Avian Monitoring in the Freds and Power Fire Areas

Final Report

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Point Blue Conservation Science

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2014 Field crew training in the Freds Fire (Photo by Z. Steel)

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Cover photo: *Fox Sparrow (*Passerella iliaca), *a prolific shrub-nester across older burned areas in the Sierra Nevada, is one of the most abundant species in the Freds and Power fires. Photos by Tom Grey and Zack Steel, respectively.*

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EXECUTIVE SUMMARY

In this report we present our 2014-2016 activities and results of avian and vegetation monitoring in the 2004 Freds and Power fires. We compared avian abundance for three guilds associated with different post-fire conditions within each fire and detected significant differences in abundance for guilds across three years of surveys and between fires, with the lowest observation rates occurring in 2016. Observed differences were likely due to drought, fire severity and post-fire management, which were assessed. We built habitat association models using vegetation data for shrub and cavity-nesting birds, assessed spatial variation of avian habitat quality within high severity areas, and assessed the effects of past salvage logging, conifer plantings, and herbicide treatments on the bird community.

The bird community varied substantially across the gradient of burn severity with forest-associated species occurring more frequently in lower severity areas and early seral, and snag-associated species occurring more frequently in higher severity areas. Results from habitat association models showed a strong relationship between increasing shrub cover and early seral and open forest bird abundance. We also documented a positive relationship between the basal area of snags and snag-nesting species. There was a mixed response to the basal area of live trees, with early seral and snag-associated birds showing negative associations, and the open forest and edge-associated species showing positive associations.

In addition to variation across severity levels, we saw further differentiation of the bird community within high severity patches. Edges of high severity patches showed slightly higher richness than interior areas, but notably the composition of the local bird community shifted with forest-associated species declining with distance from edge, and shrub- and snag-associated species becoming more common. This suggests that a range of high severity patch sizes and shapes would best accommodate the bird community.

The legacy of salvage logging had variable effects on the bird community; shrub-nesting early seral species had higher abundance in salvaged high severity areas while the post-fire snag guild had lower abundance. At moderate severity, the early seral guild showed no effect while the snag-associated species actually had higher abundance in salvaged stands, likely due to higher burn severity within the moderate category (which this guild showed a strong response to). Replanting post-fire, which occurred largely in areas that had been salvage-logged, had a positive effect on the early seral birds, and a negative effect on snag-associated birds. Perhaps more relevant to the species reliant on these older fires, herbicide treatments designed to reduce shrub competition had a negative effect on the birds foraging and nesting in the shrub layer.

These findings build on previous reports to Eldorado National Forest and complimentary studies from elsewhere in the Sierra Nevada to help inform ongoing and future management on the forest and across the range. Overall we've documented a diverse bird community in the Freds and Power fires. As compared to more recent burns and undisturbed reference sites, many species reach their highest abundance in these older fires. Using these findings, the published literature, and our knowledge of the Sierra Nevada bird community, we've developed specific recommendations for the Freds and Power fire landscapes and applicable across other burned areas. We recommend considering these areas as early seral forest reserves and moving conditions towards future fire resiliency by using managed wildfire or prescribed fire to control fuels. If more intensive management is proposed, consider setting aside dense shrub patches (> 40% shrub cover) within each unit and allow smaller patches to undergo succession naturally. Historical accounts estimate ~5% of the yellow-pine mixed-conifer zone consisted of chaparral in patches > 40 acres (16ha), with many more smaller patches interspersed among forested areas. Maintaining chaparral in the Freds and Power fires in a range of patch sizes would help maintain a diverse bird community. Finally, we recommend considering predicted future forest conditions under climate change scenarios to inform reforestation strategies.

2014-2016 Activities

- We surveyed 76 point count locations for birds in the Freds Fire that partially overlapped the Region 5 Vegetation Ecology Program Common Stand Exam plots.
- We surveyed 148 point count locations for birds in the Power Fire that partially overlapped regeneration plots established by the Region 5 Ecology program.
- We completed vegetation/habitat data collection at all point count locations.
- We presented a talk titled "Using birds as indicators to guide post-fire management of chaparral in the Sierra Nevada" to the Amador-Calaveras Consensus Group (ACCG) and participated in an ACCG field trip to the Power Fire.
- We presented bird monitoring results at Power Fire Reforestation science team meetings and participated in field trips in the Power and King fires hosted by the ACCG and the California Fire Science Consortium.
- We participated in a Society for Environmental Journalists field trip to the King fire and discussed wildlife response to high severity fire and how retaining snags in patches will promote landscape heterogeneity.
- We presented two papers at the Natural Areas Association Conference at UC Davis titled "Using birds as indicators to manage post-fire chaparral in the Sierra Nevada", and "The changing landscape of California fire: trends in burn patterns and post-fire forest heterogeneity".

Post-Fire Habitat Management Recommendations

Recommendations are a synthesis of our results, scientific literature, and expert opinion from 16 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), topographical position and availability of different habitat types as they relate to the pre-fire suppression era 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, particularly where oaks and shrubs are likely to return.
- 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 for snag-dependent wildlife.
- Retain high severity burned habitat in locations with higher densities of medium to larger diameter snags.
- 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 snag 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 communities including shrubs, grasses, and forbs. Understory plant communities provide a unique and important resource for a number of species in conifer-dominated ecosystems.
- Remnant shrub patches within management units should represent a range of patch sizes from 6 acres to at least 10-15 acres. Shrub cover should average over 40% across the patch acreage. Within the shrub patch, manage for denser clumps (>70% cover) 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 breeding 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 landscapes affect the forest composition and structure that could persist for decades to centuries (Lindemayer and Noss 2006, Swanson et al. 2011). Thus, it is necessary to carefully consider the species using post-fire habitats 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, the 2013 Rim Fire in the Stanislaus National Forest and the 2014 King Fire in the Eldorado 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, whether to retain snags in salvaged areas and how to manage early seral chaparral habitat remain significant parts of the ongoing debate over managing post-fire landscapes. The findings presented here 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. Existing studies of the post-fire avian community have largely focused on only a few years post-fire. In contrast, less is known about the avian community inhabiting older fires that have experienced varying levels of salvage logging and reforestation. Furthermore, previous studies of the effects of salvage logging on 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). To our knowledge there are currently no studies assessing salvage logging, replanting, and herbicide effects on avian communities in the Sierra Nevada a decade or more following fire.

Land managers are typically directed to rapidly reestablish forested cover on burned areas. However, burned areas that are not rapidly reforested can provide early seral habitat important to biodiversity (Swanson et al. 2011), which is often neglected when managing for late seral forests in the Sierra Nevada (Burnett and Roberts 2015). Additionally, managers are often limited by funding or logistical constraints, requiring prioritization of areas to manage, and decisions regarding what types of interventions to make. In some cases, no management actions may be necessary or desired. Using combined bird, vegetation, and fire severity datasets from the 2004 Freds and Power fires, we can identify aspects of early seral habitat, such as percent cover of shrubs, basal area of snags, and proximity to other habitat types to help guide post-fire management decisions when implementing reforestation projects.

In this report, we present results from three years of avian monitoring in the Freds and Power fires, which experienced varying fire severity and post-fire management. We quantified observed trends over the monitoring period and differences in the bird community across the gradient of fire effects found within the two fires, developed habitat association models, relating bird guild abundance with metrics of habitat structure, assessed how location within high severity patches affects bird habitat quality to inform where reforestation efforts are focused, and examined the effects of salvage logging, conifer plantings, and herbicide treatments on the post-fire bird community. The findings presented here compliment a growing body of research into the effects of fire and post-fire management on western forest bird communities, including the previous contributions stemming from Freds and Power bird monitoring (Fogg et al. 2015; Fogg et al. 2016).

METHODS

Study Design and Sampling Procedures

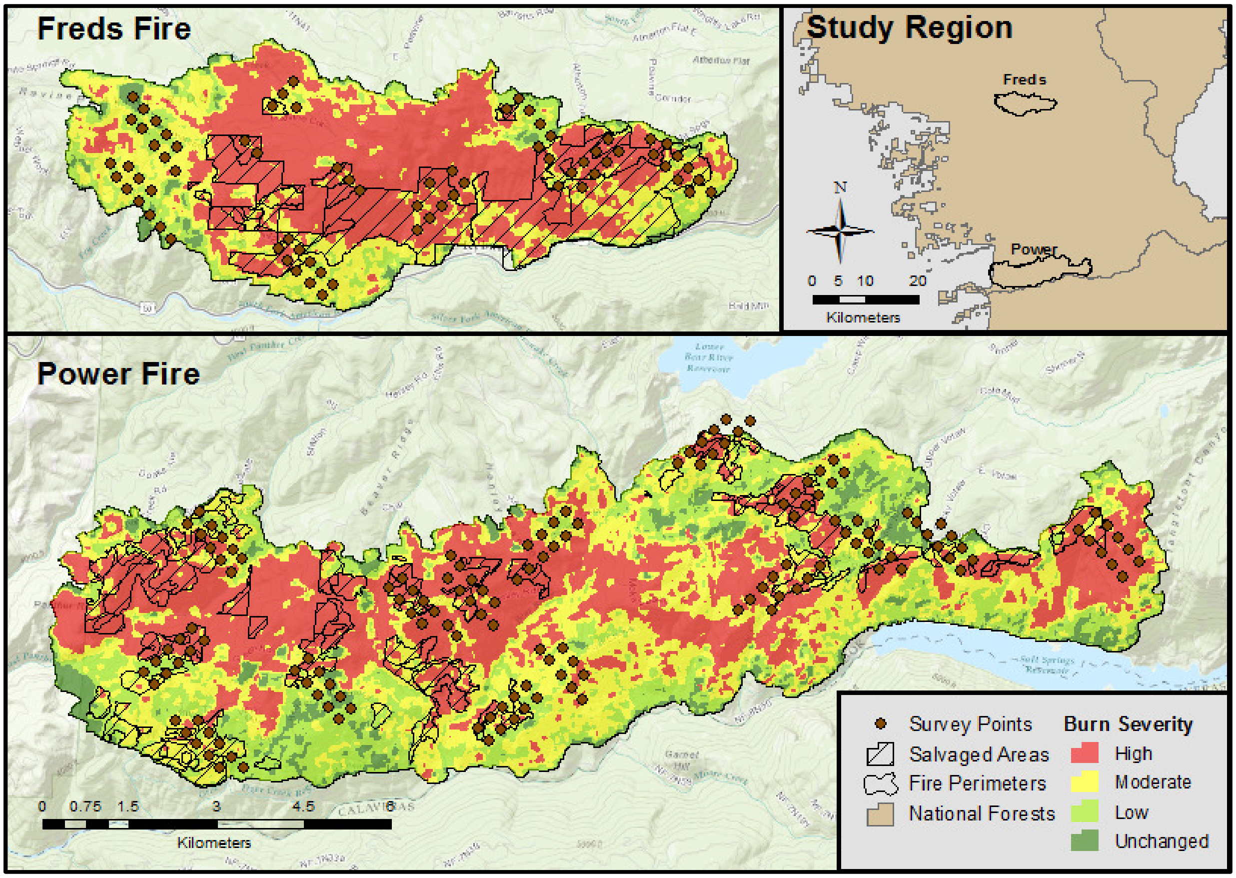
Study Location

The study area includes the 2004 Freds and Power fires, which burned on the Placerville and Amador Ranger Districts of the Eldorado National Forests, respectively. These fires burned in the central Sierra Nevada Mountains of California (Figure 1). They were human-ignited and burned predominantly on the south-facing side of river canyons during October 2004. The 3200 ha (7900 ac) Freds Fire burned along the South Fork American River canyon, and the 7000 ha (17,200 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.

Sampling Design

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 (Figure 1). Where possible, survey points were located coincident with previously sampled Common Stand Exam (CSE; Freds Fire), or regeneration (Power Fire) plots (Bohlman and Safford 2014; Richter and Safford 2016; Welch and Safford 2010). Bird transects were typically comprised of 10 points made up of two parallel five-point sub-transects, 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. Transects were limited to Forest Service land, slopes with a maximum of 35 degrees and did not require any major stream crossings. In total, 76 points on 9 transects were surveyed in Freds fire, and 148 points on 15 transects in Power fire.

Figure 1. Study area maps and survey locations for Freds and Power fires. Fire severity levels and areas that were salvaged post-fire are also shown.



Point Count Surveys

Experienced observers 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.

Vegetation/Habitat Surveys

Vegetation data was collected at all point count locations during the 2014 and 2015 field seasons. 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.

Data Analysis

General Procedures with Point Count Data

We restricted the analysis of our point count data to a subset of the species and individuals encountered. Unless explicitly noted below, we excluded: (1) all individuals >100 m from the observer, (2) individuals flying over the sampling locations but not actively using the habitat, (3) species that do not breed in the study area, and (4) 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.

Annual variation in bird abundance across fires and levels of severity

We examined the variation in bird abundance in relation to several categorical variables: year, fire, and burn severity. We followed a guild approach by selecting the species closely aligned with heterogeneous post-fire forest conditions in the Sierra Nevada. The three bird guilds we analyzed include the Early Seral Forest (ESF) guild associated with herbaceous and shrub habitats, the Post-fire Snag (PFS) guild that uses fire-killed trees and the Open Mature Forest (OMF) guild that occurs along forest edges and openings and/or utilize shade intolerant resources from the sub-canopy to the forest floor (Table 1). In Table 1 we also show species for the Mature Dense Forest (MDF) guild, which are considered fire-avoiders and not analyzed in the majority of this report. See Fogg et al. (2015) for detailed criteria for how species were assigned to guilds.

Table 1. List of species in the Early Seral Forest (ESF), Post-fire Snag (PFS), Open Mature Forest (OMF) and Mature Dense Forest (MDF) bird guilds. Scientific names can be found in Appendix A. Species are listed in taxonomic order.

Early Seral Forest (ESF)	Post-fire Snag (PFS)	Open Mature Forest (OMF)	Mature Dense Forest (MDF)
Mountain Quail	Lewis' Woodpecker	Western Wood-Pewee	Pileated Woodpecker
Dusky Flycatcher	Hairy Woodpecker	Olive-sided Flycatcher	Cassin's Vireo
Spotted Towhee	Black-backed Woodpecker	Warbling Vireo	Golden-crowned Kinglet
Green-tailed Towhee	White-headed Woodpecker	American Robin	Pacific Wren
Fox Sparrow	Northern Flicker	Nashville Warbler	Hermit Thrush
Chipping Sparrow	House Wren	Yellow-rumped Warbler	Hermit Warbler
Yellow Warbler	Mountain Bluebird	Chipping Sparrow	Red-breasted Nuthatch
MacGillivray's Warbler	Western Bluebird	Black-headed Grosbeak	Pacific-slope Flycatcher
Lazuli Bunting		Western Tanager	Hammond's Flycatcher

For these analyses, we used generalized linear mixed models with a Poisson error structure and a logarithmic link function. Modeling was done in program R version 3.2.2 (R Core Team 2015) using the packages lme4.0 version 1.1-7 (Bates et al. 2011). Our sample unit was a single point count visit and the dependent variable was the total sum of all individuals or species of a particular guild observed at that particular visit. Point and transect were included as random effects on the intercept parameter and year collected was included as a fixed effect. We first fit a model examining the effect of year (2014, 2015 and 2016) and fire (Freds or Power) as well as their interaction. The second model examined the effect of burn severity (a four-level categorical variable). To classify burn severity (Table 2, Figure 1) we utilized a geodatabase maintained by the US Forest Service for fires > 500 acres (200 ha) in California (available online at http://www.fs.usda.gov/wps/portal/fsinternet/main/r5/landmanagement/gis). Severity classifications were quantified using LANDSAT-TM satellite imagery and the Relativized differenced Normalized Burn Ratio (RdNBR). RdNBR data were converted to units of the composite burn index (CBI; Key and Benson 2006), a field-based measure of fire severity, and ultimately to the four-level severity classification used in our analysis (Miller and Thode 2007).

Table 2: Fire severity categories as defined by Miller and Thode (2007) with percentage of Freds and Power fire avian monitoring point count stations that fell within each category.

Category	Description	Freds Fire	Power Fire
Unchanged	Indistinguishable from pre-fire conditions	3%	9%
Low	Little mortality of structurally dominant vegetation	18%	17%
Moderate	Mixture of effects ranging from unchanged to high	39%	31%
High	Vegetation has high to complete mortality (>95%)	40%	43%

Habitat Associations

To examine habitat associations for the 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 guild (abundance) or the total count of guild species present (species richness). Point and transect were included as random effects on the intercept parameter and year was included as a fixed effect. We included variables generated from vegetation survey data that describe plant structural characteristics and plant species richness (Table 3). We also included the quadratic value of shrub cover as our observations indicated middle-range values could affect abundance and species richness. 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.

Variable Name	Description
BA live trees	Basal area of live trees, average of 5 measurements
BA snags	Basal area of snags, average of 5 measurements
young conifer cover	Percent cover of conifer species less than 5 m tall
shrub cover	Percent cover of all shrub species
shrub cover^2	Quadratic term for percent shrub cover
shrub richness	Number of shrub species
herbaceous cover	Percent cover of the herbaceous layer

Landscape Context within High Severity patches

By definition, high severity areas experience largely homogenous fire effects (i.e. complete or nearly complete canopy mortality). However, habitat quality within high severity patches may vary if birds utilize resources on the broader landscape and/or experience edge effects such as variable predation risk. Habitat quality may also vary due to pre-fire condition and between areas near conifer seed sources and those isolated from surviving trees if succession proceeds along different trajectories, although such an effect may not yet be evident a decade after a fire. To test the potential effect of landscape context within high severity patches, we built two models of species occurrence: 1) assessing the effect of survey distance from high severity patch edge, and 2) assessing the effect of high severity patch size. The two models were compared using the Widely-Applicable Information Criterion (WAIC) to assess which makes superior predictions (McElreath 2016). Freds and Power fire surveys conducted in high severity areas and where reforestation activities (i.e. salvaged logged or replanted) have not occurred were included in the analysis. All species that are adequately surveyed using point counts (Appendix A) and that were detected within 100m of the observer were included. Models were built using a binomial error structure and a logit link. The log-distance from survey point to patch edge, or the log-area of the high severity patch were the primary predictors of interest. Survey point, survey year and species ID were included as random intercepts, with the slope of distance to edge or patch size also varying by species ID. By allowing both the intercept and slope to vary by species, the models are simultaneously able to predict species- and community-level effects. Similar to multi-species occupancy models (Kery and Royle 2008), these models make no *a priori* assumptions of how species co-occur, but allow for correlated effects. Estimates at the guild- or full community-level are made by aggregating individual species effects estimates. Thus the sample unit for each model was the presence/non-detection of each species during each survey. In total, 87 unique points from the two fires representing 456 surveys and 71 species were included in the analysis. Modeling was done in program R (R Core Team 2015) using the statistical rethinking package (version 1.58; McElreath 2016).

Post-fire Management Effects

We built two models to examine the effects of salvage logging, replanting and follow-up herbicide treatments on guild abundance and richness. For these analyses, we used generalized linear mixed models with a Poisson error structure and a logarithmic link function. Modeling was done in program R version 3.2.2 (R Core Team 2015) using the packages lme4.0 version 1.1-7 (Bates et al. 2011). Fixed effects in the first model included binary variables for salvage, burn severity, the interaction between salvage and burn severity, and a binary variable for replanting along with year of survey. Random effects on the intercept included point ID. We used the Region 5 Forest Service Activity Tracking System (FACTS) database (available online at http://www.fs.usda.gov/detail/r5/landmanagement/gis) to classify points in both fires as salvage logged or untreated, and as actively replanted or left for natural regeneration. For this model, we only included points that burned at moderate or high severity (N = 167 points). Of all survey locations, 53% of Freds points and 28% of Power Fire points fell within salvage areas (Figure 1). However, 87% of Freds Fire points that burned at high severity were salvage logged compared to only 39% of Power Fire points. 49% of all Freds Fire points (58% of the salvaged points), and 28% of all Power Fire points (81% of salvaged points) were coincident with replanted areas (predominantly pine plantations). We also examined differences in vegetation variables (Table 3) between salvaged and unsalvaged points using two-way ANOVA and included burn severity (moderate or high), salvage status and their interaction as blocking variables. We used post-hoc Tukey HSD tests to determine the effect of salvage on each vegetation variable for the two severity levels.

The second model examined whether recent herbicide treatments in Freds Fire had an effect on the abundance and richness of the Early Seral Forest (ESF) and the Open Mature Forest (OMF) bird guild. The ESF guild is reliant on the shrub layer for nesting and foraging, but several species in the OMF also use the shrub layer extensively (e.g., Nashville Warbler, Black-headed Grosbeak). Herbicide treatments primarily consisting of the chemical glyphosate were used to reduce shrub competition for the planted conifers (Bob Carroll, Placerville Ranger District, *personal communication*). Dead shrubs were left standing with the expectation that the winter's snowpack would break down the dead biomass and subsequently reduce or redistribute fuel loads from standing to surface fuels. 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 from 2010-2015. Treatment was underway in 2015 but 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 three additional points that vegetation surveys and aerial imagery confirmed were also treated, but which did not overlap with FACTS treatment polygons (N = 25 points total). Treatment occurred in 2014 for five of the points that were only treated once. Thus, bird data for 2014 was considered a control sample and data from 2015 and 2016 were considered part of the impact sample. We initially examined effects of time since treatment and found it to be non-significant, thus this variable was eliminated from final models.

The model control sample 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). The resulting control sample (N = 28 points) had similar geographic and vegetation attributes as the treatment sample (N = 25 points), excluding shrub cover which averaged 8% at treated locations and 43% at control locations, and herbaceous cover which averaged 50% at treated locations and 21% at control locations.

To compare bird abundance and richness, we only included observations within 50m of the observer because we used our 50m-radius vegetation data to ground-truth the FACTS database. 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, fixed effects included a binary variable for treatment status, year of survey and basal area of snags (to help control for salvage effects) with point included as a random effect 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

Annual variation in bird abundance across fires and levels of severity

Across 2014-2016, a total of 82 bird species were detected in Freds Fire and 94 in Power Fire (see Appendix A for complete list of species, scientific names and mean number of detections per visit unlimited by distance). Total abundance was higher in Power Fire than Freds during 2015 and 2016 ($P < 0.05$; Figure 2). Abundance during 2014 was similar between the two fires, as was species richness across all three years. We observed declines in abundance and species richness between 2015 and 2016 ($P < 0.05$) across the full avian community as well as among the three bird guilds assessed specifically. Differences between fires in some cases depended on the year of survey, with higher abundance observed in Freds Fire as compared to Power Fire during 2014 among the Early Seral Forest (ESF) bird guild ($P < 0.001$). Post-fire Snag (PFS) guild abundance was similar between fires in all three years and the Open Mature Forest (OMF) guild had higher abundance in Power Fire in all three years ($P = 0.03$).

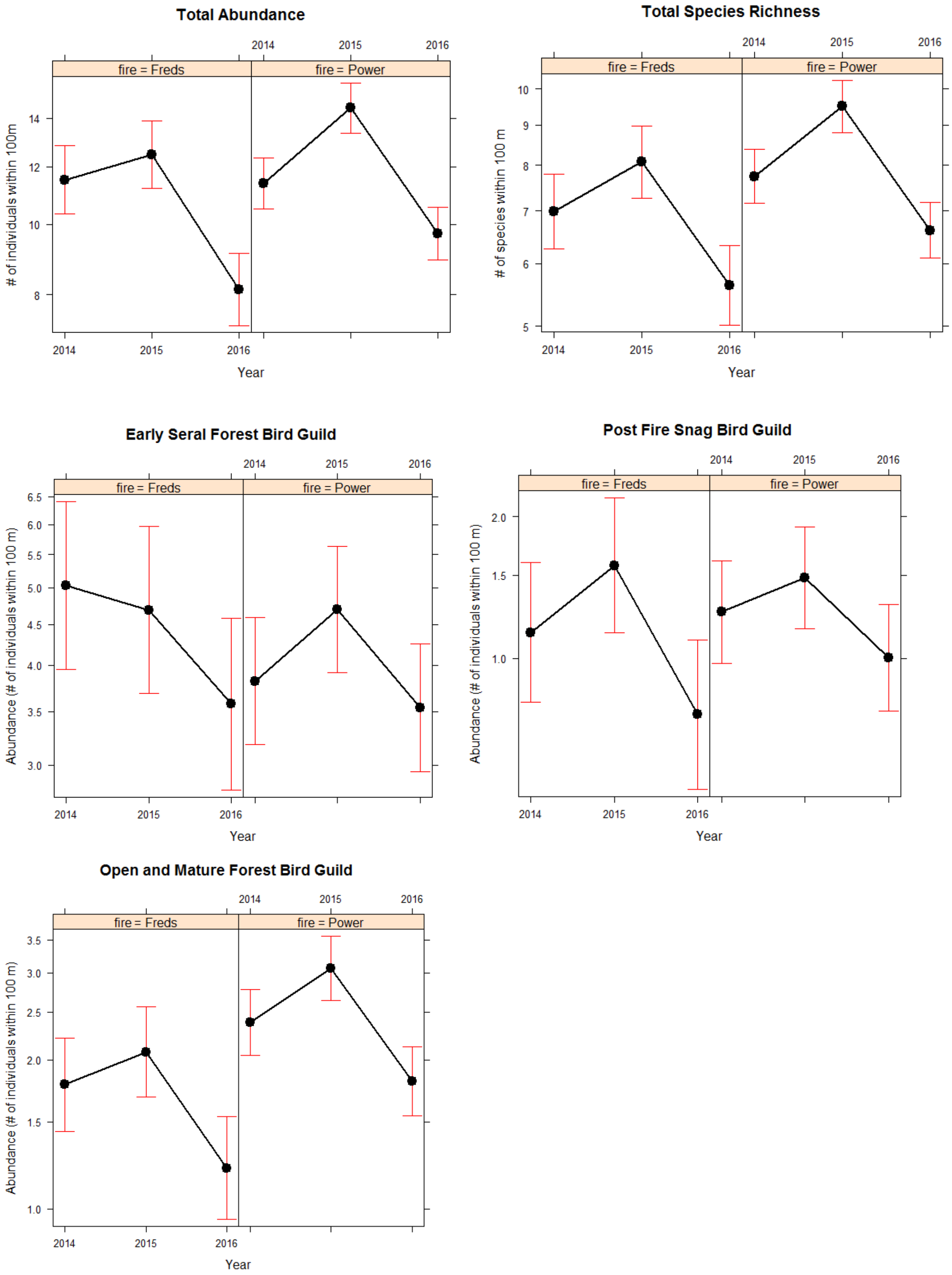
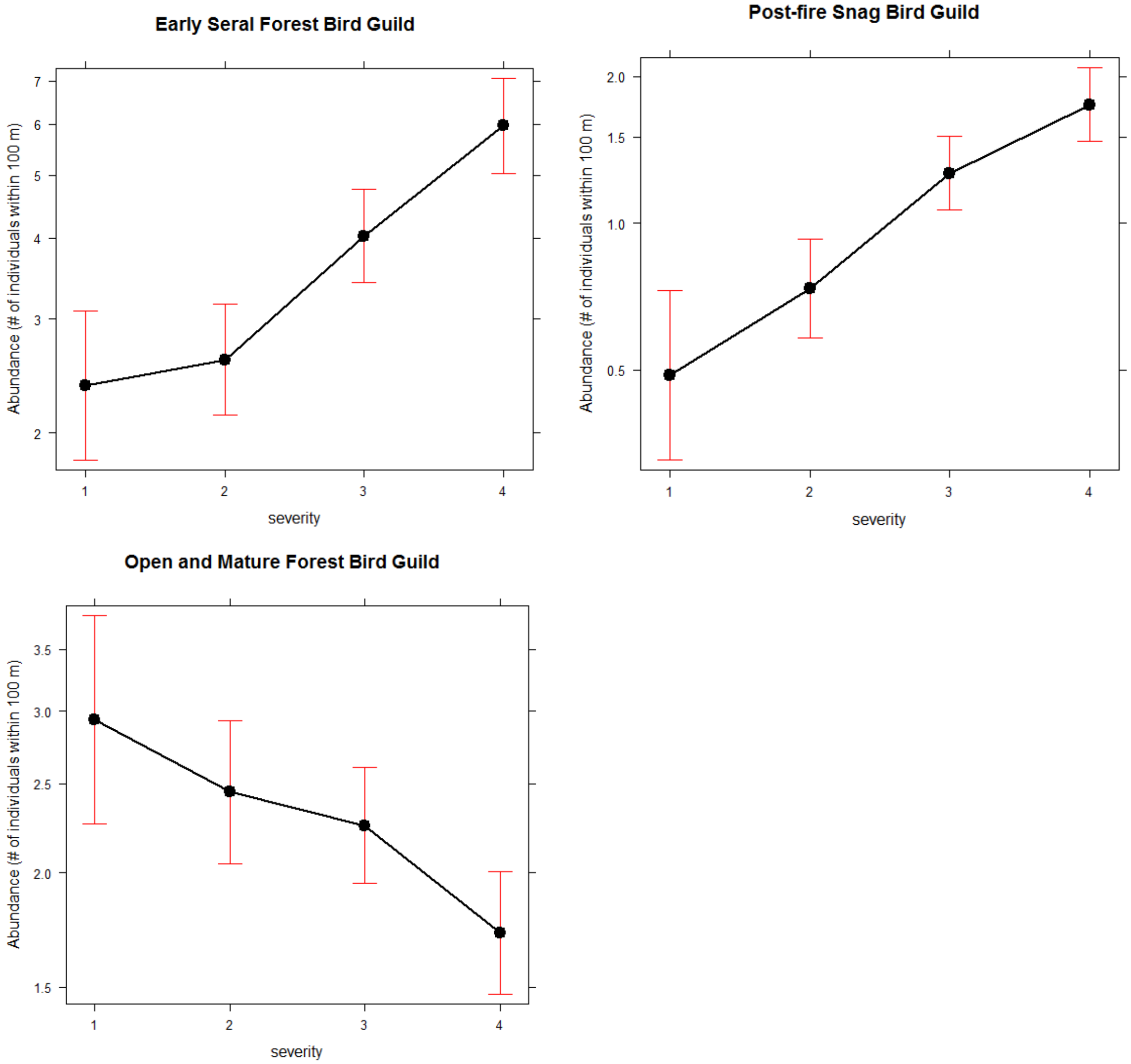


Figure 2. Predicted mean bird abundance per point (<100m from observer) averaged across two visits for three bird guilds within the Freds and Power fires across three years of surveys (2014-2016). The upper panel shows annual differences in total bird abundance and species richness. The lower panels shows differences in the three bird guilds. Bars indicate 95% confidence intervals

Burn severity had no effect on total bird abundance or species richness. However, the effect of severity varied among bird guilds (Figure 3). The ESF and PFS bird guilds showed significant differences between high, moderate and low/unchanged burn severity with over twice as many individuals occurring in high severity compared to low severity or unchanged areas. In contrast, the relationship between abundance and burn severity was negative for the OMF bird guild. Abundance was highest at unchanged locations, similar between low and moderate severity, and significantly lower at high severity points.


Early Seral Forest Bird Guild

Post-fire Snag Bird Guild

Open and Mature Forest Bird Guild

Figure 3. Predicted mean bird abundance per point (<100m from observer) in terms of burn severity averaged across two visits for three bird guilds within the Freds and Power fires across three years of surveys (2014-2016). Severity is expressed as 1=unchanged, 2=low, 3=moderate and 4=high severity. Bars indicate 95% confidence intervals.

Habitat Associations

Among all three bird guilds representing a range of conditions post-fire, increasing shrub cover had the largest effect on abundance and species richness (Table 4). The quadratic term for shrub cover was the second largest effect for all models but negative, indicating that intermediate levels of shrub cover (40-60%) are beneficial for these bird guilds (Figure 4). The Early Seral Forest (ESF) guild had a significant negative relationship with basal area of live trees and a significant positive relationship with shrub species richness and percent cover of young conifers. Herbaceous cover was dropped from the ESF models due to non-convergence.

Model results for the Post-fire Snag (PFS) guild showed a positive relationship with shrub cover, as well as a negative quadratic term for shrub cover (only significant in the abundance model). The negative effect of basal area of live trees, the positive effect of basal area of snags (Figure 4), and the positive effect of herbaceous cover all had similar effect size and were significant covariates in the model (Table 4). Young conifer cover and shrub species richness was dropped from the PFS models due to non-convergence.

Model results for the Open Mature Forest (OMF) guild showed a strong positive relationship with shrub cover as well as a negative quadratic term for shrub cover. Basal area of live trees was also significantly positive. Herbaceous cover and shrub species richness were non-significant (Table 4). Young conifer cover was dropped from the OMF model due to non-convergence.

Table 4. 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 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 species richness**	**Estimate**	**SE**	**(P|z|)**
intercept	1.43	0.06	<0.001	intercept	0.92	0.05	<0.001
shrub cover	0.45	0.09	<0.001	**shrub cover**	0.35	0.06	<0.001
shrub cover^2	-0.25	0.09	0.004	**shrub cover^2**	-0.19	0.06	0.002
BA live trees	-0.14	0.03	<0.001	**BA live trees**	-0.10	0.02	<0.001
shrub richness	0.10	0.03	<0.001	**shrub richness**	0.08	0.02	<0.001
young conifer	0.06	0.03	0.01	**young conifer**	0.05	0.02	0.01
PFS abundance				**PFS species richness**			
intercept	0.19	0.08	0.02	intercept	-0.08	0.06	0.17
shrub cover	0.35	0.12	0.003	**shrub cover**	0.27	0.10	0.009
shrub cover^2	-0.24	0.11	0.03	shrub cover^2	-0.15	0.09	0.12
BA live trees	-0.19	0.05	<0.001	**BA snags**	0.11	0.03	<0.001
herbaceous cover	0.15	0.05	0.003	**BA live trees**	-0.11	0.04	<0.001
BA snags	0.14	0.04	<0.001	**herbaceous cover**	0.11	0.04	0.01
OMF abundance				**OMF species richness**			
intercept	0.76	0.06	<0.001	intercept	0.50	0.06	<0.001
shrub cover	0.45	0.10	<0.001	**shrub cover**	0.41	0.09	<0.001
shrub cover^2	-0.31	0.10	0.002	**shrub cover^2**	-0.31	0.09	<0.001
BA live trees	0.29	0.04	<0.001	**BA live trees**	0.23	0.03	<0.001
herbaceous cover	0.04	0.04	0.31	herbaceous cover	0.02	0.04	0.53
shrub richness	0.01	0.03	0.80	shrub richness	0.01	0.03	0.68

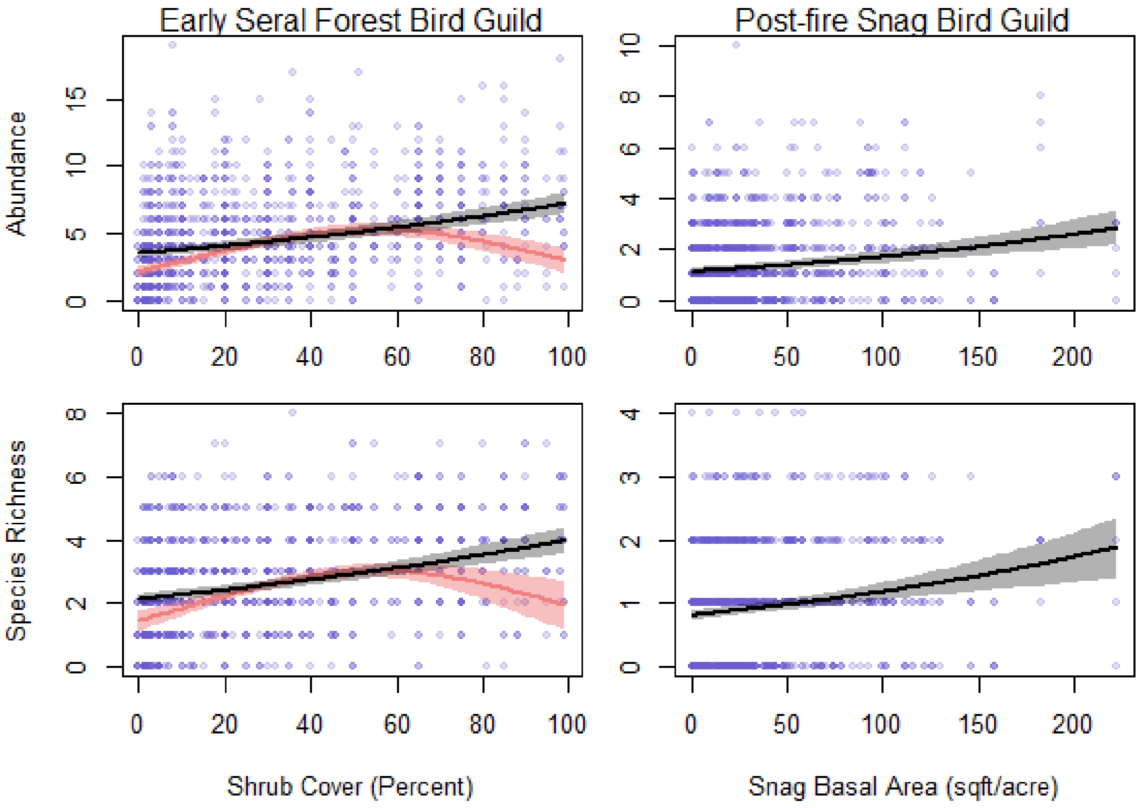


Figure 4. Marginal effects of select predictor variables on guild abundance (within 100m of the point; top row) and species richness (within 100m of the point; bottom row). Plots in the left column show alternative models of linear (gray curve) and quadratic (red curve) relationships between shrub cover and the Early Seral Forest bird guild. The right column 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.

Landscape Context within High Severity Patches

A comparison between the distance to edge and patch size models showed the distance model to vastly out-perform the size model (WAIC weights = 100% and 0%, respectively). Thus, only results from the distance model are presented here. For individual species our model predicts both positive and negative associations between occurrence and distance to edge (Figure 5, Table 5). For 5 species, the effect of distance was significantly positive, and for 13 species it was significantly negative (differences are considered significant where 95% confidence intervals did not overlap zero). Of the five species that occur more often in the interior of high severity patches, one is included in the Post-fire Snag guild, three in the Early Seral Forest guild and one was not listed among the guilds we assessed. Of the species that were observed more often near high severity patch edges, all were either listed in the Open Mature Forest or Mature Dense Forest guild or are considered habitat generalists.

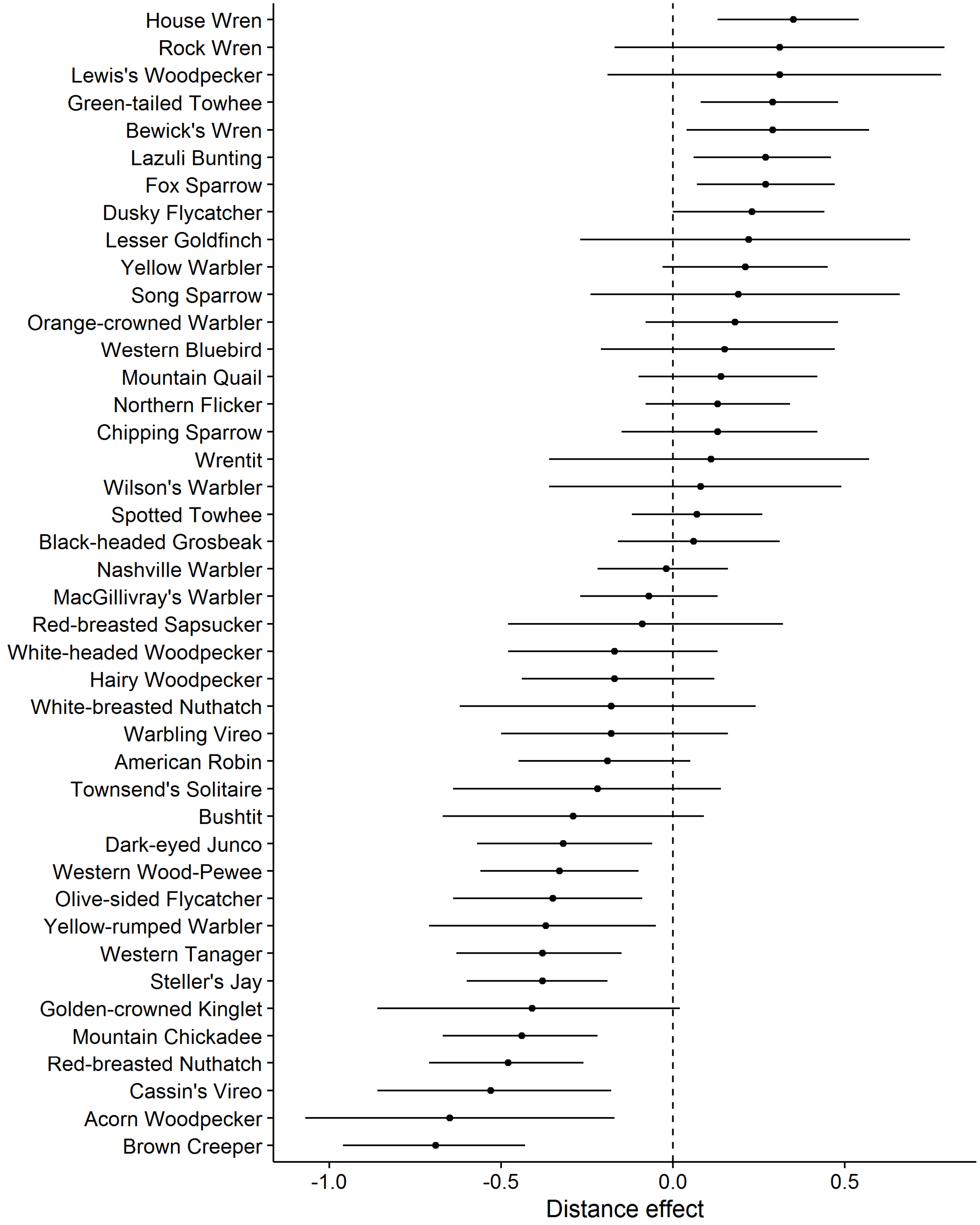


Figure 5. Distance to high severity edge effects for species with >10 detections. Positive values reflect patch interior while negative values reflect closer to the patch edge. Standardized mean estimates and 95% confidence intervals are shown.

Table 5. Occurrence predictions for the distance to edge of high severity patch model. Only species for which the distance effect was significant (i.e. 95% confidence intervals for the slope do not encompass zero) are included. Mean model predictions of species probability of occurrence are included for the minimum (Edge = 3m) and maximum (Interior = 316m) distances represented in our dataset as well as their difference. Species are listed in descending order of the absolute amount of change from patch edge to interior. Parameter estimates and occurrence predictions are listed for all modeled species in Appendix B. Guild membership includes Post-fire Snag (PFS), Early Seral Forest (ESF), Open Mature Forest (OMF) and Mature Dense Forest (MDF).

Common Name	Guild	Probability of Occurrence		
		Edge	Interior	Difference
Brown Creeper	Other	0.43	0.04	-0.39
Red-breasted Nuthatch	MDF	0.47	0.10	-0.36
Steller's Jay	Other	0.52	0.18	-0.34
House Wren	PFS	0.44	0.77	0.33
Mountain Chickadee	Other	0.40	0.09	-0.30
Green-tailed Towhee	ESF	0.42	0.71	0.29
Lazuli Bunting	ESF	0.32	0.59	0.27
Fox Sparrow	ESF	0.48	0.75	0.26
Western Tanager	OMF	0.29	0.07	-0.21
Western Wood-Pewee	OMF	0.31	0.10	-0.21
Olive-sided Flycatcher	OMF	0.20	0.05	-0.15
Bewick's Wren	Other	0.07	0.21	0.14
Dark-eyed Junco	Other	0.21	0.06	-0.14
Cassin's Vireo	MDF	0.14	0.02	-0.12
Yellow-rumped Warbler	OMF	0.12	0.03	-0.09
Acorn Woodpecker	Other	0.08	0.01	-0.07
Cassin's Finch	Other	0.04	0.00	-0.04
Canyon Wren	Other	0.03	0.00	-0.02

To produce species richness estimates we summed the predicted individual species occurrence rates for a given distance across the range of distances observed (3 - 316 m). These predictions suggest that overall species richness declines slightly with distance from edge until approximate 88 m (predicted minimum) where it levels off or potentially begins to rise slightly (Figure 6). While community richness shows a modest decrease, when broken down by bird guild the effect of distance is not uniform, indicating a compositional shift of the community from edge to interior. Richness of the Early Seral Forest guild, and to a lesser extent, the Post-fire Snag guild are predicted to increase with distance to edge. Conversely, the richness of the Open Mature Forest guild is predicted to slightly decrease with distance to edge. Common generalist species such as Stellar's Jay, Mountain Chickadee or Dark-eyed Junco or members of the Mature Dense Forest guild (Red-breasted Nuthatch, Cassin's Vireo) contribute most to the overall decline in community richness (Figure 6).

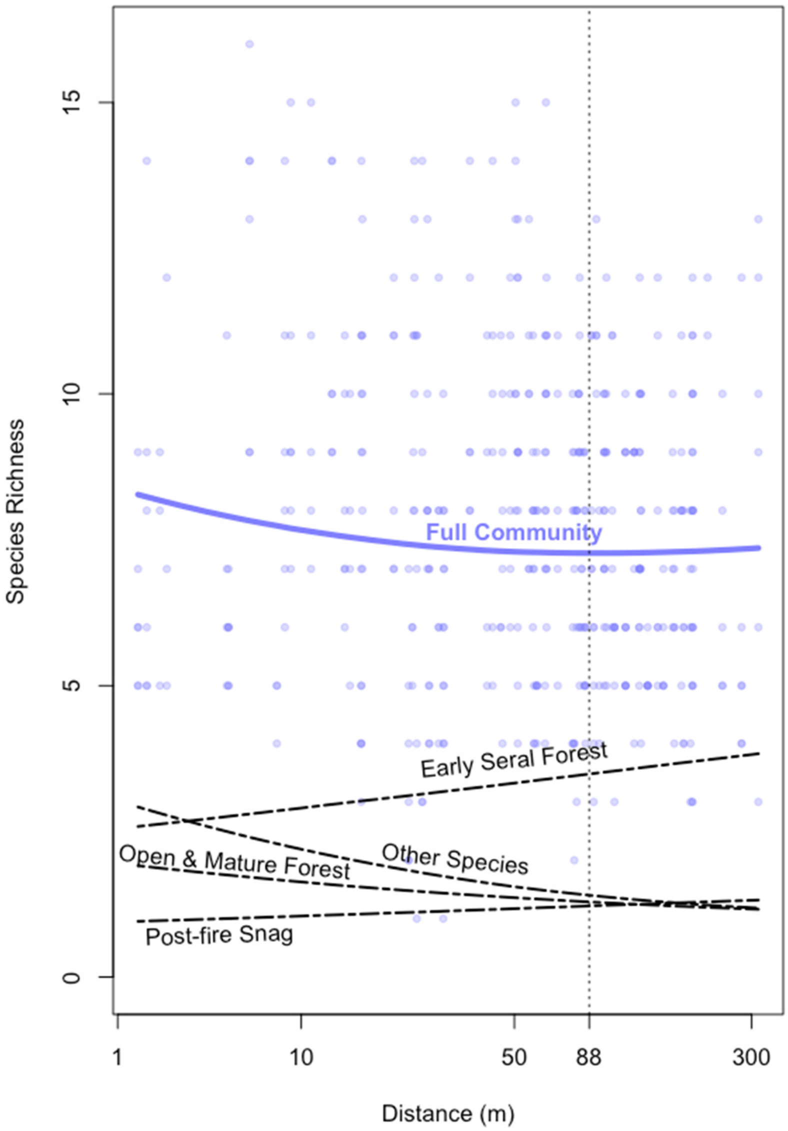


Figure 6. Modeled effect of distance to high severity edge on species richness. Blue points represent individual surveys within unmanaged high severity areas, and the blue curve represents the mean predicted richness across the range of distances sampled. The predicted richness of each of our three focal guilds and the non-focal species combined are also plotted as dashed lines. The summed area under the guild curves is equal to the full community curve above. The distance at which community richness is predicted to be at a minimum is indicated by a vertical dotted line.

Post-fire Management Effects

We found a positive effect of salvage on the Early Seral Forest (ESF) guild (*P* = 0.03) and there was a significant interaction between salvage and burn severity (*P* = 0.05; Figure 7), indicating the salvage effect was greatest at high severity. Abundance of the ESF guild was significantly higher in areas that had been replanted post-fire compared to areas that had been left to regenerate naturally ($P = 0.003$). For the Post-fire Snag (PFS) guild, there was a significant interaction between salvage and burn severity ($P = 0.04$) and the effect appears to be opposite in terms of burn severity (Figure 7). For areas that burned at high severity, unsalvaged stands had higher abundance. For areas that burned at moderate severity, the salvaged stands had higher abundance. Replanting post-fire had a negative effect on the PFS guild ($P = 0.03$). The Open Mature Forest (OMF) bird guild did not show a response to salvage logging ($P = 0.67$), nor was there a significant interaction with burn severity ($P = 0.33$). Replanting post-fire also did not show an effect on their abundance ($P = 0.78$).

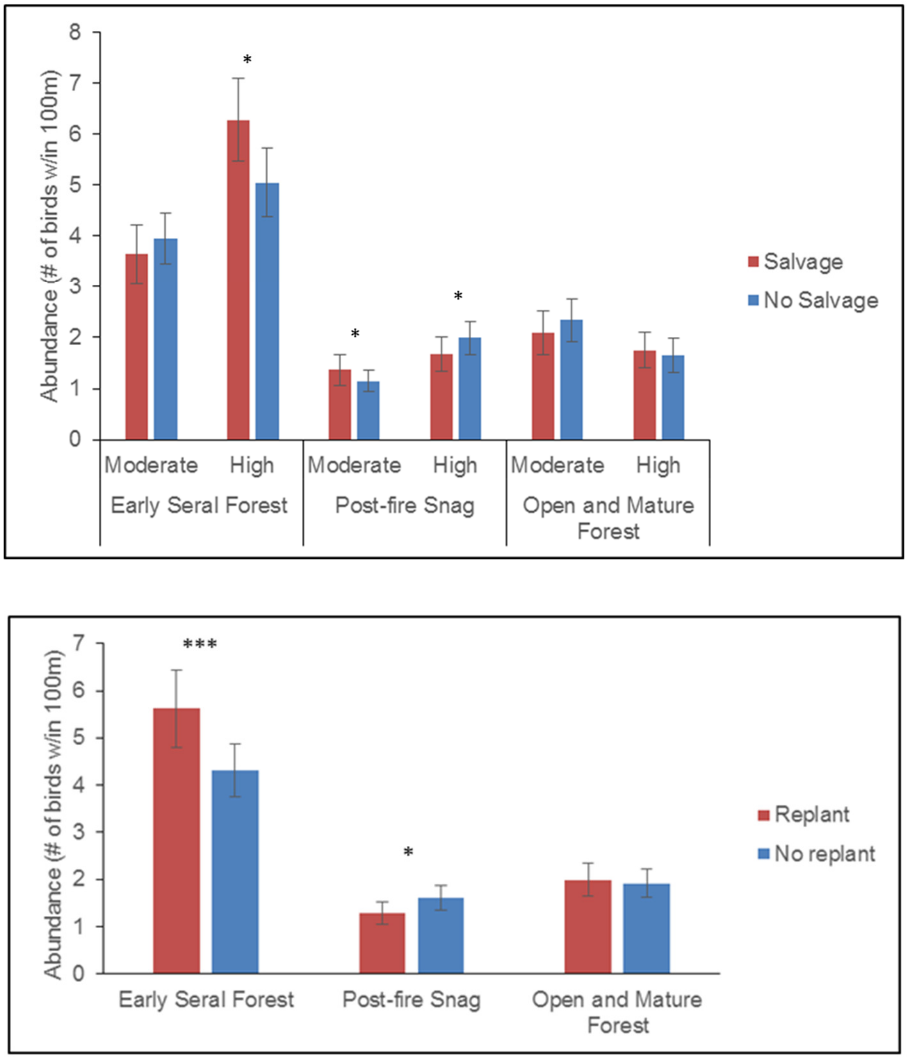
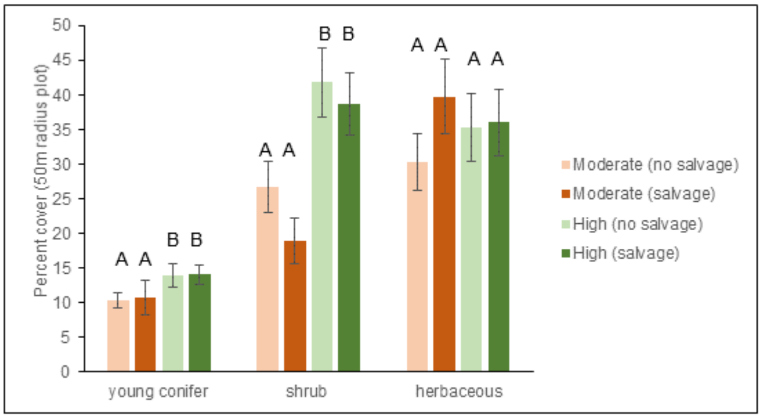


Figure 7. Early Seral Forest, Post-fire Snag and Open Mature Forest bird guild abundance (within 100m of the observer) for points affected by salvage logging (top panel) and replanting treatments (bottom panel). The top panel also shows the interaction between burn severity (moderate and high) and salvage logging. Error bars are 95% confidence intervals; significance is noted as *** = $P < 0.001$, ** = $P < 0.01$ and * = $P < 0.05$.

Nearly all vegetation covariates differed by burn severity, but only the basal area of snags differed by salvage treatments. Young conifer cover and shrub cover were both lower at moderately burned points (*F* = 4.6, *P* = 0.03 and *F* = 15.7, *P* <0.001, respectively; Figure 8*)*. Herbaceous cover was similar across severities and salvage treatments. The basal area of live trees was higher at moderately burned points (*F* = 75.9, *P* = <0.001). The basal area of snags differed among burn severity (*F* = 17.0, *P* <0.001) and salvage (*F* = 21.6, *P* <0.001) and the interaction between the two was also significant. Tukey HSD tests showed a significant difference between salvaged and unsalvaged sites at high severity but not moderate severity (*P* < 0.001). Shrub richness differed only by burn severity (*F* = 10.9, *P* = 0.001), with an average of 3.8 species (within 50m radius of point center) at moderate severity and 4.8 species at high severity.



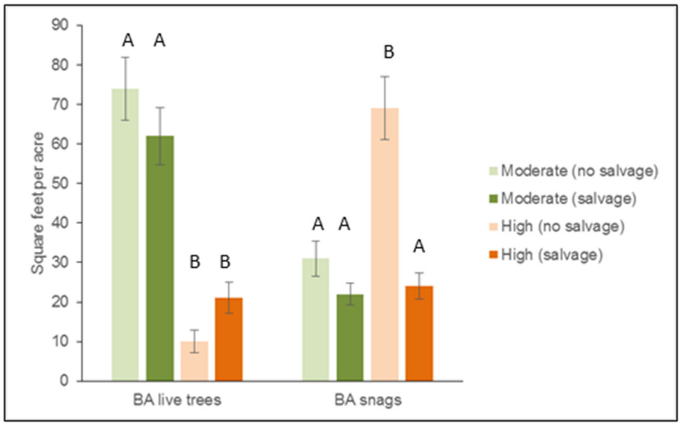


Figure 8. Differences in vegetation covariates at plots (N = 167) that had burned at moderate or high severity and salvage logged or left untreated. Letters above each covariate denote significant differences in burn severity or salvage logging (*P* < 0.05; two-way ANOVA). Error bars represent standard errors.

Model results indicated a significant negative herbicide treatment effect on ESF bird abundance and richness (both *P*-values = 0.05; Figure 9). Abundance averaged 1.8 individuals (within 50m of the observer) at treatment points and 2.4 individuals at control points (Figure 9). Species richness averaged 1.3 species at treatment points and 1.8 species at control points. Model results for the OMF bird guild showed a weaker negative treatment effect on abundance (*P* = 0.09) and richness (*P* = 0.07). Abundance averaged 0.32 individuals at treatment points and 0.48 at control points. Richness averaged 0.28 species at treatment points and 0.44 species at control points.

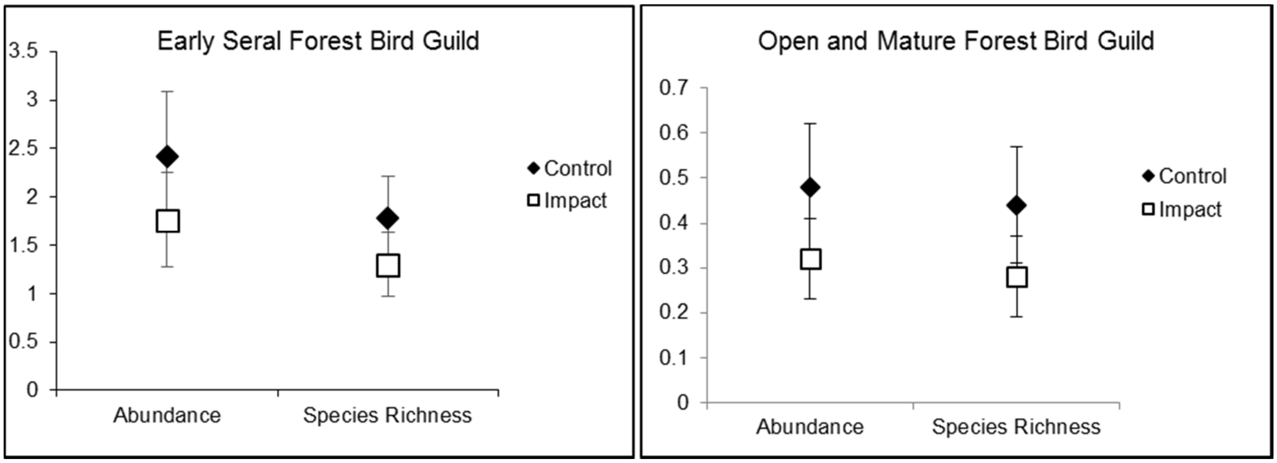


Figure 9. Early Seral Forest and Open and Mature Forest bird guild abundance and species richness (within 50m of the observer) for points affected by herbicide treatments and corresponding control points in the Freds Fire.

DISCUSSION

This report is the culmination of three years of avian monitoring conducted during the breeding seasons of 2014-2016 in Freds and Power fires in Eldorado National Forest. These efforts have resulted in two previous reports, which contain analyses and results complimentary to those presented here, and which support the conclusions and implications for management of post-fire landscapes summarized below (Fogg et al. 2015; Fogg et al. 2016). In the first report we detailed the project study design, assessed species richness and guild abundance across the range of severity levels found within the two fires, and contrasted the bird community of these burned areas with unburned sites outside the fire perimeters. In the second report, we built habitat association models that assessed the relationships of guild abundance and richness with shrub and tree canopy structural measures. These models are updated here with 2016 survey data. In this final report, we evaluate trends in abundance or richness evident in our monitoring of Freds and Power fires across the three monitoring years, and update our assessments of the effects of burn severity. We also consider whether landscape context (as defined by distance to patch edge and patch size) within high severity patches influences the local bird community composition. We limit this last analysis to high severity areas, as they are most often the focus of post-fire management. Finally, we consider the effects of past salvage logging, conifer plantings, and ongoing herbicide treatments on avian abundance and species richness.

Annual variation in bird abundance across fires and levels of severity

We documented a sharp decline in total bird abundance and species richness in 2016 compared to 2014 and 2015 in Freds Fire, with a parallel but more modest decline in Power Fire. This decline has been documented across the Sierra Nevada on Point Blue's other monitoring programs in conifer forest, meadow and other burned areas. We attribute much of this decline to drought and lower productivity for nesting birds which translates to less birds returning to breed in future years. We expect bird numbers to rebound following the wet 2016/17 winter, although this may not be immediately apparent following the recent decline.

Total abundance and Open Mature Forest (OMF) bird guild abundance was higher in Power Fire as compared to Freds Fire, with other guilds showing similar numbers between the fires. We suspect this may be because there is more edge habitat in Power Fire attracting edge-associated birds such as Western Tanager and Western Wood-Pewee. For example, the total edge between high severity fire and other severity levels (and edge:area of high severity patches) was 138 km (0.85 km/ha), and 314 km (1.19 km/ha) in Freds and Power, respectively. Many Early Seral Forest (ESF) guild species, which were more abundant in Freds Fire in 2014, prefer interior parts of high severity burned patches. Green-tailed Towhee and Lazuli Bunting were both more common in interior shrub patches and had higher abundance in Freds Fire in 2014 (Fogg et al. 2015).

We saw little variation in total bird abundance across all burn severities, averaging 11 individuals per point count location (within 100m of the observer). However, community composition changed dramatically across the severity gradient, as we would expect with different post-fire habitat associations. This indicates that all fire severities support avian diversity and mixed severity fire may in fact support high diversity (Tingley et al. 2016). Thus effects on avian diversity should be taken into account when planning post-fire management activities.

Habitat Associations

Shrub cover

Shrub cover is an important driver of avian diversity and abundance in post-fire habitat. It had the largest effect size of any variable in every guild model and was always positive. Our models predicted intermediate levels of shrub cover (40-60%) to be optimal for all guilds combined in the Freds and Power Fires. The effect of shrub species richness was also significant and positive in the ESF guild model (Table 4). These results are perhaps unsurprising given that species in the ESF guild and several of the OMF species nest and forage in the shrub layer, and several members of the PFS guild forage in the shrub layer (e.g., House Wren, by far the most abundant species in this guild; Fogg et al. 2016). 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 as this would benefit all three post-fire bird guilds and associated biodiversity (Swanson et al. 2011).

Surveys completed in 2009-2012 in the Eldorado National Forest within Sierra mixed conifer and ponderosa pine habitat (N=170 points) 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). Several factors may explain this discrepancy: 1) Shrub patch characteristics (shape, size, or distance to forest edge); 2) Shrub productivity (increased vigor post-fire, seed production or insects associated with recently burned shrubs); 3) Larger patches with extensive interior shrub habitat may be more suitable to these species; 4) Some shrub-associated species are negatively associated with basal area of live trees (as we summarize below). In summary, we demonstrate that many early seral species, and not just the commonly documented woodpeckers, are reliant on periodic high severity fire that leaves large patches of montane chaparral with extensive interior habitat (> 88 m from edge) and dense shrub cover (> 40%).

Live tree basal area

Heterogeneous severity patterns, with interspersing patches of live and dead trees, may have an effect on some species' habitat use. In particular, the ESF guild had negative associations with live tree basal area. However, as we demonstrated above, shrub cover is similar between the fires and nearby unburned forest. 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). These species may decrease 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.

The OMF guild abundance and richness had a strong positive relationship with basal area of live trees. 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 forest characterized by an active fire regime.

Snag basal area

Not surprisingly, the PFS guild was positively associated with basal area of snags, which even 10-12 years post-fire, represent important nesting and foraging resources. 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 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).

Landscape Context Within High Severity Areas

Distance to patch edge

The post-fire bird community appears to vary even within the seemingly homogenous high severity areas of Freds and Power fires. While Open and Mature Forest (OMF) species occur most often in lower severity areas, some were also observed at moderate rates along the edges of high severity patches. Likewise, the Mature Dense Forest (MDF) and other forest-associated generalist species were also observed along the edges of high severity areas. These species appear to utilize the edges of early seral habitat created by fire, but when the habitat boundary becomes increasingly distant, habitat quality may decline. For some of these species, the effect of distance from edge was quite large. For example, the predicted probability of observing a Brown Creeper, Red-breasted Nuthatch, Steller’s Jay, or Mountain Chickadee decreases by 30% or more when moving 3m to ~300m from patch edge, with observations of these species becoming rare in patch interiors. These findings are consistent with the known association of these species with forested habitats and mature trees (Beedy and Pandofino 2013). Conversely, some Early Seral Forest (ESF) and Post-fire Snag (PFS) species showed higher occurrence rates in the interior of high severity patches as compared to the edges. For example, the probability of observing a House Wren, Green-tailed Towhee, Lazuli Bunting or Fox Sparrow increases by approximately 30% when moving 3m to ~300m from patch edge, although in the case of these species the increase is from moderately common to quite common along this gradient.

The ecological mechanism driving the increased occurrence rates of ESF and PFS species from edge to interior is not immediately clear, but as discussed above, may be attributable to reduced pressure from forest-associate nest predators (Roberts et al. 2008) and/or decreased competition with MDF and generalist species. The inverse relationship with distance to edge between Steller's Jay (a nest predator) and some shrub-associated species is evidence supporting these hypotheses. This analysis coupled with our habitat association models, provide evidence that for shrub- and snag-associated species, both local habitat structure (e.g. percent shrub cover or basal area of snags), and landscape context influence species occurrence. Among our sample points, distance (log m) is only minimally correlated with percent shrub cover (r = 0.06), and snag basal area (log m^2; r = -0.15), suggesting these effects are independent and potentially additive, rather than redundant. Although not explicitly tested, we suspect that local habitat structure, such as percent shrub cover, acts as a primary filter of habitat suitability, and that landscape context is a subsequent factor influencing habitat selection.

Overall richness of the bird community declines slightly as we move from high severity edges to patch interiors. However, the observed shift in community composition from a mix of forest-, shrub-, and snag-associated species to one dominated by shrub- and snag-associated species is perhaps most notable. These results suggest that patch edges and interiors should be considered partially distinct habitats. This shift in habitat type is likely gradual, but categorizing areas of edge vs. interior habitat can be useful for informing management decisions. To this end we define a break between the two high severity types at 88m from the patch edge. Community richness was predicted to be at a minimum 88m from the patch edge, largely due to a leveling off of forest-associated species (Figure 6). In contrast, beyond the 88m threshold, predicted ESF and PFS species occurrence rates continue to increase. Thus, the approximate 88m delineation should be considered a transition point in habitat quality, not an optimal distance for any individual species or group. Working under this definition of edge vs. interior areas, 49% and 35% of the high severity areas within Freds and Power fires, respectively, are classified as interior habitat (Figure 10).

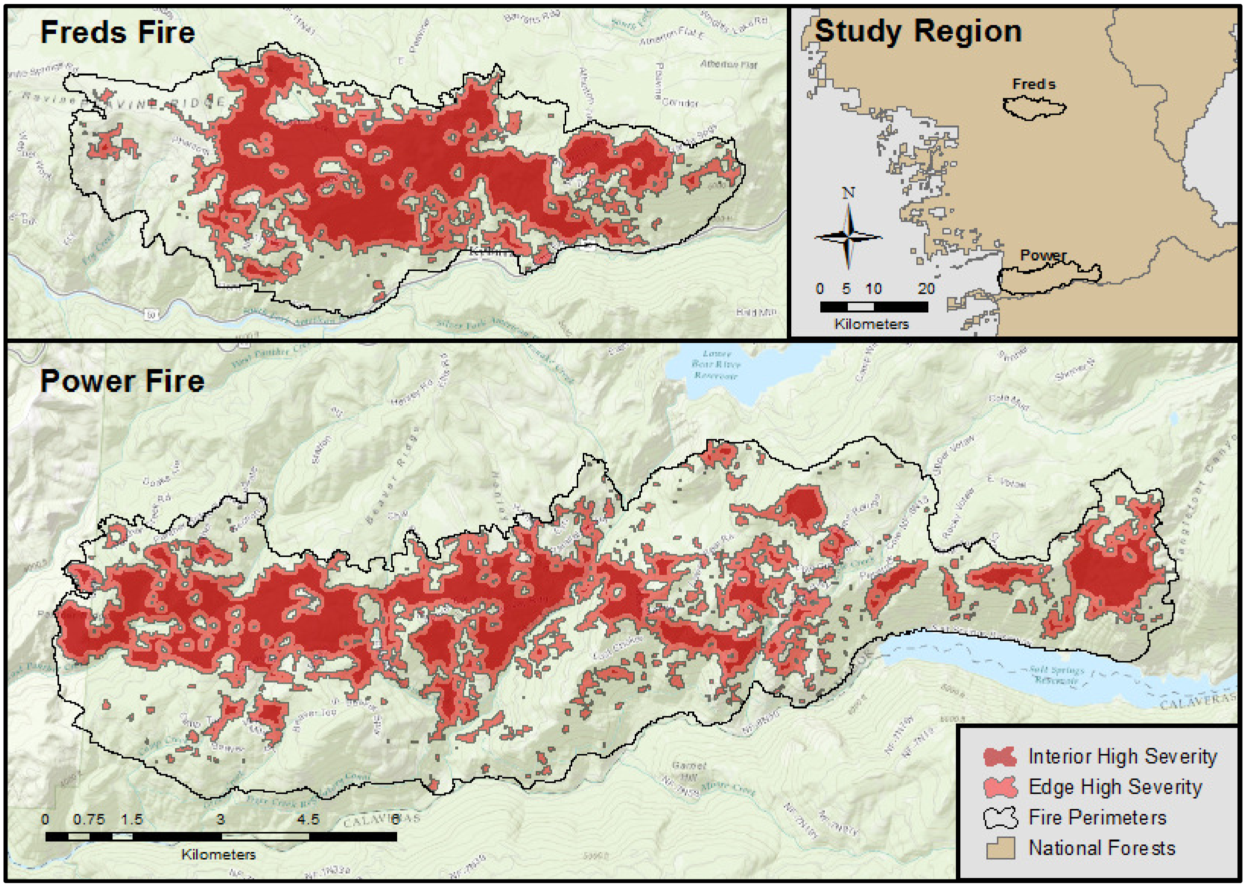


Figure 10. High severity areas of Freds and Power Fires, classified as either edge or interior habitat. The classifications are defined by an 88m-distance threshold, which should be considered an approximate split along a gradient of habitat quality.

Patch size

The amount of area on a burned landscape characterized by different distances to a patch edge is determined by the size and shape of the habitat patches in question. However, the effect of patch size and shape on species occurrence is difficult to measure directly. Here we fit a model of species occurrence as a function of high severity patch size in parallel to the distance to edge model. The size model performed poorly in part because relatively few independent high severity patches exist in Freds and Power fires. We have multiple survey points within these patches, which allow us to describe within patch variation well (e.g. for the distance model), but the statistical power needed to describe between patch variation is relatively low (e.g. for the size model). However, we can use our superior distance model to make inferences regarding the relationship between patch size and habitat quality for focal species. For example, if a goal is to maximize habitat quality for shrub-associated species, it may be necessary to maintain some interior habitat (i.e. areas beyond 88m from edge) following reforestation activities. The smallest patch that contains any interior area would be a circle with a radius greater than 88m, which translates to a minimum area of 2.4 ha (6.0 acres). Patches with more complex shapes but which contain areas at least 88m from an edge would necessarily be larger in size. Shrub-associated species are likely to benefit from much larger patch sizes (at least 10-15 acres) with substantial amounts of interior habitat. Alternatively, if trying to maximize species richness, large irregular shrub patches with high edge:interior ratios would be most effective. Estimates of historic (i.e. pre-fire suppression era) vegetation cover suggest that patches of montane chaparral predominantly created by fire followed a power law distribution with many small (< 1ha) and some large patches (Miller and Safford 2017). Vegetation maps from the 1930's (earliest available) showed approximately 5% of the yellow pine-mixed conifer zone of the Sierra Nevada was composed of chaparral patches greater than 16ha (40ac) in size (Miller and Safford 2017) which would have provided high-quality habitat for shrub-associated species. Additionally, in historically forested areas, these species would have benefited from lower canopy cover and more complex understory vegetation than is typical of current dense stand conditions. Ultimately, a management strategy that maintains a combination of small (6-10 acre) and irregular shrub patches with high amounts of edge habitat as well as some large patches (>10 acres) containing significant interior habitat, may be most beneficial to the avian community.

Management effects: Salvage logging, conifer plantings, & herbicide treatments

At 10-12 years post-fire, salvage-logging in the Freds and Power fires had mixed effects for the bird guilds we analyzed. The Early Seral Forest (ESF) guild were more abundant in areas post-salvage. Shrub volume (area x height) has been found to increase more post-fire in salvage-logged stands compared to unsalvaged areas with accordingly large increases in Fox Sparrow density (Cahall and Hayes 2009). Soil disturbance during salvage logging may stimulate shrub species by bringing viable seeds to the surface which can result in prolific shrub regeneration (Poff 1996). However, vegetation variables we measured were similar between salvaged and unsalvaged areas, except basal area of snags was lower in high severity salvaged areas. As we mentioned above, avian nest predators, including Stellar's Jay and Common Raven, may use snags as perches to observe shrubby areas and search for nests. If so, salvage-logged areas would contain fewer of these perches and potentially reduce predation pressure on some species. Similarly, mammalian nest predators, including chipmunks and tree squirrels (Family Sciuridae), tend to decrease in abundance following fire (Fisher and Wilkinson 2005), but could decrease even further if remnant green trees are unavailable to escape from their own set of predators, or if downed logs are unavailable as means to travel through dense shrub fields. In addition, in post-fire areas, small mammals will use woodpecker cavities in snags for nesting and as cover (Tarbill et al. 2015), and thus these would have been less available in salvaged stands. Historically, the EFS species likely occupied chaparral areas dominated by shrub species that burned repeatedly at high severity and thus would not have contained a large number of snags or downed wood (Coppoletta et al. 2015).

In contrast, the Post-fire Snag (PFS) guild showed slightly higher abundance in high severity areas that had not been salvaged, with an opposite pattern in moderate severity areas. This makes sense in high severity areas, as there was higher basal area of snags (69ft^2/ac in unsalvaged vs. 24ft^2/ac in salvaged areas). Moderate severity areas can show a wide range in tree mortality, and salvage is generally focused in areas with high mortality. The PFS guild, which showed a strong positive association with burn severity, may have occupied moderately burned areas with higher mortality, and thus more salvage. The Composite Burn Index (CBI), which we used in our analyses, is a convenient variable to categorize fire effects, but its weakness is in the moderate severity category with change in canopy cover ranging from no change to 100% mortality (Miller and Thode 2007). A continuous variable for burn severity, such as RnDBR, rather than CBI (a categorical variable), would further elucidate this pattern and will be used for future analyses and manuscripts.

Replanting conifers post-fire had a positive effect on the ESF guild. Looking closer at the data, replanted areas that burned at moderate severity had lower basal areas of live trees (45 vs. 84 ft^2/ac) and as we summarized above, the ESF bird guild was very sensitive to the presence of live trees. High severity areas did not show this difference. It may be likely that areas targeted for reforestation had low conifer cover post-fire and thus replanting may not be the driver of higher ESF abundance but rather correlative with post-fire conditions (i.e., lower tree survival). The PFS guild showed a negative relationship with replanted areas, which were also frequently salvaged post-fire and had lower basal area of snags (15 vs. 32 ft^2/ac at moderately burned points and 24 vs. 62 ft^2/ac at high severity points). Along with increased basal area of live trees (which this guild responded negatively to), fewer snags may have contributed to lower abundance of the PFS guild. In summary, replanting post-fire may not have direct effects on the bird guilds, rather it is the post-fire conditions already in place or perhaps salvage logging as an additive factor.

Analyses examining the herbicide treatments in Freds Fire showed 37% higher ESF bird abundance and species richness at control points compared to treated points. The Open Mature Forest (OMF) bird guild showed 50% higher abundance at control points versus treated points and 60% higher species richness. These results show a significant difference between relatively intact shrub habitats and those manipulated to accelerate forest regeneration. These treatments, while generally leaving dead shrubs standing on the ground, may provide structure for nesting and foraging, but our results suggest lower habitat quality in treated areas, possibly related to reduced food sources. Point Blue plans to initiate a new Before-After Control-Impact (BACI) study in the Power Fire as the Amador Ranger District is planning shrub abatement activities in future years, including herbicide use. We will use 2014-2016 survey data as the before sample and have secured the funding to complete surveys after treatments are completed.

Conclusions and Management Recommendations

As average burn 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 influenced by this dynamic disturbance, subsequently affecting plant and wildlife communities. 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 two previous reports on avian monitoring in the Freds and Power fires (Fogg et al. 2015; Fogg et al. 2016) show that fire age, severity, location within habitat patches, 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.

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 diverse avian community in fire-prone western forests (Fontaine and Kennedy 2012, Tingley et al. 2016). An understanding of the differences in avian community composition and habitat associations across fires of varying severity, age and habitat patch configurations can help guide the management of these areas. We found that older fires with relatively large high severity areas harbor an abundant and diverse shrub and cavity-nesting bird community. Thus prioritization of these areas in particular would help sustain populations of early successional species for decades following the original disturbance. Furthermore, 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 among 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 support a rich community of early seral birds and plants (Fontaine et al. 2009, Campos and Burnett 2015). A climate-adapted approach may include maintaining chaparral patches with at least 40-60% shrub cover and representing a range of sizes, while establishing forest cover in areas predicted to be forested under future climate scenarios (e.g. mesic and north-facing slopes). While more work is needed to establish precise guidelines of chaparral patch size distributions, reference conditions suggest these forests maintained some (~5% of the total landscape) component of chaparral patches greater than 16 ha (40 acres), and many more smaller patches (Miller and Safford 2017). Both small patches with high edge:area ratios and large patches with significant interior areas would be valuable to the post-fire avian community.

If mastication or herbicide treatments are used to reduce shrub cover, these efforts could be strategically focused near mature tree patches to reduce fuels for reducing the likelihood of 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 complimentary or alternative 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).

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APPENDICES

Appendix A. List of all species detected in Freds and Power fires during 2014-2016 point count 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 any statistical models (not sampled adequately using point count protocol). Species are sorted taxonomically.

		Freds Fire			**Power Fire**		
Common Name	**Scientific Name**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
Canada Goose*	*Branta canadensis*	---	---	---	0.02	0.03	0.01
Common Merganser*	*Mergus merganser*	---	---	---	---	0.01	---
Mountain Quail	*Oreortyx pictus*	1.02	1.64	1.13	0.85	1.44	0.98
California Quail	*Callipepla californica*	0.01	---	---	0.02	0.01	---
Sooty Grouse	*Dendragapus fuliginosus*	0.02	0.02	0.03	0.01	0.01	0.01
Turkey Vulture*	*Cathartes aura*	0.01	---	---	---	0.01	---
Osprey*	*Pandion haliaetus*	---	---	---	0.01	0.01	---
Cooper's Hawk*	*Accipiter cooperii*	---	---	---	---	---	0.01
Red-tailed Hawk*	*Buteo jamaicensis*	0.02	0.02	0.01	0.02	0.01	0.03
American Kestrel*	*Falco sparverius*	0.04	0.06	0.04	0.03	0.04	0.03
Peregrine Falcon*	*Falco peregrinus*	---	---	---	---	0.01	---
Band-tailed Pigeon	*Patagioenas fasciata*	0.05	0.01	0.05	0.02	0.01	---
Mourning Dove	*Zenaida macroura*	0.07	0.06	0.05	0.01	0.01	0.03
Northern Pygmy-Owl*	*Glaucidium gnoma*	---	0.03	---	---	0.04	0.03
Common Nighthawk	*Chordeiles minor*	---	---	---	---	---	0.01
White-throated Swift	*Aeronautes saxatalis*	---	0.01	---	---	---	0.01
Anna's Hummingbird	*Calypte anna*	0.02	0.01	0.02	0.01	0.03	0.01
Belted Kingfisher	*Megaceryle alcyon*	---	---	---	0.01	---	---
Lewis's Woodpecker	*Melanerpes lewis*	0.02	0.03	0.03	0.03	0.01	0.02
Acorn Woodpecker	*Melanerpes formicivorus*	0.22	0.14	0.11	0.14	0.17	0.08
Red-breasted Sapsucker	*Sphyrapicus ruber*	0.03	0.07	0.12	0.04	0.08	0.11
Downy Woodpecker	*Picoides pubescens*	---	---	---	---	0.01	---
Hairy Woodpecker	*Picoides villosus*	0.12	0.16	0.14	0.15	0.18	0.26
White-headed Woodpecker	*Picoides albolarvatus*	0.13	0.10	0.11	0.20	0.22	0.21
Northern Flicker	*Colaptes auratus*	0.52	0.71	0.73	0.76	0.82	0.54
Pileated Woodpecker	*Dryocopus pileatus*	0.01	0.04	0.02	0.04	0.02	0.03
Olive-sided Flycatcher	*Contopus cooperi*	0.25	0.26	0.23	0.26	0.31	0.33
Western Wood-Pewee	*Contopus sordidulus*	0.31	0.30	0.39	0.58	0.60	0.50
Hammond's Flycatcher	*Empidonax hammondii*	---	0.01	0.01	0.05	0.02	0.03
Gray Flycatcher*	*Empidonax wrightii*	---	---	---	0.02	---	---
Dusky Flycatcher	*Empidonax oberholseri*	0.18	0.33	0.25	0.23	0.30	0.42
Pacific-slope Flycatcher	*Empidonax difficilis*	---	---	0.02	---	0.01	0.01
Black Phoebe	*Sayornis nigricans*	---	---	---	---	0.01	---
Cassin's Vireo	*Vireo cassinii*	0.06	0.13	0.17	0.21	0.23	0.26

		Freds Fire			Power Fire		
Common Name	**Scientific Name**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
Hutton's Vireo	*Vireo huttoni*	0.01	0.01	---	0.02	0.02	0.01
Warbling Vireo	*Vireo gilvus*	0.08	0.11	0.17	0.21	0.24	0.43
Steller's Jay	*Cyanocitta stelleri*	0.90	1.32	1.14	0.89	1.36	1.11
Western Scrub-Jay	*Aphelocoma californica*	0.02	0.05	---	---	---	---
Clark's Nutcracker	*Nucifraga columbiana*	---	---	---	---	0.01	---
Common Raven*	*Corvus corax*	0.02	0.02	0.02	0.02	0.04	0.02
Violet-Green Swallow	*Tachycineta thalassina*	---	0.01	0.01	---	---	0.01
Cliff Swallow	*Petrochelidon pyrrhonota*	---	---	0.02	---	---	---
Mountain Chickadee	*Poecile gambeli*	0.40	0.46	0.57	0.52	0.56	0.58
Bushtit	*Psaltriparus minimus*	0.07	0.13	0.03	0.06	0.12	0.09
Red-breasted Nuthatch	*Sitta canadensis*	0.12	0.31	0.35	0.46	0.68	0.69
White-breasted Nuthatch	*Sitta carolinensis*	---	0.02	0.01	0.06	0.06	0.01
Pygmy Nuthatch	*Sitta pygmaea*	0.02	0.01	0.02	0.01	---	0.01
Brown Creeper	*Certhia americana*	0.12	0.18	0.26	0.34	0.33	0.37
Rock Wren	*Salpinctes obsoletus*	0.15	0.09	0.02	0.02	0.01	0.01
Canyon Wren	*Catherpes mexicanus*	0.04	0.03	0.05	0.01	0.03	0.01
Bewick's Wren	*Thryomanes bewickii*	0.04	0.10	0.02	0.29	0.30	0.15
House Wren	*Troglodytes aedon*	0.65	0.96	0.95	0.89	1.12	1.09
Pacific Wren	*Troglodytes pacificus*	---	---	---	0.01	0.01	0.01
American Dipper	*Cinclus mexicanus*	---	---	---	---	0.01	0.01
Golden-crowned Kinglet	*Regulus satrapa*	0.07	0.13	0.10	0.15	0.27	0.18
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.01	0.04	0.01	0.01	---	---
Western Bluebird	*Sialia mexicana*	0.08	0.11	0.04	0.08	0.07	0.03
Mountain Bluebird	*Sialia currucoides*	0.01	0.01	---	0.02	0.01	---
Townsend's Solitaire	*Myadestes townsendi*	0.05	0.11	0.05	0.07	0.07	0.08
Hermit Thrush	*Catharus guttatus*	0.01	0.01	---	---	0.01	---
American Robin	*Turdus migratorius*	0.26	0.32	0.40	0.30	0.29	0.26
Wrentit	*Chamaea fasciata*	0.11	0.11	0.11	0.03	0.06	0.03
Orange-crowned Warbler	*Oreothlypis celata*	0.16	0.13	0.11	0.27	0.15	0.04
Nashville Warbler	*Oreothlypis ruficapilla*	0.30	0.66	0.63	0.45	0.82	0.71
Yellow Warbler	*Setophaga petechia*	0.28	0.31	0.41	0.14	0.18	0.22
Yellow-rumped Warbler	*Setophaga coronata*	0.15	0.14	0.22	0.28	0.29	0.15
Black-throated Gray Warbler	*Setophaga nigrescens*	0.04	0.10	0.12	0.07	0.15	0.05
Hermit Warbler	*Setophaga occidentalis*	0.04	---	0.02	0.16	0.14	0.20
MacGillivray's Warbler	*Geothlypis tolmiei*	0.53	0.43	0.46	0.40	0.44	0.63
Wilson's Warbler	*Cardellina pusilla*	0.02	0.02	0.03	0.04	0.02	0.04
Green-tailed Towhee	*Pipilo chlorurus*	1.15	1.16	1.30	0.66	0.89	0.76
Spotted Towhee	*Pipilo maculatus*	0.81	0.82	1.24	0.97	1.02	1.06
California Towhee	*Melozone crissalis*	---	0.06	0.03	0.01	0.01	---
Chipping Sparrow	*Spizella passerina*	0.21	0.19	0.12	0.22	0.13	0.07
Brewer's Sparrow	*Spizella breweri*	0.03	---	---	---	---	---

		Freds Fire			Power Fire		
Common Name	**Scientific Name**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
Black-chinned Sparrow	*Spizella atrogularis*	0.08	0.01	0.02	0.01	---	---
Fox Sparrow	*Passerella iliaca*	1.10	1.29	1.39	1.18	1.57	1.23
Song Sparrow	*Melospiza melodia*	0.04	0.01	---	0.03	0.02	0.02
Lincoln's Sparrow	*Melospiza lincolnii*	---	---	---	---	0.01	0.01
Dark-eyed Junco	*Junco hyemalis*	0.18	0.23	0.14	0.25	0.30	0.42
Western Tanager	*Piranga ludoviciana*	0.41	0.48	0.52	0.56	0.54	0.75
Black-headed Grosbeak	*Pheucticus melanocephalus*	0.39	0.48	0.54	0.49	0.63	0.63
Lazuli Bunting	*Passerina amoena*	0.81	0.76	1.24	0.82	0.69	1.00
Red-winged Blackbird	*Agelaius phoeniceus*	0.03	---	---	---	---	---
Western Meadowlark	*Sturnella neglecta*	0.02	0.04	0.01	---	---	---
Brown-headed Cowbird	*Molothrus ater*	0.02	---	0.01	---	0.01	0.01
Bullock's Oriole	*Icterus bullockii*	0.03	---	0.01	0.01	---	---
Purple Finch	*Carpodacus purpureus*	0.02	0.04	0.02	0.04	0.06	0.03
Cassin's Finch	*Carpodacus cassinii*	0.02	0.08	0.05	0.05	0.04	0.02
Red Crossbill	*Loxia curvirostra*	---	---	---	0.01	0.02	---
Pine Siskin	*Carduelis pinus*	---	0.07	0.04	---	---	0.02
Lesser Goldfinch	*Spinus psaltria*	0.15	0.05	0.08	0.05	0.03	---
Lawrence's Goldfinch	*Spinus lawrencei*	0.01	---	---	---	---	---
Evening Grosbeak	*Coccothraustes vespertinus*	0.04	0.05	---	0.02	0.01	0.01

Appendix B. Parameter estimates and occurrence predictions for the distance to edge of high severity patch model. Mean model predictions of species probability of occurrence are also included for the minimum (Edge = 3m) and maximum (Interior = 316m) distances represented in our dataset as well as their difference. Species are listed in descending order of the absolute amount of change from patch edge to interior.

	Parameter Estimates (95% CIs)		**Probability of Occurrence**		
Common Name	**Intercept**	**Slope**	**Edge**	**Interior**	**Difference**
Brown Creeper	-2.0 (-3.0, -1.2)	-0.7 (-1.0, -0.4)	0.43	0.04	-0.39
Red-breasted Nuthatch	-1.4 (-2.2, -0.6)	-0.5 (-0.7, -0.3)	0.47	0.10	-0.36
Steller's Jay	-0.9 (-1.8, -0.1)	-0.4 (-0.6, -0.2)	0.52	0.18	-0.34
House Wren	0.6 (-0.2, 1.4)	0.3 (0.1, 0.5)	0.44	0.77	0.33
Mountain Chickadee	-1.6 (-2.4, -0.7)	-0.4 (-0.7, -0.2)	0.40	0.09	-0.30
Green-tailed Towhee	0.4 (-0.5, 1.2)	0.3 (0.1, 0.5)	0.42	0.71	0.29
Lazuli Bunting	-0.1 (-0.9, 0.8)	0.3 (0.1, 0.5)	0.32	0.59	0.27
Fox Sparrow	0.6 (-0.2, 1.5)	0.3 (0.1, 0.5)	0.48	0.75	0.26
Western Tanager	-1.9 (-2.8, -1.1)	-0.4 (-0.6, -0.1)	0.29	0.07	-0.21
Western Wood-Pewee	-1.6 (-2.5, -0.8)	-0.3 (-0.6, -0.1)	0.31	0.10	-0.21
Dusky Flycatcher	-1.0 (-1.9, -0.2)	0.2 (-0.0, 0.4)	0.17	0.34	0.17
Olive-sided Flycatcher	-2.3 (-3.2, -1.4)	-0.3 (-0.6, -0.1)	0.20	0.05	-0.15
Bewick's Wren	-1.8 (-2.6, -0.9)	0.3 (0.0, 0.6)	0.07	0.21	0.14
Dark-eyed Junco	-2.1 (-3.0, -1.3)	-0.3 (-0.6, -0.1)	0.21	0.06	-0.14
Cassin's Vireo	-3.2 (-4.1, -2.3)	-0.5 (-0.9, -0.2)	0.14	0.02	-0.12
Yellow Warbler	-1.5 (-2.4, -0.7)	0.2 (-0.0, 0.5)	0.12	0.24	0.12
American Robin	-1.7 (-2.6, -0.8)	-0.2 (-0.5, 0.1)	0.22	0.11	-0.11
Northern Flicker	-1.1 (-2.0, -0.3)	0.1 (-0.1, 0.3)	0.19	0.29	0.10
Yellow-rumped Warbler	-2.9 (-3.8, -2.0)	-0.4 (-0.7, -0.1)	0.12	0.03	-0.09
Mountain Quail	-1.6 (-2.5, -0.8)	0.1 (-0.1, 0.4)	0.13	0.21	0.08
Spotted Towhee	0.0 (-0.8, 0.9)	0.1 (-0.1, 0.3)	0.46	0.54	0.08
Acorn Woodpecker	-4.1 (-5.2, -3.1)	-0.7 (-1.1, -0.2)	0.08	0.01	-0.07
Hairy Woodpecker	-2.1 (-3.0, -1.3)	-0.2 (-0.4, 0.1)	0.15	0.08	-0.07
MacGillivray's Warbler	-0.6 (-1.5, 0.2)	-0.1 (-0.3, 0.1)	0.40	0.33	-0.07
Orange-crowned Warbler	-2.1 (-2.9, -1.3)	0.2 (-0.1, 0.5)	0.07	0.14	0.07
White-headed Woodpecker	-2.5 (-3.3, -1.6)	-0.2 (-0.5, 0.1)	0.12	0.06	-0.06
Bushtit	-3.3 (-4.2, -2.4)	-0.3 (-0.7, 0.1)	0.07	0.02	-0.05
Chipping Sparrow	-2.1 (-3.0, -1.2)	0.1 (-0.1, 0.4)	0.08	0.13	0.05
Black-headed Grosbeak	-1.5 (-2.3, -0.6)	0.1 (-0.2, 0.3)	0.16	0.20	0.04
Cassin's Finch	-4.5 (-5.6, -3.4)	-0.5 (-1.0, -0.0)	0.04	0.00	-0.04
Golden-crowned Kinglet	-4.1 (-5.2, -3.2)	-0.4 (-0.9, 0.0)	0.05	0.01	-0.04
Warbling Vireo	-3.0 (-3.9, -2.1)	-0.2 (-0.5, 0.2)	0.08	0.04	-0.04
Western Bluebird	-2.6 (-3.5, -1.8)	0.1 (-0.2, 0.5)	0.05	0.08	0.04
Rock Wren	-3.8 (-4.8, -2.9)	0.3 (-0.2, 0.8)	0.01	0.04	0.03
Townsend's Solitaire	-3.5 (-4.4, -2.5)	-0.2 (-0.6, 0.1)	0.05	0.02	-0.03
Canyon Wren	-4.9 (-6.1, -3.6)	-0.5 (-1.1, -0.0)	0.03	0.00	-0.02
Lesser Goldfinch	-3.9 (-4.9, -2.8)	0.2 (-0.3, 0.7)	0.01	0.03	0.02
Lewis's Woodpecker	-3.9 (-4.9, -2.9)	0.3 (-0.2, 0.8)	0.01	0.03	0.02
Nashville Warbler	-0.3 (-1.1, 0.6)	-0.0 (-0.2, 0.2)	0.45	0.43	-0.02
Song Sparrow	-3.7 (-4.6, -2.7)	0.2 (-0.2, 0.7)	0.02	0.03	0.02

	Parameter Estimates (95% CIs)		Probability of Occurrence		
Common Name	**Intercept**	**Slope**	**Edge**	**Interior**	**Difference**
White-breasted Nuthatch	-3.9 (-4.9, -2.9)	-0.2 (-0.6, 0.2)	0.03	0.01	-0.02
Brown-headed Cowbird	-5.3 (-6.9, -3.9)	-0.2 (-0.8, 0.3)	0.01	0.00	-0.01
Black-throated Gray Warbler	-5.0 (-6.4, -3.8)	-0.3 (-0.8, 0.2)	0.02	0.00	-0.01
Hammond's Flycatcher	-5.3 (-6.6, -3.8)	-0.2 (-0.8, 0.3)	0.01	0.00	-0.01
Hutton's Vireo	-5.2 (-6.7, -3.9)	-0.2 (-0.8, 0.4)	0.01	0.00	-0.01
Lincoln's Sparrow	-5.7 (-7.5, -4.2)	-0.3 (-0.9, 0.2)	0.01	0.00	-0.01
Red-breasted Sapsucker	-3.6 (-4.6, -2.7)	-0.1 (-0.5, 0.3)	0.03	0.02	-0.01
Wilson's Warbler	-3.5 (-4.5, -2.5)	0.1 (-0.4, 0.5)	0.02	0.03	0.01
Wrentit	-3.9 (-4.8, -2.9)	0.1 (-0.4, 0.6)	0.02	0.02	0.01
American Dipper	-6.2 (-8.5, -4.5)	-0.2 (-0.8, 0.5)	0.00	0.00	0.00
Anna's Hummingbird	-4.3 (-5.5, -3.3)	0.0 (-0.5, 0.5)	0.01	0.01	0.00
Black-chinned Sparrow	-6.3 (-8.4, -4.6)	-0.3 (-0.9, 0.4)	0.00	0.00	0.00
Blue-gray Gnatcatcher	-7.4 (-10.3, -4.8)	-0.3 (-1.0, 0.4)	0.00	0.00	0.00
Band-tailed Pigeon	-5.2 (-6.8, -3.9)	-0.1 (-0.7, 0.5)	0.01	0.00	0.00
Bullock's Oriole	-6.2 (-8.5, -4.4)	-0.2 (-0.8, 0.5)	0.00	0.00	0.00
California Towhee	-5.2 (-6.6, -3.9)	-0.1 (-0.7, 0.6)	0.01	0.00	0.00
Cliff Swallow	-7.5 (-10.2, -4.7)	-0.3 (-1.0, 0.4)	0.00	0.00	0.00
Common Nighthawk	-7.5 (-10.3, -5.0)	-0.3 (-1.0, 0.4)	0.00	0.00	0.00
Evening Grosbeak	-7.5 (-10.3, -4.9)	-0.3 (-1.1, 0.4)	0.00	0.00	0.00
Hermit Warbler	-5.7 (-7.4, -4.2)	-0.2 (-0.8, 0.4)	0.01	0.00	0.00
Mourning Dove	-5.2 (-6.6, -3.8)	-0.1 (-0.7, 0.5)	0.01	0.00	0.00
Pacific Wren	-7.5 (-10.4, -5.0)	-0.3 (-1.0, 0.4)	0.00	0.00	0.00
Pine Siskin	-5.2 (-6.6, -3.9)	-0.2 (-0.7, 0.4)	0.01	0.00	0.00
Pileated Woodpecker	-6.4 (-8.4, -4.5)	-0.4 (-1.0, 0.3)	0.00	0.00	0.00
Pacific-slope Flycatcher	-7.4 (-10.4, -5.0)	-0.3 (-1.1, 0.4)	0.00	0.00	0.00
Purple Finch	-6.3 (-8.3, -4.5)	-0.2 (-0.9, 0.4)	0.00	0.00	0.00
Pygmy Nuthatch	-6.3 (-8.2, -4.5)	-0.3 (-0.9, 0.3)	0.00	0.00	0.00
Sooty Grouse	-6.3 (-8.3, -4.4)	-0.3 (-0.9, 0.4)	0.00	0.00	0.00
Violet-green Swallow	-7.5 (-10.4, -4.8)	-0.3 (-1.1, 0.4)	0.00	0.00	0.00
Western Meadowlark	-7.4 (-10.3, -5.0)	-0.3 (-1.0, 0.4)	0.00	0.00	0.00
White-throated Swift	-7.4 (-10.3, -5.1)	-0.3 (-0.9, 0.5)	0.00	0.00	0.00