.25-1.0 inch diameter branches), 100-hr (branches and stems 1-3 inches in diameter), and 1,000-hr (large downed woody debris) fuel loadings along subplot fuels transects.

We summarized these plot measurements to estimate basal area per acre, trees per acre, quadratic mean diameter, species composition, snag component, fuel loading, and shrub cover for each FIA plot. We made exploratory comparisons of vegetation metrics between treatment and non-treatment foraging locations using mixed-model logistic regression with repeated measures in SAS 9.2.

RESULTS

We tracked a total of 10 spotted owls (6 females, 4 males) during the study; we were able to track 6 owls continuously between May 2007 and October 2008 (Fig. 3). Eight owls (3 males, 5 females) were radio-marked in 2007, including 2 pairs. Two birds were found deceased in early 2008: a male was predated, and necropsy results for a female indicated parasitism and emaciation. One additional male and 1 female were radio-marked in 2008, bringing the sample size again to 8 owls: 3 males and 5 females, including 2 pairs (Fig. 3).

During the 2007 season, we gathered a total of 236 nocturnal use locations across all individuals, with 4 locations occurring within fuels treatments. In 2008, we gathered nocturnal use locations for 7 owls within the study area; one bird remained outside of the study area and was tracked during daytime hours. For the 7 individuals tracked in 2008, we gathered a total of 210 nocturnal use locations, and 32 of these locations occurred within fuels treatments.

Home Range Analysis

We estimated home ranges for 9 owls; 30-60 owl use locations established each home range (Seaman et al. 1999). One female (M44) made a large northward movement outside of the study area in 2007, and remained outside of the study area in 2008; we were logistically unable to gather 30 nocturnal use locations for her. This female was excluded from home range, second-order selection, and third-order selection analyses, but was included in analysis of foraging site vegetation plots.

Home ranges estimated by the 100% Minimum Convex Polygon (MCP) method were similar across years ($F_{1,4} = 3.53$, $p= 0.134$; Table 1). Home ranges estimated with the 95% fixed kernel estimator were also similar across years ($F_{1,4} = 1.17$, $p= 0.341$), and were consistently larger than 100% MCP home ranges (Table 1). Fixed kernel home range sizes were similar for both sexes ($F_{1,7} = 0.35$, $p= 0.575$) and breeding and non-breeding owls ($F_{1,3} = 0.55$, $p= 0.511$). Home range area, as calculated by the fixed kernel estimator, was not correlated with the area of understory thin ($F_{1,3} = 0.08$, $p= 0.792$) or underburn ($F_{1,2} = 4.23$, $p= 0.176$) within the home range. However, home range area increased as the total area of fuels treatments within the home range increased ($F_{1,7} = 5.68$, $p= 0.049$; Fig. 4), and there were suggested trends of increasing home range size with increasing area of DFPZ ($F_{1,7} = 4.24$, $p= 0.078$) and group selection ($F_{1,7} = 4.96$, $p= 0.061$) within the home range.

Of the 4 treatment types, owl home ranges contained primarily DFPZs ($\bar{x} =$ 234 ha, SE = 51.8, $n = 9$), while group selections comprised little home range area ($\bar{x} =$ 36.8 ha, SE = 8.8, $n = 9$). Underburn ($\bar{x} =$ 236 ha, SE = 70.6, $n = 4$), and understory thin ($\bar{x} =$ 222 ha, SE = 70.1, $n = 5$) were not available within all owl home ranges, and showed greater variation in area. The total area of fuels treatments within owl home ranges was not correlated with year ($F_{1,4} = 0.42$, $p = 0.551$), sex ($F_{1,7} = 2.40$, $p = 0.165$), or reproductive status of the owl ($F_{1,3} = 2.34$, $p = 0.224$).

Owl Use of Treatment Areas: Home Range Placement

The proportions of each treatment type within home ranges varied widely among owls (Table 2), especially for understory thins and underburn treatments, which were not uniformly distributed across the study area. The resource selection function includes PAC and untreated, undesignated forest areas for comparison purposes. Although PACs are created around owl site centers, due to movement of pairs between alternate core areas and territoriality of resident birds, it is atypical for all PACs to be concurrently occupied. Thus, owl home ranges may include one or, rarely, more neighboring PACs, and use a total PAC area greater than 300 acres. In this study, owl home ranges included an average of 13.4% (SE = 1.4%, $n = 9$) PAC.

Selection ratios ($\hat{w}_i$) suggest that proportions of treated areas within owl home ranges were similar to proportions of treatments available on the landscape, with the exception of understory thin (Table 2). However, there is large variation between owl home ranges and all 90% Bonferoni confidence intervals for fuels treatments widely overlap 1, indicating composition of all fuels treatments within home ranges is similar to that available within the study area. PAC was the only habitat type clearly selected for, which is expected based on the location of PACs at the center of most home ranges.

Owl Use of Treatment Areas: Foraging

At the foraging scale, owl use of fuels treatments varied widely, and independently of the percentage of the home range that had been treated. Four owls (D83, M07, S49, and S89) did not have any nocturnal use locations within fuels treatments, although fuels treatments accounted for 7-18% of these home ranges. Locations within fuels treatments comprised 3-13% of the nocturnal use locations for 4 owls (B74, D72, W01, and W31), while fuels treatments accounted for 7-35% of these home ranges. Interestingly, 53% of the nocturnal use locations for 1 owl (P58) were within fuels treatments, while the owl's home range contained a total of 28% treatment; in 2007, this owl colonized a previously treated area. Across all birds and both study years, a total of 36 owl locations (8%) were within fuels treatments; 44% of these locations are accounted for by the P58 male.

The amount of fuels treatments available within each owl home range varied widely (Table 2), but owls utilized all fuels treatment types on at least 1 occasion (Table 3). The mean proportion of owl locations in DFPZ (2.8%, SE = 1.2%, $n = 9$) was lower than expected at random (7.8%, SE = 1.0%, $n = 9$; $F_{1,8} = 10.79$, $p = 0.006$). In contrast, the proportions of owl and random locations within group selection treatments were similar ($F_{1,8} = 0.77$, $p = 0.41$).

As understory thin and underburn treatments were not uniformly distributed across the study area, we restricted underburn and understory thin analyses to owls whose site centers were within 1 mile of the respective treatment. For the 5 home ranges which contained understory thin, the number of owl and random locations within understory thins was similar ($F_{1,4} = 0.77$, $p = 0.41$; Fig. 5). Four owl home ranges contained similar proportions of owl and random locations within underburn ($F_{1,3} = 3.82$, $p = 0.15$).

Owls consistently foraged closer to the site center ($\bar{x}$= 1770 m, SE = 241 m, *n* = 9) than random ($\bar{x}$= 2157 m; SE = 229 m, *n* = 9; $F_{1,8}$ = 22.48, *p* = 0.002), which is expected for central-place foragers. The second-order derivative of distance to site center (distance + distance^2) also was much smaller amongst owls than expected at random ($F_{1,8}$ = 9.66, *p* = 0.015), but the third- order derivative of distance (distance + distance^2 + distance^3) was similar amongst owl and random points ($F_{1,8}$ = 3.63, *p* = 0.093). This differs from the results of other telemetry studies, in which the third-order polynomial distance was shown to be important in modeling owl foraging habits (Rosenberg and McKelvey 1999, Glenn et al. 2004).

While owl use of DFPZs was less than expected by random chance, the distance of owl locations to DFPZs was similar to random ($F_{1,8}$ = 3.39, *p* = 0.103). Furthermore, owl distances to fuels treatments were also similar to random for group selections ($F_{1,8}$ = 0.03, *p* = 0.87), understory thin ($F_{1,4}$ = 0.17, *p* = 0.70), and underburn ($F_{1,3}$ = 3.01, *p* = 0.18).

The model that best described owl selection of fuels treatments for foraging included owl identity, survey year, and distance to the nearest PAC as metrics (w_i= 0.438; Table 4). We considered 4 models ($\Delta AIC_c \leq 2.11$) to be competitive. However, parameters of owl identity, year, and distance to PAC were shared by all competitive models, which vary in complexity from 5 to 6 parameters. As the addition of a parameter to a well-supported model can result in a ΔAIC_c value of ≤ 2 of the original model, even if the new variable is of poor explanatory value (Burnham and Anderson 2002, Arnold 2006), we argue that the distance to site center parameters of the competitive models provide little additional explanatory information beyond the simpler top model. Distance to site center and its polynomial derivatives were supported as weakly informative throughout the model set. Models containing sex consistently ranked > 10 ΔAIC_c units from the competitive models, and were not considered explanatory.

The distance of owl locations from fuels treatments was best explained by owl, year, and third-order distance to site center as parameters (w_i= 0.965; Table 5). Based on the Akaike weights (w_i), the top model is 30 times more likely than the next best model to explain the variation in these data, among the models in the suite. Sex and linear distance to the site center consistently ranked poorly in the model set (> 20 ΔAIC_c units from the top model).

The proportion of owl locations within fuels treatments was best described by the model of owl identity (Table 6); there was no improvement over the null model. Although the model of owl identity and year achieved the highest Akaike weight (w_i= 0.401) it is within 1 ΔAIC_c value and contains 1 more parameter than the model with the next lowest AIC_c value. Therefore, the additional parameter of 'year' cannot be relied upon to provide any additional explanatory power over the simpler competitive model of owl identity. There was mild support for the distance from the site center to the nearest understory thin, underburn, and group selection ($\Delta\text{AIC}_c \leq 4$) in the model set. Sex, cumulative area of fuels treatments, and areas of DFPZ, group selection, and underburn within the home range did not contribute explanatory power to any models (> 20 ΔAIC_c).

Vegetation Analysis: Foraging Locations

FIA plots were conducted at 132 owl foraging locations, including 31 owl locations within fuels treatments. Owl foraging sites were composed predominantly of mixed conifer forest dominated by trees in the 12-24-inches size class, with an additional large proportion of trees in the ≥30-inches diameter size class (Figs. 6, 8; Table 7). Smaller size classes contributed the most trees per acre, but not the most basal area, suggesting a multi-layered understory with numerous small trees (Figs. 6, 7). Overall, owl foraging sites contained a mean basal area of 267 feet^2/acre (SE = 18.1, n = 132), with snags >15-inches diameter averaging 14.7% (SE = 0.31, n = 132) of the total basal area. Average plot density for owl foraging plots was 476 trees/acre (SE = 30.1, n = 132), with a snag contribution of 12 snags > 15-inches diameter per acre or 2.5% (SE = 0.5, n = 132; Table 7). Quadratic mean diameter averaged 10.6 inches (SE = 0.4, n = 132), across plots, with little variation between treated and untreated forest (Table 8).

Although 31 FIA plots were centered on owl locations within fuels treatments, with 7 additional plots having ≥1 subplots in a fuels treatment, most fuel loadings across plots were similar among treated and untreated areas (Table 8). Unexpectedly, treatment and non-treatment plots contained similar tonnages of litter ($F_{2,8} = 0.02$, p= 0.979), duff ($F_{2,8} = 2.02$, p= 0.195), 1-hour fuels ($F_{2,8} = 2.89$, p= 0.113), 10-hour fuels ($F_{2,8} = 0.00$, p= 0.999), and 100-hour fuels ($F_{2,8} = 1.36$, p= 0.310). Thousand-hour fuels, which typically occur as downed logs, were 4-7 times more prevalent in untreated forest plots than plots encompassing fuels treatments ($F_{2,8} = 7.63$, p= 0.014).

Large diameter trees (≥30-inches diameter) had less basal area per acre within treated forest, compared with untreated forest (Fig. 6, Table 8); this was significant for live trees ($F_{2,8} = 4.62$, p= 0.046), while a trend was suggested for snags ($F_{2,8} = 3.20$, p= 0.095). Black oak (*Quercus kelloggii*) basal area was similar among treated and untreated forest ($F_{2,8} = 0.22$, p= 0.808). Similarly, basal area of other hardwoods, such as big leaf maple (*Acer macrophyllum*), canyon live oak (*Quercus chrysolepis*), and Pacific dogwood

(*Cornus nuttallii*), were similar between treated and untreated forest ($F_{2,8} = 1.71$, $p = 0.242$).

DISCUSSION

Completion of the Meadow Valley Project area presented a unique opportunity to investigate spotted owl foraging patterns immediately following implementation of a landscape-scale fuels reduction project. Results presented here document an exploratory case study designed with a passive adaptive management approach, and should be viewed within this framework.

At the scale of the entire study area, owls did not appear to select treated or untreated parts of the landscape; however, within their home ranges, owls selected against DFPZ treatments. Our data preclude resolution of the influence of habitat modification (e.g. fuels treatment) versus a simple influence of distance. As expected for a central-place forager, spotted owl foraging locations were closer to their site center than would be expected by random movements. Glenn et al. (2004) and Bond et al. (2009) reported that spotted owls selected foraging habitat based at least partly on proximity to the site center. Because fuels treatments are not permitted within the 300-acre PAC that surrounds the owl site center, available fuels treatments within each owl's home range were, by default, not available for owl choice near the core, thus complicating the interpretation of this result.

One noteworthy exception to the above pattern is the foraging location choice of male P58 (Table 3). This bird colonized a new site in 2007; approximately 30% of its home range had been treated 1-7 years prior to occupancy, primarily in the form of thin followed by underburn. Thus distance of treatments to site center for this bird were notably smaller than for other spotted owl home ranges, which may have contributed to the dramatic difference between the number of foraging locations in treatment between this bird and other birds in the study area. The P58 home range also is unparalleled in the amount of underburned forest it contains, and there is not a comparable home range within the study area to further clarify whether the foraging choices of this bird are primarily derived from distance to the site center, or habitat and prey characteristics of underburned forest.

Positive and neutral post-fire effects have been noted for 2 common California spotted owl prey species, dusky-footed woodrat (*Neotoma fuscipes*) and deer mice (*Peromyscus* spp.). In California's southern Coast Range, low to moderate intensity understory fire did not reduce survival or abundance of dusky-footed woodrats in oak woodlands (Lee and Tietje 2005). In the north-central Sierra Nevada, Amacher et al. (2008) recorded an increase in deer mouse (*P. maniculatus*) populations following either underburn of a mechanical thin, or underburn without thinning. In Arizona and northern New Mexico, Converse et al. (2006) also reported increasing deer mouse populations after fire, particularly in areas that had been dense forest stands before thinning.

The effects of underburn treatments on another primary spotted owl prey species, the northern flying squirrel (*Glaucomys sabrinus*), are less understood. Flying squirrels preferentially select microhabitats with hypogeous fungi (truffles; Pyare and Longland 2002); Waters et al. (1994) found no difference in the production of hypogeous fungi between burned and unburned stands. In the southern Sierra Nevada, flying squirrel density was positively associated with increasing litter depth following underburn treatments, while there was no association of flying squirrels with log volume in burned areas (Meyer et al. 2007). Within the MVP area, litter depth at owl locations in untreated forest was similar to litter depth at owl locations within fuels treatments; this suggests either that litter depths are consistent throughout the study area, or that owls select treated areas that have litter depths similar to untreated forest.

Within home ranges, spotted owls selected against DFPZs while foraging. While owls foraged less in DFPZ than would be expected by chance, the distance of their locations to the nearest DFPZ did not differ from random, suggesting that avoidance of DFPZs is limited to the treatment itself and not the area surrounding treatment. DFPZs are characterized by a reduction of understory components such as debris, shrub, and herbaceous cover: all habitat characteristics critical to the abundance of small mammals, particularly woodrats (Lee and Tietje 2005, Innes et al. 2007). Zabel et al. (1995) reported smaller spotted owl home ranges among owls that consumed more woodrats, compared to a weak correlation between home range size and proportion of late-seral forest. Supporting this, Ward (1998) concluded that dusky-footed woodrats provided an energetic benefit to spotted owls over other prey species, and reported that owls selected edge sites for foraging where woodrats were abundant. In the Plumas National Forest, woodrats were positively associated with large downed wood (Innes et al. 2007); vegetation plots within fuels treatments contained fewer large decaying downed logs (1,000-hr fuels), than untreated forest plots, possibly indicating reduced habitat suitability for woodrats within fuels treatments.

While Converse et al. (2006) reported that deer mice respond positively to the presence of scattered or piled slash after thinning, the trends of increased spotted owl home ranges sizes with increasing area of DFPZ and total fuels treatment suggest a possible degradation of habitat character (Carey et al. 1992). Although Abacher et al. (2008) reported an increase in deer mice populations following underburn, they also recorded a decrease in deer mice abundance following mechanical thin without underburn. Northern flying squirrels preferentially select hypogeous fungi (truffle) and arboreal lichens as food, and truffle biomass is strongly associated with decaying logs and well-developed soil organic layers (Williams et al. 1992). Waters and Zabel (1995) reported low densities of flying squirrels in post-treatment shelterwood stands, suggesting a negative impact of intensive site preparation and logging. While Waters and Zabel reported no influence of understory cover on flying squirrel density, Carey (1995) found that flying squirrel density was positively correlated with the presence of ericaceous shrubs. Meyer et al. (2007) reported a positive association of flying squirrels with canopy cover in thinned forest, with no association with other overstory features such as large diameter trees or snags. Meyer et al. (2007) suggested that mechanical thinning, which removes a large amount of forest overstory, may reduce the microhabitat suitability for flying squirrels for several years post-treatment, as the canopy regenerates.

At the foraging scale, analysis of spotted owl use of group selections is limited. As group selections are small treatments (<0.8-ha), and comprise the lowest total area among all 4 treatment types, the practical likelihood of selection for group selections is low. Although spotted owl foraging locations in group selections did not differ from random, caution is warranted; only 1 of 446 owl use locations occurred in a group selection. Analyses suggest a positive correlation of home range size and area of group selections within the home range; however, as group selections compose an average <1% of owl home ranges, and are typically embedded within or located near DFPZs, we argue that this pattern is correlated with DFPZ trends. A prohibitively large sample size likely is required to draw statistical inferences regarding spotted owl use of group selections, due to the small total area of group selection on the landscape.

At the landscape scale, spotted owl home ranges contained fuels treatments in relative proportion to their prevalence in the landscape. However, foraging scale analyses indicate that spotted owls avoided DFPZ treatments, and Bonferroni confidence limits for the resource selection function varied from 0-2.62, suggesting that a larger sample size is required for clarification of trends. With these findings in consideration, it seems likely that the spatial configuration of spotted owl home ranges in the landscape is correlated with habitat factors other than fuels treatments, which compose a total of 17% of the study area.

Four of the 5 spotted owls with estimated home ranges for both breeding seasons exhibited an increase in home range area of 80% during the second year of study. Furthermore, 89% of all foraging locations within fuels treatments were recorded in 2008; these may be attributable to annual variation in owl foraging, or the introduction of 2 birds into the sample (to replace 2 birds lost during winter), including the P58 male. As we note above, due to the absence of fuels treatments within PACs, the spatial configuration of fuels treatments within owl home ranges necessitates longer travel distances for selection of fuels treatments for foraging. Across this study area and the adjacent Plumas demographic study area, more spotted owl pairs made successful reproductive attempts in 2007 than in 2008 (2007, 55% of pairs, $n = 29$; 2008, 5% of pairs, $n = 26$; PSW, unpublished data). Below-average reproduction throughout the study area in 2008 may have influenced home range size; without the restriction of transporting prey to a nest, owls may have ventured longer distances from the site center (Zabel et al. 1992). An apparent long-term decline of woodrats in the Plumas National Forest (Jesmer et al. 2009), also may have encouraged longer owl foraging distances, and thus larger home range sizes, in 2008.

MANAGEMENT IMPLICATIONS

Our objectives were to establish a baseline of information regarding spotted owl foraging habits in a post-treatment landscape. At the scale of our study area, owl home ranges contained fuels treatments in proportion to their availability on the landscape. Spotted owls used DFPZ, understory thin, group selection, and underburn treatments for nocturnal activities on at least one occasion; 51% of these locations were in underburn. Spotted owls selected against DFPZs, but not other fuels treatments, for nocturnal activities; we hypothesize that the habitat character of DFPZs may be unfavorable for common spotted owl prey species. One owl strongly selected underburn treatments over untreated forest for foraging; limited availability of underburn within the study area prevents further extrapolation of this result. Spotted owls foraged much closer to their site center than expected by chance; because fuels treatments are not permitted within PACs (located at most owl site centers), the required travel distance between the site center and fuels treatments complicates interpretation of results. We recommend further exploration of spotted owl use of fuels treatments, particularly underburn, across multiple time periods and at patch, home range, and landscape spatial scales. Additionally, considerations should be given to the design and implementation of rigorous experimental studies to address the effects of fuels treatments on spotted owl nesting and foraging habitat. A repeat of this study in 4-5 years, coupled with a study of spotted owl population dynamics, would provide a comprehensive assessment of owl response in the MVP area. Evaluation of long-term effects is critical for long-lived species such as the spotted owl (Blakesley et al. 2006); effects of fuels treatments on the owl may manifest after short and long time periods, each with ramifications for ecological understanding in the Sierra Nevada.

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Figure 1. The 238 km^2 (58,867-acre) spotted owl study area located in the Plumas National Forest, in the northern Sierra Nevada of California.

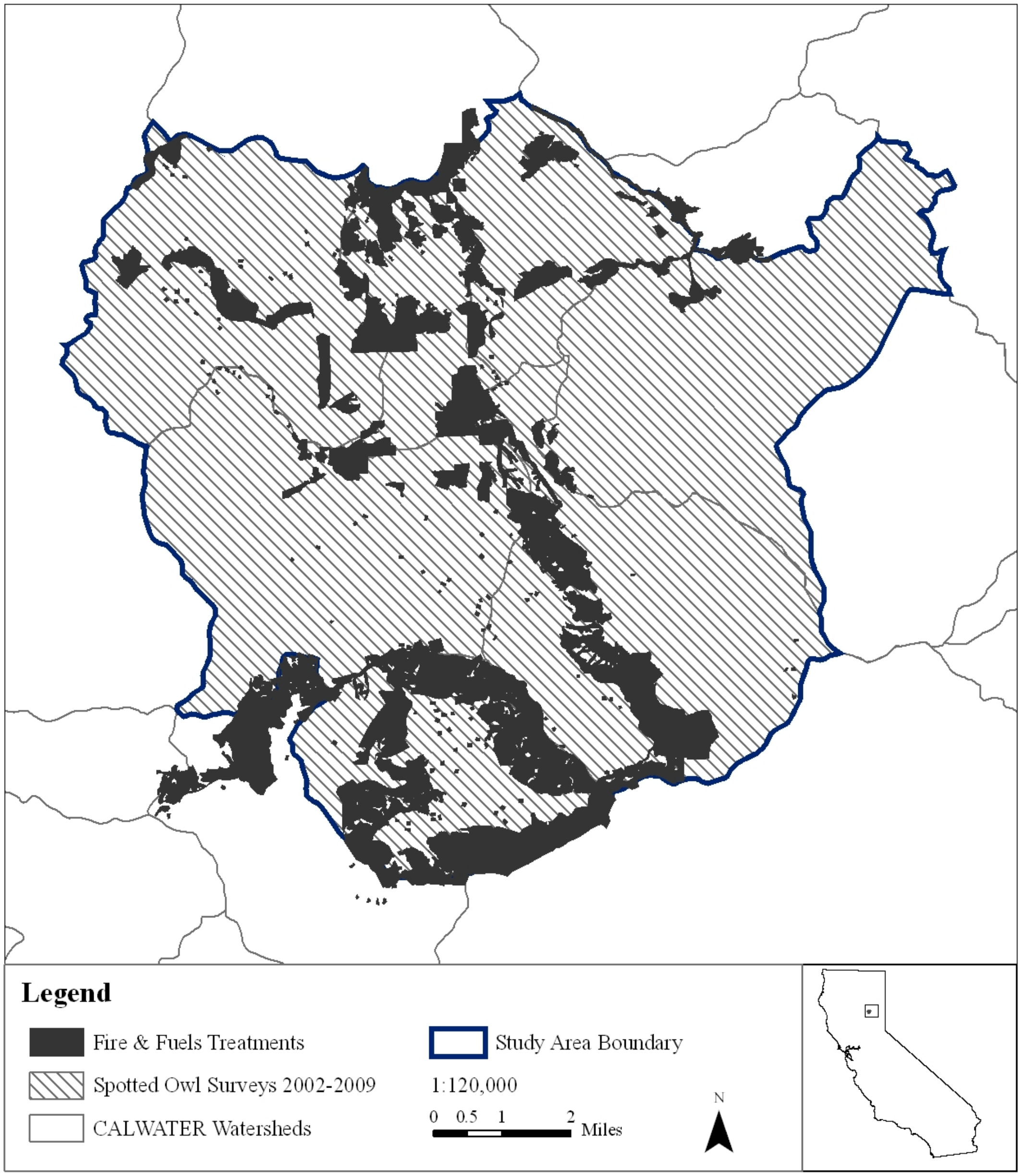

Figure 2. Spotted owl sites within the Meadow Valley Project area in the northern Sierra Nevada of California.

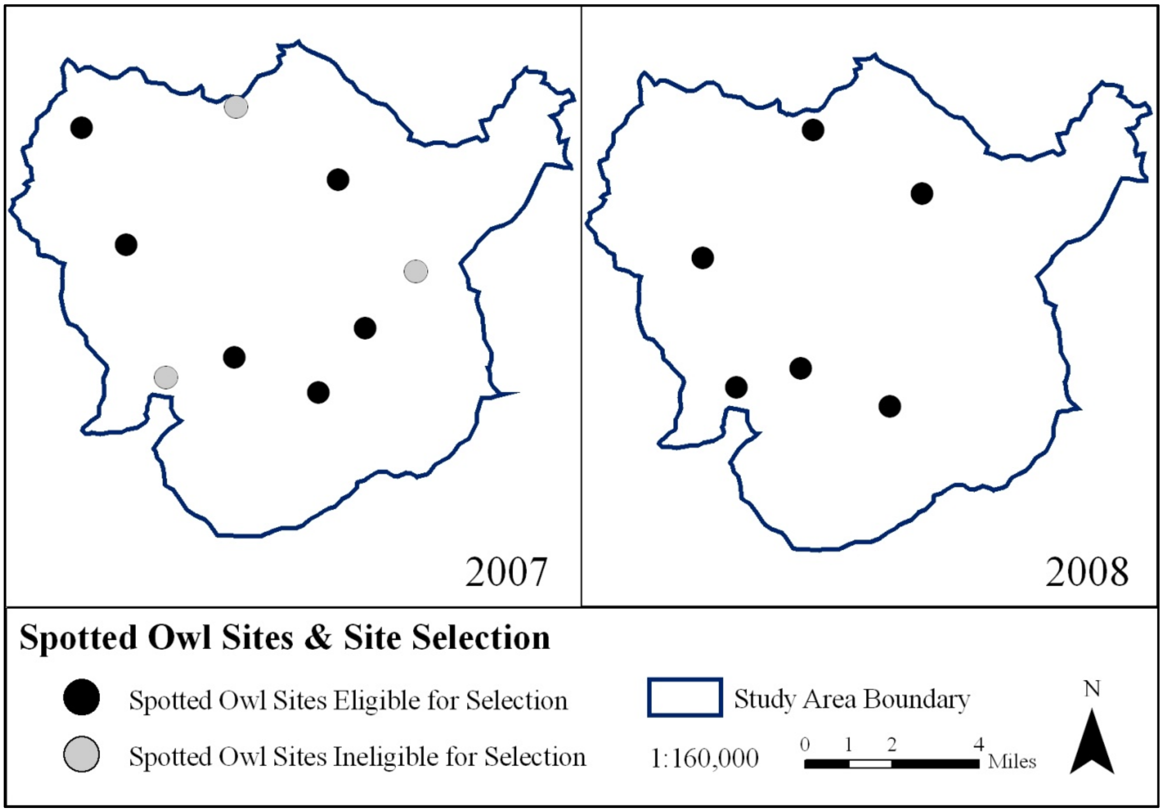

Figure 3. Tracking periods for individual spotted owls during the study period 2007-2008, in the Meadow Valley Project area in the northern Sierra Nevada, California.