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Plumas-Lassen Administrative Study
2011 Post-fire Avian Monitoring Report

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List of Figures & Tables

Executive Summary

In 2009 the avian module of the Plumas-Lassen Area Study (PLAS) expanded to address important questions related to post-fire habitat and its management. The primary objective of this study is to assess the influence of post-fire conditions on spatial and temporal variation in bird abundance, and to use this information to guide forest management actions of post-fire environments. In 2011 we continued sampling three areas that have burned in recent years within the boundaries of the original PLAS study: the Storrie, Moonlight, and Cub fires as well as 40 transects in the adjacent PLAS green forest treatment units.

We compared the abundance of 36 species that breed in the study area - representing a range of habitat types and conditions - between the three burned areas and green forest study sites. Sixteen species were significantly more abundant in burned areas and 14 were significantly more abundant in unburned habitat.

Shannon index of diversity, species richness, and total bird abundance were significantly higher in PLAS green forest in 2011 than any of the three burned areas. Among the three burned areas, Storrie had the highest indices for each of these three metrics. All three metrics were significantly lower in both the Moonlight and Storrie private lands than in the adjoining Forest Service lands.

Burn severity was a significant predictor of avian diversity and total bird abundance across burned areas with values highest at moderate burn severity though these point level measures of burn severity explained a relatively small portion of the variance in avian metrics.

We found and confirmed 122 active nests of 11 cavity nesting species in 2011 for a total of 366 nests found from 2009 – 2011. We found 14 Black-backed Woodpecker nests in 2011 for a total of 34 from 2009 – 2011. Black-backed and Hairy Woodpecker both showed strong selection for high snag densities (>8 per .1 acre plot) surrounding nests.

Here we present 24 management recommendations; a culmination of our results, scientific literature, and expert opinion. Some of these are hypotheses that should be tested to ensure the best possible management practices are being employed to sustain avian communities in the Sierra Nevada.

Post Fire Habitat Management Recommendations

General

- Whenever possible restrict activities that depredate breeding bird nests and young to the non-breeding season (August - April)
- Consider post-fire habitat as an important component of the Sierra Nevada ecosystem because it maintains biological diversity
- Consider the area of a fire that burned in high severity, as opposed to the area of the entire fire, when determining what percentage of the fire area to salvage log
- Consider the landscape context (watershed, forest, ecosystem) and availability of different habitat types when planning post-fire management actions
- Consider that snags in post-fire habitat are still being used by a diverse and abundant avian community well beyond the 5 to 10 year horizon often suggested

Snags

- Manage a substantial portion of post-fire areas for large patches (10 - 50 acres) burned with high severity as wildlife habitat
- Retain high severity burned habitat in locations with higher densities of larger diameter trees
- Retain high severity patches in areas where pre-fire snags are abundant as these are the trees most readily used in the first five years after a fire
- Retain snags in salvaged areas far greater than green forest standards and retain some in dense clumps
- Snag retention immediately following a fire should aim to achieve a range of snag conditions from heavily decayed to recently dead in order to ensure a longer lasting source of snags for nesting birds
- When reducing snags in areas more than five years post fire (e.g. Storrie fire) snag retention should favor large pine and Douglas Fir but decayed snags of all species with broken tops should be retained in recently burned areas

- Retain snags (especially large pine trees that decay slowly) in areas being replanted as they can provide the only source of snags in those forest patches for decades to come
- Consider retaining smaller snags in heavily salvaged areas to increase snag densities as a full size range of snags are used by a number of species for foraging and nesting from as little as 6 inches diameter, though most cavity nests were in snags over 20 inches

Early Successional Habitat

- Manage post-fire areas for diverse and abundant understory plant community including shrubs, grasses, and forbs. Understory plant communities provide a unique and important resource for a number of species in a conifer dominated ecosystem
- Most shrub patches should be at least 10 acres and shrub cover should average over 50% across the area in order to support area sensitive species such as Fox Sparrow
- Retain natural oak regeneration with multiple stems (avoid thinning clumps) as these dense clumps create valuable understory bird habitat in post-fire areas 10 – 15 years after the fire
- When treating shrub habitats to ensure some dense patches are retained. In highly decadent shrub habitat consider burning or masticating half the area (in patches) in one year and burning the rest in the following years once fuel loads have been reduced.
- Maximize the use of prescribed fire to create and maintain chaparral habitat and consider a natural fire regime interval of 20 years as the targeted re-entry rotation for creating disturbance in these habitat types

Shaping Future Forest

- Limit replanting of dense stands of conifers in areas with significant oak regeneration and when replanting these areas use conifer plantings in clumps to enhance the future habitat mosaic of a healthy mixed conifer hardwood or pine-hardwood stand
- Consider managing smaller burned areas (<5000 acres) exclusively for post-fire resources especially when there have been no other recent fires in the adjoining landscape.

- Retain patches of high burn severity adjacent to intact green forest patches as the juxtaposition of unlike habitats is positively correlated with a number of avian species including those declining such as Olive-sided Flycatcher, Western Wood-Pewee, and Chipping Sparrow
- Incorporate fine scale heterogeneity in replanting by clumping trees with unplanted areas interspersed to create fine scale mosaics and invigorate understory plant communities and natural recruitment of shade intolerant tree species
- Plant a diversity of tree species where appropriate as mixed conifer stands generally support greater avian diversity than single species dominated stands in the Sierra Nevada
- Consider staggering plantings across decades and leaving areas to naturally regenerate in order to promote uneven-aged habitat mosaics at the landscape scale
- Consider fuels treatments to ensure the fire resiliency of remnant stands of green forest within the fire perimeter as these areas increase avian diversity within the fire and the edges between unlike habitats support a number of species (e.g. Olive-sided Flycatcher)
- Avoid planting conifer species in or adjacent (depends on the size of riparian corridor) to riparian areas to avoid future shading of riparian deciduous vegetation and dessication. Consider replanting appropriate riparian tree species (cottonwood, willow, alder, aspen) where appropriate

Introduction

In the Sierra Nevada, there is a pressing need to understand the nexus of silvicultural practices, wildfire, and fuels treatments in order to maintain forest ecosystems that are ecologically diverse and resilient. In the context of a century of fire suppression, at the core of the debate over how to manage Sierra forests is how to most appropriately manage areas where natural disturbance regimes have been disrupted. Land managers need more information about the suitability of habitat created through fire suppression, fuel treatments (DFPZ, groups, mastication), and wildfire and post-wildfire management to ensure the goals of maintaining biological diversity are achieved.

The challenge of integrating wildfire and forest management into wildlife conservation is not unique to the Sierra Nevada. Because large, infrequent disturbances are responsible for long-lasting changes in forest structure and composition (Foster et al. 1998), they are recognized as a critical element of bird community dynamics (Brawn et al. 2001). In many regions of western North America, fires burn with considerable spatial and temporal variability (Agee 1993), creating complex mosaics of vegetation patches. In these systems, changes in bird abundance are often linked to post-fire vegetation characteristics and landscape composition (Saab et al. 2002, Huff et al. 2005, Smucker et al. 2005).

In addition to fire suppression, there are a number of management activities that influence post-fire vegetation characteristics and landscape composition in working forests. These activities include salvage-logging, the mechanical mastication and herbicidal treatments to reduce broadleaf shrubs, and planting of conifer species that are favored by forestry. As a result, management activities may have profound influences on post-fire conditions- locally and across landscapes.

Beginning in 2009 the avian module of the Plumas-Lassen Administrative Study (PLAS) expanded to address important questions related to post-fire habitat and its management. The primary objective of this study is to assess the influence of post-fire conditions on spatial and temporal variation in bird abundance, and to use this information to guide forest management that can maintain avian diversity across multiple spatial scales. We began sampling three areas affected by fire within the boundaries of the original PLAS study: the Storrie fire that burned in the fall of 2000, the Moonlight Fire that burned in the Fall of 2007, and the Cub Fire that burned in the summer of 2008. Each of these fires burned at similar elevations and through primarily mixed conifer and true fir vegetation communities, but with varying severity patterns. This report provides results from the first three years of avian monitoring and uses ongoing monitoring of unburned actively managed "green" forest in the study area to provide context.

Methods

Study Location

The Plumas-Lassen Area Study avian module encompasses portions of the Mount Hough Ranger District of Plumas National Forest and the Almanor Ranger District of Lassen National Forest in the Sierra Nevada Mountains of Northeastern California (Figure 1). In 2009 we added three separate burned areas to our study within this same area. The elevations of sites surveyed ranged from 1126 – 1998 m with a mean of 1658 in the Cub fire, 1199 – 2190 m with a mean of 1779 in the Moonlight Fire, 1107 – 2011 m with a mean of 1528 m in the Storrie fire, and 1094 – 1902 m with a mean of 1483 m at the existing PLAS green forest sites.

Site Selection

Random starting points for each burned transect were generated in ArcGIS 9.2 within the boundaries of each fire (ESRI 2004). The original sampling area was limited to forest service land and sites with a slope of less than 40 degrees to allow access and safe navigation on foot in a timely manner. We maintained a minimum distance between transect starting points of 1500 m to ensure transects would not overlap and maximize a spatial balance within the sampling frame of each fire. Four more points were added to the starting point on a random compass bearing at 250 m spacing resulting in a 1 km long, five-point transect. We minimized the number of point counts to allow ample time to conduct cavity nest searches during the prime morning hours when bird activity is greatest.

Even with stratification to eliminate areas with steep slopes we had to drop approximately 10% of the original transects selected following field reconnaissance due to issues with access, safe navigation, or noise from nearby streams. We replaced the majority of these transects with new locations until nearly all surveyable areas in each fire were covered. However, due to steep topography and large road less areas in the Storrie fire – and to a lesser degree the Cub fire – our sampling is not evenly distributed across these fires as it is in the Moonlight.

In 2010 we added an additional ten transects on private land managed by W. M. Beaty & Associates, Inc; six in the Moonlight Fire, and four in the Storrie fire. These transects were selected using the same protocol as described above, but in this case, the sample area was defined as the private land within the fire boundary, shown in white on the map (Figure 1). We then selected the maximum number of transects that the sample area size would allow.

A total of 60 transects (300 stations) were surveyed across the three fires in 2011. A total of 32 transects were surveyed in the Moonlight fire (including 6 on private land), 13 in the Cub Fire, and 15 in the Storrie fire (including 4 on private land). Snow prevented access to two Storrie transects (ST04 and ST15) before July, thus they were not surveyed in 2010 or 2011. Site selection for PLAS green forest study sites followed a similar random selection protocol except each transect contained 12 points instead of five, and approximately 25% of transects were systematically established in areas where treatments were planned (many now implemented). The PLAS site selection protocol for the unburned "green forest" sample is described in detail in the original PLAS study plan and previous annual reports (Stine et al. 2005, Burnett et al. 2009).

Figure 1. The location of PRBO point count transects in the Plumas-Lassen study area in 2010 & 2011.

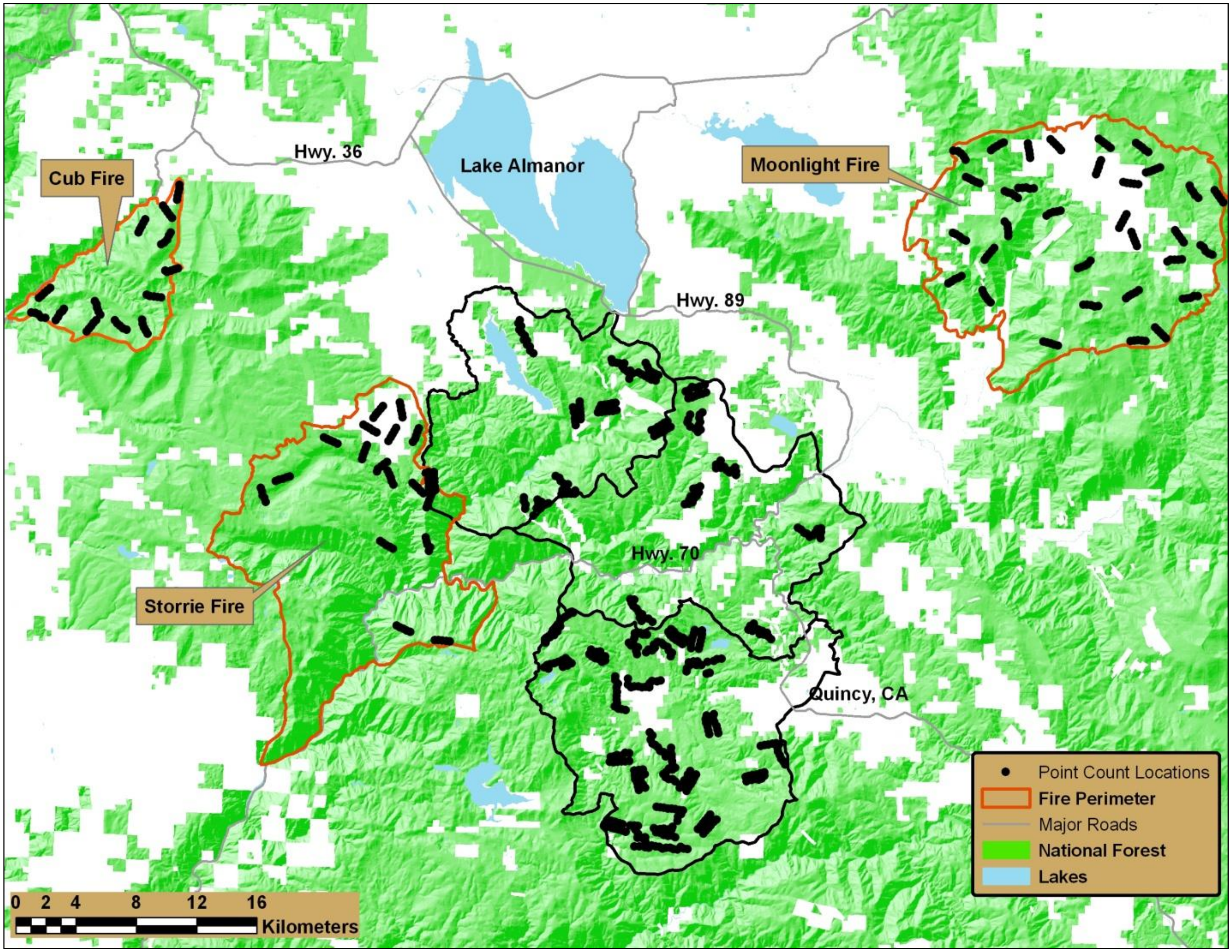
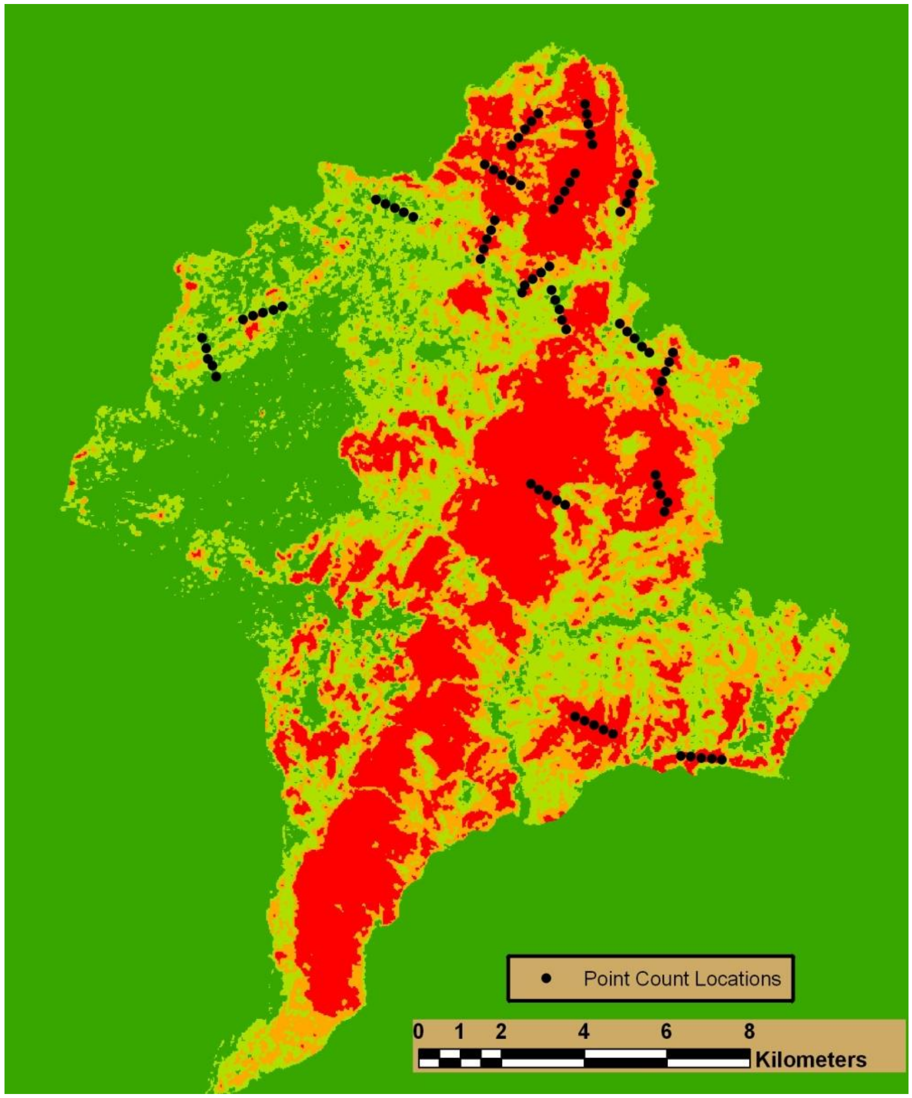
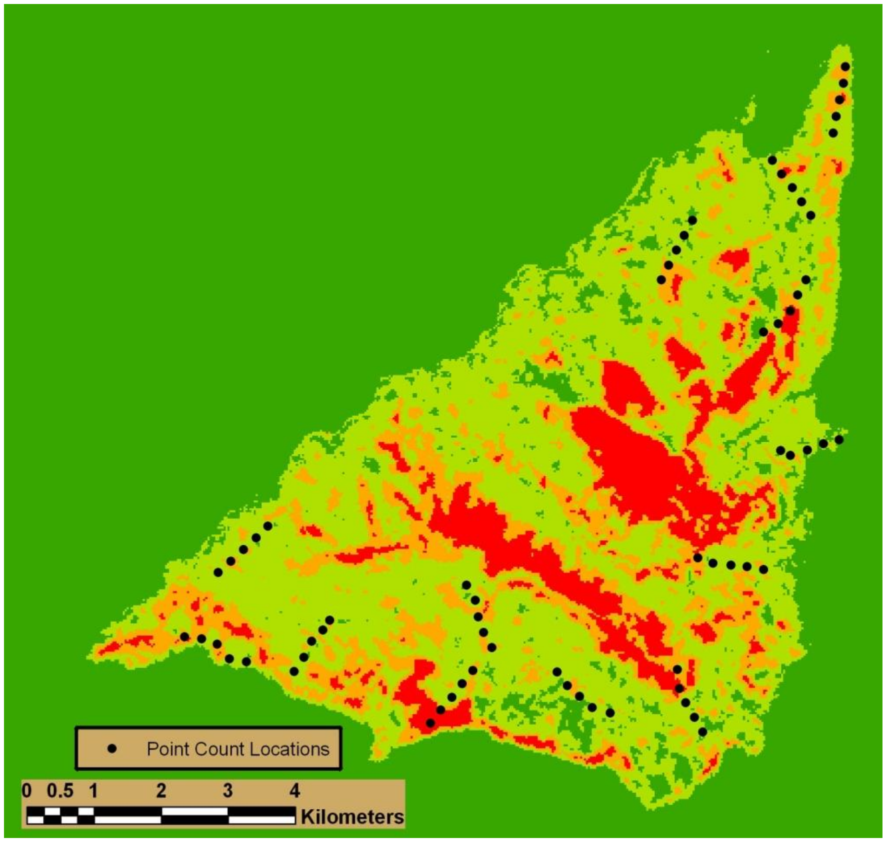


Figure 2. Location of PRBO point count stations overlaid on composite burn index fire severity maps for each of three fires in the study area. Red = high severity, Orange = moderate, Lime = low severity, and green is unburned.

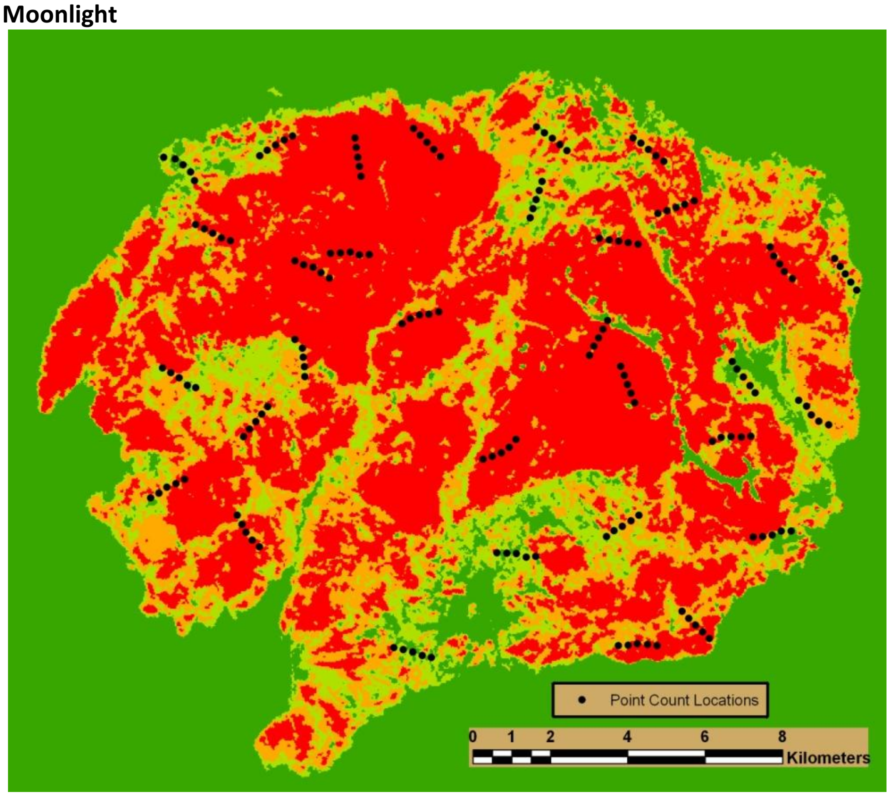
Storrie



Cub



Moonlight



Bird community surveys

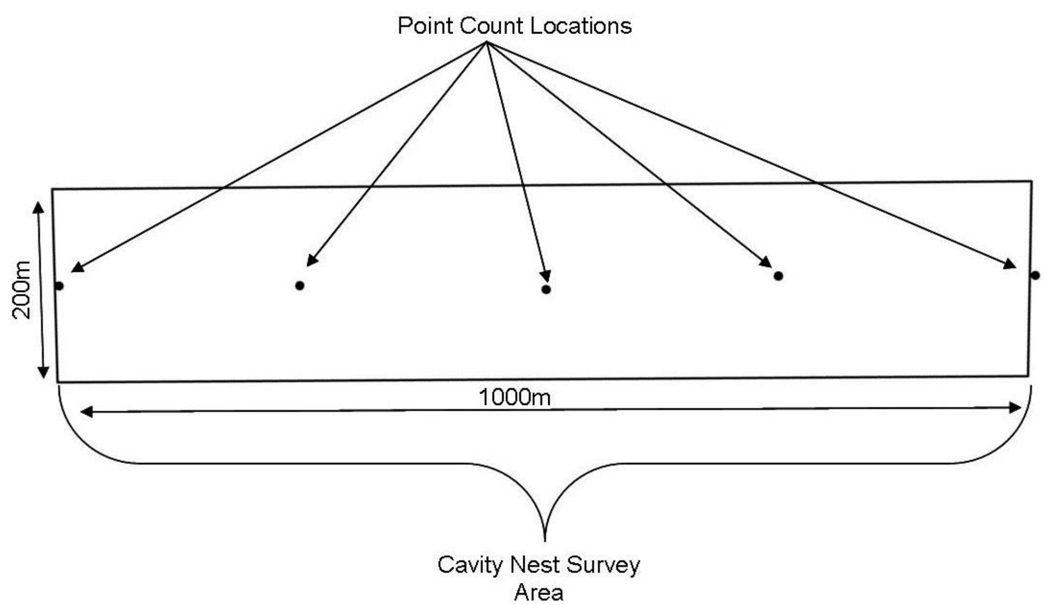
The avian community was sampled using a five minute, exact-distance, point count census (Reynolds et al. 1980, Ralph et al. 2005). In this method points are clustered in transects, but data are only collected at the individual point. All birds detected at each point during the five-minute survey were recorded according to their initial distance from the observer. The method of initial detection (song, visual, or call) for each individual was also recorded. All observers underwent an intensive, three week training period focused on bird identification and distance estimation prior to conducting surveys. Laser rangefinders were used to assist in distance estimation at every survey point. Counts began around local sunrise, were completed within four hours, and did not occur in inclement weather. Aside from the two transects that were not accessible for the entire season (ST04 and ST15), all but 2 transects were visited twice during the peak of the breeding season from mid May through the first week of July. Cub 7 and Cub 8 were only visited once in 2011 due to administrative forest closures in those areas.

Cavity nest surveys

In addition to point count censuses, at each fire transect a 20 ha area (200 x 1000 m rectangle) surrounding the point count stations was surveyed for nests of cavity-nesting birds following the protocol outlined in "A field protocol to monitor cavity-nesting birds" (Dudley and Saab 2003). In order to focus our attention on species of interest we ignored some of the more common cavity-nesters. Our focal species included both species of bluebird, all woodpeckers, and all cavity-nesting raptors.

After the point count census was complete, the nest survey was conducted for between two and four hours depending on the habitat, terrain and time spent waiting to confirm a cavity's status. All nest surveys were completed by noon. The primary search method for finding nests was bird behavior though once suspicious birds were located observers often conducted a systematic search of snags in the vicinity. Once a potential nest was found, it was observed from a distance for approximately 20 minutes to confirm the cavity was an active nest. If that cavity was confirmed active, a variety of characteristics of both the nest tree and the cavity were recorded. These characteristics included diameter at breast height (DBH), tree height, tree species, cavity height, tree decay class, and the orientation of the cavity opening. For tree decay, we used a qualitative scale of decay ranging from one to eight, with one being a live, intact tree and eight being a severely decayed stump (Appendix C). If the observer was unable to confirm the cavity was active, its location was recorded to aid nest searchers during the second visit. Only confirmed active nests were used in analysis presented herein.

Figure 3. PRBO Northern Sierra post-fire habitat survey plots.



Vegetation surveys

Vegetation data was collected at all burned points in 2009, 2010, and 2011. We measured vegetation characteristics within a 50 m radius plot centered at each point count station following the relevé protocol outlined in Stine et al. (2005). On these plots we measured shrub cover, live tree cover, and herbaceous cover as well as the relative cover of each species in the shrub and tree layers through ocular estimation. We also collected basal area of live trees and snags using a 10-factor basal area key. To estimate the density of snags across the plot, we recorded data (e.g. DBH, species, height, decay) on every snag within 11.3 m of the center of the point count location. In addition to the point count stations, we collected the same snag data at all active nests, as well as at 5 random locations distributed throughout the 20 ha nest plot. To select these random points, coordinates were first generated in ArcGIS 9.2 to serve as a guide

(ESRI 2004). Once in the field, the observer navigated to within 10 m of the random point and then chose the closest tree over 12 cm DBH as the center of the random snag plot. The center trees of these random snag plots were used as a sample of “random nest trees” and all data collected for active nests were also collected for these random “nests.”

Analysis

We compared an index of the abundance of 36 species (detections within 50 m of observer) on Forest Service land across all three fires combined and the PLAS green forest. The index was derived by taking the summed detections per year (2 visits to each site) within 50 m of observers. We then used negative binomial regression with total count of each species as the independent variable and burn status as the dependent variable. We limited our analysis to species with a mean per point abundance for all fires combined or all green forests sites combined of at least 0.10. We used this cutoff as previous analysis with this data suggested it was a good estimate of the level for which we had enough power to detect significant effects. We also included Black-backed Woodpecker and Mountain Quail – two management indicator species for National Forest lands in the Sierra Nevada that did not meet this abundance threshold as they are Management Indicator Species. This resulted in a list of 36 species which represented 95% of all detections within 50 meters of observers in our dataset. We present mean detections within 50 m of observers per point count station per visit to be comparable to previous reports using this data but analysis was conducted on total detections to meet the assumptions of negative binomial regression (Cameron and Trivedi 1998).

In order to quantify the overall songbird community in the study areas we used three different metrics, the Shannon Index of species diversity, species richness, and total bird abundance. The Shannon index used a transformation of Shannon’s diversity index (or H', Krebs 1989) denoted N_1 (MacArthur 1965). The transformation expresses the data in terms of number of species and thus is more easily interpreted. Expressed mathematically:

$$N_1 = e^{H'} \text{ and } H' = \sum_{i=1}^{i=S} (p_i)(\ln p_i)(-1)$$

Where S = total species richness and p_i is the proportion of the total numbers of individuals for each species (Nur et al. 1999). High Shannon index scores indicate both high species richness and more equal distribution of individuals among species. Species richness is defined simply as the number of species detected within 50 m of each point summed across the two visits and total bird abundance is the sum of all species detected per visit within 50 m. All species that do not breed or naturally occur in the study area and those that are not adequately sampled using the point count method including waterfowl, shorebirds, waders, and raptors were excluded from each calculation. These metrics were investigated for each fire, and the Plumas Lassen Administrative Study green forest study sites (Figure 4).

We investigated the effect of burn severity on avian diversity and total bird abundance across each of the three fires and all fires combined. To classify burn severity we used a relative differenced normalized burn ration (RdNBR) ground truthed and converted to Composite Burn Index (CBI) units using regression (Miller and Thode 2007). This index represents the magnitude of effects caused by the fire and incorporates various strata including changes to soil, amount of vegetation and fuels consumed, re-sprouting from burned plants, and blackening or scorching of trees (Key and Benson 2005). The values of CBI were derived from the Relative Differenced Normalized Burn Ratio (RdNBR) which was in turn derived from Landsat Thematic Mapper imagery, a method discussed by Miller and Thode (2007). The values range from zero, representing no sign of burning, to three, representing the highest severity. The Landsat data used to derive CBI was collected on 23 July 2008 for Cub, 7 July 2008 for the Moonlight, and 21 August 2001 for the Storrie fire and was provided by the Forest Service.

We excluded all sites that had been treated (e.g. salvaged or masticated) and all private lands. We used linear regression with untransformed bird data to evaluate the effect of CBI on these metrics. We standardized values of CBI in order to evaluate non-linear relationships of the effect of fire severity on avian community metrics expressed as:

$$z = \frac{x - \mu}{\sigma}$$

Where x = each point level estimate of CBI, μ = the sample mean, and σ = standard deviation of the sample.

For each metric we ran the models again with a squared standardized CBI term and compared the goodness of fit between the linear and 2nd order models using a likelihood ratio test. For each best fit model we present F-statistics and p-values and for goodness of fit tests we present χ^2 likelihood ratio statistics and associated p-values in Appendix A.

We compared an index of abundance of the 30 species that were showed a preference for burned or unburned forest between salvaged private land and un-salvaged National Forest land in the Moonlight and Storrie fires. We compared the summed total detections of all species in each group averaged per point count station across 2010 and 2011. We used detections within 50m of observers to reduce any biases in detectability. We evaluated the differences in abundance using a two-tailed t-test with the assumption of unequal variance and assumed statistical significance at the $p < 0.05$ level. All point count data collected for this study are available on the Sierra Nevada Avian Monitoring Information Network: http://data.prbo.org/apps/snamin/index.php?page=fire-home-page .

We evaluated selection for snag densities surrounding nest trees for the six cavity nesting species for which we had adequate sample sizes (Black-backed, Hairy, and White-headed woodpeckers, Mountain Bluebird, Northern Flicker, and Red-breasted Sapsucker) in the Cub and Moonlight fires. We excluded the Storrie due to lack of sample size for both Black-backed and Hairy Woodpeckers. We considered all randomly-selected trees to be available to nesting, such that we were comparing a sample of available nest trees to a sample of the used nest trees. This corresponds to the Sampling Protocol A and Design I described by Manly et al. (2002). We pooled data across the three years of the study. Because we searched the same plots in all years, it was likely that the same pairs were recorded in multiple years. This corresponds to Design 1 and is appropriate for making inferences about the population in our study area (Manly et al. 2002).

We evaluated snag density for each burn separately as well as combined. For each of the three snag density categories, we calculated the proportion of used and available trees. We treated both the used and available trees as a sample of the larger population and calculated the standard error of the proportion in each category following Manly et al. (2002). After preliminary analyses revealed relatively minor differences between the two burns, we limited our subsequent analyses of selection ratios to the pooled data set.

We calculated selection ratios by dividing the proportion of a used resource by the proportion of the corresponding available resource. If nest trees were used in proportion to their availability they would have a selection ratio of 1.0. A selection ratio > 1 implied preference, while a value < 1 implied avoidance. We first used a Pearson's chi-square goodness-of-fit test to evaluate if the pattern of nest tree use differed from the pattern of available trees (Manly et al. 2002). If we found evidence of preference ($P < 0.05$), we further interpreted the selection ratios for each category using simultaneous 95% Bonferroni confidence interval calculated over all categories. If these confidence intervals did not include one, we rejected the null hypothesis of use proportional to availability (Manly et al. 2002). Nest site snag density selection analysis was conducted in program R (R Version 2.10.1, http://cran.r-project.org/, accessed 27 November 2011), using the package adehabitat (Calenge 2006).

Results

Avian Community Composition

Comparing the abundance of 36 species that breed in the study area and represent a range of habitat types and conditions, 16 were significantly more abundant in burned areas, 14 in unburned areas, and 6 showed no statistical difference (Table 1). Of the six showing no difference, each reached their greatest abundance in one of the three burns.

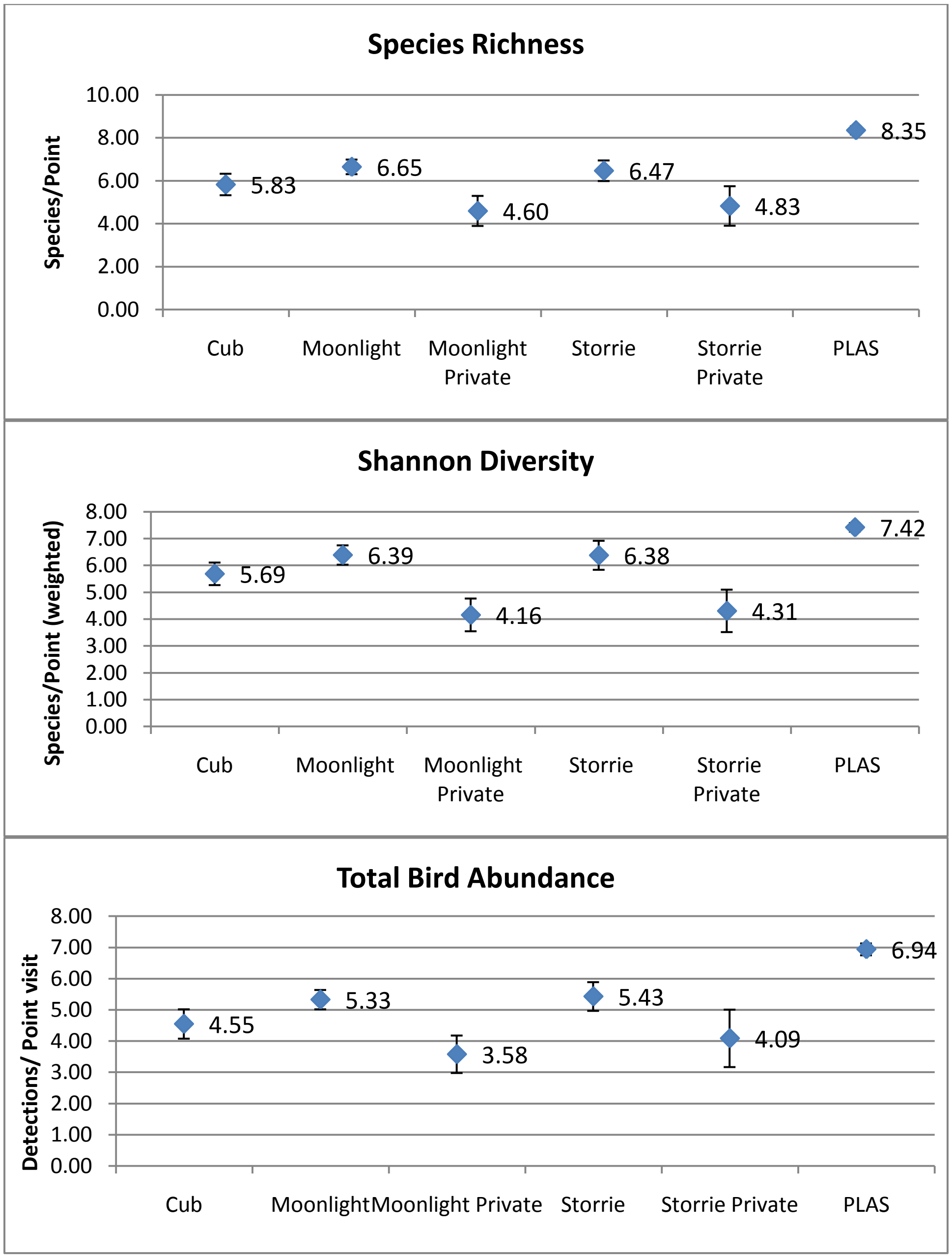
The patterns in species distribution observed in 2009 and 2010 continued in 2011 with species associated with low severity fire and unburned green forest being among the most abundant in the Cub Fire; while in the Moonlight and Storrie fires species more strongly associated with early successional habitats and disturbance (e.g. woodpeckers, shrub nesters) among the most abundant (Table 1). One exception was Black-backed Woodpecker which was found in relatively small patches of high snag density throughout the Cub fire.

Shannon index of avian diversity, species richness, and total bird abundance continued to show similar patterns in 2011. Each index was highest in unburned forest and lowest on private land (Figure 4). All three indices increased across each of the three fires and the PLAS green forest in 2011 for the second consecutive year with Moonlight showing the greatest increases; in 2011 indices there were the highest for any of the three fire areas monitored.

Table 1. An index of the abundance (mean detections per point per visit < 50m) of 36 species on National Forest land in three burned areas and the adjacent unburned Plumas-Lassen Area Study (PLAS) averaged from 2009 - 2011.Species are listed based on whether they were significantly (p<0.05) more abundant within all burned areas combined or the PLAS green forest study area. SE = Standard Error.

More Abundant Inside Burn	**Cub**	SE	**Moonlight**	SE	**Storrie**	SE	**PLAS**	SE
Mountain Quail	**0.01**	0.01	**0.01**	<0.01	**0.03**	0.02	**0.004**	<0.01
Hairy Woodpecker	**0.12**	0.02	**0.11**	0.02	**0.03**	0.01	**0.03**	<0.01
White-headed Woodpecker	**0.09**	0.02	**0.05**	0.01	**0.03**	0.01	**0.02**	<0.01
Black-backed Woodpecker	**0.02**	0.01	**0.03**	0.01	**0.00**	0.00	**0.002**	<0.01
Olive-sided Flycatcher	**0.05**	0.01	**0.04**	0.01	**0.07**	0.02	**0.03**	<0.01
Western Wood-Pewee	**0.06**	0.02	**0.09**	0.01	**0.13**	0.03	**0.03**	<0.01
Mountain Bluebird	**0.01**	0.01	**0.09**	0.01	**0.01**	0.01	**0.001**	<0.01
Brown Creeper	**0.23**	0.03	**0.15**	0.02	**0.13**	0.03	**0.13**	0.01
House Wren	**0.01**	0.01	**0.06**	0.01	**0.25**	0.04	**0.04**	0.01
Lazuli Bunting	**0.02**	0.01	**0.32**	0.03	**0.37**	0.05	**0.03**	<0.01
Spotted Towhee	**0.04**	0.01	**0.04**	0.01	**0.33**	0.04	**0.07**	0.01
Green-tailed Towhee	**0.05**	0.01	**0.06**	0.01	**0.09**	0.02	**0.01**	0.02
Chipping Sparrow	**0.02**	0.01	**0.17**	0.02	**0.15**	0.02	**0.03**	<0.01
Fox Sparrow	**0.12**	0.03	**0.35**	0.03	**0.55**	0.06	**0.22**	0.01
Dark-eyed Junco	**0.37**	0.04	**0.72**	0.04	**0.40**	0.04	**0.45**	0.01
Cassin's Finch	**0.05**	0.01	**0.11**	0.01	**0.06**	0.02	**0.03**	<0.01
More Abundant Outside Burn								
Hammond's Flycatcher	**0.18**	0.04	**0.14**	0.02	**0.03**	0.01	**0.26**	0.01
Dusky Flycatcher	**0.16**	0.03	**0.36**	0.03	**0.25**	0.03	**0.36**	0.02
Cassin's Vireo	**0.05**	0.01	**0.03**	0.01	**0.04**	0.01	**0.21**	0.01
Mountain Chickadee	**0.40**	0.04	**0.26**	0.02	**0.23**	0.03	**0.42**	0.01
Red-breasted Nuthatch	**0.42**	0.04	**0.13**	0.02	**0.17**	0.03	**0.43**	0.02
Golden-crowned Kinglet	**0.12**	0.02	**0.07**	0.01	**0.06**	0.01	**0.33**	0.01
Hermit Thrush	**0.01**	<0.01	**0.02**	0.01	**<0.01**	<0.01	**0.06**	<0.01
Nashville Warbler	**0.08**	0.02	**0.05**	0.01	**0.38**	0.04	**0.40**	0.02
Yellow-rumped Warbler	**0.45**	0.04	**0.33**	0.03	**0.20**	0.03	**0.48**	0.01
Hermit Warbler	**0.30**	0.05	**0.15**	0.02	**0.13**	0.02	**0.89**	0.02
Western Tanager	**0.27**	0.03	**0.33**	0.02	**0.11**	0.02	**0.32**	0.01
Black-headed Grosbeak	**0.07**	0.02	**0.03**	0.01	**0.10**	0.02	**0.11**	0.01
Evening Grosbeak	**0.06**	0.02	**0.01**	<0.01	**0.08**	0.02	**0.14**	0.01
Pine Siskin	**0.04**	0.02	**0.09**	0.02	**0.03**	0.01	**0.11**	0.01
No Statistical Difference								
Calliope Hummingbird	**0.01**	0.01	**0.05**	0.01	**0.06**	0.01	**0.04**	<0.01
Warbling Vireo	**0.09**	0.02	**0.10**	0.02	**0.04**	0.01	**0.10**	0.01
Stellar’s Jay	**0.10**	0.02	**0.06**	0.02	**0.07**	0.02	**0.08**	<0.01
American Robin	**0.05**	0.01	**0.10**	0.01	**0.07**	0.02	**0.07**	<0.01
Yellow Warbler	**0.03**	0.01	**0.03**	0.01	**0.15**	0.03	**0.05**	<0.01
MacGillivray's Warbler	**0.06**	0.02	**0.17**	0.02	**0.23**	0.03	**0.15**	0.01

Figure 4. An index of avian richness, ecological diversity (Shannon index), and total bird abundance from detections within 50m of point count stations on National Forest and private land in the Storrie, Moonlight, and Cub fires and Plumas unburned forest (PLAS)



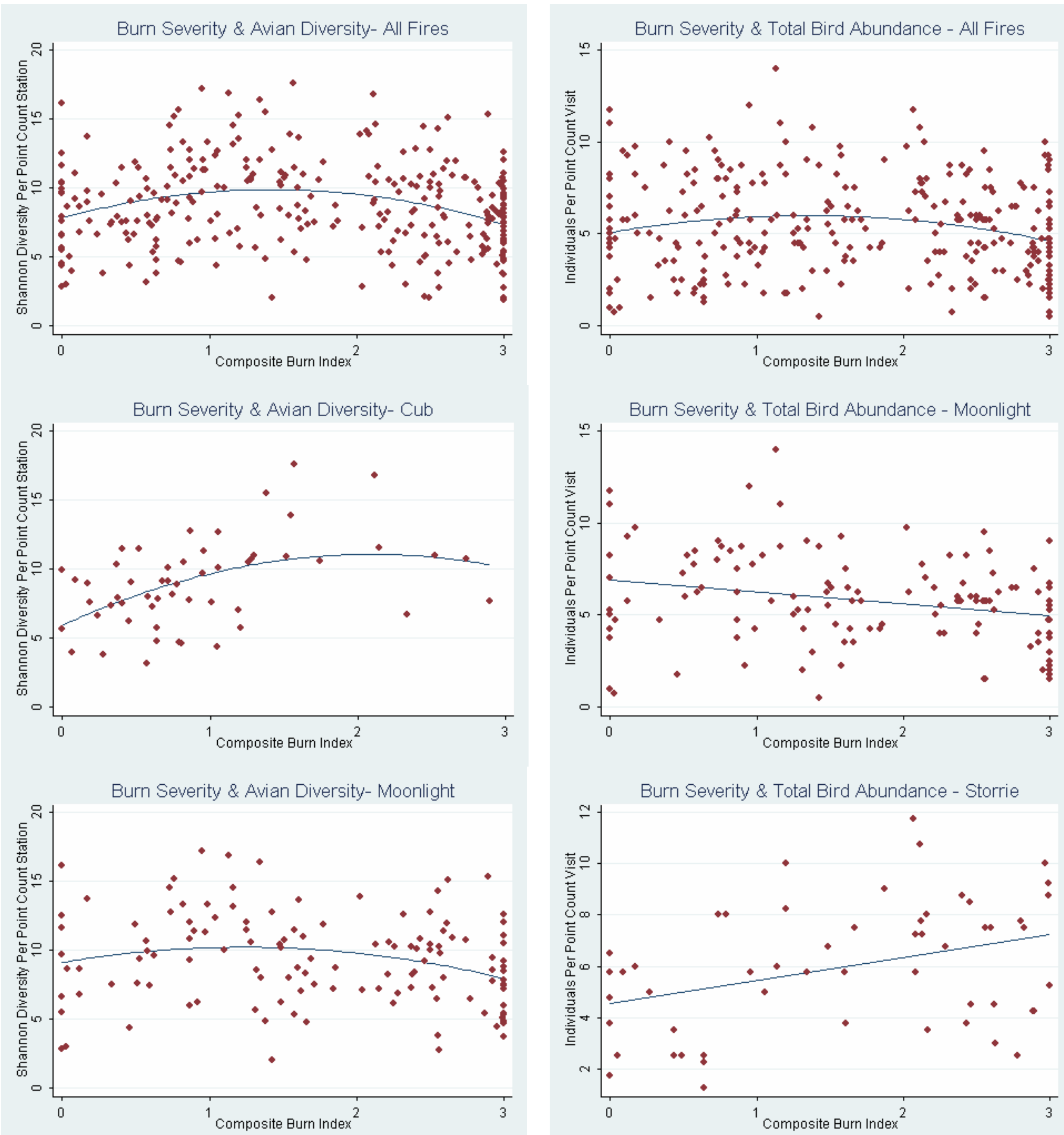
Effect of Burn Severity on Avian Community Metrics

Burn severity had significant effects on avian community indices but explained relatively small portion of the variance observed (Figure 5). Burn severity had a significant effect on avian diversity for the Cub, Moonlight, and all fires combined. The fit was significantly improved by including a squared term for burn severity for each, with avian diversity highest at sites that burned at moderate severity. Burn severity did not have a significant effect on avian diversity in the Storrie fire though there was some evidence (p=0.12) of a similar quadratic effect. Burn severity explained relatively small portion of the variance in species diversity for all fires combined and Moonlight (~6%). For the Cub fire model performance was better with 21% of the variance explained by severity. For all fires combined the effect of severity on the abundance of all species combined was significant with a squared term improving fit and abundance greatest at moderate severity. However, the Storrie and Moonlight fires showed significant linear but opposite effects of severity with Storrie total abundance increasing with increased severity and Moonlight decreasing. The effect of severity was not a significant predictor of total bird abundance in the Cub fire. The variance in total bird abundance explained by burn severity was relatively small for all fires combined and Moonlight (~6%) but better for Storrie fire (14%). Though there was some evidence of an effect of severity on these metrics for private land, with the relatively small sample size (n=30 & n=20) and lack of variation in fire severity on these lands, we considered fitting a regression inappropriate. When data from private land on both the Storrie and Moonlight fires was combined there was no effect of severity for avian diversity (p=0.44) or abundance (p=0.80) on private land (P=0.80).

Salvaged vs. Un-salvaged

The extensively salvaged logged private land within both the Moonlight and Storrie fires had significantly lower avian diversity and abundance in 2010 and 2011 than adjacent Forest Service land (Figure 4). In the Moonlight Fire, private land averaged 2.05 fewer species per point and 1.75 fewer total birds than Forest Service land. The pattern was similar for the Storrie fire where private land supported 1.36 fewer species and 1.75 total birds per point compared to Forest Service land. Extrapolating these figures out to the acreage of private land in each fire would result in approximately 17,000 fewer total individual birds in the roughly 19,000 acres of private land in the Moonlight fire and 800 fewer individuals in the roughly 4,000 acres of private land in the Storrie fire compared to similar acreage of Forest Service land in these fires.

Figure 5. The effect of burn severity (Composite Burn Index) on avian community indices per point count station at three fires in the Northern Sierra from 2010 & 2011 with best fit line. All graphed relationships had a significant effect of fire severity ($p<0.05$). See Appendix A for full regression models.



Ten of the 50 point count stations on private land randomly fell within or immediately adjacent to (<30 m) riparian areas that were not subjected to the same mechanical salvage or herbicide treatments as the surrounding uplands. Avian species richness and total bird abundance were significantly higher within these riparian areas across both fires (Figure 6). The values observed in riparian areas were similar to those on un-salvaged National Forest land. The elevated avian community metrics in these areas was attributable to open cup shrub nesting species which were more than three times more abundant in riparian areas than they were in un-salvaged upland private land. Cavity nesters were not significantly more abundant in riparian areas though snag densities were higher and we did observe a number of Lewis' Woodpecker using these areas in the Storrie fire.

An index of the total abundance of both burn and green forest associated species were significantly greater on un-salvaged Forest Service land than salvaged private land (Figure 7). The difference in abundance was far greater for green forest associated species than it was for burned forest associates. However, the index of total woodpecker abundance was more than 2.5 times greater on un-salvaged Forest Service land (0.48 per point) than on private land (0.18). These results were very consistent across the two burns investigated.

Figure 6. Mean per point Shannon index of bird diversity and total bird abundance (<50m per point per visit) at salvaged and un-salvaged private land and adjacent un-salvaged naturally regenerating National Forest land in the Storrie and Moonlight fires in 2010.

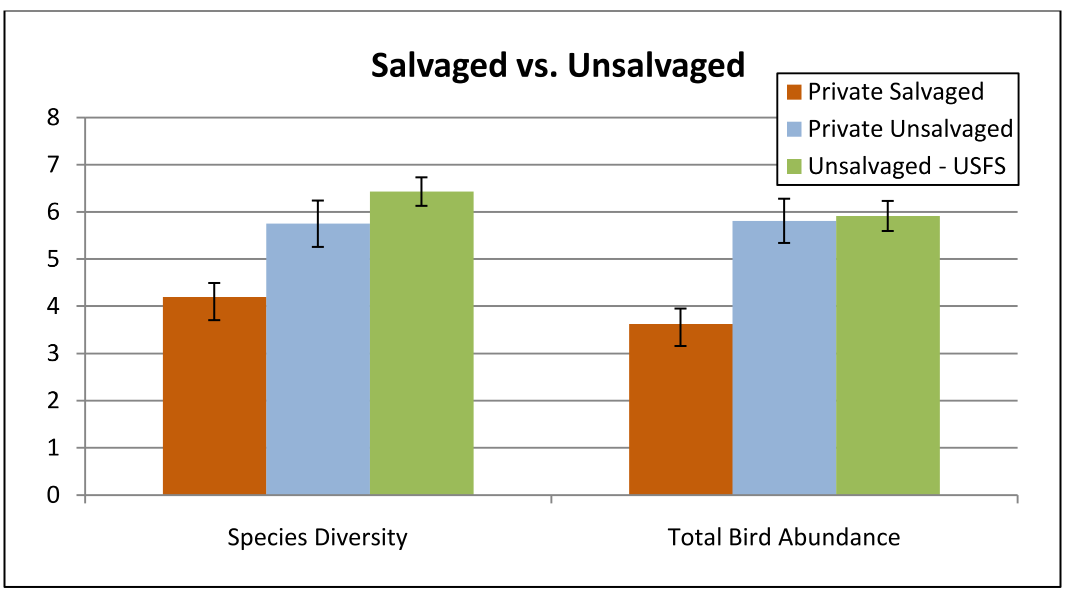
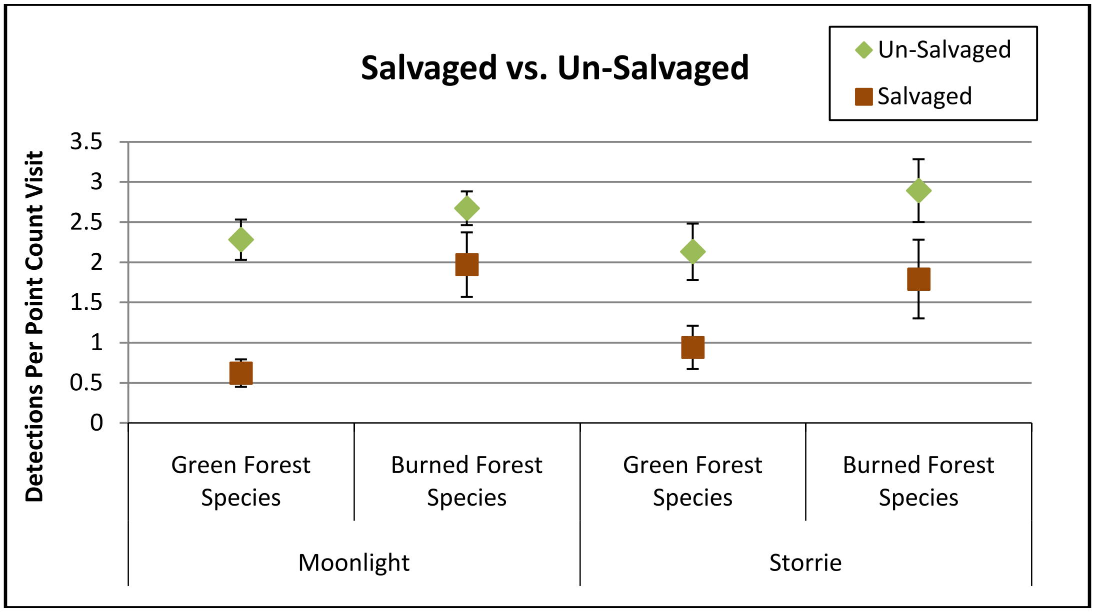


Figure 7. An index of the abundance (mean detections <50m per point per visit) of two species groups on salvaged (private) and un-salvaged (National Forest) land in the Moonlight and Storrie fires in 2010 and 2011 with 95% confidence intervals. The first group includes all species who were significantly more abundant in unburned areas in our study area and the second group is comprised of those species signifiantly more abundnt in burned areas (following results in Table 1).



Cavity Nests

A total of 122 active cavity nests of 11 species were located in 2011 across the Cub, Moonlight, and Storrie fires. 31 nests were found in the Cub fire, 71 in the Moonlight Fire, and 20 in the Storrie fire. In the Cub fire we found more nests for Hairy Woodpecker than any other species, in the Moonlight Mountain Bluebird, and in the Storrie Red-breasted Sapsucker (Table 2). For the third consecutive year we did not find Black-backed Woodpecker nests in the Storrie fire, and for the first year we did not find any Hairy Woodpecker nests there either.

There was evidence of selection for areas with the highest snag densities and avoidance of areas with low snag densities surrounding nests for four of the six cavity nesting species we had sufficient sample sizes to investigate in the Cub and Moonlight fires (Figure 8). White-headed woodpecker and Red-breasted sapsucker showed no strong selection though they appear to be avoiding nesting in areas with the lowest snag densities. Mean snag density in the 0.1 acre surrounding nests was 13.3 (7.6 SD) for Black-backed Woodpecker, 9.8 (5.8 SD) for

Hairy Woodpecker, 6.8 (5.7) for White-headed Woodpecker, and 5.0 (5.4 SD) at randomly selected locations.

Table 2. Number of cavity nests confirmed by species and fire in the Plumas-Lassen Study 2011 with totals from 2009 - 2011.

	Cub		Moonlight		Storrie		Grand
	2011	Total	2011	Total	2011	Total	Total
American Kestrel	0	0	1	2	0	0	2
Black-backed Woodpecker	6	15	8	19	0	0	34
Hairy Woodpecker	11	26	7	41	0	5	72
White-headed Woodpecker	3	13	6	26	6	17	56
Lewis' Woodpecker	0	0	2	7	0	7	14
Northern Flicker	5	13	8	27	4	18	58
Pileated Woodpecker	3	4	0	1	0	0	5
Red-breasted Sapsucker	2	2	10	25	7	11	38
Williamson's Sapsucker	0	0	1	3	0	0	3
Mountain Bluebird	1	4	24	61	1	4	69
Western Bluebird	0	0	4	8	2	7	15
Total	**31**	**77**	**71**	**220**	**20**	**69**	**366**

The nest trees selected across the three fires were quite variable in both size and species, though the vast majority of nests were found in trees greater than 50 cm (20 in) DBH (Figure 9). There was more evidence for preference for tree decay which is shown by both decay class and top condition of the nest tree (Figure 10). The vast majority of the nests were in dead trees (decay class 3 or greater) despite roughly a third of the “available” trees being alive. Hairy Woodpecker, Black-backed Woodpecker, and Red-breasted Sapsucker chose mostly trees of decay class 3 and 4, while White-headed Woodpecker, Northern Flicker, and Lewis’ Woodpecker chose trees of higher decay classes. Most Woodpeckers showed preference for broken top trees with the one exception being Black-backed Woodpecker, which chose trees with top condition similar to availability. Black-backed Woodpecker appear to be using the least decayed and most intact snags of any woodpecker species across these fires. All of these patterns were consistent across the three years of monitoring.

Figure 8. Snag densities measured within an 11.3 m radius plot centered on nest trees for six species in two burns compared to snag densities at available sites. The upper panel presents the proportion of all nest trees and randomly-selected trees with 95% confidence intervals. The p-values are from Pearson's chi-squared goodness-of-fit tests for the null hypothesis that the proportion of nest trees did not differ from the available proportions. Bottom panel presents selection ratios for each category, if nest trees were used in proportion to their availability they would have a selection ratio of 1; a selection ratio > 1 implies preference, whereas a value < 1 implies avoidance.

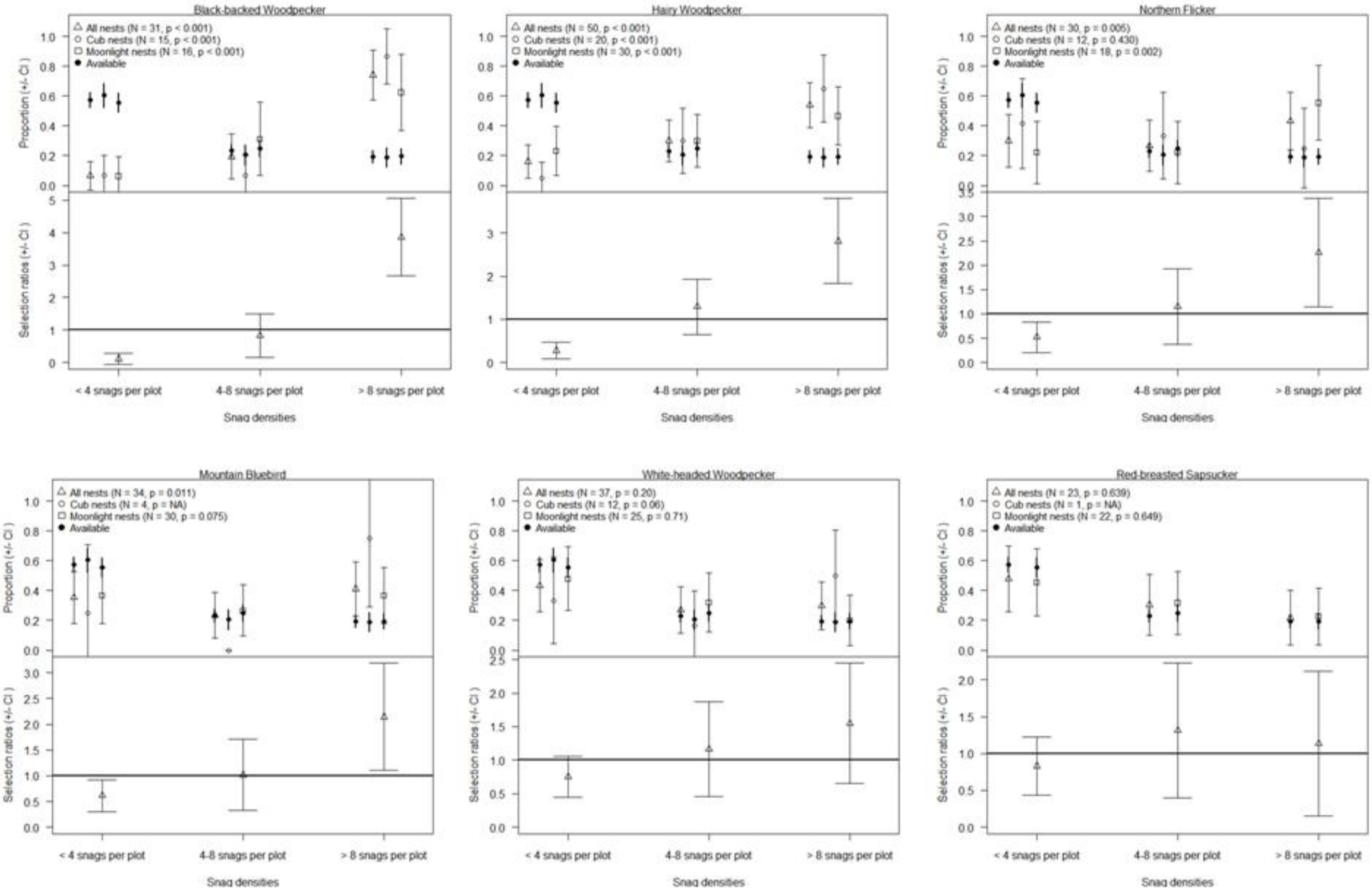
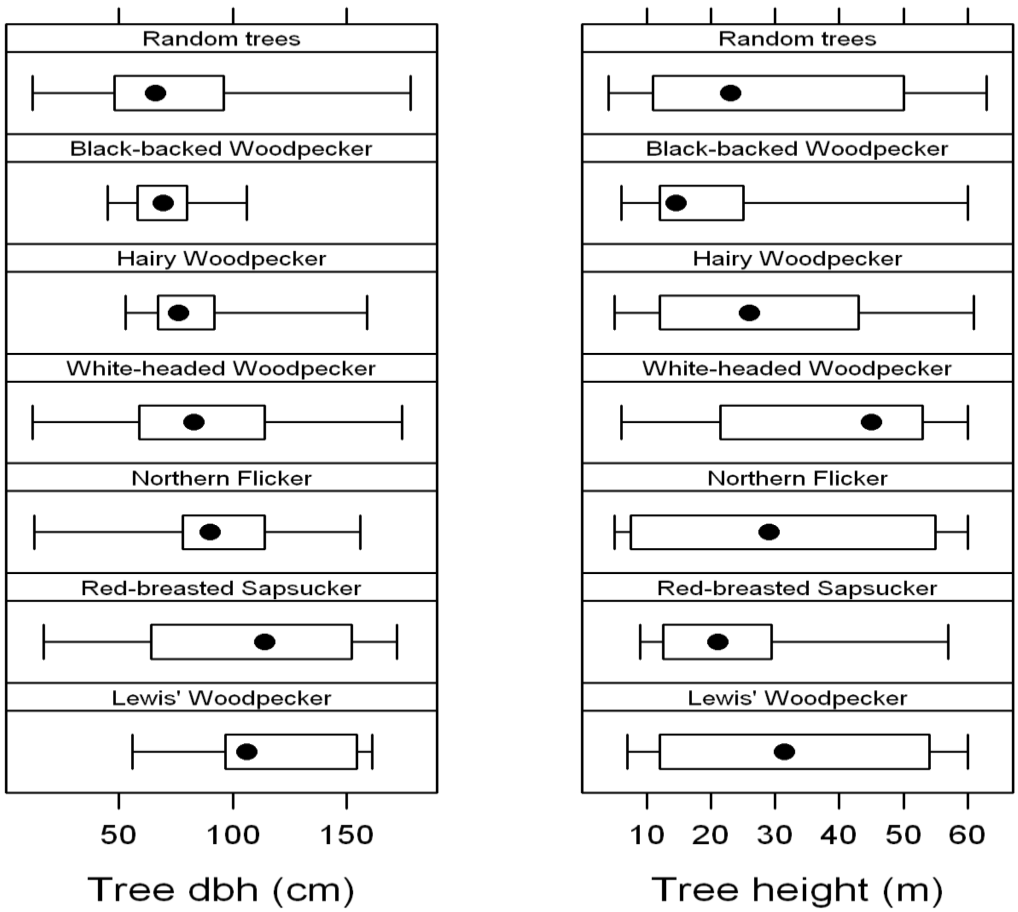


Figure 9. Median (dot), 25-75% interquartile range (box), and extremes (bars) in nest tree diameter at breast height (DBH) and nest tree height for six woodpecker species and randomly selected trees in the Storrie, Moonlight, and Cub fires in 2009 - 2011.



Nests were found in eight tree species/species groups from 2009 – 2011 (Figure 11). However, the majority of nests were found in five species/species groups: true fir (both red and white), yellow pine (includes both Ponderosa and Jeffrey), and Douglas-fir. These were some of the most common tree species available based on our sample of random trees. However, incense cedar was also one of the more common available trees, though only one nest (White-headed Woodpecker) was found in a cedar. Black-backed Woodpecker almost exclusively selected true fir and pine species, while Hairy Woodpecker, White-headed Woodpecker, and Northern Flicker were less particular with the relative frequencies of use reflecting what was available. Over a quarter of the Red-breasted Sapsucker nest were found in aspen despite this tree species having an extremely small proportion of the available trees. Similarly, Lewis'

Woodpecker chose Douglas-fir as a nest tree more than it was available, while none of the nine Lewis' Woodpecker nests were in true Fir, the most prevalent tree species.

Figure 10. The decay class and top condition of the nests of 6 woodpecker species compared to the sample of randomly selected trees across three fires in the Northern Sierra Nevada from 2009 - 2011.BA=Broken After Fire, BB=Broken Before Fire, DT=Dead Top, F= forked, I= Intact.

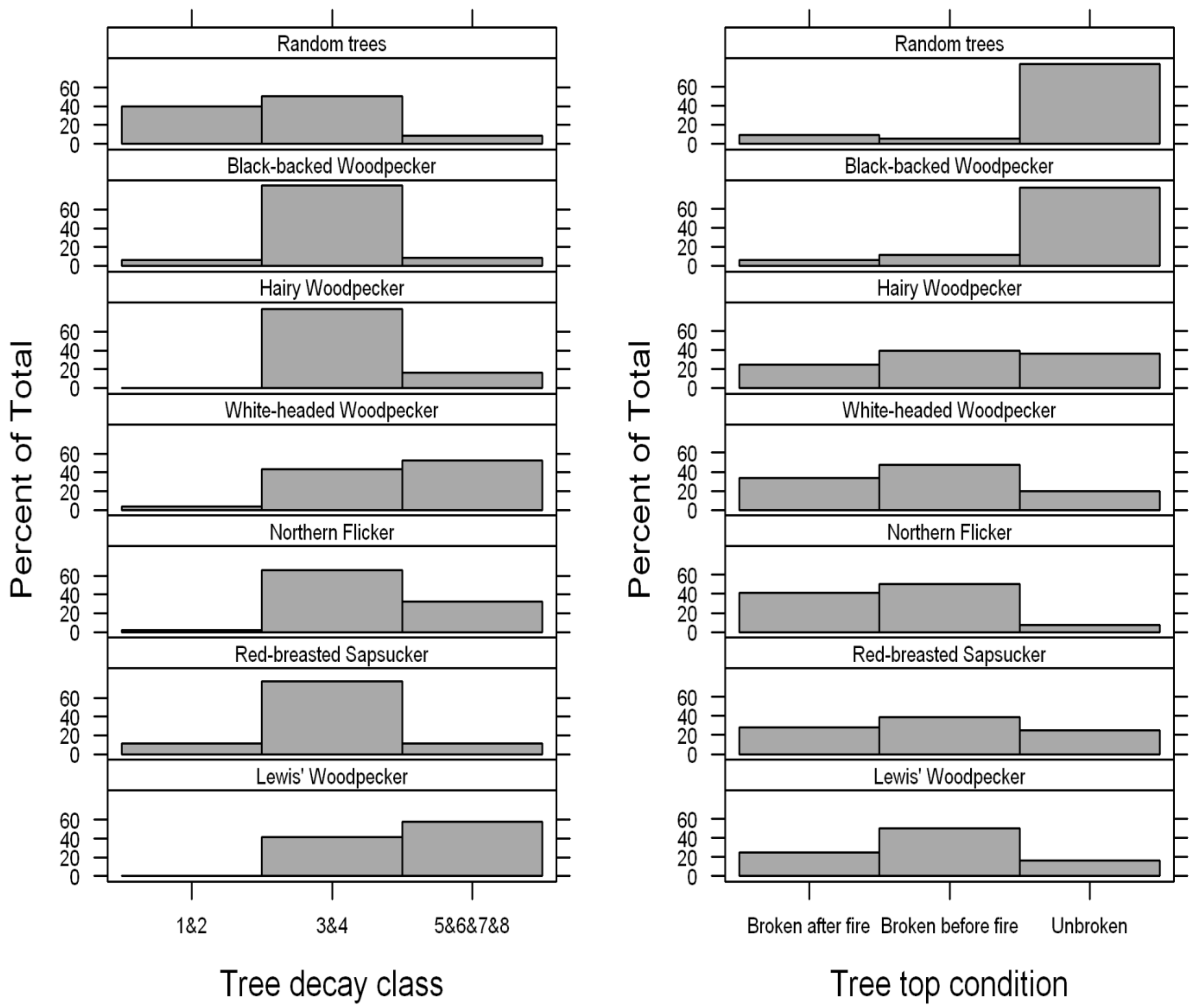
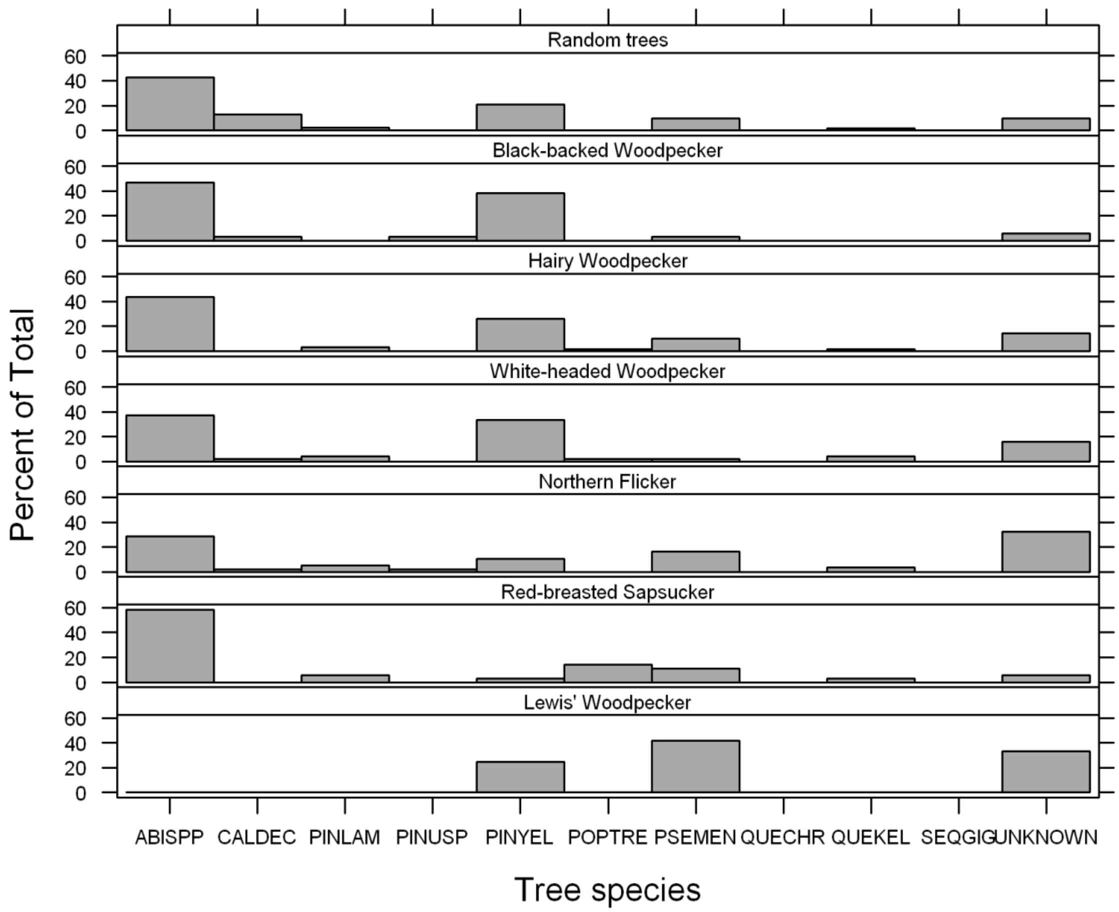


Figure 11. Figure 11. Nest tree species for 6 woodpecker species compared to the sample of random trees across three fires in the Northern Sierra Nevada from 2009 - 2011. ABISPP = true fir, CALDEC = incense cedar, PINCON = lodgepole pine, PINLAM = sugar pine, PINMON = western white pine, PINPON = ponderosa pine, POPTRE = quaking aspen, PSEMEN = Douglas-fir, QUEKEL = black oak, SEQGIG = giant sequoia.



Discussion

Avian Community Composition Burned vs. Green Forest

The vast majority of species breeding in our study area showed a preference for either burned or unburned forest. This illustrates the profound effect these fires have on the habitat composition and hence distribution of biological diversity in the Sierra Nevada. This dichotomy in the avian community suggests the need for different management strategies in burned areas compared to those developed for green forests in the Sierra Nevada. For example, several woodpecker species in the study area are avoiding nesting in areas with snag densities less than 40 per acre. Thus, green forest snag retention guidelines of 4 per acre should be considered inappropriate for sustaining habitat for cavity nesting species in post-fire areas (Hutto 2006). Many of the species more abundant in post-fire areas are associated with habitat components such as high snag densities or dense shrub layers, herbaceous vegetation, and regenerating hardwoods (e.g. oak & aspen). Snag retention guidelines, broad leaf herbicides or mastication, and ground disturbance may have significant effects on the avian community in post-fire environments. While some snag associated species (e.g. Black-backed Woodpecker) decline five or six years after a fire, those associated with understory plant communities take their place resulting in similar avian diversity three and eleven years after fire (e.g. Moonlight and Storrie).

An understanding of the differences in avian community composition and specifically the relative abundance of species between unburned forest, mechanical fuels reductions, and post-fire habitats can help guide the management of these areas. With high severity burns having lower densities of late seral associated species, these areas might best be prioritized for sustaining populations of early successional species. Likewise, later seral habitat areas are probably not the ideal location for creating large quantities of disturbance dependent habitat elements. Ensuring areas valued for their late seral habitat characteristics are resilient to stand replacing fire seems a far better strategy for managing for species like the Spotted Owl than eliminating early successional habitat in burned areas in order to speed the return of mature forest. However, habitat mosaics are also an important part of ensuring biological diversity in these forests, thus a science driven adaptive management approach to strategic salvage and reforestation in large fires that burned at high severity (e.g. Moonlight) may result in long-term benefits to avian diversity. A greater understanding of appropriate patch sizes and configuration is needed to guide this process both in terms of the negative impacts of salvage and positive impacts of creating uneven aged future stand heterogeneity.

Time Since Fire & Burn Severity

The effects of burn severity on the avian community varied across the three fires. Factors such as time since fire, landscape patterns of severity, and pre-fire habitat conditions are likely interacting with severity to influence the avian community at the 50 m scale we sampled birds and the pixel level scale we sampled fire severity (Saab et al. 2007, 2009). Hence, a relatively small portion of the variation in avian metrics was explained by burn severity alone even though models were highly significant. One pattern that appears fairly consistent across the three fires is a non-linear (quadratic) effect of burn severity on avian species diversity with highest values in the moderate severity categories. Further investigation into severity patterns at the landscape scale is necessary to understand if it is moderate severity specifically or if moderate severity is potentially a good predictor of mixed severity in the larger surrounding landscape. Across each of the three fires, the lowest avian diversity was recorded for the highest severity class but, for the Cub and Storrie fires the unburned areas within the fire perimeter also had relatively low avian diversity. These results suggest that managing for mixed severity wildfire with the majority of the landscape burning at moderate severity (1 – 2 on the CBI scale) may maximize local and landscape level avian diversity. In 2012 we plan to evaluate the local and landscape level predictors of avian distribution across these three burned areas including co-variates of time since fire, patch size and configuration, and pre-fire habitat conditions.

Managing for dense and diverse shrub habitats interspersed with areas of green forest should maximize avian diversity in post-fire environments. Information about colonization rates and how long after a fire shrub dependent species persists at maximum levels can be used to determine appropriate re-entry rotations for managing habitat following fire. Based on our results and observations made of habitat conditions within the fires, there is a five year lag before dense shrub habitats form that maximize densities of species such as Fox Sparrow, Dusky Flycatcher, and MacGillivray's Warbler. These species have shown substantial increases in abundance in the Moonlight fire each year since 2009 but shrub nesting species are still more abundant in the eleven year post-burn Storrie fire. This suggests early successional shrub habitats in burned areas provide high quality habitat for shrub dependent species well beyond a decade after fire. A re-entry rotation of 20 - 30 years for managing chaparral habitat may maximize abundance of these species. This re-entry timeframe would mimic the historic fire return interval for montane chaparral habitat in the Sierra Nevada (Barbour and Major 1988).

Results from the PLAS green forest study suggests the use of prescribed fire has far more positive effects on the avian community compared to the use of mechanical mastication in shrub habitats in the region (Burnett et al. 2009). If mechanical mastication is used, especially in high quality shrub bird habitat - as currently exists in the Storrie fire – retaining leave islands of very dense shrubs will help provide nesting habitat and reduce negative impacts to shrub dependent species. However, best management practices for these species would be to avoid disturbing this habitat for a number of years beyond the eleven since the Storrie fire burned.

Post-fire Cavity Nest Characteristics

The importance of post-fire habitats for cavity-nesting and bark-foraging birds is well established (Raphael et al. 1987, Hutto 1995, Saab and Dudley 1998). However, little information exists for the Sierra Nevada describing the important characteristics in post-fire snag-dominated habitats that determine the density and diversity of cavity nesting species. Our results here provide some of the only detailed information for a whole suite of cavity nesting species in post-fire habitats in the Sierra Nevada (also see Raphael and White 1984).

Patterns in nest tree characteristics were remarkably consistent across the three years of this study. Higher decay classes and broken top snags are still being used more than they are available. Though, in 2011 we started to see more birds using the fire killed snags for nesting than they did in 2009 suggesting those snags are now becoming suitable for nesting. Black-backed woodpecker continued to show very little selection for tree species, size, or decay class through 2011. They readily used what was available on the landscape suggesting other factors are driving this species occupancy within these fires.

Both Black-backed and Hairy Woodpeckers showed strong selection for high snag densities surrounding their nest trees. Extrapolating from our 0.1 acre plot this would suggest they are selecting for areas with greater than 80 snags per acre or 200 per hectare. This density coincides well with those reported from other studies in the west (Saab et al. 2009). These other studies have suggested that temporally limited food resources are the most important factor for determining these species distribution in high severity fire areas (Saab and Dudley 1998, Dixon and Saab 2000). Thus, management of snag density in post-fire areas should consider woodpecker nesting and foraging needs.

Private vs. Public Land

Through 2011, the majority of public land had been untouched since these fires, whereas private land has been extensively salvaged, prepped, and replanted. As such, the differences in the avian community between the two were considerable. Private land in the Storrie and Moonlight fire supported a significantly less diverse and abundant avian community than the surrounding Forest Service land. The reduced avian diversity and overall abundance in salvaged areas was primarily a result of significantly less green forest associated species on private land. This is likely a result of severity being higher on private land but also private land management practices that err on the side of taking trees that might survive versus leaving trees that might die. This is clearly evidenced at the property boundaries where no green trees remain on private land but a substantial number do immediately across the boundary on Forest Service land. This practice results in little if any overstory trees left and thus little habitat for the diverse group of tree-nesting foliage-gleaning species, especially those associated with green forest edges.

Olive-sided Flycatcher and Western Wood-pewee, two edge species shown to be declining in the Sierra Nevada (Sauer et al. 2011), were absent from private lands despite being more abundant in post-fire areas. These birds are not typically associated with one particular habitat, but rather the juxtaposition of unlike habitats. Management practices that produce homogenous landscapes such as those on private land in the Storrie and Moonlight fires are unlikely to support these and other species associated with habitat mosaics. Additionally, as these even-aged stands develop over time they are unlikely to provide habitat for a wide range of species associated with stand and landscape level heterogeneity. We found several even aged plantations supported significantly lower avian diversity and abundance and nearly lacked cavity nesting species 20 to 40 years after planting on the Almanor Ranger District (Burnett et al. 2010). Reducing the threshold from retaining only trees with an 80% or greater chance of survival to something considerably less would result in greater habitat heterogeneity, a mature green tree component, and greater snag densities in the long term. All of these aspects would undoubtedly increase avian diversity in heavily salvaged post-fire landscapes.

In riparian areas on private land avian diversity and abundance was similar to the un-salvaged Forest Service land. This was primarily due to an elevated abundance of understory nesting species. The riparian areas within private land were not entered during salvage operations or subjected to herbicide treatments in both fires resulting in far more snags, live trees, shrubs, and herbaceous vegetation. Leaving more patches of un-salvaged habitat and limiting the use of herbicides on private land would undoubtedly increase avian diversity in the short term and help promote a more heterogeneous forest in the future.

Conclusions

There is a growing need to understand the value of the habitats created by wildfire and the critical elements required by the unique and relatively diverse avian community in the Sierra Nevada. Wildfires provide a unique opportunity to mold a landscape into the forest composition that will exist there for decades to come. Though the severity and scale of fires in the Sierra Nevada in the last few decades may exceed historic averages, there is little doubt that even the areas that burn at the highest severity support a unique and relatively diverse avian community. In fact, many of bird species declining in the Sierra reach their greatest abundance in severely burned areas where many habitat elements that have been eliminated or degraded by past management actions (e.g. snags, herbaceous understory, hardwoods) flourish. The results from this ongoing study are providing important information to help inform management of burned areas to ensure wildlife needs are met while addressing other post-fire objectives. It is also providing valuable information on Black-backed Woodpecker as they undergo a status review for consideration to be listed under the California Endangered Species Act. In 2012 we will use available remotely sensed data on burn severity, pre-fire habitat composition, and our ground based habitat data to better understand the importance of severity class, patch size, and snag densities for the various species associated with post-fire habitat. In addition, we will be synthesizing results on the effects of fuels treatments in unburned forest and will complete several publications related to both of these efforts.

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Appendix A. Models of the effect of burn severity on avian community metrics.

Burn Severity Effect on Shannon Index of Avian Diversity

All Fires – Linear

```
    Source |       SS      df       MS              Number of obs =     238
-------------+------------------------------           F(  1,   236) =    0.00
     Model |  .039         1        .04              Prob > F      =  0.9497
  Residual | 2329.64   236   9.87              R-squared     =  0.0000
-------------+------------------------------           Adj R-squared = -0.0042
     Total |  2329.68    237    9.83              Root MSE      =  3.1419
------------------------------------------------------------------------------
        sw |      Coef.       Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.0129807   .2056272    -0.06   0.950     -.41808    .3921186
      cons |   9.201774   .3728396    24.68   0.000    8.467255    9.936293
------------------------------------------------------------------------------
```

All Fires – Quadratic

```
    Source |       SS       df       MS           Number of obs =     238
-------------+------------------------------        F(  2,   235) =    8.11
     Model |    150.41     2     75.21         Prob > F      =  0.0004
  Residual |  2179.27   235     9.27         R-squared     =  0.0646
-------------+------------------------------        Adj R-squared =  0.0566
     Total |  2329.68     237     9.83         Root MSE      =  3.0452
------------------------------------------------------------------------------
        sw |      Coef.      Std. Err.       t       P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.1876925   .2039705    -0.92   0.358    -.5895368    .2141518
   cbistd2 |  -.9923164   .2464236    -4.03   0.000    -1.477798   -.5068347
      cons |   10.45303    .476593    21.93   0.000      9.51409    11.39197
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                        LR chi2(1)  =     15.88
(Assumption: a nested in .)                    Prob > chi2 =    0.0001
```

Cub Fire - Linear

```
    Source |       SS            df      MS           Number of obs =      54
-------------+------------------------------           F(  1,    52) =   10.25
     Model |   85.744483     1    85.74               Prob > F      =  0.0023
  Residual |  434.882529    52    8.36                R-squared     =  0.1647
-------------+------------------------------           Adj R-squared =  0.1486
     Total |  520.627012     53    9.82               Root MSE      =  2.8919
------------------------------------------------------------------------------
        sw |      Coef.    Std. Err.       t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      cbi   |1.845325   .5763072    3.20   0.002    .6888798    3.00177
      cons |7.216832   .6688934   10.79  0.000    5.874599   8.559065
------------------------------------------------------------------------------
```

Cub Fire - Quadratic

```
    Source |       SS            df      MS           Number of obs =      54
-------------+------------------------------           F(  2,    51) =    6.95
     Model |  111.566824     2    55.78               Prob > F      =  0.0021
  Residual |  409.060188    51    8.02                R-squared     =  0.2143
-------------+------------------------------           Adj R-squared =  0.1835
     Total   |  520.627012    53  9.82                Root MSE      =  2.8321
------------------------------------------------------------------------------
        sw |      Coef.   Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   1.087257   .705006     1.54    0.129    -.3281033    2.502616
   cbistd2 |   -1.18411 .659937   -1.79    0.079    -2.508991    .1407697
      cons |   9.048374   1.21287     7.46    0.000     6.61342    11.48333
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                        LR chi2(1)  =      3.31
(Assumption: a nested in .)                     Prob > chi2 =    0.0690
```

Moonlight Fire – Linear

```
    Source |      SS      df      MS              Number of obs =     129
-------------+------------------------------      F(  1,   127) =    3.64
     Model |    36.72     1     36.72             Prob > F      =  0.0587
  Residual |1281.96   127  10.09                  R-squared     =  0.0278
-------------+-----------------------------       Adj R-squared =  0.0202
     Total |  1318.68   128  10.30                Root MSE      =  3.1771
------------------------------------------------------------------------------
        sw |     Coef.   Std. Err.      t   P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.5408663   .2835703   -1.91   0.059   -1.102001    .0202681
      cons |   10.26458   .5677839   18.08   0.000    9.141036    11.38812
------------------------------------------------------------------------------
```

Moonlight Fire – Quadratic

```
    Source |      SS      df      MS              Number of obs =     129
-------------+------------------------------       F(  2,   126) =    4.32
     Model |  84.53       2     42.26             Prob > F      =  0.0154
  Residual | 1234.15   126   9.79                 R-squared     =  0.0641
-------------+------------------------------      Adj R-squared =  0.0493
     Total |  1318.69   128    10.30              Root MSE      =  3.1
------------------------------------------------------------------------------
        sw |     Coef.         Std. Err.       t      P>|t|    [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.5806961      .2799145    -2.07   0.040   -1.134639   -.0267534
   cbistd2 |  -.7303744    .3305633    -2.21   0.029    -1.384549   -.0761993
      cons |   11.05376    .6636233    16.66   0.000     9.740474    12.36706
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                      LR chi2(1)  =      4.90
(Assumption: a nested in .)                    Prob > chi2 =    0.0268
```

Storrie fire – Linear

. fit sw cbi if fire=="ST" & private==0

```
    Source |       SS       df       MS                 Number of obs =      55
-------------+------------------------------            F(  1,    53) =    0.10
     Model |  .91          1       .92                  Prob > F      =  0.7524
  Residual |  483.43    53    9.12                      R-squared     =  0.0019
-------------+------------------------------            Adj R-squared = -0.0169
     Total |  484.35       54   8.97                    Root MSE      =  3.0202
------------------------------------------------------------------------------
        sw |      Coef.         Std. Err.          t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   .1257289   .3965484       0.32   0.752   -.6696464    .9211041
     _cons |   8.885906   .7419523   11.98   0.000    7.397738    10.37407
------------------------------------------------------------------------------
```

Storrie fire – Quadratic

```
    Source |       SS       df       MS                 Number of obs =      55
-------------+------------------------------            F(  2,    52) =    2.17
     Model |  37.36     2     18.68                     Prob > F      =  0.1241
  Residual | 446.99    52    8.60                       R-squared     =  0.0771
-------------+------------------------------            Adj R-squared =  0.0416
     Total |  484.35    54   8.97                       Root MSE      =  2.9319
------------------------------------------------------------------------------
        sw |      Coef.        Std. Err.        t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |    -.2221794   .4204127    -0.53   0.599   -1.065799    .6214403
   cbistd2 | -1.031637   .5010589    -2.06   0.045   -2.037085   -.0261883
     _cons | 10.52268   1.072738      9.81    0.000     8.370076    12.67529
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                          LR chi2(1)  =      4.31
(Assumption: a nested in .)                         Prob > chi2 =    0.0379
```

Burn Severity Effect on Total Bird Abundance

All Fires – Linear

```
     Source |       SS       df       MS                 Number of obs =     238
-------------+------------------------------              F(  1,   236) =    0.00
      Model |    .01        1         .01                Prob > F      =  0.9773
   Residual |  1531.24 236    6.49                       R-squared     =  0.0000
-------------+------------------------------              Adj R-squared = -0.0042
      Total |   1531.24   237  6.46                      Root MSE      =  2.5472
------------------------------------------------------------------------------
  indpervis |    Coef.     Std. Err.       t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |   .0047399   .1667082    0.03    0.977    -.3236863    .3331662
       cons |   5.696583   .3022723    18.85   0.000     5.101086    6.292079
------------------------------------------------------------------------------
```

All Fires – Quadratic

```
     Source |       SS       df       MS                 Number of obs =     238
-------------+------------------------------              F(  2,   235) =    2.90
      Model |  36.86       2     18.43                   Prob > F      =  0.0571
   Residual |1494.38  235     6.36                       R-squared     =  0.0241
-------------+------------------------------              Adj R-squared =  0.0158
      Total |   1531.24   237  6.46                      Root MSE      =  2.5217
------------------------------------------------------------------------------
  indpervis |    Coef.     Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |  -.0817539    .168905    -0.48   0.629    -.4145154    .2510076
    cbistd2 |  -.4912619   .2040599    -2.41   0.017    -.8932824   -.0892415
       cons |   6.316037   .3946599    16.00   0.000     5.538514     7.09356
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                          LR chi2(1)  =      5.80
(Assumption: a nested in .)                       Prob > chi2 =    0.0160
```

Cub Fire - Linear

```
    Source |      SS      df      MS              Number of obs =     54
-------------+------------------------------           F(  1,    52) =    0.57
     Model |   4.32        1     4.32             Prob > F      =  0.4544
  Residual |  395.73    52    7.61              R-squared     =  0.0108
-------------+------------------------------           Adj R-squared = -0.0082
     Total |  400.05      53    7.55              Root MSE      =  2.7586
------------------------------------------------------------------------------
  indpervis |     Coef.     Std. Err.      t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   .4143932   .5497508    0.75   0.454    -.6887624    1.517549
      cons |   4.824047   .6380706    7.56   0.000     3.543665    6.10443
------------------------------------------------------------------------------
```

Cub Fire - Quadratic

```
    Source |      SS      df      MS              Number of obs =     54
-------------+------------------------------           F(  2,    51) =    0.29
     Model |  4.52          2  2.25808164         Prob > F      =  0.7486
  Residual |  395.53    51  7.75558358         R-squared     =  0.0113
-------------+------------------------------           Adj R-squared = -0.0275
     Total |  400.05      53  7.55              Root MSE      =  2.7849
------------------------------------------------------------------------------
  indpervis |      Coef.     Std. Err.          t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         cbi |   .3489983   .6932533    0.50   0.617    -1.042766    1.740762
    cbistd2 |  -.1021475   .6489357   -0.16   0.876    -1.40494     1.200645
     _cons |   4.982046   1.192658    4.18   0.000      2.587685    7.376407
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                          LR chi2(1)  =      0.03
(Assumption: a nested in .)                        Prob > chi2 =    0.8713
```

Moonlight Fire – Linear

```
    Source |      SS      df      MS              Number of obs =     129
-------------+------------------------------      F(  1,   127) =    8.45
     Model |  56.21       1     56.21             Prob > F      =  0.0043
  Residual |  844.43   127   6.65                 R-squared     =  0.0624
-------------+------------------------------      Adj R-squared =  0.0550
     Total |  900.63   128  7.04                  Root MSE      =  2.5786
------------------------------------------------------------------------------
  indpervis |   Coef.      Std. Err.       t       P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.6691473   .2301459   -2.91    0.004    -1.124564   -.2137302
      cons |   7.008948   .4608138    15.21   0.000     6.09708    7.920815
------------------------------------------------------------------------------
```

Moonlight Fire – Quadratic

```
    Source |      SS      df      MS              Number of obs =     129
-------------+------------------------------      F(  2,   126) =    5.69
     Model |  74.56       2    37.28              Prob > F      =  0.0043
  Residual |  826.07   126    6.56                R-squared     =  0.0828
-------------+------------------------------      Adj R-squared =  0.0682
     Total |  900.63      128   7.04              Root MSE      =  2.5605

------------------------------------------------------------------------------
  indpervis |     Coef.   Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -.6938253   .2290076   -3.03   0.003    -1.147025   -.2406261
   cbistd2| -.4525304   .2704451   -1.67    0.097    -.9877333    .0826724
      cons |  7.497918   .5429327   13.81   0.000     6.42347    8.572366
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                      LR chi2(1)  =      2.84
(Assumption: a nested in .)                  Prob > chi2 =    0.0922
```

Storrie fire – Linear

```
    Source |      SS      df      MS                Number of obs =     55
-------------+------------------------------            F(  1,    53) =    8.82
     Model |  47.52    1    47.53                   Prob > F      =  0.0045
   Residual |285.45   53   5.39                     R-squared     =  0.1427
-------------+------------------------------            Adj R-squared =  0.1265
     Total |  332.97   54   6.17                    Root MSE      =  2.3207
------------------------------------------------------------------------------
 indpervis |   Coef.      Std. Err.       t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   .9051152   .3047148    2.97   0.004    .2939347    1.516296
      cons | 4.543491     .5701294    7.97   0.000    3.399956    5.687025
------------------------------------------------------------------------------
```

Storrie fire – Quadratic

```
    Source |      SS      df      MS                 Number of obs =     55
-------------+------------------------------            F(  2,    52) =    5.50
     Model |  58.16       2    29.08                Prob > F      =  0.0068
   Residual |  274.81    52    5.28                 R-squared     =  0.1747
-------------+------------------------------            Adj R-squared =  0.1429
     Total |  332.97    54  6.17                    Root MSE      =  2.2989
------------------------------------------------------------------------------
  indpervis |   Coef.    Std. Err.         t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   .7170877   .3296395    2.18   0.034    .0556177    1.378558
  cbistd2 | -.5575495   .3928731   -1.42   0.162   -1.345907    .2308081
      cons |  5.428089   .8411183    6.45   0.000    3.740261    7.115916
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                        LR chi2(1)  =      2.09
(Assumption: a nested in .)                     Prob > chi2 =    0.1483
```

Private Land Burn Severity Effect on Shannon Index of Avian Diversity

Storrie fire – Linear

```
     Source |       SS      df       MS                 Number of obs =      20
-------------+------------------------------            F(  1,    18) =    1.68
      Model |  10.28     1   10.28                      Prob > F      =  0.2110
   Residual |  110.00  18   6.11                        R-squared     =  0.0855
-------------+------------------------------            Adj R-squared =  0.0347
      Total |  120.28    19  6.33                       Root MSE      =  2.4721
------------------------------------------------------------------------------
  indpervis |    Coef.      Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |   1.544273   1.190498    1.30   0.211    -.9568703    4.045416
       cons |    .216883   3.091542    0.07   0.945    -6.278206    6.711972
------------------------------------------------------------------------------
```

Storrie fire – Quadratic

```
     Source |       SS      df       MS                 Number of obs =      20
-------------+------------------------------            F(  2,    17) =    2.07
      Model |  23.59     2    11.79                     Prob > F      =  0.1564
   Residual |  96.70     17    5.69                     R-squared     =  0.1961
-------------+------------------------------            Adj R-squared =  0.1015
      Total |  120.28     19    6.33                    Root MSE      =   2.385
------------------------------------------------------------------------------
  indpervis |   Coef.       Std. Err.       t      P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |  -1.102668   2.077185   -0.53   0.602   -5.485144    3.279808
    cbistd2 |    2.37748   1.554568    1.53   0.145   -.9023727    5.657333
       cons |   4.437707   4.063601    1.09   0.290   -4.135742    13.01116
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                         LR chi2(1)  =      2.58
(Assumption: a nested in .)                      Prob > chi2 =    0.1084
```

Moonlight Fire - Linear

```
    Source |      SS      df      MS                Number of obs =     30
-------------+------------------------------        F(  1,    28) =    4.12
     Model |  9.36       1     9.36                  Prob > F      =  0.0520
  Residual |  63.61    28    2.27                   R-squared     =  0.1282
-------------+-----------------------------         Adj R-squared =  0.0971
     Total |  72.96      29    2.52                 Root MSE      =  1.5072
------------------------------------------------------------------------------
  indpervis |   Coef.      Std. Err.          t     P>|t|    [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |  -.5882569   .2898696   -2.03   0.052    -1.182028    .0055141
       cons |   5.241523   .7579351    6.92   0.000     3.688964    6.794083
------------------------------------------------------------------------------
```

Moonlight Fire – Quadratic

```
    Source |      SS      df      MS                Number of obs =     30
-------------+------------------------------         F(  2,    27) =    2.20
     Model |  10.23       2     5.11                Prob > F      =  0.1302
  Residual |  62.73      27     2.32                R-squared     =  0.1402
-------------+------------------------------        Adj R-squared =  0.0765
     Total |  72.96        29     2.52              Root MSE      =  1.5243
------------------------------------------------------------------------------
  indpervis |    Coef.     Std. Err.       t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        cbi |  -.6146719    .296324   -2.07   0.048    -1.222678   -.0066653
    cbistd2 |   .2866468   .4684363    0.61   0.546    -.6745051    1.247799
       cons |   4.861685   .9863563    4.93   0.000     2.837849     6.88552
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                        LR chi2(1)  =      0.41
(Assumption: a nested in .)                      Prob > chi2 =    0.5204
```

Private Land Burn Severity Effect on Total Bird Abundance

Storrie fire – Linear

```
    Source |       SS       df       MS              Number of obs =      20
-------------+------------------------------           F(  1,    18) =    1.68
     Model |  10.28       1     10.28              Prob > F      =  0.2110
  Residual |  110.00    18     6.11               R-squared     =  0.0855
-------------+------------------------------           Adj R-squared =  0.0347
     Total |  120.28      19     6.33              Root MSE      =  2.4721
------------------------------------------------------------------------------
  indpervis |   Coef.     Std. Err.        t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |   1.544273   1.190498    1.30   0.211    -.9568703    4.045416
      cons |    .216883   3.091542    0.07   0.945    -6.278206    6.711972
------------------------------------------------------------------------------
```

Storrie fire – Quadratic

```
    Source |       SS       df       MS              Number of obs =      20
-------------+------------------------------           F(  2,    17) =    2.07
     Model |  23.59       2     11.79              Prob > F      =  0.1564
  Residual |  96.69      17      5.69              R-squared     =  0.1961
-------------+------------------------------           Adj R-squared =  0.1015
     Total |  120.28     19      6.33              Root MSE      =   2.385
------------------------------------------------------------------------------
  indpervis |    Coef.    Std. Err.        t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       cbi |  -1.102668   2.077185   -0.53   0.602    -5.485144    3.279808
   cbistd2 |    2.37748   1.554568    1.53   0.145    -.9023727    5.657333
      cons |   4.437707   4.063601    1.09   0.290    -4.135742    13.01116
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                         LR chi2(1)  =      2.58
(Assumption: a nested in .)                      Prob > chi2 =    0.1084
```

Moonlight – Linear

```
     Source |       SS       df       MS              Number of obs =      30
-------------+------------------------------           F(  1,    28) =    4.12
      Model |  9.35          1      9.36              Prob > F      =  0.0520
   Residual |  63.61        28      2.27              R-squared     =  0.1282
-------------+------------------------------           Adj R-squared =  0.0971
      Total |  72.96        29      2.52              Root MSE      =  1.5072
------------------------------------------------------------------------------
   indpervis |     Coef.     Std. Err.       t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         cbi |  -.5882569   .2898696    -2.03   0.052    -1.182028    .0055141
        cons |   5.241523   .7579351     6.92   0.000     3.688964    6.794083
------------------------------------------------------------------------------
```

Moonlight - Quadratic

```
     Source |       SS       df       MS              Number of obs =      30
-------------+------------------------------           F(  2,    27) =    2.20
      Model |  10.23         2      5.11              Prob > F      =  0.1302
   Residual |  62.73        27      2.32              R-squared     =  0.1402
-------------+------------------------------           Adj R-squared =  0.0765
      Total |  72.96        29      2.52              Root MSE      =  1.5243
------------------------------------------------------------------------------
   indpervis |     Coef.     Std. Err.       t     P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         cbi |  -.6146719    .296324    -2.07   0.048    -1.222678   -.0066653
     cbistd2 |   .2866468   .4684363     0.61   0.546    -.6745051    1.247799
        cons |   4.861685   .9863563     4.93   0.000     2.837849     6.88552
------------------------------------------------------------------------------
```

Test for Goodness of Fit of Quadratic over Linear

```
Likelihood-ratio test                          LR chi2(1)  =      0.41
(Assumption: a nested in .)                    Prob > chi2 =    0.5204
```