# Avian Monitoring in Central Sierra Post-fire Areas

2015 Annual Report

April 2016

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**Cover photo**: *Lazuli Bunting (*Passerina amoena), *an early fire colonizer across the Sierra Nevada landscape, is one of the most abundant species in post-fire areas. Photos by Tom Grey and Alissa Fogg, respectively.*

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## EXECUTIVE SUMMARY

In this report we present our 2015 activities and results of avian and vegetation monitoring in central Sierra post-fire habitats. The fires we monitored included the 2004 Freds and Power fires, the 2008 Government Fire on the Tahoe National Forest and the 2013 Rim Fire on the Stanislaus National Forest, with Rim Fire work funded through a private donor. We compared avian abundance for three guilds within each fire and detected significant differences in abundance for individual bird species across different fires, likely due to fire age, severity and post-fire management. In addition, we summarize vegetation data collected in Freds and Power fires and built habitat associations models using vegetation and topographic data for shrub and cavity-nesting birds to help inform ongoing and future management. As a modification to the current monitoring agreement, we also helped guide post-fire habitat recommendations for the King Fire Restoration and implemented a snag patch retention design in salvage logging units by locating and marking high-quality wildlife habitat in units. Within King Fire salvage unit snag patches and nearby control areas, we also measured snag attributes to monitor the factors that affect snag longevity.

**2015 Activities**

- We surveyed point count locations in the Freds Fire (94 point count stations on 9 transects) that partially overlapped the Region 5 Vegetation Ecology Program Common Stand Exam plots.
- We surveyed point count locations in the Power Fire (148 point count stations on 15 transects) that partially overlapped regeneration plots established by the Region 5 Ecology program.
- We completed vegetation/habitat data collection at 38 point count stations located in the Power Fire footprint (all points now have vegetation data).
- We completed vegetation/habitat data collection at 94 point count stations located in the Freds Fire footprint (all points now have vegetation data).
- We surveyed point count locations in the Government Fire, located on Tahoe National Forest and burned in 2008 (129 point count stations on 26 transects).
- We surveyed point count locations in the Rim Fire, located on Stanislaus National Forest and burned in 2013 (271 point count stations on 29 transects).
- We marked 305 snag retention patches in King Fire salvage units
- We completed snag plot measurements at 47 salvage unit retention patches and 50 control plots outside salvage units.
- We presented bird monitoring results at Power Fire Reforestation science team meetings and participated in field trips in the Power and King fires.

**Post-Fire Habitat Management Recommendations**

Recommendations are a synthesis of our results, scientific literature, and expert opinion from 15 years of studying birds in the Sierra Nevada. Some of these are hypotheses that should be tested and further refined to ensure they are achieving the desired outcome of sustaining biological diversity in the Sierra Nevada.

*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 that maintains biological diversity.
- Consider the area of a fire that burned at high severity, as opposed to the area of the entire fire, when determining what percentage of the fire area to salvage log. Consider the natural range of variability for high severity patch size, as not all of these areas should be targeted for salvage logging.
- Consider the landscape context (watershed, forest, and ecosystem) and availability of different habitat types when planning post-fire management actions.
- Approach post-fire management through a climate-smart lens - use the past to inform but plan for the future – find solutions that promote resiliency and foster adaptation.
- Use existing climate predictions of vegetation communities to guide reforestation locations and species mixes, but be mindful of remaining uncertainties regarding the rate of species' range shifts. Favor fire-tolerant species and consider whether lower elevations on south-facing slopes should be planted with conifers.
- Monitor, evaluate, be patient, strategic, and constrained in aiding the recovery of a post-fire landscape.

*Snags*

- Manage a substantial portion of post-fire areas for large patches (20–300 acres) burned at high severity as complex early seral forest for wildlife.
- Retain high severity burned habitat in locations with higher densities of medium to 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 three years after a fire by cavity nesting birds.
- Retain snags in salvaged areas in far greater densities than green forest standards and retain snags 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 long lasting continuous source of suitable cavity and foraging trees.
- When reducing snags in areas more than five years post-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.
- 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 of Black-backed Woodpeckers.
- 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 because a large range of snags sizes are used by a number of species for foraging and nesting from as little as 6 inches DBH. Though, most cavity nests were in snags over 15 inches DBH.

*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 conifer dominated ecosystems.
- Most shrub patches should be at least 10-15 acres and shrub cover should average over 50% across the patch acreage. Within the shrub patch, manage for denser clumps (>70%) in order to support area-sensitive species such as Fox Sparrow.
- Retain natural oak regeneration with multiple stems as these dense clumps create valuable understory bird habitat in post-fire areas 5–15 years after the fire.
- In highly decadent shrub habitat consider burning or masticating half the area (in patches) in one year and burning the remaining area several years later once fuel loads have been reduced. Treatments should be done outside of the breading season (August – April).

- Maximize the use of prescribed fire to create and maintain chaparral habitat and consider a natural fire return 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) and substantial portions of larger fires exclusively for post-fire resources for wildlife especially when there have been no other recent fires (within the last 10 years) in the adjoining landscape.
- Retain patches of high severity burned areas adjacent to intact green forest patches as the juxtaposition of disparate 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 mosaics that will invigorate understory plant communities, increase natural recruitment of shade intolerant tree species, and help reduce future fire risk.
- 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. 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 to riparian areas (dependent on riparian corridor size), primarily in the floodplain, to avoid future shading of riparian deciduous vegetation from the south or west, and increased competition.
- Consider replanting riparian tree species (cottonwood, willow, alder, aspen) in riparian conservation areas affected by stand replacing fire where natural regeneration is lacking.

## INTRODUCTION

After nearly a century of successful fire suppression (Calkin et al. 2005), the subsequent densification of Sierra Nevada forests and accumulation of fuels (Sugihara et al. 2006), has led to increasingly large and severe wildfires across the range (Miller and Safford 2012; Steel et al. 2015). With the important role of fire as a primary driver of ecosystem structure and function, there is a substantial need to understand the value of habitats created and altered by wildfire and how post-fire habitats are used by the unique avian community that occupy them. In the Sierra Nevada, considerable debate surrounds the management of post-fire habitat. Management actions in post-fire habitat affect the forest composition and structure that could persist for decades (Lindemayer and Noss 2006, Swanson et al. 2011). Thus, it is necessary to carefully consider the species using post-fire habitat under different management prescriptions, both in the short- and long-term. With an increasing emphasis on ecological restoration to improve ecosystem resilience and the delivery of ecosystem services, there is also a need to use monitoring to assess tradeoffs, seek complementarities among values, and optimize benefits among objectives (Hutto and Belote 2013).

Until recently there has been little study of bird communities in post-fire areas in the Sierra Nevada. Starting in 2009 Point Blue began studying bird communities within burned areas in the Lassen and Plumas National forests and in 2014 expanded into the central Sierra Nevada with the 2004 Freds and Power Fires in the Eldorado National Forest, the 2008 Government Fire (also known as the American River Complex Fire) in the Tahoe National Forest, and the 2013 Rim Fire in the Stanislaus National Forest. By expanding the work we began in the northern Sierra and including fires of different age, severity and management throughout the Sierra Nevada, we have increased our ability to detect differences in avian associations among these variables. While we have provided a considerable amount of new information to help guide the management of burned areas, especially recently burned areas, many uncertainties remain. For example, snag retention in salvaged areas and management of early seral chaparral habitat remain significant parts of the ongoing debate over managing landscapes following large fires. Our findings will help inform the future design of such management actions.

The 2004 Freds and Power fires afforded several opportunities to increase our knowledge of the effects of fire and post-fire management on Sierra Nevada avian communities. Little is known about the avian community inhabiting older fires that have experienced varying levels of salvage logging and reforestation. Previous studies of the effects of salvage logging on western forest avian communities have largely focused outside of the Sierra Nevada and often only on relatively short-term effects (e.g. Hutto and Gallo 2006, Saab et al. 2007, Cahall and Hayes 2009, Kronland and Restani 2011, Rost et al. 2013). At least one study found salvage logging can reduce snag density for over 50 years following harvest (Lindenmayer et al. 1997). To our knowledge there are currently no studies assessing salvage logging effects on avian communities in the Sierra Nevada a decade or more following fire. Point Blue is also leading a Before-After Control-Impact (BACI) study to quantify salvage logging effects on the bird community in the 2012 Chips Fire, located in the northern Sierra and the 2013 Rim Fire. The 2008 Government Fire was affected by very little post-fire management and represents a different age and burn severity pattern than the other fires we are currently studying. By including fires of varying age, severity, pre-fire habitat and post-fire management, we can evaluate the effects of post-fire management by controlling for these diverse variables which have been found to affect avian communities elsewhere (Smucker et al. 2005, Fontaine and Kennedy 2012, Seavy and Alexander 2014).

Vegetation data can complement avian observation data by identifying variables managers can manipulate that are most important to birds. Land managers are typically directed to rapidly reestablish forested cover on burned areas. However, burned areas that are not rapidly reforested can provide the early seral habitat important to biodiversity (Swanson et al. 2011), which is often neglected when managing for late seral habitat in the Sierra Nevada (Burnett and Roberts 2015). Using a combined bird and vegetation dataset from the 2004 Freds and Power fires, we can identify aspects of early seral habitat, such as percent cover of shrubs, oaks and basal area of snags to help guide post-fire management decisions when implementing reforestation projects.

In this report, we assess the effects of fire on birds for four major fires of varying age under different severity and management scenarios in the central Sierra mixed-conifer zone. In addition, we present habitat association models for three bird guilds and four shrub-nesting species to assess which variables best predict their abundance and richness. We also examine the effects of herbicide treatments on shrub-nesting birds. The findings presented here compliment a growing body of research into the effects of fire and post-fire management on western forest bird communities.

# METHODS

## Study Location

The study area includes four fires located on the Eldorado, Tahoe and Stanislaus National Forests in the Sierra Nevada Mountains of California (Figure 1). The Freds Fire, located on Placerville Ranger District, and the Power Fire, located on the Amador Ranger District burned within the Eldorado National Forest. Both fires were human-ignited and burned predominantly on the south-facing side of river canyons during October 2004. The 3116 ha (7700 ac) Freds Fire burned along the South Fork American River canyon, and the 6880 ha (17,000 ac) Power Fire burned along the Mokelumne River canyon. The elevations of avian monitoring locations in the Freds Fire ranged from 1315 – 2089 m (mean = 1720m; *N* = 94) and from 1120 – 2016m (mean = 1611m; *N* = 148) in the Power Fire.

The 8094 ha (20,000 ac) Government Fire (also known as the American River Complex Fire) is located within the American River Ranger District of the Tahoe National Forest, and was ignited by multiple lightning strikes. It burned during June-July 2008 on the north and south-facing sides of the North Fork American River canyon. Overall fire severity was low to moderate and the burned area experienced very little post-fire management. The elevations of avian monitoring locations ranged from 1128 – 1982m (mean = 1668m; *N* = 129).

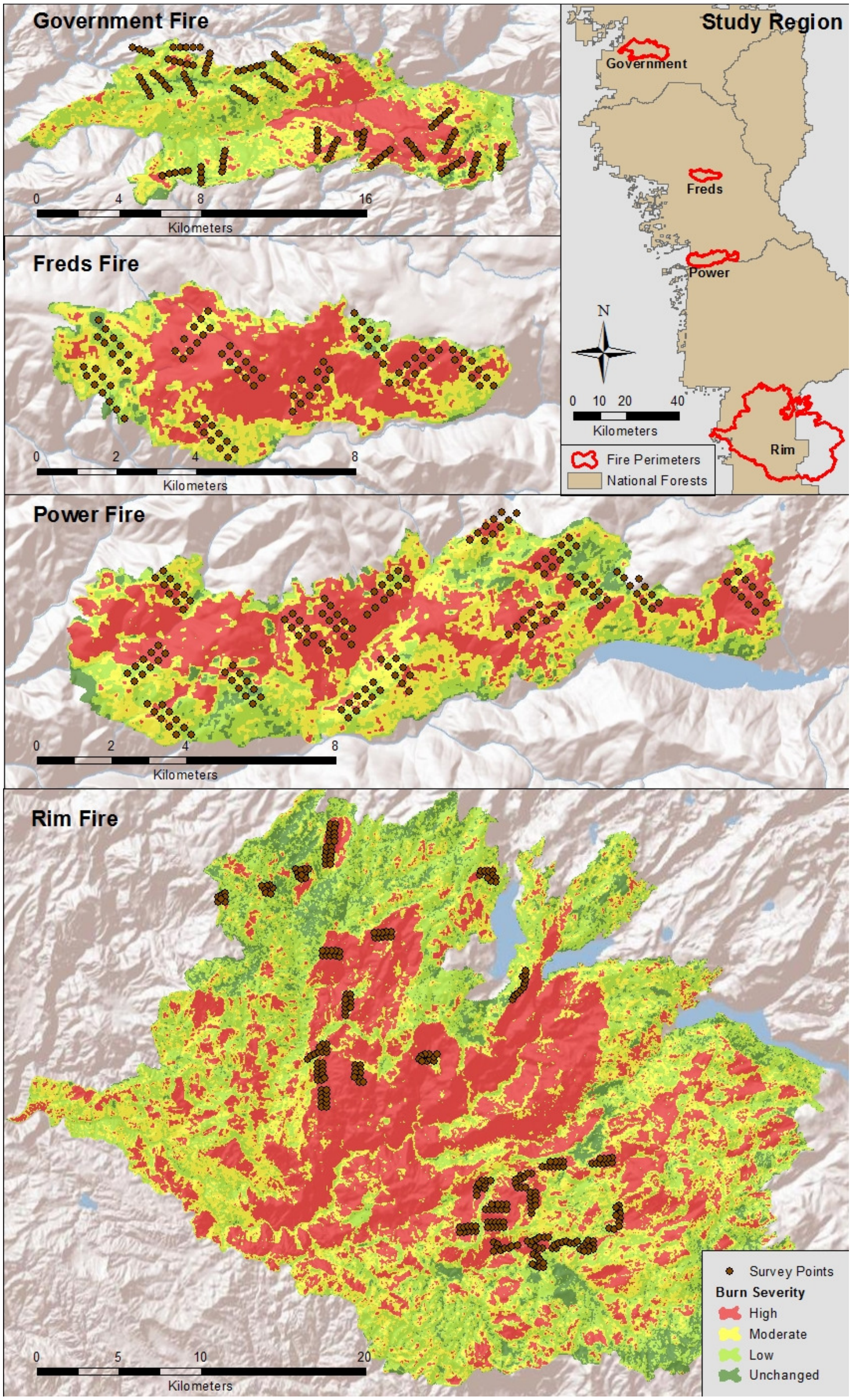
The human-caused 104,131 ha (257,314 ac) Rim Fire is located within the Miwok and Groveland Ranger Districts of the Stanislaus National Forest and within Yosemite National Park. It burned during the summer-fall of 2013 through the Tuolumne and Clavey River watersheds and grew to be the third largest fire in California history (largest within the Sierra Nevada), containing very large patches (max = 17,311 ha; mean = 16 ha) of high severity vegetation effects. The elevations of avian monitoring locations in Rim ranged from 1139 – 1963m (mean = 1423m, *N* = 271).

## Sampling Design

*Freds, Power and Government Fires*

In the Freds and Power fires, point count transects were established so as to take advantage of previous and ongoing vegetation surveys conducted by the US Forest Service Region 5 and UC Davis scientists. Where possible, survey points were located coincident with previously sampled Common Stand Exam (CSE; Freds Fire), or regeneration (Power Fire) plots. These vegetation plots were established along either a 400m (CSE) or 200m (regeneration) grid. CSEs were conducted in Freds fire during 2009, 2012 and 2013 (Bohlman and Safford 2014), and will be conducted in the Power fire during 2014-2016 (Clark Richter, UC Davis, *personal communication*). Regeneration surveys were conducted in Power Fire during 2009 (Welch and Safford 2010).

**Figure 1.** Study area maps and survey locations for Government, Freds, Power, and Rim fires. Fire severity levels are also shown. With the exception of Freds and Power fires map scales differ between maps.



To maximize the number of points surveyed in a morning, bird transects were typically comprised of 10 points made up of two parallel five-point sub-transects and were located within one kilometer of a road. These transects were placed at a diagonal along the vegetation plot grids making point count locations approximately 283m apart. Each transect was located a minimum of 500m from any other transect.

In Government Fire, we used a similar sampling approach as the northern Sierra fires we've surveyed since 2009 (Burnett et al. 2012). Five-point transects were located in a GIS using random starting points and random bearings. Points within transects were located 250m apart. Transects were located a minimum of 500m apart and within 1km of a road. Given these distance restrictions, and sampling limitations due to land ownership and terrain (detailed below), a maximum of 39 transect locations were identified. From this maximum pool, 30 transects were randomly selected for field reconnaissance.

Although all sampled fires burned across a variety of terrain and across multiple landownerships, transects were limited to Forest Service land, slopes with a maximum of 35 degrees and did not require any major stream crossings. Knowing that actual terrain can often be more hazardous than it appears using remotely sensed imagery and digital elevation models alone, we initially established more transects than could be sampled with the expectation that some would be dropped due to safety concerns. Our final sample size resulted in 76 points on 9 transects in Freds, 150 points on 15 transects in Power, and 125 points on 25 transects in Government Fire. Occasionally individual points were moved slightly and rarely points were removed all together for the same reason. Thus, our sample represents a compromise between statistical randomness and logistical feasibility. This likely results in at least one clear bias – we are under-sampling the steepest terrain in each of these fires and any areas far from navigable roads.

*Rim Fire*

Point locations in the Rim Fire were established to evaluate the effects of post-fire salvage logging on the avian community in a Before-After-Control-Impact (BACI) framework. Our strategy involved selecting sampling locations within proposed salvage locations and then selecting a control sample with similar conditions from the standpoint of the avian community. We conducted site selection in a GIS environment by employing ArcGIS and Google Earth with a number of layers to assist in selection. Layers included fire severity (accessed through the Region 5 GIS clearinghouse: http://www.fs.usda.gov/wps/portal/fsinternet/main/r5/landmanagement/gis), proposed salvage unit boundaries (provided by Stanislaus National Forest), aerial photos of pre and post-fire condition, CALVEG habitat (USDA 2004) and a digital elevation model.

We first selected the salvage sampling locations using the salvage polygons identified in the USFS proposed action. We then used the Military Grid Reference System (MGRS) 100m resolution grid and clipped it to the proposed salvage polygons. We then sampled the statewide digital elevation model (30m resolution) for slope in a 3-cell radius surrounding each grid point and removed all areas with slopes greater than 30%.

We then generated a list of spatially balanced random starting points using a Generalized Random Tessellation Stratification (GRTS) in the proposed salvage areas. We generated an ordered list of potential transect starting points. We then attempted to establish a series of 10 point count locations (transect) around each starting point. Locations were established every 250m and at least 100m from the salvage polygon boundary. We first attempted to establish transects as two parallel five-point lines. If 10 points could not be established in this manner we attempted to fit them in a non-linear array. If we could not establish 10 points in high enough density to allow a single observer to sample all stations in a four hour period, we dropped that starting point and selected the next point in the list. If a subsequent starting point overlapped a previously established transect it was dropped from consideration and the next subsequent point was selected. We intentionally weighted our sampling to proposed salvage units expecting that a number of units would be dropped between the proposed plan and the final Record of Decision. We selected 40 potential random starting points for consideration in the salvage sample and established a total of 20 transects in proposed salvage units (13 in a linear fashion, 7 in non-linear).

We then evaluated the CWHR forest type, tree size, density class, elevation, and burn severity at each of our salvage point count locations. We used CALVEG to delineate forest type, size and density classes, the statewide digital elevation model to assess elevation, and the Relativized differenced Normalized Burn Ratio (RdNBR) – converted to units of the composite burn index (CBI; Key and Benson 2006) to assess burn severity. We used the range of these conditions to stratify our reference sample starting points. We limited the reference sample to elevations above 867m, slopes <30%, conifer CWHR types, dense, moderate, and open density classes, and weighted the GRTS point selection to match the frequency of low, moderate, and high severity in our salvage sample. We then removed all areas within 100m of any proposed salvage polygon boundary. Many of the potential reference points were located in small isolated areas that would not support a large enough sample of the comparable habitat to our salvage sample (at least 6 point count locations). We removed these small isolated areas from consideration. GRTS was then used to select 20 potential reference transect starting points with intention to establish 10 refrence transects. We intentionally weighted our initial sampling to proposed salvage areas knowing that a number of the proposed salvage polygons would eventually be dropped from consideration. Thus our initial sample was 200 point count locations on 20 salvage transects.

We then determined the pre-fire CWHR habitat type, size class, density class, and burn severity for each salvage point count location selected. We used this information to inform reference site selection. We used a similar approach for selecting reference site transects using the GRTS generated starting points with 250m spacing and at least 200m from any salvage unit boundary. Even following our stratifications we found that the areas surrounding the random starting points in our control sample tended to be lower burn severity, have lower tree density, occur in pine and pine hardwood forest types (vs. Sierra mixed conifer for proposed salvage units), and occur in size class 3 and 5 forest (vs. size class 4 for salvage). To account for this when establishing reference transects we dropped potential starting points if the surrounding habitat was dominated by pine hardwood, low density, or small size class forest. The potential reference sites also tended to be far steeper than proposed salvage areas which resulted in dropping several potential areas from consideration. With these considerations we established nine reference transects (only one in a linear fashion). Once the salvage plan was finalized by the Stanislaus National Forest and the majority of salvage logging completed as of November 2015, we used a GIS layer provided by Stanislaus National Forest to estimate that our sample consisted of 98 salvage point count locations and 183 reference point count locations. Reference and salvage points are overall similar but reference points are located in lower burn severity, have more size class 3 and 5 forest and a higher proportion of Sierra mixed conifer and ponderosa pine forest compared to salvage points which has more pine hardwood (Table 1). Surveys in 2016 will ground-truth salvage status by estimating area treated within 50 and 100m of the point count locations; once salvage status is verified, we will build a sample from the reference points that match characteristics of the salvage points.

**Table 1**. Characteristics of salvage (N = 98) and reference (N = 183) point count locations in the Rim Fire. Elevation is expressed in meters; all other metrics are percentages.

| | | Salvage | Reference |
|---|---|---|---|
| CWHR type (%) | Sierra Mixed Conifer | 65 | 73 |
| | Ponderosa Pine | 15 | 22 |
| | Montane Hardwood Conifer | 17 | 5 |
| | Lodgepole Pine | 3 | 0 |
| CWHR size class (%) | Class 3 (6-11in dbh) | 4 | 12 |
| | Class 4 (11-24 in dbh) | 79 | 68 |
| | Class 5 (>24 in dbh) | 17 | 20 |
| CWHR density class (%) | Moderate (40-59%) | 11 | 14 |
| | Dense (60-100%) | 89 | 86 |
| Burn Severity (%) | High | 93 | 80 |
| | Moderate | 6 | 9 |
| | Low | 1 | 11 |
| Elevation (m) | Mean (SD) | 1373 (134) | 1448 (170) |
| | Range | 1147-1620 | 1134-1952 |

### Point Count Surveys

Surveyors conducted standardized five-minute exact-distance point counts at each point count station (Ralph et al. 1995). With the aid of rangefinders, surveyors estimated the exact distance to each individual bird. The initial detection cue (song, visual, or call) for each individual was also recorded. Counts began around local sunrise, were completed within four hours, and did not occur in inclement weather. Surveyors received two weeks of training to identify birds and estimate distances and passed a double-observer field test. The majority of transects were visited twice during the peak of the breeding season from mid-May through the end of June. Due to logistic constraints, four points (out of 76) were only visited once in Freds Fire. In the Rim Fire, active logging operations hindered access; one transect was not visited at all and three transects only had a first visit.

### Vegetation/Habitat Surveys

Vegetation data was collected at all point count locations for all fires except Government during the 2014 and 2015 field seasons. Results from Freds and Power fires are presented here. We measured vegetation characteristics within a 50m radius plot centered at each point count station following a modified version of the relevé protocol, outlined in Ralph et al. (1993). On these plots, we measured shrub cover, live tree cover, herbaceous cover, as well as the relative cover of each species in the shrub and tree layers. We also measured basal area of live trees and snags using a 10-factor basal area key at five fixed locations in each plot.

### Analysis: General Procedures with Point Count Data

We restricted the analysis of our point count data to a subset of the species encountered. We excluded: (1) all birds >100 m from the observer, (2) species flying over the sampling locations but not actively using the habitat, (3) species that do not breed in the study area, and (4) those species that are not adequately sampled using the point count method (e.g., waterfowl, raptors, waders; Appendix A). Several of our analyses are further restricted to different species guilds whose habitat requirements we believe represent a broad range of habitat conditions within burned landscapes. For the majority of analyses, we used two metrics to investigate the bird community: abundance and species richness. Abundance is defined as the mean number of individuals detected per point count survey. Bird species richness is defined as the mean number of species detected per survey.

### Analysis: Bird Species Abundance Across Fires

To examine the effect of fire on abundance (number of individuals detected) for 22 individual species with sufficient sample sizes that are indicative of conditions created by fire, we built generalized linear mixed models with Poisson error structure and a logarithmic link function using the package lme4.0 version 1.1-7 (Bates et al. 2011) in program R version 3.2.2 (R Core Team 2015). Our sample unit was a single point count visit and the dependent variable was the total sum of all individuals of a particular species. Point was included as a random effect on the intercept parameter. We fit a single model where fire location (Freds, Power, Government or Rim) was a categorical fixed effect. We excluded all Rim Fire points that were located in salvage units due to varying levels of logging during the 2015 field season. We report model mean predictions for abundance and richness with 95% confidence intervals (CI) using only 2015 data. Significant differences are reported at the $P < 0.05$ level.

### Analysis: Habitat Associations in Freds and Power Fires

We chose the top four most abundant bird species in Freds and Power fires, in addition to abundance and richness for three bird guilds, to build habitat association models using vegetation variables collected in the field and topographic variables. The four most abundant species were Fox Sparrow, Green-tailed Towhee, Spotted Towhee and Lazuli Bunting (scientific names can be found in Appendix A). All four species forage and nest in the understory, primarily in shrubs.

The three bird guilds we analyzed include the early seral forest (ESF) species associated with herbaceous and shrub habitats, the post-fire snag (PFS) guild species that use fire-killed trees and the open and mature forest (OMF) guild species that occur along forest edges and openings and/or utilize shade intolerant resources from the sub-canopy to the forest floor (Table 2). See Fogg et al. (2015) for detailed criteria for how species were assigned to guilds.

**Table 2.** List of species in the early successional, open and edge, and mature and dense avian guilds. Scientific names can be found in Appendix B. Species are listed in taxonomic order.

| Early Seral Forest (ESF) | Post-fire Snag (PFS) | Open and Mature Forest (OMF) |
|---|---|---|
| Mountain Quail | Lewis' Woodpecker | Western Wood-Pewee |
| Dusky Flycatcher | Hairy Woodpecker | Olive-sided Flycatcher |
| Spotted Towhee | Black-backed Woodpecker | Warbling Vireo |
| Green-tailed Towhee | White-headed Woodpecker | American Robin |
| Fox Sparrow | Northern Flicker | Nashville Warbler |
| Chipping Sparrow | Brown Creeper | Yellow-rumped Warbler |
| Yellow Warbler | House Wren | Chipping Sparrow |
| MacGillivray's Warbler | Mountain/Western bluebirds | Black-headed Grosbeak |
| Lazuli Bunting | | Western Tanager |

To examine habitat associations for these four species and abundance and species richness for the bird guilds, we built generalized linear mixed models with Poisson error structure and a logarithmic link function. Our sample unit was a single point count visit and the dependent variable was the total sum of all individuals of a particular species or guild (abundance) or the total count of guild species present (species richness). Point count transect and point were included as a random effects on the intercept parameter.

We included a large number of variables generated from vegetation survey data that describe plant structural characteristics and plant species richness, in addition to topographic variables (Table 3). Topographic variables included elevation, percent slope and solar radiation index (SRI; Keating et al. 2007), the latter a measure of aspect. We initially examined correlations between potential predictor variables and did not include any variables with $r$ >0.50 in the same model (see Appendix B for correlation coefficients). We used a stepwise model selection process to select variables that best described each species' and guilds' abundance and richness (Table 3). We began with a global model containing all vegetation and topographic parameters and then used backward stepwise model selection based on Akaike information criterion (AIC) rankings. To identify the most parsimonious model, we iteratively removed the parameter estimate with lowest significance ($P>|z|$) until the removal of a variable did not improve AIC by more than 2 units. We report scaled coefficient estimates (to aid in comparison among variables), standard errors and ($P|z|$) for the final model. Significant differences are reported at the $P < 0.05$ level.

**Table 3.** Vegetation and topographic covariates included in habitat associations models for the early seral forest (ESF), post-fire snag (PFS) and open and mature forest (OMF) bird guilds. Variables associated with the ESF guild were included in individual species models.

| Variable Name | Description | Guild |
|---|---|---|
| BA live trees | Basal area of live trees, average of 5 measurements | all |
| BA dead trees | Basal area of dead trees, average of 5 measurements | PFS, OMF |
| young conifer cover | Percent cover of conifer species less than 5 m tall | ESF, OMF |
| shrub cover | Percent cover of all shrub species | ESF, OMF |
| shrub cover$^2$ | Quadratic term for percent shrub cover | ESF, OMF |
| shrub richness | Number of shrub species | ESF, OMF |
| herbaceous | Percent cover of the herbaceous layer | ESF, OMF |
| elevation | (m) | all |
| slope | Percent slope calculated using a digital elevation model | all |
| SRI | Solar radiation index, a measure of aspect | all |

## Analysis: Effects of Herbicide Treatments in Freds Fire

We examined whether recent herbicide treatments in Freds Fire had an effect on the abundance and richness of the Early Seral Forest bird guild, as this community of species is reliant on the shrub layer for nesting and foraging. Herbicide treatments were targeted at reducing shrub competition for the planted conifers; glyphosate was the main chemical used (Bob Carroll, Placerville Ranger District, *personal communication*) and dead shrubs were left standing with the expectation that the winter's snowpack would break down the dead biomass and subsequently reduce fuel loads. We used the Region 5 Forest Service Activity Tracking System (FACTS) database (available online at http://www.fs.usda.gov/detail/r5/landmanagement/gis), specifically the 'METHOD' and 'EQUIPMENT' fields to classify points in Freds Fire as treated using chemical methods and equipment. Areas were treated in 2010, 2011, 2012 and 2014. Treatment was underway in 2015 but this largely occurred after bird surveys were completed. Sixteen points were treated in multiple years, six points were treated once, primarily in 2014, and we included six more points that vegetation surveys and aerial imagery confirmed were also treated (N=28 points total). We initially examined effects of time since treatment and found it to be non-significant, thus this variable was eliminated from future models.

To build a control sample, we included all Freds Fire points that burned at moderate or high severity and had a similar average and range of vegetation covariates as the treatment sample (excluding shrub cover which is affected by the treatment). However only thirteen control points within the fire perimeter were available, resulting in a relatively small sample size. To increase our sample of untreated points we expanded selection of control points to the Power Fire, which is similar topographically and burned under similar conditions as the Freds Fire. To help account for geographic and management differences between fires, we excluded points in both fires unaffected by salvage logging (confirmed using FACTS), points that had basal area of live trees > 100ft$^2$, and elevations > 1400m. The resulting control sample (N=49 points) had similar geographic and vegetation attributes as the treatment sample, excluding shrub cover which averaged 8% at treated locations and 37% at control locations.

To compare bird abundance and richness, we only included observations within 50m of the observer. We built generalized linear mixed models with a Poisson error structure and a logarithmic link function. Our sample unit was a single point count visit and the dependent variable was the total sum of all individuals of a particular species or guild (abundance) or the total count of guild species present (species richness). For each model, a binary variable for treatment status was the single fixed effect and transect and point were included as a random effects on the intercept parameter.

## Data Management and Access: Sierra Nevada Avian Monitoring Information Network

All avian data from this project is stored in the California Avian Data Center and can be accessed through the Sierra Nevada Avian Monitoring Information Network web portal (http://data.prbo.org/apps/snamin). At this website, species lists, interactive maps of study locations, as well as calculations of richness, density, and occupancy can be generated as selected by the user. Survey locations can be downloaded in various formats for use in GPS, GIS, or online mapping applications. Non-avian data (e.g., site narratives, vegetation, photos) are stored on Point Blue's server.

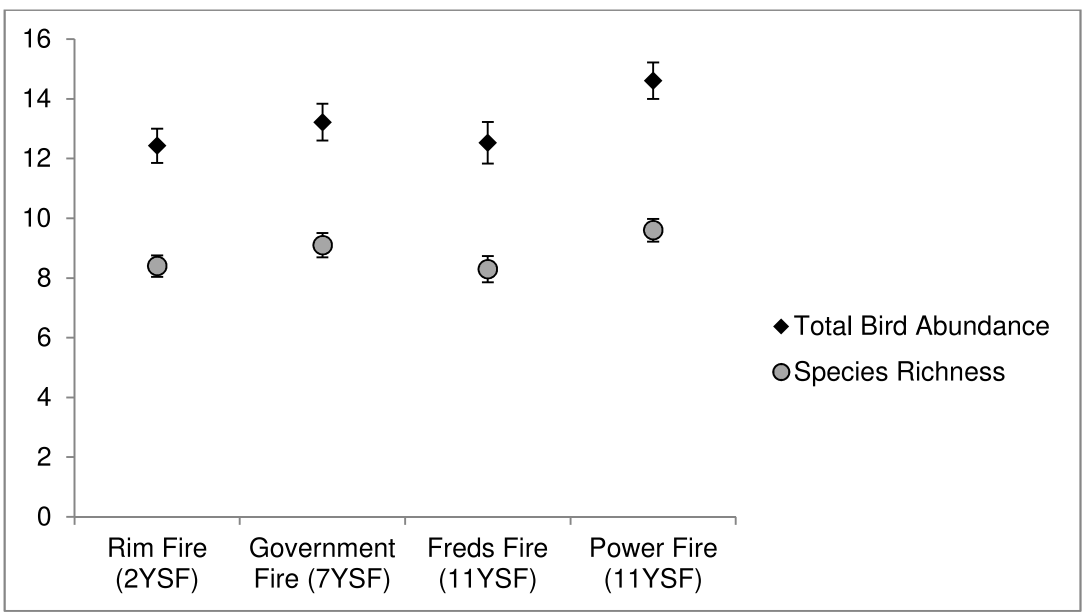
# RESULTS

## Bird Species Abundance Across Fires

A total of 69 bird species were detected in Freds Fire, 77 in Power Fire, 65 in Government Fire and 84 in Rim Fire (see Appendix A for complete list of species, scientific names and mean number of detections per visit unlimited by distance). Model predictions of total bird abundance within 100m were highest in Power Fire with a mean of 14.6 individuals per point (CI: 14.0 – 15.3, $P = 0.03$, Figure 2). Abundance was similar (all $P > 0.10$) between Freds (mean = 12.5, CI: 11.8 – 13.3), Government (mean = 13.2, CI: 12.6 – 13.9) and Rim Fire (mean = 12.4, CI: 11.9 – 13.0).

Species richness was also highest in Power Fire with a mean of 9.6 species per point (CI: 9.3 – 10.0), and significantly higher than Rim Fire (mean = 8.4, CI: 8.0 – 8.8, $P < 0.001$) and Freds Fire (mean = 8.3, CI: 8.0 – 8.8, $P < 0.001$) but not significantly different from Government Fire (mean = 9.1, CI: 8.7 – 9.5; $P = 0.40$).

**Figure 2**. Predicted mean bird abundance and species richness per point (<100 m from observers) for Rim, Government, Freds and Power fires, with years since fire (YSF) indicated after each fire name. Bars indicate 95% confidence intervals.

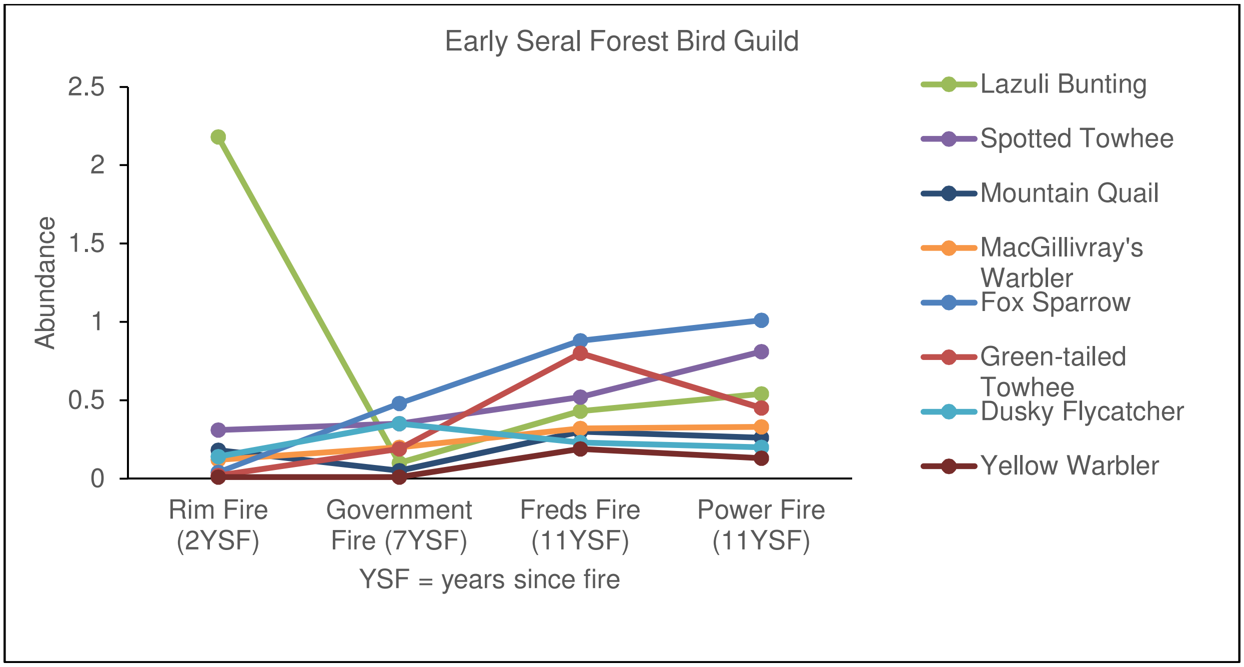


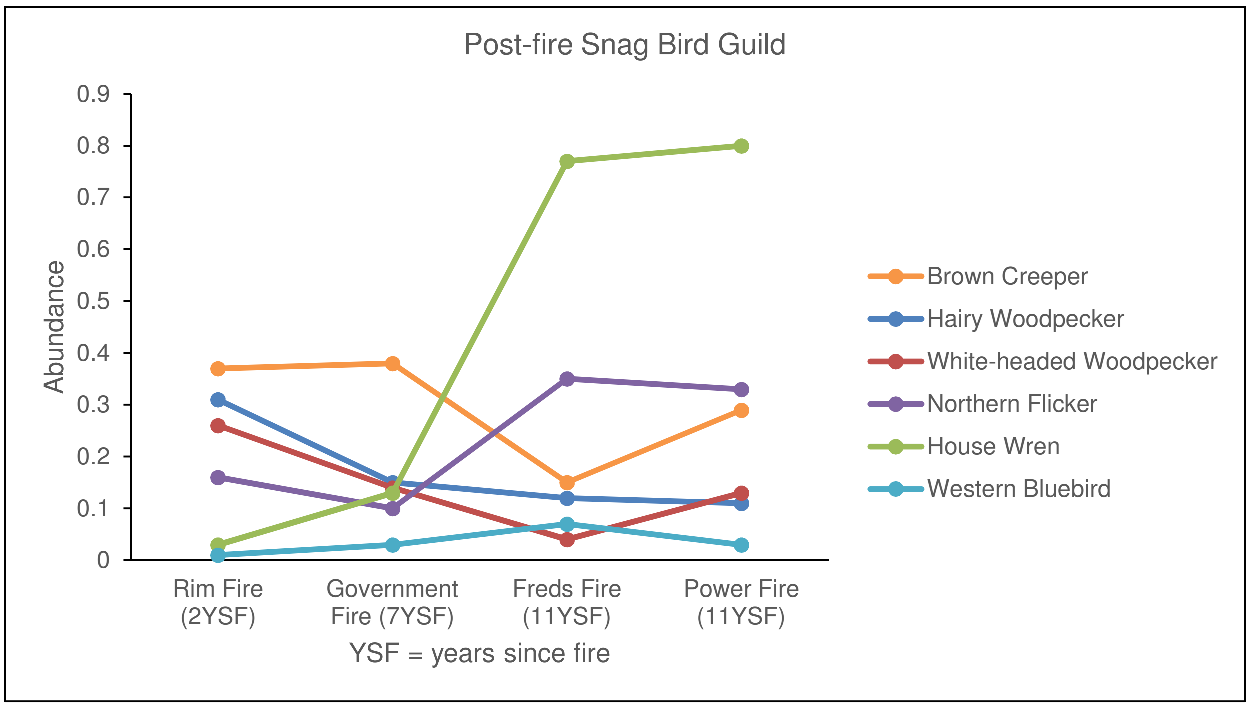

Individual species models showed several different patterns across the four different fires (Figure 3). Species in the Early Seral Forest (ESF) guild (primarily associated with shrub and understory layer) showed greater abundance in older fires that support mature chaparral, especially in the higher severity fires affected by post-fire salvage logging (Freds and Power fires). A clear exception to this pattern is Lazuli Bunting, which was by far the most abundant bird in Rim Fire with densities approaching some of the highest of any bird species Point Blue has monitored within upland habitats in the Sierra Nevada.

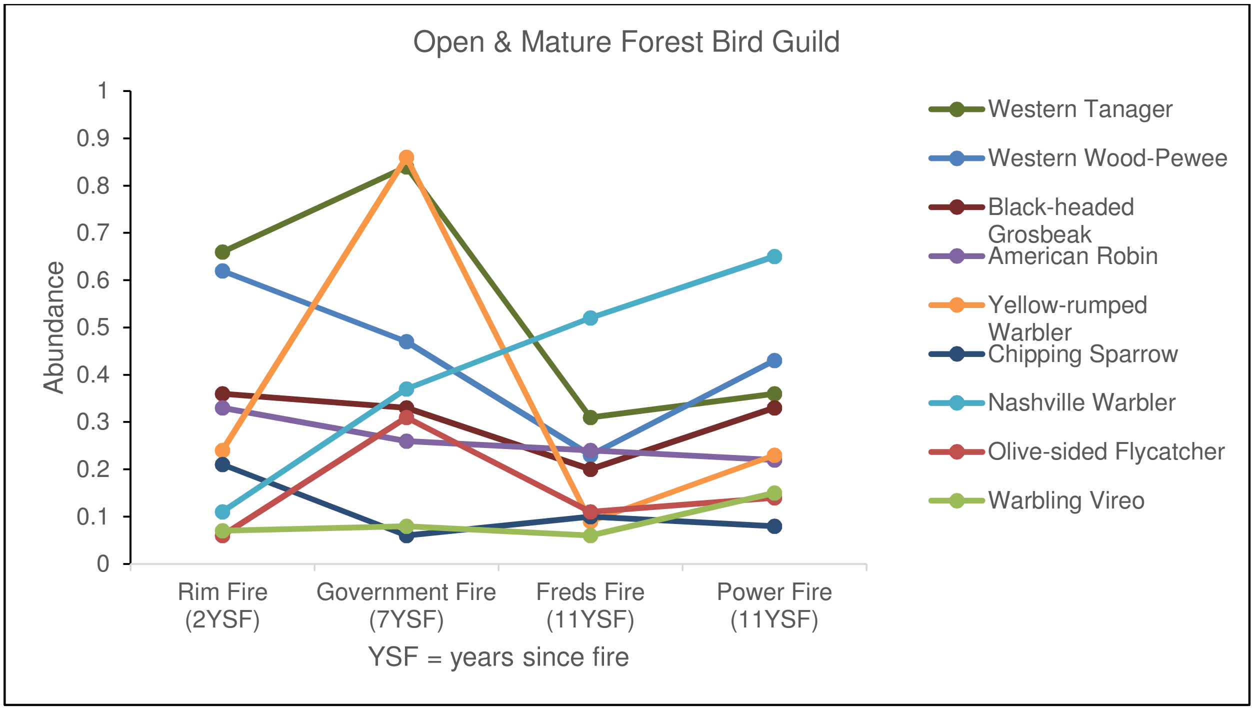
Primary cavity-nesting species that forage directly on the tree bole in the Post-fire Snag (PFS) guild, including Hairy Woodpecker and White-headed Woodpecker, showed higher abundance in the Rim Fire with a decreasing to flat trend as fire age or levels of post-fire management increased. Species that nest in cavities but prefer open areas to forage, including Northern Flicker and Western and Mountain bluebirds, increased with fire age. Brown Creeper had its highest abundance in the Rim and Government fires. House Wren was nearly absent from Rim Fire but abundant in Freds and Power fires. Because House Wren is a secondary cavity nester, this pattern may be attributable to the greater presence of shrub cover in these older fires.

For several species in the Open and Mature Forest (OMF) guild (e.g., Western Tanager, Yellow-rumped Warbler, Olive-sided Flycatcher), peak abundance occurred in the Government Fire, which burned at lower severity and experienced less post-fire management compared to the other two older fires. Western Wood-Pewee and Chipping Sparrow had their highest abundance in the Rim Fire and the remaining species showed similar abundance across all fires. For nearly all species, abundance was lowest in Freds Fire where due to landscape factors, fire behavior or post-fire management, areas of green forest within the fire perimeter are sparse.

**Figure 3.** Modeled avian abundance across four fires for bird species associated with three habitat guilds. Abundance values are in terms of the mean expected number of individuals observed per point count survey. Species are listed in order of abundance relative to Rim Fire. Years since fire (YSF) is noted after each fire name.






## Vegetation Data Summary

The distributions of vegetation attributes between Freds and Power Fire were largely similar with the exception of snag basal area and shrub cover (Figure 4). Power Fire had a median snag basal area of 6.0 $m^2/ha$ (26 $ft^2/ac$) compared to Freds Fire with 3.2 $m^2/ha$ (14 $ft^2/ac$). Power Fire also had higher median percent shrub cover (20%) compared to Freds Fire (12%). Power Fire had slightly higher median live tree basal area relative to Freds fire (10.3 $m^2/ha$ [45 $ft^2/ac$] vs. 8.7 $m^2/ha$ [38 $ft^2/ac$], respectively) and a slightly higher percentage of young conifer cover (10% vs. 8.5% respectively).

We identified a total of 18 shrub species or genera in Freds Fire and 32 in Power Fire. Seven species made up approximately 90% of shrub species cover (Figure 5). Both fires had similar relative cover of manzanita (*Arctostaphylos* spp.) and mountain whitethorn (*Ceanothus cordulatus*) in the shrub layer. Power Fire had higher deerbrush *(Ceanothus integerrimus)* cover (38% vs. 26%). Freds Fire had higher cover of less dominant shrub species including bush chinquapin (8%; *Chrysolepis sempervirens*) and cherry species (5%; *Prunus* spp.). Huckleberry oak (*Quercus vacciniifolia*) made up 5% of the sampled Power Fire cover compared to <1% in Freds Fire.

**Figure 4.** Boxplots of select vegetation attributes measured within a 50m radius plot (1.94 acre) centered on each point count location in the Freds and Power Fires.

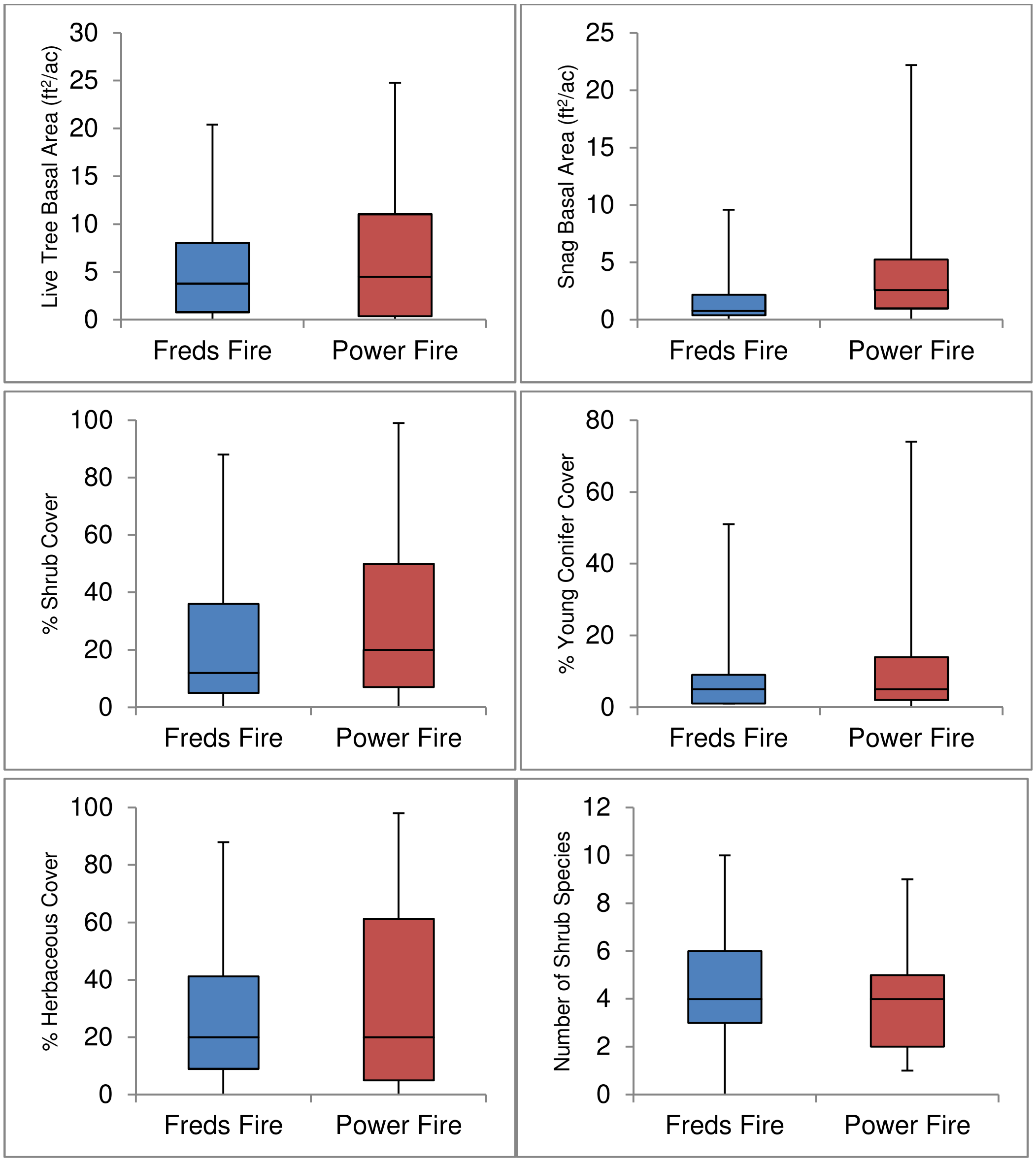
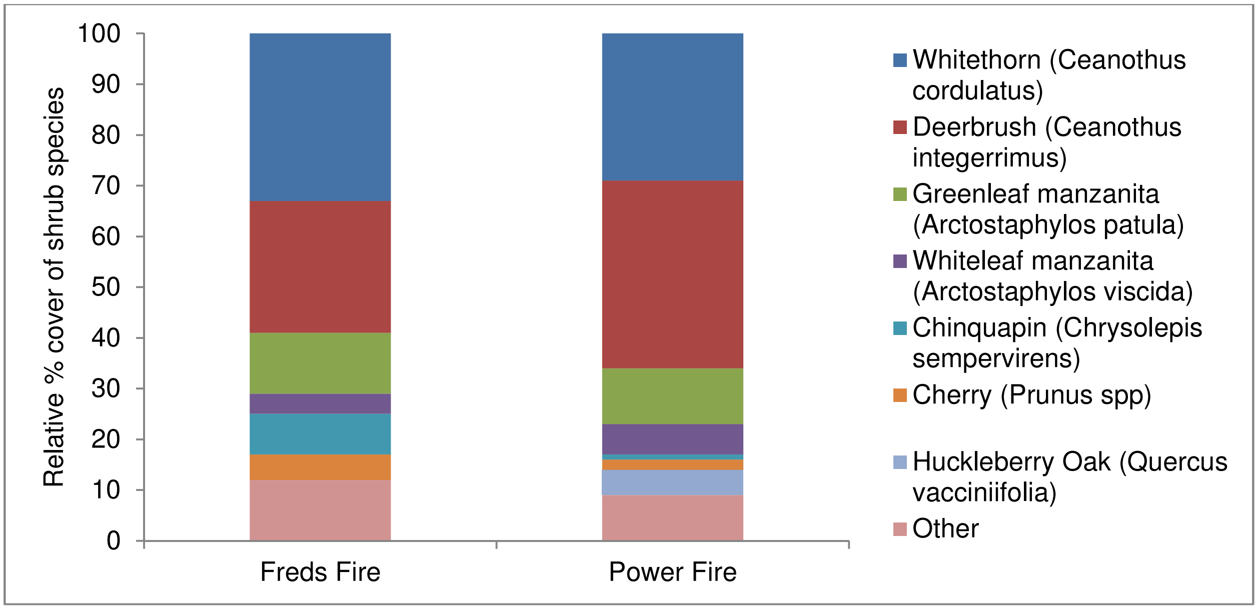


**Figure 5.** Average relative percent cover of shrub species within the shrub layer in the Freds and Power fires. Relative cover was calculated by multiplying percent shrub cover within a 50m-radius plot centered on the point location by the percent cover of the shrub species occurring on the plot.




## Habitat Associations in Freds and Power Fires

*Individual species*

We examined habitat associations for four of the most common species in the Freds and Power fires: Fox Sparrow, Green-tailed Towhee, Spotted Towhee and Lazuli Bunting. All nest and forage in the shrub or understory layer. Few covariates were eliminated during the model selection process (see Table 3 for covariates). Elevation had the largest effect size for three of four species, showing either a preference for higher (Fox Sparrow and Green-tailed Towhee or lower elevations (Spotted Towhee, Lazuli Bunting; Table 4). Models also showed a relatively strong negative association of basal area of live trees on all species except for Fox Sparrow. This association was especially strong for Lazuli Bunting where basal area of live trees was estimated to have the largest effect size of all variables considered. The linear term for shrub cover was significantly positive for all species, and the quadratic term for shrub cover was significant and negative for Lazuli Bunting. Thus abundance of these individuals generally increases with shrub cover with the exception of Lazuli Bunting where abundance may peak at intermediate levels. For all species except for Spotted Towhee, species abundance was significantly positively associated with young conifer cover (conifers < 5m tall). Shrub species richness was included in the final model for three of four species, with positive associations with Fox Sparrow and Green-tailed Towhee abundance but negative with Spotted Towhee abundance. Elevation and shrub species richness was positively correlated ($r = 0.42$; Appendix B). Thus the Spotted

Towhee model may be a reflection of preference for lower elevations rather than low shrub species richness. However, additional analysis would be needed in this case to parse out these potentially confounding variables.

**Table 4**. Coefficient estimates, standard errors (SE) and significance value (P|z|) derived from habitat associations abundance models for the four most common species in the Freds and Power Fires. Variables with significant estimates (P|z| < 0.05) are bolded and sorted by effect size. Model variables were scaled prior to conducting analyses, thus estimate values represent relative correlations and can be compared among variables.

| **Fox Sparrow** | **Estimate** | **SE** | **(P\|z\|)** | **Spotted Towhee** | **Estimate** | **SE** | **(P\|z\|)** |
|---|---|---|---|---|---|---|---|
| intercept | -0.02 | 0.10 | 0.83 | intercept | -0.33 | 0.12 | 0.006 |
| **elevation** | 0.57 | 0.09 | <0.001 | **elevation** | -0.50 | 0.10 | <0.001 |
| **shrub cover** | 0.28 | 0.05 | <0.001 | **shrub richness** | -0.26 | 0.07 | <0.001 |
| **slope** | -0.14 | 0.05 | 0.005 | **shrub cover** | 0.23 | 0.08 | 0.003 |
| **young conifer** | 0.12 | 0.04 | 0.004 | BA live trees | -0.20 | 0.07 | 0.003 |
| herbaceous | -0.05 | 0.06 | 0.47 | SRI* | 0.12 | 0.07 | 0.10 |
| shrub richness | 0.04 | 0.05 | 0.39 | young conifer | 0.09 | 0.05 | 0.07 |
| | | | | shrub cover$^2$ | -0.08 | 0.05 | 0.11 |
| **Green-tailed Towhee** | | | | **Lazuli Bunting** | | | |
| intercept | -0.48 | 0.10 | <0.001 | intercept | -0.75 | 0.15 | <0.001 |
| **elevation** | 0.77 | 0.10 | <0.001 | **BA live trees** | -0.75 | 0.11 | <0.001 |
| **BA live trees** | -0.27 | 0.07 | <0.001 | **elevation** | -0.38 | 0.12 | 0.001 |
| **SRI*** | 0.17 | 0.06 | 0.008 | **shrub cover** | 0.20 | 0.09 | 0.04 |
| **young conifer** | 0.14 | 0.06 | 0.01 | **shrub cover$^2$** | -0.12 | 0.06 | 0.05 |
| **shrub cover** | 0.13 | 0.07 | 0.05 | young conifer | 0.09 | 0.06 | 0.12 |
| **shrub richness** | 0.12 | 0.06 | 0.03 | shrub richness | -0.06 | 0.08 | 0.41 |
| herbaceous | 0.09 | 0.08 | 0.24 | herbaceous | -0.06 | 0.08 | 0.47 |

*SRI = Solar Radiation Index

*Bird Guilds*

Nearly all covariates were retained in the model selection process for the ESF guild (Table 5). In contrast to some of the individual species models, increasing shrub cover had the largest effect size on the abundance and species richness of the ESF guild. The quadratic term for shrub cover was estimated to be relatively large but negative, indicating that intermediate levels of shrub cover (40-60%) benefits the entire guild. However, the estimate of the quadratic term for the species richness model is relatively uncertain, and an alternative model omitting this predictor shows species richness increasing linearly (Figure 6). Elevation showed relatively large positive association with ESF abundance, and basal area of live trees relatively large negative associations in both ESF models. Model estimates also indicate significant but weaker positive relationships with young conifer cover in both models, and a negative relationship with slope in the richness model.

Model selection results retained nearly all covariates for the abundance and richness of the PFS guild, with similar significant positive effect sizes for basal area of snags (Figure 6) and elevation, and negative relationship with basal area of live trees.

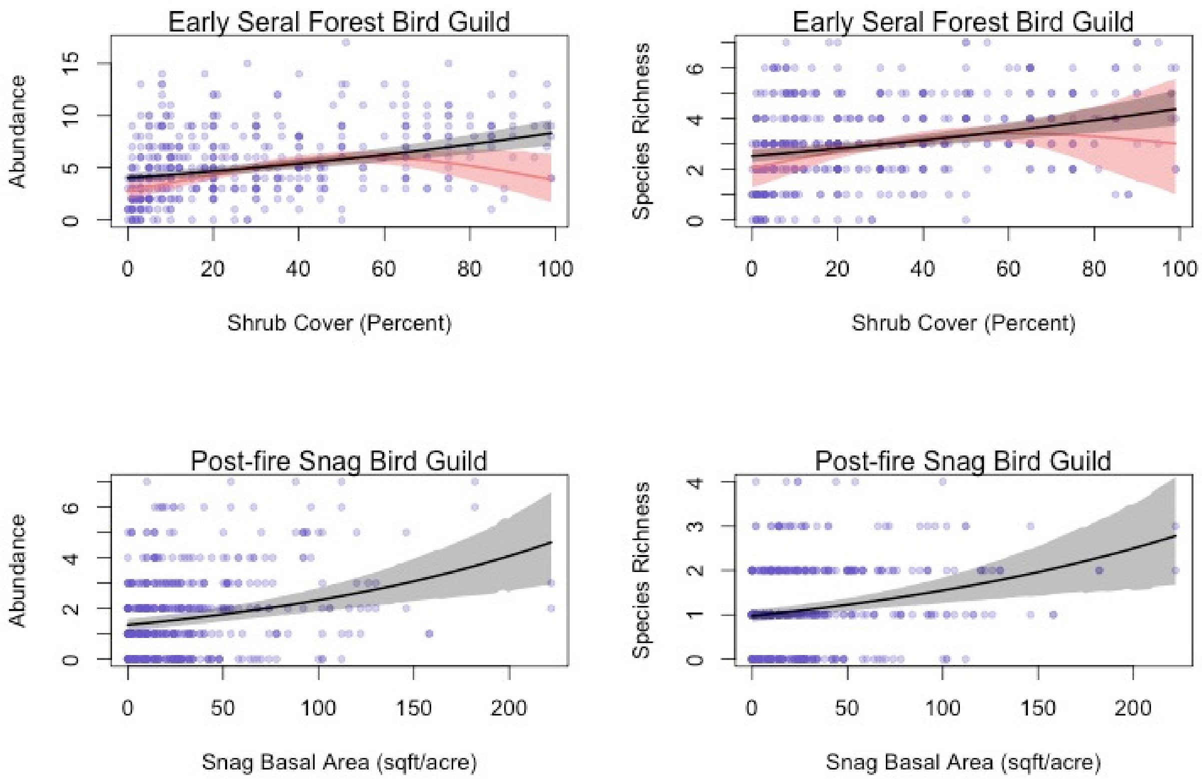
Abundance model selection results for the OMF guild retained all covariates except for basal area of snags. The richness model dropped basal area of snags, young conifer cover and herbaceous cover. A positive relationship with the basal area of live trees had the largest effect size among the remaining covariates. Other covariates with similar effect sizes in the abundance model included a positive relationship with shrub cover and a negative relationship with the quadratic of shrub cover, elevation, slope and solar radiation index (suggesting avoidance of south-facing slopes). A significantly positive relationship with basal area of live trees had the largest effect size in the richness model for the OMF guild. A negative relationship with solar radiation index was the only other significant covariate in the richness model.

**Table 5.** Coefficient estimates, standard errors (SE) and significance value (P|z|) derived from habitat association abundance models for three bird guilds in the Freds and Power Fires. ESF = Early Seral Forest bird guild, PFS = Post-fire Snag bird guild and OMF = Open and Mature Forest bird guild. Variables with significant estimates (P|z|) < 0.05) are bolded and sorted by effect size. Model variables were scaled prior to conducting analyses, thus estimate values represent relative correlations and can be compared among variables.

| **ESF abundance** | **Estimate** | **SE** | **(P\|z\|)** | **ESF richness** | **Estimate** | **SE** | **(P\|z\|)** |
|---|---|---|---|---|---|---|---|
| intercept | 1.60 | 0.05 | <0.001 | intercept | 1.08 | 0.04 | <0.001 |
| **shrub cover** | 0.38 | 0.07 | <0.001 | **shrub cover** | 0.25 | 0.09 | 0.007 |
| **shrub cover$^2$** | -0.18 | 0.06 | 0.008 | **BA live trees** | -0.11 | 0.03 | <0.001 |
| **elevation** | 0.17 | 0.05 | <0.001 | shrub cover$^2$ | -0.10 | 0.09 | 0.26 |
| **BA live trees** | -0.15 | 0.03 | <0.001 | **slope** | -0.07 | 0.03 | 0.02 |
| **young conifer** | 0.08 | 0.02 | <0.001 | **young conifer** | 0.06 | 0.03 | 0.04 |
| **slope** | -0.08 | 0.03 | 0.002 | shrub richness | 0.05 | 0.03 | 0.13 |
| shrub richness | 0.03 | 0.03 | 0.18 | | | | |
| SRI* | 0.03 | 0.03 | 0.30 | | | | |
| **PFS abundance** | | | | **PFS species richness** | | | |
| intercept | 0.47 | 0.08 | <0.001 | intercept | 0.12 | 0.06 | 0.05 |
| **BA live trees** | -0.22 | 0.05 | <0.001 | **BA snags** | 0.16 | 0.04 | <0.001 |
| **BA snags** | 0.19 | 0.04 | <0.001 | **elevation** | -0.14 | 0.06 | 0.02 |
| **elevation** | -0.19 | 0.07 | 0.008 | **BA live trees** | -0.12 | 0.05 | 0.02 |
| SRI* | 0.06 | 0.05 | 0.19 | slope | 0.07 | 0.05 | 0.12 |
| slope | 0.04 | 0.04 | 0.28 | | | | |
| **OMF abundance** | | | | **OMF richness** | | | |
| intercept | 1.12 | 0.06 | <0.001 | intercept | 0.81 | 0.06 | <0.001 |
| **BA live trees** | 0.22 | 0.04 | <0.001 | **BA live trees** | 0.18 | 0.03 | <0.001 |
| **shrub cover** | 0.19 | 0.05 | <0.001 | **shrub cover** | 0.13 | 0.05 | 0.008 |
| **SRI*** | -0.11 | 0.03 | 0.001 | **SRI*** | -0.11 | 0.04 | 0.004 |
| **elevation** | -0.11 | 0.06 | 0.05 | **shrub cover$^2$** | -0.07 | 0.03 | 0.04 |
| **shrub cover$^2$** | -0.08 | 0.03 | 0.001 | slope | -0.06 | 0.04 | 0.11 |
| **slope** | -0.07 | 0.03 | 0.03 | elevation | -0.04 | 0.05 | 0.43 |
| herbaceous | 0.06 | 0.04 | 0.18 | | | | |
| young conifer | 0.02 | 0.03 | 0.49 | | | | |

*SRI = Solar Radiation Index

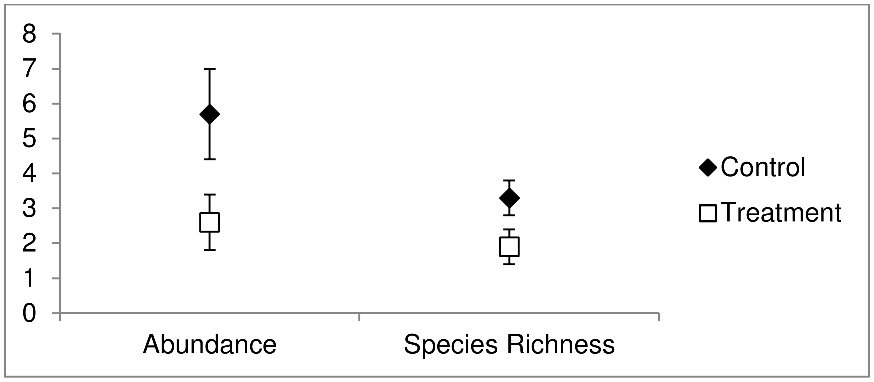
**Figure 6**. Marginal effects of select predictor variables on guild abundance (left column) and species richness (right column). Plots along the top row show alternative models of linear (gray curve; parameter estimates not listed above) and quadratic (red curve) relationships between shrub cover and the Early Seral Forest bird guild. The bottom row shows modeled linear relationships between snag basal area and the Post-fire Snag bird guild. 95% confidence intervals of effect estimates (red and gray shaded areas) are also shown.




## Effects of Herbicide Treatments in Freds Fire

Model results indicated a strong negative treatment effect on ESF bird abundance and richness ($p < 0.001$). Abundance averaged 2.6 individuals (within 50m of the observer) at treatment points and 5.7 individuals at control points (Figure 7). Species richness averaged 1.9 species at treatment points and 3.3 species at control points.

**Figure 7.** Early Seral Forest bird guild abundance and species richness (within 50m of the observer) for points affected by herbicide treatments in the Freds Fire and control points located in the Freds and Power fires.




## DISCUSSION

As average fire severity, fire size and overall annual burned area increases in the Sierra Nevada (Westerling et al. 2006, Miller and Safford 2012), increasing amounts of forest habitat is affected by this dynamic disturbance, subsequently impacting plant and wildlife communities. In this report, we assess bird abundance across four fires in the central Sierra Nevada region that burned at varying times, severity and experienced different post-fire management. Additionally we examined avian habitat associations in the Freds and Power Fires eleven years following the disturbances. Birds are excellent indicators of ecological processes and can provide important feedback regarding the health of managed fire-prone ecosystems (Alexander et al. 2007). The combined results from this contribution and our 2014 report on avian monitoring in the Power and Freds fires (Fogg et al. 2015) show that fire age, severity and post-fire management can significantly affect bird species abundance and diversity. Habitat association models can then help us infer the dominant drivers of species occurrence and abundance. Model results elucidating avian associations with habitat characteristics like snag basal area, which can be directly influenced by management can inform the timing and type of interventions. Complementary, insight into species relationships with fixed habitat characteristics such as elevation can inform where on a landscape management is likely to have the desired effect. The findings presented here supplement a growing body of research into the effects of fire and post-fire management on western montane bird communities. Their value for management will increase as we continue data collection and analysis in subsequent years.

### Avian Community Composition Across All Fires

Differences in species occurrence and abundance between fires are likely due to a combination of factors including fire severity pattern, successional stage, management actions and topography. Of the four fires assessed, Power and Freds are the most similar in terms of these drivers of habitat structure with the two more recent fires providing contrasting examples. Our findings suggest that for all the species adequately assessed through point count surveys, average avian abundance was highest in the 2004 Power Fire compared to the three other fires surveyed. Average species richness of Power was highest as compared to Freds and Rim fires but similar to the lower-severity and less-managed Government Fire. More species were detected overall in Rim Fire, but this is likely attributable to greater sampling effort across a far larger geographic area. The Early Seral Forest (ESF) guild showed a fairly clear pattern across fires with abundance of most species increasing with time since fire. The Post-Fire Snag (PFS) and Open and Mature Forest (OMF) species exhibited more idiosyncratic responses to conditions created by the four fires.

*Early Seral Forest Guild*

The ESF guild had the most consistent response to fire age and management. At two years post-fire, the 2013 Rim Fire likely does yet not contain the structure (i.e., shrubs) necessary for optimal ESF nesting and foraging habitat. The 2008 Government Fire shows a slightly higher abundance, and much higher abundance was observed in the 2004 Freds and Power fires. Thus, among the four fires assessed, abundance of ESF species appears to increase with time since fire. Lazuli Bunting provides the clearest exception to this pattern as it was observed more frequently in the Rim Fire than any other species. This species is a ready colonizer of high severity fires in the Sierra Nevada (Burnett et al. 2012) and throughout the western U.S. (Hutto 1995, Leidolf et al. 2007). Such findings suggest that periodic high-severity fire may help sustain their populations.

In addition to their more advanced successional stage, Freds and Power also experienced higher fire severity and more salvage logging. These two factors can help lead to increased shrub recruitment (Poff 1996, Cahall and Hayes 2009, Crotteau et al. 2013) than the lower-severity and less-managed Government Fire. Additionally topographic and edaphic differences between fires that are not directly assessed here and may also influence the local plant community and subsequently bird occurrence and abundance.

*Post-Fire Snag Guild*

Post-Fire Snag species responses to each fire varied with their individual life history strategies. Early colonizers of post-fire landscapes, including Hairy Woodpecker and White-headed Woodpecker, had their highest abundance in Rim Fire but were present in all other fires. Black-backed Woodpeckers, also an early colonizer (Saracco et al. 2011) was present only in the Rim Fire but at lower densities than other woodpeckers (see Appendix A). Secondary cavity nesters, such as House Wren, or weak excavators, such as Northern Flicker, rose in abundance in older fires once snags began to decompose. Brown Creeper showed similar abundance in the four fires assessed except for Freds Fire, despite the differences in fire age, severity and management. This species builds its nest in loose bark of snags and may be sensitive to snag availability, as most snags were removed in Freds Fire. Future landscape-scale analyses that incorporate patch size, shape and type will help provide additional insight into distribution patterns for Brown Creepers and other species.

*Open and Mature Forest Guild*

The Open and Mature Forest species showed highly variable patterns likely related to foraging and nesting strategies in the overstory or understory layers. Most species had their lowest abundance in Freds Fire, which due to high fire severity and extensive post-fire management has comparatively low tree and snag basal area. Canopy nesters and foragers such as Western Tanager and Yellow-rumped Warbler had their highest abundance in Government Fire, which presumably had more green trees than the other fires. Western Wood-Pewee, an aerial flycatcher was most abundant in Rim Fire, likely taking advantage of open foraging conditions and potentially high numbers of insects using the herbaceous layer; however, Olive-sided Flycatcher did not show the same pattern. Species that use the understory vegetation, for example Nashville Warbler, had their highest abundance in the older fires.

**Habitat Associations**

*Shrub cover*

Shrub cover was found to be strongly and positively associated with the ESF guild as a whole. Of the four individual ESF species models, all had positive significant associations with shrub cover. Additionally, ESF guild models predict intermediate levels of shrub cover (40-60%) to be optimal for Freds and Power Fires (Figure 6). South-facing chaparral stands within the Sierra mixed conifer zone that are uninfluenced by logging are characterized by 30-70% shrub cover on average (Nagel and Taylor 2005). These findings along with our observations suggest maintenance of moderate to high shrub cover on predominantly south-facing slopes within Freds and Power fires would benefit ESF species and associated biodiversity (Swanson et al. 2011).

From surveys completed in 2009-2012, Eldorado National Forest bioregional monitoring points within the Sierra mixed conifer and ponderosa pine zone (N=170) show similar average shrub cover (23% ± 22SD; Roberts et al. 2011, Point Blue Conservation Science, *unpublished data*) compared to Freds Fire (24% ± 24SD) and slightly lower compared to Power Fire (31% ± 28SD). However, most shrub-nesting bird species had significantly higher abundance in Freds and Power fires than nearby unburned forest points (Fogg et al. 2015). Other factors aside from shrubs may influence this guild, such as distance to nearest green forest patch, shrub species, shrub vigor or size of the shrub patch. We plan to use future analyses to address these questions.

*Live tree basal area*

Burn severity heterogeneity, with interspersing patches of live and dead trees, may have an effect on some species' distribution. In particular, all ESF species (except for Fox Sparrow) and the ESF guild as a whole had negative associations with live tree basal area. However, as we demonstrated above, shrub cover is similar between the fires and nearby unburned forest. This may imply that shrub patch characteristics (shape, size, or distance to forest edge) or shrub productivity (increased vigor, seed production or insects associated with recently burned shrubs) may draw early seral specialists to high severity burned areas. Tree presence may bring an increase in nest predators such as Stellar's Jay or mammals that are associated with forested cover. Mammalian nest predators, including chipmunks and tree squirrels (Family Sciuridae), tend to decrease in abundance following fire (Fisher and Wilkinson 2005), especially within larger patches of high severity fire (Roberts et al. 2008) but could decrease even further if remnant green trees are unavailable to escape from their own set of predators, or if downed snags are unavailable (i.e., removed through salvage logging) as means to travel through dense shrub fields.

ESF species and guild responded positively to young conifer cover, implying they are well-adapted to regenerating forests and take advantage of this ephemeral habitat. Some species, like Fox Sparrow, appear to persist at far lower abundance in shrub openings within forested areas but for all members of the ESF guild, once forest cover matures, their numbers tend to be sparse (Fogg et al. 2015).

The Open and Mature Forest guild abundance and richness had strong positive relationship with basal area of live trees and a negative relationship with solar radiation index, thus they avoided deforested expanses with a southern exposure. Several members of this guild showed no preference between Freds and Power fires compared to unburned forest (Olive-sided Flycatcher, Warbling Vireo, American Robin, Nashville Warbler, Western Tanager and Black-headed Grosbeak; Fogg et al. 2015) and are well adapted to pockets of low and moderately-burned areas that occur in Sierra fires. Protecting these areas of green trees within older burned areas from future high-severity fire may be an important strategy for creating habitat heterogeneity and sustaining avian diversity in a higher severity more active fire regime.

*Snag basal area*

Not surprisingly, the PFS guild was positively associated with basal area of snags, which even 11 years post-fire, represent important nesting and foraging substrates. The PFS guild abundance model was largely driven by House Wren which had double the abundance in Freds and Power fires compared to any other PFS guild species. House Wrens appear to prefer burned areas with medium to dense snag stands (Haggard and Gaines 2001, White et al. 2015) and occur at very low density in nearby unburned forest unlike most woodpecker species (Fogg et al. 2015). House Wren presence had less of an effect on the PFS richness model compared to the abundance model and in that case, basal area of snags had a larger effect size compared to basal area of live trees. Future analyses will include a diversity metric (e.g., Shannon index) that accounts for the dominance of a particular species, such as House Wren, and will look more specifically at individual woodpecker species. White-headed Woodpecker and Brown Creeper had higher abundance in Power Fire as compared to Freds, potentially due to the lower snag basal area in the latter. Efforts to remove snags post-fire could negatively impact these species; complete 2014-2017 results from the Rim Fire will help answer these and other salvage-logging related questions. Other PFS species (i.e., Northern Flicker and bluebird species) show similar abundance across both fires, however they forage on the ground more and are likely less sensitive to changes in snag basal area.

### Herbicide Treatments

Preliminary analyses examining the herbicide treatments in Freds Fire showed 120% higher bird abundance and 75% higher species richness at control points versus treated points. These results show a marked difference between relatively intact shrub habitats and those manipulated to accelerate forest regeneration. We lack a sample of treated points in the Power fire, but attempted to choose Power control points that closely matched conditions of the treated points in terms of fire severity, post-fire salvage logging and reforestation efforts, topographic and vegetation conditions (aside from shrub cover). Inherent differences between the two fires (e.g., prefire forest structure) may account for a portion of the difference in bird abundance and richness. Additionally, the small sample of control points in Freds Fire showed similar abundance and richness compared to treated points. It may be possible that using herbicides on the majority of an appropriate early seral forest habitat, such as in Freds Fire which also includes commercial forestry land, can negatively affect shrub-associated birds in the remaining landscape that has not been treated with herbicides. A Before-After Control-Impact (BACI) approach would help account for these confounding factors. If herbicide efforts occur on the Power Fire as part of the developing reforestation EIS, continued monitoring and data would help reduce uncertainties surrounding the use of these management tools in post-fire landscapes.

## Conclusions and Management Recommendations

Our results support earlier work showing that many species are reliant on periodic fire with a mix of severity levels, and that landscapes containing both burned and unburned forests are necessary to maintain a healthy avian community in fire prone western forests (Fontaine and Kennedy 2012). An understanding of the differences in avian community composition and habitat associations across fires of varying severity, age and post-fire conditions can help guide the management of these areas. We found that older fires in particular harbor an abundant and diverse shrub and cavity-nesting bird community, and thus these areas may best be prioritized for sustaining populations of early successional species. Naturally regenerated early successional ecosystems are well-adapted to the current climate and may be more adaptable to future climate conditions (Swanson et al. 2011).

Managing for dense and diverse shrub habitats interspersed with areas of green forest should maximize avian diversity in post-fire habitats. Protecting these green forest 'islands' from future high severity fire would also ensure a conifer seed base and provide a habitat mosaic for a diversity of species. Post-fire management strategies such as prescribed fire or managed wildland fire implemented under favorable weather conditions and within a short time frame can reduce fuel loads that reinforce high severity fire (Brown et al. 2003), and may be the most cost-effective approach to restore ecological resiliency and heterogeneity to Sierra Nevada forests (North et al. 2015). However, large shrub fields that have burned multiple times by high severity fire supports a rich community of early seral birds and plants (Fontaine et al. 2009, Campos and Burnett 2015); a climate-adapted approach may be to allow these areas to remain chaparral while establishing forest cover in areas predicted to be forested under future climate scenarios.

If mastication or herbicide treatments are used to reduce shrubs, these efforts could be strategically focused near mature tree patches to reduce fuels for future high-severity fire. However, best management practices for shrub-nesting species would be to avoid disturbing this habitat for at least 20 years post-fire, to mimic the natural fire return interval in Sierra Nevada chaparral (Barbour and Major 1988), and to use prescribed fire or managed wildland fire as management tools (Coppoletta et al. 2015). When managing for multiple objectives including biodiversity, resilience from future high-severity fire, and climate change adaptability, management actions (including non-interventions) that target specific areas based on fire patterns, habitat quality and topography are advisable (North 2009).

**Future Directions**

These data and the data we are continuing to collect in all central Sierra fires will be applied to many upcoming products. The analyses in this report will be expanded upon and finalized in coming years. Future directions with additional data include: 1) assessing landscape context as a potential driver of the bird community (e.g., distance of point from edge of high-severity patch/fire perimeter, size and shape of burned patches, etc.), 2) employing more sophisticated models that incorporate detection probability (e.g., multi-species occupancy models) for assessing fire severity and management actions, 3) incorporating monitoring data into plans for mastication, reforestation and potential herbicide treatments in current and future fires, and 4) pooling central and northern Sierra fires for a broader-scale (both geographically and temporally) analysis. We will also use these results to refine Point Blue's post-fire habitat management recommendations and provide assistance to post-fire planning for land managers in the Sierra Nevada.

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## APPENDICES

**Appendix A**. List of all species detected in Freds, Power, Government and Rim fires during 2015 point surveys (unlimited by distance). Detections are listed as mean individuals observed per point count survey. Asterisks (*) following the common name indicate the species was not included in the total abundance and total species richness analysis. Species are sorted taxonomically.

| Common Name | Scientific Name | Freds Fire | Power Fire | Government Fire | Rim Fire |
|---|---|---|---|---|---|
| Canada Goose* | *Branta canadensis* | --- | 0.03 | --- | --- |
| Common Merganser* | *Mergus merganser* | --- | 0.01 | --- | --- |
| Mountain Quail | *Oreortyx pictus* | 1.64 | 1.44 | 0.44 | 1.19 |
| California Quail | *Callipepla californica* | --- | 0.01 | --- | 0.01 |
| Sooty Grouse | *Dendragapus fuliginosus* | 0.02 | 0.01 | 0.01 | --- |
| Turkey Vulture* | *Cathartes aura* | --- | 0.01 | --- | --- |
| Osprey* | *Pandion haliaetus* | --- | 0.01 | --- | --- |
| Sharp-shinned Hawk* | *Accipiter striatus* | --- | --- | --- | 0.01 |
| Cooper's Hawk* | *Accipiter cooperii* | --- | --- | 0.01 | --- |
| Northern Goshawk* | *Accipiter gentilis* | --- | --- | --- | 0.01 |
| Red-tailed Hawk* | *Buteo jamaicensis* | 0.02 | 0.01 | --- | 0.01 |
| American Kestrel* | *Falco sparverius* | 0.06 | 0.04 | 0.01 | 0.02 |
| Peregrine Falcon* | *Falco peregrinus* | --- | 0.01 | --- | --- |
| Band-tailed Pigeon | *Patagioenas fasciata* | 0.01 | 0.01 | 0.01 | 0.04 |
| Eurasian Collared Dove* | *Streptopelia decaocto* | --- | --- | --- | 0.01 |
| Mourning Dove | *Zenaida macroura* | 0.06 | 0.01 | --- | 0.35 |
| Great-horned Owl* | *Bubo virginianus* | --- | --- | 0.01 | --- |
| Northern Pygmy-Owl* | *Glaucidium gnoma* | 0.03 | 0.04 | 0.01 | 0.04 |
| Common Nighthawk | *Chordeiles minor* | --- | --- | 0.01 | --- |
| White-throated Swift | *Aeronautes saxatalis* | 0.01 | --- | 0.01 | --- |
| Anna's Hummingbird | *Calypte anna* | 0.01 | 0.03 | 0.02 | 0.10 |
| Calliope Hummingbird | *Selasphorus calliope* | --- | --- | 0.01 | 0.01 |
| Lewis's Woodpecker | *Melanerpes lewis* | 0.03 | 0.01 | --- | --- |
| Acorn Woodpecker | *Melanerpes formicivorus* | 0.14 | 0.17 | --- | 0.39 |
| Williamson's Sapsucker | *Sphyrapicus thyroideus* | --- | --- | 0.01 | --- |
| Red-breasted Sapsucker | *Sphyrapicus ruber* | 0.07 | 0.08 | 0.07 | 0.03 |
| Downy Woodpecker | *Picoides pubescens* | --- | 0.01 | 0.01 | 0.01 |
| Hairy Woodpecker | *Picoides villosus* | 0.16 | 0.18 | 0.20 | 0.57 |
| White-headed Woodpecker | *Picoides albolarvatus* | 0.10 | 0.22 | 0.20 | 0.30 |
| Black-backed Woodpecker | *Picoides arcticus* | --- | --- | 0.01 | 0.05 |
| Northern Flicker | *Colaptes auratus* | 0.71 | 0.82 | 0.36 | 0.31 |
| Pileated Woodpecker | *Dryocopus pileatus* | 0.04 | 0.02 | 0.06 | 0.06 |
| Olive-sided Flycatcher | *Contopus cooperi* | 0.26 | 0.31 | 0.62 | 0.22 |

| Common Name | Scientific Name | Freds Fire | Power Fire | Government Fire | Rim Fire |
|---|---|---|---|---|---|
| Western Wood-Pewee | *Contopus sordidulus* | 0.30 | 0.60 | 0.59 | 0.73 |
| Hammond's Flycatcher | *Empidonax hammondii* | 0.01 | 0.02 | 0.11 | 0.01 |
| Dusky Flycatcher | *Empidonax oberholseri* | 0.33 | 0.30 | 0.50 | 0.14 |
| Pacific-slope Flycatcher | *Empidonax difficilis* | --- | 0.01 | --- | 0.05 |
| Black Phoebe | *Sayornis nigricans* | --- | 0.01 | --- | 0.01 |
| Cassin's Vireo | *Vireo cassinii* | 0.13 | 0.23 | 0.44 | 0.21 |
| Hutton's Vireo | *Vireo huttoni* | 0.01 | 0.02 | 0.01 | 0.04 |
| Warbling Vireo | *Vireo gilvus* | 0.11 | 0.24 | 0.17 | 0.08 |
| Steller's Jay | *Cyanocitta stelleri* | 1.32 | 1.36 | 0.90 | 0.64 |
| Western Scrub-Jay | *Aphelocoma californica* | 0.05 | --- | --- | 0.01 |
| Clark's Nutcracker | *Nucifraga columbiana* | --- | 0.01 | --- | --- |
| Common Raven* | *Corvus corax* | 0.02 | 0.04 | 0.07 | 0.10 |
| Violet-Green Swallow | *Tachycineta thalassina* | 0.01 | --- | 0.01 | --- |
| Mountain Chickadee | *Poecile gambeli* | 0.46 | 0.56 | 0.69 | 0.09 |
| Chestnut-backed Chickadee | *Poecile rufescens* | --- | --- | 0.03 | --- |
| Bushtit | *Psaltriparus minimus* | 0.13 | 0.12 | --- | --- |
| Red-breasted Nuthatch | *Sitta canadensis* | 0.31 | 0.68 | 0.95 | 0.54 |
| White-breasted Nuthatch | *Sitta carolinensis* | 0.02 | 0.06 | 0.01 | 0.03 |
| Pygmy Nuthatch | *Sitta pygmaea* | 0.01 | --- | --- | --- |
| Brown Creeper | *Certhia americana* | 0.18 | 0.33 | 0.44 | 0.43 |
| Rock Wren | *Salpinctes obsoletus* | 0.09 | 0.01 | --- | 0.08 |
| Canyon Wren | *Catherpes mexicanus* | 0.03 | 0.03 | --- | 0.01 |
| Bewick's Wren | *Thryomanes bewickii* | 0.10 | 0.30 | 0.01 | 0.01 |
| House Wren | *Troglodytes aedon* | 0.96 | 1.12 | 0.26 | 0.09 |
| Pacific Wren | *Troglodytes pacificus* | --- | 0.01 | 0.06 | 0.01 |
| American Dipper | *Cinclus mexicanus* | --- | 0.01 | --- | --- |
| Golden-crowned Kinglet | *Regulus satrapa* | 0.13 | 0.27 | 0.22 | 0.04 |
| Blue-gray Gnatcatcher | *Polioptila caerulea* | 0.04 | --- | --- | 0.01 |
| Western Bluebird | *Sialia mexicana* | 0.11 | 0.07 | 0.08 | 0.14 |
| Mountain Bluebird | *Sialia currucoides* | 0.01 | 0.01 | 0.07 | 0.01 |
| Townsend's Solitaire | *Myadestes townsendi* | 0.11 | 0.07 | 0.28 | 0.22 |
| Swainson's Thrush | *Catharus ustulatus* | --- | --- | --- | 0.01 |
| Hermit Thrush | *Catharus guttatus* | 0.01 | 0.01 | 0.01 | 0.02 |
| American Robin | *Turdus migratorius* | 0.32 | 0.29 | 0.38 | 0.48 |
| Wrentit | *Chamaea fasciata* | 0.11 | 0.06 | --- | 0.01 |
| European Starling* | *Sturnis vulgaris* | --- | --- | --- | 0.01 |
| Orange-crowned Warbler | *Oreothlypis celata* | 0.13 | 0.15 | 0.05 | 0.01 |
| Nashville Warbler | *Oreothlypis ruficapilla* | 0.66 | 0.82 | 0.48 | 0.10 |
| Yellow Warbler | *Setophaga petechia* | 0.31 | 0.18 | 0.02 | 0.01 |
| Yellow-rumped Warbler | *Setophaga coronata* | 0.14 | 0.29 | 1.05 | 0.37 |
| Black-throated Gray Warbler | *Setophaga nigrescens* | 0.10 | 0.15 | 0.01 | 0.21 |

| Common Name | Scientific Name | Freds Fire | Power Fire | Government Fire | Rim Fire |
|---|---|---|---|---|---|
| Townsend's Warbler* | *Setophaga townsendi* | --- | --- | 0.01 | --- |
| Hermit Warbler | *Setophaga occidentalis* | --- | 0.14 | 0.25 | 0.13 |
| MacGillivray's Warbler | *Geothlypis tolmiei* | 0.43 | 0.44 | 0.27 | 0.14 |
| Wilson's Warbler | *Cardellina pusilla* | 0.02 | 0.02 | 0.05 | 0.01 |
| Green-tailed Towhee | *Pipilo chlorurus* | 1.16 | 0.89 | 0.57 | 0.02 |
| Spotted Towhee | *Pipilo maculatus* | 0.82 | 1.02 | 0.47 | 0.36 |
| California Towhee | *Melozone crissalis* | 0.06 | 0.01 | --- | 0.01 |
| Chipping Sparrow | *Spizella passerina* | 0.19 | 0.13 | 0.09 | 0.51 |
| Black-chinned Sparrow | *Spizella atrogularis* | 0.01 | --- | --- | 0.01 |
| Fox Sparrow | *Passerella iliaca* | 1.29 | 1.57 | 0.95 | 0.11 |
| Song Sparrow | *Melospiza melodia* | 0.01 | 0.02 | --- | 0.02 |
| Lincoln's Sparrow | *Melospiza lincolnii* | --- | 0.01 | --- | 0.01 |
| Dark-eyed Junco | *Junco hyemalis* | 0.23 | 0.30 | 0.89 | 1.10 |
| Western Tanager | *Piranga ludoviciana* | 0.48 | 0.54 | 1.15 | 0.89 |
| Black-headed Grosbeak | *Pheucticus melanocephalus* | 0.48 | 0.63 | 0.54 | 0.80 |
| Lazuli Bunting | *Passerina amoena* | 0.76 | 0.69 | 0.16 | 2.92 |
| Indigo Bunting | *Passerina cyanea* | --- | --- | --- | 0.01 |
| Red-winged Blackbird | *Agelaius phoeniceus* | --- | --- | --- | 0.01 |
| Western Meadowlark | *Sturnella neglecta* | 0.04 | --- | --- | --- |
| Brewer's Blackbird | *Euphagus cyanocephalus* | --- | --- | --- | 0.01 |
| Brown-headed Cowbird | *Molothrus ater* | --- | 0.01 | --- | 0.03 |
| Bullock's Oriole | *Icterus bullockii* | --- | --- | --- | 0.01 |
| Purple Finch | *Carpodacus purpureus* | 0.04 | 0.06 | 0.05 | 0.22 |
| Cassin's Finch | *Carpodacus cassinii* | 0.08 | 0.04 | 0.37 | 0.09 |
| House Finch | *Carpodacus mexicanus* | --- | --- | --- | 0.01 |
| Red Crossbill | *Loxia curvirostra* | --- | 0.02 | 0.06 | 0.07 |
| Pine Siskin | *Carduelis pinus* | 0.07 | --- | 0.03 | 0.06 |
| Lesser Goldfinch | *Spinus psaltria* | 0.05 | 0.03 | --- | 0.06 |
| Lawrence's Goldfinch | *Spinus lawrencei* | --- | --- | --- | 0.17 |
| Evening Grosbeak | *Coccothraustes vespertinus* | 0.05 | 0.01 | 0.12 | 0.01 |

**Appendix B.** List of correlation coefficients for topographic and vegetation survey variables included in habitat associations models.

| | elevation | slope | SRI | BA live trees | BA dead trees | % young conifer cover | % shrub cover | shrub richness | % herba-ceous cover |
|---|---|---|---|---|---|---|---|---|---|
| elevation | 1.00 | -0.14 | 0.35 | -0.01 | 0.17 | -0.07 | 0.11 | 0.42 | -0.29 |
| slope | -0.14 | 1.00 | 0.10 | -0.07 | -0.02 | -0.25 | 0.00 | -0.13 | -0.03 |
| SRI | 0.35 | 0.10 | 1.00 | -0.11 | 0.18 | 0.01 | -0.14 | 0.07 | 0.07 |
| BA live trees | -0.01 | -0.07 | -0.11 | 1.00 | -0.06 | -0.12 | -0.23 | -0.15 | -0.33 |
| BA dead trees | 0.17 | -0.02 | 0.18 | -0.06 | 1.00 | -0.08 | 0.34 | 0.12 | -0.05 |
| % young conifer cover | -0.07 | -0.25 | 0.01 | -0.12 | -0.08 | 1.00 | -0.18 | 0.15 | 0.20 |
| % shrub cover | 0.11 | 0.00 | -0.14 | -0.23 | 0.34 | -0.18 | 1.00 | 0.13 | -0.40 |
| shrub richness | 0.42 | -0.13 | 0.07 | -0.15 | 0.12 | 0.15 | 0.13 | 1.00 | -0.05 |
| % herbaceous cover | -0.29 | -0.03 | 0.07 | -0.33 | -0.05 | 0.20 | -0.40 | -0.05 | 1.00 |