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O'Hearn, Karyn C

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Effect of Fire History on Nonbreeding Bird Communities in a Giant Sequoia (*Sequoiadendron giganteum*) Forest

By

KARYN C. O'HEARN  
THESIS

Submitted in partial satisfaction of the requirements for the degree of

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Avian Sciences

in the

OFFICE OF GRADUATE STUDIES

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DAVIS

Approved:

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Professor Thomas P. Hahn, Chair

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Professor Marcel Holyoak

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Dr. Rodney Siegel

Committee in Charge

2021

## ABSTRACT

Despite birds being heavily studied members of forest communities, few generalities exist regarding species response to fire. Further, there very few studies of bird communities outside the breeding season. Quality of nonbreeding habitat is critically important to migrants, local transients, and wintering species, and changes to nonbreeding habitats can have important consequences for communities across seasons. In 2015, the Rough Fire burned part of the Grant Grove sequoia forest within Sequoia Kings Canyon National Park (SEKI) in areas with different fire management histories. Subsequently, SEKI deployed acoustic recording units (ARUs) at nine stations in five sites in areas with (prescribed and wildfire) and without prior fire management activities (old growth and second generation mature forest). The aim of this study was to test the effects of these fire histories on nonbreeding community composition by quantifying and comparing species richness and composition in fall and in winter. A secondary aim was to determine the efficacy of manually detecting winter species from surveys of nonbreeding-season recordings.

Random 10-minute samples were manually surveyed from each point recording six times September 2017 – February 2018 for a total of 540 minutes surveyed. Differences in richness and composition between fall and winter were analyzed by site type and sites organized into fire history categories. Richness was evaluated with a general linear mixed model and a Poisson regression with fixed factor effects to test for significance. Differences in species composition were compared and tested with non-metric multidimensional scaling (NMDS) using a community-by-species matrix. Frequency was examined to evaluate individual species contribution to composition.

There were 45 total species detected, 22 across both seasons. Winter season had significantly lower species richness ( $\beta = -0.88$ ,  $p < 2e-16$ ) than fall. The second generation mature forest ( $\beta = -0.4$ ,  $p = 0.033$ ) and the site burned during the Rough Fire ( $\beta = -0.3$ ,  $p = 0.09$ ) both had significantly lower species richness in winter. The prescribed fire history category had significantly greater species richness ( $\beta = 0.37$ ,  $p = 0.002$ ). Species richness was also significantly higher at sites with increasing numbers of prescribed fires ( $\beta = 0.12$ ,  $p=0.0023$ ). Species composition was more similar in fall than in winter. There were significant differences in species composition among all sites ( $r^2=0.80$ ,  $P=0.02$ ) and for three of the five fire-associated categories in winter: sites with and without fire history ( $r^2=0.4$ ,  $P=0.01$ ), with different time since fire ( $r^2=0.52$ ,  $P=0.01$ ), and increasing total number of prescribed fires ( $r^2=0.86$ ,  $P=0.01$ ). Differences among sites grouped by prescribed fire or wildfire did not significantly correlate with species composition.

Overall, this study indicates that fire history positively affects winter bird communities, and demonstrates that acoustic recordings are effective in detecting winter species. This baseline investigation will benefit SEKI's efforts to understand how to best use these long-duration recordings for examining relationships between species and habitat, and future studies of how fire histories affect winter communities. Understanding the differences in these avian communities can assist land managers in protecting associated birds in fire-prone landscapes across all seasons.

## **DEDICATION**

This effort is dedicated to my Dad and to the birds.

“In National Parks and wilderness areas we must approach the assignment of restoring natural environmental conditions with humility and great ecologic sensitivity.”

*Bruce Kilgore, 1973, The Ecological Role of Fire in Sierran Conifer Forests: Its Application to National Park Management*

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## INTRODUCTION

The Sierra Nevada comprises a fire forest: a forest adapted to and dependent on fire (Rough Fire Soundscapes Study Plan, 2016, Appendix A). In giant sequoia (*Sequoiadendron giganteum*) forests, local fire regimes shape landscape patterns via effects on vegetation structure and species composition (Kreisel and Stein 1999; Smith et al. 2000). Roughly 100 years of fire suppression combined with 50-years of prescribed fire and natural wildfire management in national parks of the Sierra Nevada (Rothman 2005) have altered the patterns of forest structures and community compositions and consequently the quality and availability of habitat that organisms such as forest birds depend on (Huff et al. 2005). Birds are conspicuous and heavily studied members of forest communities. Nevertheless, few generalities exist regarding species response to fire, indicating a need for local investigations of species and community patterns (Fontaine and Kennedy 2012; Brown et al. 2015). Bird species benefit differentially from fire-created habitat and for many Western species the extent of these benefits is unknown. Until recently there has been little study of bird communities in post-fire areas in the Sierra Nevada (Fogg et al. 2015). Furthermore, despite there being more than 450 published papers describing the effects of fire on birds (Hutto et al. 2015), there is a paucity of studies investigating the effects of fire history on bird communities outside the breeding season (Blake 1982; King et al. 1998; Kreisel and Stein 1999; Brown et al. 2015).

High-quality winter habitat is known to have effects on neotemperate migrants and year-round residents. Resource availability, predation risk, habitat structure, and microclimate may all change between the summer and winter seasons benefiting species differentially. Nonbreeding bird communities can differ from breeding communities in burned and unburned sites. Some species select different sites across seasons based on vegetation structure, while others

differentially prefer either burned or unburned habitat during the nonbreeding season (Blake 1982; Samuels et al. 2005; Guyot et al. 2017). In some systems, the summer and winter bird community composition changes based on species-specific habitat preferences (Brown et al. 2015).

Fire can also affect nonbreeding birds species differently depending on feeding guild and plant structure changes over time (Samuels et al. 2005). For some wintering communities, high-quality riparian habitat has been shown to have important impacts on population dynamics (Dybala et al. 2015). One study in the Jack-pine forest of Michigan found that, during the nonbreeding season, abundance and richness were higher in patches of forest where there were biological legacies (Anthony, 2013), defined as the “organically-generated environmental patterns that persist through a disturbance and are incorporated into the recovering ecosystem” (Franklin et al. 2000). These remaining patches following stand-replacing wildfire, such as “surviving trees, snags, downed wood, serotinous species, banked seeds, and underground vegetative components,” contribute to a diversity of vegetation characteristics that in turn may benefit multiple species across seasons (Cannon, 2011; Haslem et al. 2012; Anthony, 2013). The 2015 Rough Fire, the largest wildfire in California that year, burned part of the Grant Grove, an iconic expanse of old-growth giant sequoia forest within Sequoia Kings Canyon National Park (SEKI). This fire added variation in habitat structures in areas with different fire management histories within the Grant Grove providing an opportunity to examine the effects of those fire histories on post-fire communities. Investigating the effects of fire history on these nonbreeding communities will assist land managers to incorporate historic management strategies in determining future management and conservation measures that protect habitats and their associated birds in fire-prone landscapes across all seasons.

Over time, incidents of large fires, length of fire season, fire severity, and overall annual burn area have increased throughout the Sierra Nevada mixed-conifer forest (Westerling et al. 2006; Miller and Safford 2012). Compounding these alterations, the western United States is experiencing a long-term drought with hotter, drier conditions, and extreme die-off of forests in Sierra Nevada mid-elevation zones (Gilpin 2016). Most remnant old-growth sequoia forests are on protected federal and state lands (e.g., Yosemite and SEKI National Parks). In such places, the natural role of fire has been recognized and re-introduced as a management tool through prescribed fire or by allowing natural lightning-caused fires to burn without major suppression (Beedy et al. 2013). The effects of fire history on associated bird communities are varied depending on fire severity, time-since-fire, and individual species' ecological niche (Bock and Lynch 1970; Saab and Powell 2005; Russell et al. 2009; Fontaine et al. 2009; Kalies et al. 2010; Fogg et al. 2015). Breeding season studies have shown many Sierra Nevada bird species depend on and benefit from natural fire regimes. Prescribed fire has been a management strategy in Sierra Nevada parks since the 1960's, and has the potential to restore avian community characteristics in systems affected by fire suppression (Bagne and Purcell 2011). Beneficial effects of wildfires on birds can be negatively affected by human disruptions to natural fire regimes, such as fire suppression or prescribed fire (Odion et al. 2014; Hutto et al. 2015). Burn severity also effects bird communities, and the effects of varying burn severities are species dependent (Huff et al. 2005; Alexander et al. 2004; Meehan and George 2003; Bock and Block 2005; Russell et al. 2009; White et al. 2015). Burn severity that mirrors historical conditions to which individual bird species have adapted often benefit those species (Latif et al. 2016). Fire-created biological legacies in the form of unburned or lightly burned forest patches within larger burned areas can influence the effects of future fire on species and communities (Kalies et al.



2010; Artman et al. 2001; Cannon 2011; Fogg et al. 2015; Holoubek & Jensen 2015). The effects of time-since-fire (the number of years following a fire event) plays a significant role in bird species response to fire, and is important for managers to consider when using fire for resource protection (Hutto and Patterson 2016; Tingley et al. 2016; Haslem, et al. 2012). As time progresses after a fire event, the diversity of forest structures resulting from varying degrees of burn severity can lead to differentiated bird communities over time (Tingley et al. 2016). For example, as time-since-fire increases the prevalence of live and dead stems containing hollows, critical habitat for many forest species (Haslem et al., 2012), increases and bird abundances can vary among species across varying years since a fire event (Hutto and Patterson, 2016).

Fire effects can increase bird diversity (Kalies et al. 2010; Fogg et al. 2015), which is often used as a proxy of ecosystem health. One study from a mixed-conifer forest in Washington state found that overall avian species occupancy rates and species richness were not heavily impacted by prescribed fire (Russell et al. 2009). This same study determined that although species diversity overall was the same before and after prescribed fire, the species compositions before and after differed (George et al. 2005; Russell et al. 2009). Predicting effects of prescribed fire on birds requires identifying the individual species that benefit from or are harmed by changes induced by fire. Community composition can reveal nuances in the effects of habitat changes that richness alone cannot detect (Blake 1982; Smith et al. 2000; Russel et al. 2009; Curtis and Robinson 2015; Tingley et al. 2016). Regional as well as local drivers, like prescribed fire, can affect community change over time, and only long-term community composition observations can reveal these patterns (Curtis and Robinson 2015; Russell et al. 2009).

Prior to the reintroduction of fire (Figure 1), the Grant Grove giant sequoia forest in SEKI had a long history of fire suppression, making it an excellent model for studying how fire history

and the application of management methods affect forest communities. The SEKI 2005 Fire and Fuels Management Program objectives included monitoring and evaluating the effects of the program on wildlife (Sequoia and Kings Canyon National Park, 2005). High bird diversity and presence of important habitats for breeding, migration stopover, and wintering have led to these parks being designated Globally Important Bird Areas, and birds are considered high priorities for monitoring (Steel et al. 2012). Understanding these long-protected areas is important for assessing the effects of warming climates and land-use changes on bird populations that are affected globally by stressors such as climate change and habitat loss, and locally by altered fire regimes and non-native species invasions (Meyer et al. 2019). The giant sequoia forests within SEKI are transition zones for several species. They occur at elevations that can be either the top or bottom edge of breeding ranges, with some species passing through as they move up in elevation prior to fall migration or downslope for winter, and other nonbreeding species arriving for the winter (Beedy et al. 2013). Understanding how fire history affects the nonbreeding bird communities in the Sierra Nevada will complement current investigations of the effects of fire management on breeding communities.

Quality of nonbreeding habitat is critically important to migrants, local transients, and wintering species, and can affect survival through to the breeding season (Blake 1982; Kreisel and Stein 1999). Nonbreeding season survival can be affected by such factors as weather or availability of suitable wintering habitats that provide predictable food sources with low risk of predation (Kricher 1975; Faaborg et al. 1995). Non-migratory Song Sparrow (*Melospiza melodia*) populations on Mandarte Island are regulated by density-dependent factors (successful female reproduction during the breeding season and juvenile recruitment in fall), and these factors influence their overwinter survival during unusual weather events (Arcese et al. 1992).

Nonbreeding bird communities contribute to overall population demographics, and changes to nonbreeding habitats can have important consequences for abundance and population trends for both stationary and migratory species (Calvert et al. 2009). We know for neotropical migrants that breeding season abundance is dependent on environmental conditions at over-wintering grounds. American Redstart (*Setophaga ruticilla*) populations are partially regulated by a crowding mechanism acting in high-quality winter habitat (Marra et al. 2015). Furthermore, American Redstarts from high-quality winter habitats arrive on breeding grounds earlier than those from poor-quality habitats and produce a higher proportion of offspring (Reudink et al. 2009; Wilson et al. 2011). Further, wintering birds behave differently than breeding birds in a number of important ways. Species that predominantly forage on arthropods in territorial pairs during the breeding season often form heterospecific flocks in the nonbreeding season and serve as potential seed dispersers when they switch to predominantly consuming seeds during the nonbreeding season (Whelan et al. 2008).

Following the Rough Fire, SEKI deployed acoustic recording units (ARUs) throughout the Grant Grove sequoia forests (Table 1, Figure 2) in areas with and without prior fire management activities. One might expect that year-round resident species would be less active during winter than spring/summer, offering fewer detections using any method, and that detections from recordings would be difficult to identify from the few subtle call notes (as opposed to songs) many species make during winter. Contrary to these expectations, one study from California's Central Valley using traditional on-the-ground point count methods found that winter species richness was just as high as summer species richness (Dybala et al. 2015). The soundscape monitoring in the Grant Grove provides a potentially powerful management tool (Meyer et al. 2019). One study from these recordings investigated relationships between acoustic

indices and their ability to predict diversity and abundance of sounds, as well as their viability as a means for biodiversity monitoring (Buxton et al. 2018). Using acoustic data to characterize communities is becoming popular among land managers concerned with preservation of natural processes (Pijanowski et al. 2011; Farina et al. 2011). Acoustic studies have identified associations between bird species composition and landscape characteristics (Tucker et al. 2014; Alvarez-Berríos et al. 2016). Studies comparing ARU surveys with traditional point counts showed that baseline estimates of species presence can be obtained through manual analysis of acoustic samples (Hutto and Stutzman 2009; Wimmer et al. 2013; La and Nudds 2016). Understanding the significance of such findings will require method standardization and ground-truthing to facilitate consistent and reliable acoustic monitoring that best informs conservation (Buxton et al. 2018). There are limitations to surveying with soundscape recordings. They require sophisticated technical knowledge and incur costs and time limitations when processing large amounts of recorded data that require storage (Pieretti et al. 2015). They also offer benefits over traditional methods, including increased survey time with simultaneous surveys at multiple locations and without the need for highly qualified persons in the field (Kułaga and Budka, 2019). The use of recordings minimizes disturbances caused by human surveyors and offers a permanent record where detections and identification are enhanced when replayed or listened to by multiple experts (Celis-Murro et al. 2009, Pieretti et al. 2011). While traditional point count methods have been found to better detect rare species, acoustic recordings have been found to be as good as point counts for estimating richness and composition (Hutto and Stutzman 2009, Celis-Murro et al. 2012). Passive acoustic recordings offer more efficient and cost-effective means of long-term monitoring for resource managers when limitations such as winter access or insufficient personnel exist, opening opportunities to examine less-studied phenomena such as

nonbreeding season community ecology. Further, park scientists will be able to archive these long-duration recordings, making them available for future studies as funding allows, and as advancements in software for automated data collection inspire new studies (Meyer et al. 2019).

In forest areas like SEKI, where there is a lack of pre- and post-fire comparisons, managers are interested in understanding the types of fire-created conditions that birds prefer and the extent to which fire history affects bird communities. Currently, using acoustic measures of animal diversity requires the input of experienced observers, who identify species manually while listening to the recorded sounds (Zhang et al., 2016). Manually scoring current recordings now will provide a baseline for future studies using these initial recordings. In the present study, I manually surveyed the recordings from the ARUs deployed in the Grant Grove by SEKI to test the effects of fire management history on post-fire nonbreeding community composition, and to determine the effectiveness of nonbreeding-season recordings to detect winter species. The ARUs were placed at nine stations (referred to as ‘points’) in five sites throughout the greater Grant Grove sequoia forests (Figure 2, Table 1). These ARUs continuously recorded from spring 2016 through 2019. I quantified species richness and community composition (presence-absence) in fall and in winter two years following the Rough Fire, and compared species composition across each point and site within each fire history category (Table 1). I conducted traditional point counts at each ARU station to ground truth manual detections from recordings.

## **METHODS**

### *Study Area*

The 154-acre Grant Grove sits at 1937 m elevation in old-growth mixed coniferous forest in Kings Canyon National Park and is home to the second-largest giant sequoia on Earth, the

General Grant Tree ('General Grant Grove,' 2019). This area is geographically isolated from the rest of Kings Canyon National Park and surrounded by U.S. Forest Service land (Vignettes of the 2015 Rough Fire, 2017). After a lightning strike on July 31, 2015, the Rough Fire burned 151,623 acres, nearly 9,500 acres in the park ('Rough Fire,' 2020). The Rough Fire reached the northern section of the Grant Grove, burning into old-growth forest historically treated with prescribed fire (Vignettes of the 2015 Rough Fire, 2017). The Grant Grove area was first deliberately burned in 1979, and subsequently this grove and surrounding sequoia groves have been burned up to three times (Vignettes of the 2015 Rough Fire, 2017) (Figure 1). The nine ARU stations were established in spring 2016 based on the Rough Fire Soundscapes Study Plan (Appendix A; Ralph et al. 1995). There are nine ARU points identified by their ARU designated box numbers, 10-90 (Figure 3). Table 1 lists the nine points by which of the five sites they are associated with, and fire history. Four sites are in old-growth giant sequoia forest (Figure 2). The fifth site is 2.9 km (1.8 miles) south in the Big Stump area, a second-generation sequoia stand that was logged up to the 1890s. This site was chosen to increase the number of sampling points within areas with no recorded fire history because the Grant Grove site with no fire history was only able to accommodate selection requirements for one point. These sites were further sorted into fire history categories for analysis (Table 1).

#### *Data Collection: Traditional Point Counts*

All species detections and quantifications were performed by a single observer skilled in aural and visual identification of Sierra birds.

Traditional point counts were conducted for comparison with and validation of ARU recording count surveys. During May-June 12, 2017 all nine ARU points were visited at least

one time for 10 minutes during the sunrise and sunset ARU recording times. Counts began within 20 minutes prior to local sunrise, and as close to local sunrise as possible. Dusk counts were initiated 1 hour prior to sunset. Seven point counts were conducted at each of the nine ARU points during sunrise recording times and four counts at each during sunset recording times between June 28 and December 20, 2017 (Table 2). Sunrise counts 1-5 were conducted during June 28-August 25, every 12-14 days. Two more sunrise counts were added September 21-22 and December 20, 2017 making a total of three dawn surveys at all nine points August-December 2017. These were used to validate fall and winter ARU surveys. All surveys were conducted within the ARU recording time with a few exceptions, when either the ARU was unexpectedly not operating upon arrival, or the three counts at point 30 where part of the 10-minute count period extended outside the recording time (Table 2). The point count protocol was designed based on methods developed by The Institute for Bird Populations (IBP) methods, a Point Blue sample data form, and Sierra Nevada Network (SIEN) Landbird Monitoring Protocol (Siegel et al. 2010; Appendix B).

#### *Data Collection: Acoustic Recording Counts*

Best practices for detecting species using point counts (Hutto et al. 1986; Ralph et al. 1995) and practice with manual detections from a subset of SEKI recordings were initially used to develop a manual detection scheme. Targeted random sampling (e.g., six 5-minute segments) with manual detections of sound recordings across as much time as possible (e.g., over six days) has been found to detect more species compared with traditional point counts (Wimmer et al. 2013). Initial ARU count surveys followed a protocol of every 15-20 days for a 3-day window beginning in August 2017 (Table 3). Due to technology malfunctions that led to recording gaps,

protocol was shifted to surveying all nine points once per month beginning with the September 9<sup>th</sup> ARU survey. Each point was surveyed six times (three times during September - November and three times during December – February) producing 60 minutes surveyed per point, and a total of 540 minutes surveyed. For this purpose, fall was considered September – November and winter December – February (Table 3).

Each ARU point was sampled on the same day when complete 4-hour recordings for each point for that day were available. When recordings were not available for all points on the same day, then the nearest day with recordings for that point was used. Each ARU recording was manually surveyed from a 10-minute sub-sample with a start time randomly generated between sunrise and 2-hours post sunrise (Wimmer et al. 2013; White et al. 2015; La & Nudds 2016). For each survey period, survey order rotated between points (e.g., the first set of surveys started with point 10, then the second period of surveys began with point 90) in an effort to reduce any possible bias from survey order (Brown et al. 2015). All surveys were conducted using Raven Pro 1.5.0 Sound Analysis Software Pro (Bioacoustics Research Program, Ithaca, NY, USA) for visualization of recording spectrograms on a 2015 MacBook Air, and Skullcandy Knockout Women's On-Ear Headphones for aural assessment of sounds (Figure 4). To facilitate use of my surveys in future analyses using these recordings, data collection protocol and Raven Pro preset protocol (i.e. selection number, high and low frequency, and average power) mirrored the SEKI biodiversity study manual data collection protocol wherever possible (Appendix A). All recordings are in a waveform (wav) audio file format.

Following SEKI manual survey protocols, where an identifiable sound was detected, the next subsequent detection of a sound from that species was also selected for reference. If an individual vocalization was in a bout or a series (e.g. Red-breasted Nuthatch and Golden-



crowned Kinglets often call in a series), a single bout was distinguished by an auditory and visual break in the sound, and the entire bout was selected as one detection. For each survey, several identified call and song examples for some species were selected and put into a library for reference and review (Buxton et al. 2018, Appendix S3). Examples from this library, live recordings made on site during fall 2018, consultations with experts, personal expertise, and online catalogues, such as Macaulay Library at the Cornell Lab of Ornithology (<https://search.macaulaylibrary.org/catalog?view=List>) and Xeno-Canto Foundation (<https://www.xeno-canto.org/>), as well as the online resource for practicing bird identification NatureInstruct (<https://www.natureinstruct.org/dendroica/>), were used to make identifications. Species detected that were considered nocturnal (i.e. Great-horned Owl [*Bubo virginianus*] and California Spotted Owl [*Strix occidentalis occidentalis*]), were excluded from analysis. The Northern Pygmy-Owl (*Glaucidium gnoma*) was included as this species often vocalizes during survey times. All final data tables were saved with labels to match the original wav file for easier cross-referencing. Detailed supplemental protocols can be found in Appendix B.

### *Statistical Analyses*

R programming language version 3.6.0 (R Core Team, 2019) and RStudio version 1.2.5033 (RStudio Team, 2015) were used for all analyses. Species detected were compared at each point and site, during each season, and within each fire history category. Species richness was analyzed from detections at each of the nine points from five sites (Table 1). Richness was evaluated with a general linear mixed model for count data. Due to the small sample size and two factor levels, a Poisson regression was used with fixed factor effects tested for significance. The glm, vif, and StepAIC functions (R Core Team, 2019) were used to test

models for multicollinearity (factors that are too similar) and select the best model for predictor variables. Chosen models were used to evaluate relationships between factors and total number of species detected and test the linear relationship between each factor (explanatory/predictor variable) and the total estimated number of species detected (dependent/response variable). Differences in species composition (presence-absence) at each point and site across fall and winter were compared with non-metric multidimensional scaling (NMDS) to visualize similarities using an ordination plot (Mammides et al. 2017). The NMDS results were plotted with fire history categories and tested to determine any effect fire history had on species detected at sites across seasons. The metaMDS function (Oksanen et al., 2019) uses a community-by-species matrix to calculate the Bray-Curtis dissimilarity index (sometimes called Sorensen index when used for presence-absence data) using presence/absence detections. This index ranks the results (dissimilarity = 1 – similarity index) to indicate similarity between sites; proximity on an ordination plot indicates similarity. For the Bray–Curtis dissimilarity ranking, 0 means sites have the same composition, and 1 means the two sites do not share any species.

After the community composition index was calculated for sites in fall and in winter, the envfit function from the R vegan package (Oksanen et al., 2019) was used to determine relationships between fire history and species composition. I tested for correlation between species composition ordination rankings and site type as well as each fire history category (Table 1). Using the envfit function, NMDS ordination scores for factor levels (environmental variables) were calculated for goodness of fit statistic and P-value based on 999 permutations, and the results (centroid or vector) plotted. Categorical variables (site types and four of the fire history category factors) results were plotted as factors. The total prescribed fires category is a continuous variable and was plotted as a vector. Site type and each fire history category were

considered to be significantly correlated with species composition when the goodness of fit ( $r^2$ ) had a p-value equal to or less than 0.05. To determine if reduced species detections played a role in winter's correlations with site type and fire history categories, the same NMDS ordination and envfit categorical test was performed with only the detected species shared between fall and winter. The dplyr (Wickham et al., 2019), tidyr (Wickham, 2020), ggplot2 (Wickham, 2016) and cowplot (Wilke, 2019) packages were used to organize and present data. Frequency of species detections at points and sites across seasons was determined to evaluate individual species contribution to composition.

## RESULTS

### *Richness*

The three point count surveys at all points spanning August 2017-December 2017 detected a total of 27 species: the August survey detected 10 species, the September survey detected 17 species, and the December survey detected 15 species. Of these, all but three species (Black-headed Grosbeak, Green-tailed Towhee, and Pacific-slope Flycatcher) were detected during ARU surveys. These three species were visually or auditorily confirmed to be in Grant Grove during detections from unused recordings and during sampling day in-person observations. Of the 24 species detected during both point count and ARU surveys, all 24 were detected during fall and 17 during the winter ARU surveys. There were 21 species detected during the ARU surveys and not during point count surveys. Many of these were summer breeding migrants (e.g., Wilson's Warbler) or irruptive migrants (e.g., Pine Siskin, Evening Grosbeak) that would have been transiently present during surveys and therefore less likely to be detected in just a few point count surveys.

For the manual ARU surveys spanning September 2017-February 2018, species detections in the five different fire history site types (Table 1) differed between fall and winter. Of the total 45 species detected in both seasons combined, there were 43 detected in fall and 24 detected in winter (Table 4). The Rough Prescribed site had the most species detected in both seasons (35 in fall, 19 in winter). In fall the fewest species were detected at the Second Generation site (21), and in winter the fewest species were detected at the Rough Fire site (12). There were 21 species detected only in fall, and two species detected only in winter.

The StepAIC function determined three models of factors to be the best predictors of total estimated richness (Table 5). In contrast with Fall, winter season had significantly lower species richness ( $\beta = -0.88$ ,  $p < 2e-16$ ). The glm function pulls factors alphabetically from a data table by default, therefore the Old Growth site was used to compare species richness between sites, the all-fire history combined category was used to contrast fire histories, sites with no time since fire and sites with one total prescribed fire were both used to compare other groups in these categories (Table 5). Compared with the Old Growth site, the Second Generation site had significantly lower species richness in winter ( $\beta = -0.4$ ,  $p = 0.033$ ). Species richness at the Rough Fire site was marginally significantly ( $\beta = -0.3$ ,  $p = 0.09$ ) lower compared with the Old Growth site in winter. The model indicates that the Prescribed Fire site had lower species richness ( $\beta = -0.02$ ,  $p = 0.9$ ) and the Rough Prescribed site higher richness ( $\beta = 0.092$ ,  $p = 0.5$ ) in winter compared with the Old Growth site, but due to the small sample size these non-significant relationships are uncertain. Both the Old Growth site and the Second Generation site combined represent the areas with no fire history. Since there was a significant difference in their species richness, I re-modeled the sites with the Second Generation site set as the intercept with all other sites contrasted (Appendix C, Table 2). In this case, all other sites had positive species richness

estimates, with the Old Growth, Prescribed Fire, and Rough Prescribed sites having significantly greater richness ( $p = 0.03$ ,  $p = 0.02$ ,  $p = 0.001$  respectively). All fire history categories in winter had positive species richness estimates: sites with all-fire history, no fire history, wildfire history, and prescribed fire history (Table 5). The prescribed fire history category had significantly greater species richness ( $p = 0.002$ ). When the time since fire and total number of prescribed fire categories were analyzed, increasing time since fire had lower richness ( $\beta = -0.0023$ ,  $p = 0.82$ ), whereas species richness was significantly higher at each site with increasing numbers of prescribed fires ( $\beta = 0.12$ ,  $p = 0.0023$ ). The small sample size, with only two levels of factors, contributed to high multicollinearity (substantial similarity) between categories making all non-significant results uncertain.

#### *Multivariate Tests of Community Composition (NMDS)*

Differences in species composition (presence-absence) between each point and site were observed across fall and winter. Non-metric multidimensional scaling (NMDS) in 3-dimensions ( $k=3$ ) offered the best results (stress < 0.05) when comparing species composition in fall, and in winter. From the three dimensions calculated, the two most different dimensions provided the NMDS ordination axes. A series of envfit tests of the correlation between site types or sites grouped into factors was statistically correlated with community composition at these sites (at  $P < 0.05$ ) in winter. Composition did not differ among sites in fall (Figure 5; envfit  $r^2 = 0.57$ ,  $P = 0.26$ ). In winter there were significant differences in species composition among sites (Figure 5; envfit  $r^2 = 0.80$ ,  $P = 0.02$ ). Further investigation demonstrated that this difference among sites in winter was attributable to several types of fire-associated differences. These included differences among sites with and without fire history (Figure 6; envfit  $r^2 = 0.4$ ,  $P = 0.01$ ), time since fire

(before vs. after 2015; Figure 8; envfit  $r^2=0.52$ ,  $P=0.01$ ), and total number of prescribed fires (Figure 9; envfit  $r^2=0.86$ ,  $P=0.01$ ). Differences among sites in whether fires were prescribed (Figure 7; envfit  $r^2=0.26$ ,  $P=0.13$ ) or were wildfires (Figure 7; envfit  $r^2=0.20$ ,  $P=0.2$ ) did not significantly correlate with species composition.

Differences in species composition were observed between each point and site across fall and winter despite a difference in total number of species detected in each season. When comparing only the 22 species detected during both fall and winter, the envfit tests of correlation between site types and sites grouped into factors was still significantly correlated with community composition in winter, and attributable to the same types of fire-associated differences among sites. Fall composition of these 22 species showed the same similarity among sites (Appendix C, Figure 1; envfit  $r^2=0.61$ ,  $P=0.344$ ). In winter, there were significant differences in species composition among sites (Appendix C, Figure 1; envfit  $r^2=0.80$ ,  $P=0.036$ ) and three of the fire history categories: sites with and without fire history (Appendix C, Figure 2; envfit  $r^2=0.40$ ,  $P=0.02$ ), sites with different time since fire (before vs. after, Appendix C, Figure 5; envfit  $r^2=0.51$ ,  $P=0.02$ ), and sites with different total numbers of prescribed fires (Appendix C, Figure 6; envfit  $r^2=0.85$ ,  $P=0.02$ ).

#### *Differences Among Communities: Individual Species Contributions*

To further investigate differences in species composition (presence-absence) at each point and site and within each fire history category, I examined the frequency of detection of individual species across the six surveys. Frequency of species detected varied at each site across seasons (Table 4). The most frequently detected species across both fall and winter were Yellow-rumped Warbler, Golden-crowned Kinglet, Brown Creeper, and Red-breasted Nuthatch. They

were detected at all points and all sites at least one time during each season (Figure 10). Of the least frequently detected species, Cassin's Finch, Cassin's Vireo, Cedar Waxwing, Mountain Bluebird, Olive-sided Flycatcher, Pine Grosbeak, Red-tailed Hawk, and Williamson's Sapsucker were each detected only once, all in fall except the Red-tailed Hawk (Table 4). Least frequently detected species were spread among sites with different fire histories. Cassin's Vireo and Cedar Waxwing were only detected at sites with no fire history (Second Generation and Old Growth sites respectively). Pine Grosbeak was detected at the Prescribed Fire site, and Cassin's Finch, Mountain Bluebird, Olive-sided Flycatcher, Red-tailed Hawk, and Williamson's Sapsucker were detected at the Rough Prescribed site (wildfire and prescribed fire history).

For the 22 species detected across both seasons, frequency of detection patterns differed (Table 4, Figure 11). From fall to winter, 13 species declined in the number of sites where they were detected, six were detected in new sites where they were not detected in fall, and two species increased the number of sites where detected. American Robin, Brown Creeper, Dark-eyed Junco, Golden-crowned Kinglet, Mountain Chickadee, Red-breasted Nuthatch, Ruby-crowned Kinglet, Steller's Jay, Townsend's Solitaire, Western Bluebird, White-headed Woodpecker, and Yellow-rumped Warbler were detected most frequently at all sites during fall. Of these, Brown Creeper, Golden-crowned Kinglet, Red-breasted Nuthatch, and Yellow-rumped Warbler remained frequently detected during winter. Pacific Wren and Pileated Woodpecker increased in frequency of detection sites during winter. Pacific Wren was detected three times in fall at two sites: at a site with no fire history and a site with wildfire and prescribed fire history, and six times in winter at four sites: sites with no fire history, prescribed fire history, and wildfire and prescribed fire history. Pileated Woodpecker was detected at five different points representing three site types in winter compared to three different points representing two sites

during fall. Of the six species that were detected at new sites during winter, Northern Pygmy-Owl and Pileated Woodpecker were detected at a site with fire history where they had not been detected during fall.

Frequency of detection also differed for each fire history category. During fall, all 22 species detected during both seasons were detected at sites with fire history and 20 were detected at sites with no fire history (Table 4, Figure 11). During winter, 21 were detected at sites with fire history and 17 were detected at sites with no fire history. The total number of species detected at sites with prescribed fire history and no prescribed fire history remained the same during fall and winter, 21 species detected at both during fall and 19 at both during winter. Similarly, sites with wildfire history had consistent detections in both seasons. During fall, 19 of the 22 species were detected in sites with and without wildfire history, and during winter, 18 of 22 species were detected in sites with wildfire and sites with no wildfire history. Despite there being similar total number of species at these sites in both seasons, of the 13 species detected at fewer sites during winter, six were no longer detected at the Prescribed Fire site (Common Raven, Dark-eyed Junco, Steller's Jay, Townsend's Solitaire, and Western Bluebird), and 7 were no longer detected at the Rough Fire site (American Robin, Common Raven, Mountain Chickadee, Purple Finch, Townsend's Solitaire, and Western Blue Bird). With regard to time since fire, there were 16 species detected in all three categories (no fire history, 13 years since fire, and 2 years since fire) during fall and eight species detected in all categories during winter. The site with 13 years since fire showed the greatest drop in detections between fall and winter. Of the 14 species detected in winter that were not detected in all three times since fire categories, 12 were detected in sites with two years since the last fire.



Individual species were also detected in different fire history categories in different seasons. During fall, Black Phoebe and Red-breasted Sapsucker were detected only in sites with wildfire history and Pileated Woodpecker only in sites with no wildfire history. Black Phoebe was the only species to be detected during fall solely in sites with fire history, and then in winter at sites both with and without fire history. Conversely, White-breasted Nuthatch was the only species during winter to be detected solely in sites with no fire history, whereas it was detected in a site with no fire history and one with wildfire and prescribed fire history during fall. Likewise, American Robin, Hairy Woodpecker, Northern Flicker, and Northern Pygmy-Owl went from being detected in sites with and without fire history during fall to only being detected in sites with fire history during winter. In winter, Purple Finch was only detected in sites with no wildfire history, and Northern Pygmy-Owl was detected only at a site with wildfire history. Western Bluebird, Townsend's Solitaire, Steller's Jay, Dark-eyed Junco, and Common Raven went from being detected at sites with all three time since fire categories during fall to no detections in the site with only prescribed fire history (13 years since fire) during winter.

## **DISCUSSION**

### *Main Findings*

Most studies evaluating the effect of fire on bird species have been conducted during the breeding season, whereas the current study investigated the effect of fire history on bird communities during nonbreeding seasons. Most postfire breeding season studies have concluded that richness is greater in areas with recent fire history (Bock and Block 2005; Russel et al. 2009; Burnett et al. 2011; Bagne and Purcell 2011). Other studies have found that long-unburned patches (mature/old-growth stands) can have greater species richness than recently burned areas

(Robinson et al. 2014, Fogg et al. 2015). This present study found significantly lower species richness during winter compared with fall, and of the five sites, richness was significantly lower at the Second Generation site (Table 5). The Rough Fire site (old-growth site with recent wildfire and no prescribed fire history) had marginally significantly lower species richness. The Old Growth and Rough Prescribed (wildfire and prescribed fire history) sites had overall greater richness in winter, the Old Growth site significantly greater richness compared to the Second Generation site (the only other site of mature unburned forest). While the Prescribed Fire site had lower richness, the prescribed fire history category (all sites with prescribed fire history combined) had significantly greater richness in winter. Likewise, sites with any number of prescribed fires had significantly greater richness. In fact, the remaining fire history categories: all-fire history combined, no fire history, and wildfire history, all had higher estimated richness in winter. This marginally changed when only the 22 species detected in both seasons were analyzed (Appendix C, Table 1).

Corroborating previous nonbreeding season studies that found differing bird species composition between burned and unburned treatments (Kreisel and Stein 1999), this study found significant differences in winter species composition according to site (Figure 5), and in three of the fire history categories: sites with and without fire history (Figure 6), sites with different time since fire (Figure 8), and sites with increasing total number of prescribed fire (Figure 9). Surprisingly, fall species composition at these sites was not significantly correlated with any fire history category. This remained the case when only the group of species detected in both fall and winter was analyzed (Appendix C, Figures 1-6). In general, species composition across sites and fire history categories in fall was more similar than in winter (compare Figure 5 through Figure

9). In winter, composition was most similar at the sites in the prescribed fire and wildfire categories (Figure 7).

While each of the prescribed fire and wildfire history categories were not significantly dissimilar in bird community composition in either season, sites with prescribed fire history combined had significantly higher species richness during winter. Whereas sites with prescribed and wildfire history combined were significantly correlated with community composition in winter, and had greater richness. There were no such differences in richness or composition observed during fall even when the 22 species detected during both seasons were analyzed. Most of the 21 species detected only during fall were summer breeding migrants or local species (except for the likely transient Evening Grosbeak), and many were detected across multiple sites (14). The two species (Red-tailed Hawk and Bushtit) only detected during winter are local and likely to be detected year-round. Differences shown between fall and winter suggest fire history can affect year-round residents differentially across seasons. In this present study, for the 22 species detected during both seasons, Pacific Wren and Pileated Woodpecker were detected at more sites in winter while Common Raven, Dark-eyed Junco, Steller's Jay, Townsend's Solitaire, and Western Bluebird were no longer detected at the Prescribed Fire site and American Robin, Common Raven, Mountain Chickadee, Purple Finch, Townsend's Solitaire, and Western Bluebird were no longer detected at the Rough Fire site (Table 4, Figures 10-11). Individual species respond differently to different vegetation characteristics created by different fire regimes. Some respond neutrally to fire because they are less restricted in their forest characteristic preferences (live trees, snag densities, ground cover, etc.) while many other species show strong associations with specific forest structures created by different fire regimes (White et al. 2015). For example, White et al. (2015) found that probabilities of occurrence of Hairy

Woodpecker, Brown Creeper, and Townsend's Solitaire were significantly correlated with sites that had greater snag densities, while Brown Creeper was also positively associated with both higher shrub cover and density of live trees and Townsend's Solitaire was found in a narrower range of post fire habitat conditions. We know from breeding season studies that fire-created structural changes benefit bird communities differently, and similar benefits may extend through the nonbreeding season for multiple species in this study, explaining why they are limited to winter detections in sites with or without fire history. This study detected American Robin, Hairy Woodpecker, Northern Flicker, and Northern Pygmy-Owl at sites with and without fire history during fall but only at sites with fire history in winter. Townsend's Solitaire was only detected in old-growth sites with no fire history or the site with combined prescribed and wildfire history, and Brown Creeper remained universally detected at all sites across both seasons. Local movement by resident bird species taking advantage of fire-created resources has been seen during the nonbreeding season, but the extent of these advantages may only be determined when examining time-since-fire effects where nonbreeding communities change over time post-fire (Kreisel and Stein 1999).

Diverse habitat structures within the same forest system can increase biodiversity by increasing desirable habitat for more species (Artman et al. 2001; Kalies et al. 2010; Cannon 2011; Fogg et al. 2015; Holoubek and Jensen 2015; Latif et al. 2016; Tingley et al. 2016). A challenge to understanding the impacts of these effects on birds is understanding the impacts of multiple disturbances (e.g. repeated fires) (Fontaine et al. 2009), as well as the impacts of those disturbances across seasons and over time. In breeding season studies that compared unburned areas and areas with varied burn severities created by wildfire, species habitat specializations and time contributed to diverse community assemblages across the landscape comprising these

different histories (Fontaine et al. 2009; Burnett et al. 2011; Tingley et al 2016; Taillie et al. 2018; Wills et al. 2020). Initial breeding season studies using these same recordings found at the old-growth site burned in the recent Rough Fire (Rough Fire site) less acoustic diversity (distinct biological sounds) that declined over three years following the Rough Fire compared with the site that also burned in the Rough Fire and had prescribed fire history (Rough Prescribed site) (Meyer et al. 2019). Likewise, this present study found that the Rough Prescribed site, with wildfire history and multiple prescribed fire history (beginning 37 years prior), tended to have higher species richness and had significantly dissimilar composition in winter (Table 5, Figure 5, and Figure 10). Even when the 22 species detected during both seasons were analyzed, the individual sites with only prescribed fire history and wildfire history each had fewer species detected in winter compared with the Rough Prescribed site, which consistently had a greater number of species detected across both seasons (20 detections during fall, 18 during winter), including five of the eight species that were only detected one time. During winter, the site with only wildfire history had the fewest detections and the old-growth site the second highest detections (Table 4, Figures 10-11). This study corroborates for winter what we know from breeding season findings: fire history at sites in a giant sequoia forest positively affects richness in winter, and those areas with combinations of prescribed fire and mixed-severity wildfires correlate with diverse winter communities.

Fire history has been shown to differentially affect richness and composition of nonbreeding season bird communities by altering complexity of vegetation structure (Hamel 2003; Samuels et al. 2005; Ruth et al. 2014; Farnsworth et al. 2014; Barton et al. 2014; Brown et al. 2015). Over time, communities can differ significantly after fire in areas with different burned and unburned management strategies (Izhaki and Adar, 1997), and these differences may extend

into the nonbreeding seasons. Prescribed fire is an effective tool for landscape-scale forest management and has potential to restore avian community characteristics in systems affected by fire suppression (Bagne and Purcell 2011; White et al. 2015). Breeding season studies have shown that prescribed fire benefits insectivores (bark, aerial, and ground) and cavity nesting species whereas foliage gleaners preferred unburned habitat (Saab and Powell 2005, Russell et al. 2009), and over time in areas managed with prescribed fire neotropical migrants decline (Thompson et al. 2008). One winter season study in a mature pine forest found no significant difference between wintering communities in burned and unburned forests managed with prescribed fire (King et al. 1998). Overall, this present study indicates important effects of fire history on winter bird communities in the southern Sierra Nevada. The small sample size, only nine sites with one or two points per site, increases the likelihood of high multicollinearity between categories limiting some conclusions. A greater sample size investigated over time and across seasons is needed to better understand the combined effects of fire history on winter species and their communities throughout this giant sequoia forest. Future studies will need to include all wildfire and prescribed fire histories with comparisons of multiple replicates. Studies of species' season-specific preferences and habitat selection at different spatial scales across seasons and time are needed to inform management of fire's effects on these communities (King et al. 1998; Guyot et al. 2017).

### *Effectiveness and Value of ARU Recordings in the Nonbreeding Season*

This study demonstrates that acoustic recording units collecting long-duration recordings are effective in detecting winter species in a giant sequoia forest. Techniques for autonomous identification of species and describing aspects of diversity with the use of acoustic indices

calculated from sound characteristics are continuously being improved and hold the promise of cost-effective monitoring at a landscape scale (Darras et al., 2018; Wood et al. 2019). These methods will greatly benefit future research where access to certain mid- to higher elevation locations in the Sierra Nevada in winter are prohibitive or sensitive species require noninvasive monitoring strategies (Wood et al. 2019). In the Sierra, collaborative efforts are underway to develop methods for automated detections of species, so far successfully with bats, California Spotted Owls, and Barred Owls (*Strix varia*) (Wood et al. 2019; Meyer et al. 2019). In the present, study several owl species were detected during the nonbreeding season, with one *Strix* sp. identified with the aid of experts, and confirmed with scientists investigating detections of Barred and California Spotted Owls in the Grant Grove and surrounding Sierra forests. The California Spotted Owl is an indicator species for late-seral forests (DellaSala et al. 2014) and learning how fire affects indicator species across seasons will benefit managers looking to protect both individual species and communities.

Giant sequoia forests are shaped by fire, and old-growth forests can be proxies for the past. Sierra parks have some of the longest protected resources providing glimpses into ecosystem health prior to modern human impacts. Ultimately, long-duration recordings will allow for a greater number of surveys across many points, and across time, increasing detections and accurate estimations of richness and composition (Kułaga and Budka, 2019). Comparing autonomous detection of species with humans, the human outperformed the autonomous detections in forests, and combined human and autonomous detections together found more species (Kułaga and Budka, 2019). As new technologies are applied and tested on recordings, the manual detections reported herein will serve as a baseline for future studies. Until these newer automated technologies are perfected and validated, manual detections like these remain a valid,

and in fact the most reliable form of detection. This present study demonstrates that ARUs are effective for investigating nonbreeding season bird communities and will aid future endeavors to find effective methods for monitoring species and diversity using soundscape recordings.

### *Future Studies*

This study provides a baseline for investigating how fire histories affect winter communities in a giant sequoia forest and will benefit SEKI's efforts to understand how to best use these long-duration recordings for examining relationships between species and habitat. This study corroborates past studies showing that even when richness has been found to be similar between unburned areas and those with different fire histories, species composition can differ between mature, old-growth forests and sites with both recent and longer time-since-fire histories (Fontaine et al. 2009; Wills et al. 2020). Richness alone should not be the sole measure of post-fire effects on bird species and success of restoration efforts (Russel et al. 2009; George et al. 2005). An understanding of the differences in avian community composition between unburned forest and post-fire habitats can help guide the management of these areas and provide understanding of drivers of long-term variability of species composition (Burnett et al. 2011; Curtis and Robinson 2015). Sierra bird communities differentiate gradually over time following fire, gradated by severity, and areas varying in time-since-fire have been shown to possess unique bird communities with richness and density comparable to unburned forests (Raphael et al. 1987; Fontaine et al. 2009; Tingley et al. 2016). A next step would be to survey the breeding season from the same recording year and determine fire's effects on richness and composition for comparison with the present findings regarding autumn and winter to create an annual baseline for future comparisons.



Sequoia Kings Canyon National Park's mission is to preserve the natural features and the wildlife therein and to these ends, park stewards endeavor to understand how to best use soundscape measures to examine relationships between species and habitat. When new questions arise and as new technologies advance the effectiveness of using acoustic recordings to measure and examine species-habitat relationships, this study and the soundscape recordings surveyed can be revisited for future studies. Investigating the effects of fire history on nonbreeding bird communities, especially in the Sierra Nevada where many bird species depend on and benefit from natural fire regimes either directly or over time, will assist land managers to incorporate past management strategies in determining future management and conservation measures that protect birds and their associated habitats in fire prone landscapes across all seasons.

## TABLES

*Table 1. Fire history categories at all 9 points and 5 sites. There are 2 points for each site type except for the Old Growth (OG) site, where the sampling protocol only allowed for one point. Fire history classifications come from the Rough Fire Soundscapes Study Plan (Appendix A). The fire history codes come from the Envfit program (vegan package, Oksanen et al., 2019).*

Points	Site Code	Site Name	Fire History	Fire History Categories				
				Fire	Perscription (Rx)	Wildfire	Time Since Fire	Total Perscriptions (Rx)
10, 20	PF	Prescribed Fire	Prescribed fire ONLY	fire	Rx	Nw	2004 (13 years)	2
30	OG	Old Growth	No Fire History	Nfire	NRx	Nw	0	0
40, 50	SG	Second Generation	No Fire History	Nfire	NRx	Nw	0	0
60, 70	RF	Rough Fire	Rough Fire ONLY	fire	NRx	w	2015 (2 years)	0
80, 90	RP	Rough & Prescribed Fire	Rough Fire and Prescribed Fire	fire	Rx	w	2015 (2 years)	2, 3

Table 2. Original Point Count Period Plan with date and time of morning (AM) and dusk (PM) count noted for each point. Dusk counts were not used in final analysis.

Point Count	Date	early AM	mid AM	late AM	Point Count	Date	early PM	mid PM	late PM
1st	28-Jun	90,80	60,70		1st	1-Jul	40	30	
	2-Jul	50,40	30,20	10		2-Jul	60	80	10
2nd	14-Jul	10,20	90,80	30	2nd	12-Jul	20	70	90
	15-Jul	70,60	50,40			13-Jul	80	40	10
3rd	27-Jul	80,20	10,90	70, 60	3rd	26-Jul	50	20	
	28-Jul	30,50	40,			27-Jul	90	60	70, 30*
4th	11-Aug	90,10	30,50	40	4th	10-Aug	10	60	90
	12-Aug	60,70	80,20			11-Aug	80	30	20
5th	24-Aug	40,50	30,10	20	5th	23-Aug	20	40	60
	25-Aug	80,90	70,60			24-Aug	70	90	50
6th**									
7th	21-Sept ***	10,20	50,40	30*	7th	20-Sep	20	10	30*
	22-Sep	70,60	90,80			21-Sep	70	90	80
8th	20-Dec	90,80	60,70	50,	8th****				
	20-Dec	30,40	20,10						

\*Point 30 count ended outside the ARU recording time

\*\*The 6th point count period was skipped as it was determined to survey 3 times for compare with ARU counts, ultimately Period 5, 7 & 8 were used.

\*\*\*Heavy rain Sept 21st forced all counts to be shifted to Sept 22nd AM. On Sept 22nd onlu point 30 count was conducted outside the ARU recording time.

\*\*\*\*A snow storm and new protocol to not use PM recordings lead to this PM count being skipped.

Table 3. ARU survey periods with point number and date of survey. Grey Font are incomplete surveys that were not completed or included in final analysis. Highlighted font are survey dates (2017-2018) that deviate from same day due to lack of complete or survey-worthy recordings. P1: August 21 P2: September 9, P3: October 1, P4: October 16, P5: November 4, P6: November 16, P7: December 11, 16, & 31, P8: January 24 & 25, P9: February 17.

FALL					WINTER			
P1	P2	P3	P4	P5	P6	P7	P8	P9
10_20170821	10_20170909	10_20171001	10_20171016	10_20171104	10_20171116	10_20171216	10_20180125	10_20180217
20_20170821	20_20170909	20_20171001	20_20171016	20_20171104	20_20171116	20_20171216	20_20180124	20_20180217
30_20170821	30_20170909	30_20171001	30_20171016	30_20171104	30_20171116	30_20171216	30_20180124	30_20180217
40_20170821	40_20170909	40_20171001	40_20171016	40_20171104	40_20171116	40_20171216	40_20180124	40_20180217
50_20170821	50_20170909	50_20171001	50_20171016	50_20171104	50_20171116	50_20171216	50_20180124	50_20180217
60_20170821	60_20170909	60_20171001	60_20171016	60_20171104	60_20171116	60_20171216	60_20180124	60_20180217
70_20170821	70_20170909	70_20171001	70_20171016	70_20171104	70_20171116	70_20171231	70_20180124	70_20180217
80_20170821	80_20170909	80_20171001	80_20171016	80_20171104	80_20171116	80_20171216	80_20180124	80_20180217
90_20170821	90_20170909	90_20171001	90_20171016	90_20171104	90_20171116	90_20171211	90_20180124	90_20180217

Table 4. Species manually detected from ARU recordings sorted by points and sites detected at each season, fire history categories, and total detections per season.

Species: common name	Alpha code (SPID)	Categories and Sites										Total Sites Detected	
		No Fire History			Fire History								
		Old Growth (OG)	Second Generation (SG)		Rough Fire (RF)		Prescribed Fire (PF)		Rough & Prescribed (RP)		F	W	
			30	40	50	60	70	10	20	80			90
American Robin	AMRO	F	F	F	F	F	F,W	F	F,W	F,W	5	2	
Black Phoebe	BLPH	W	---	---	---	F,W	---	---	F	F	3	2	
Brewer's Blackbird	BRBL	F	---	---	---	---	---	---	F	---	2	0	
Brown Creeper	BRCR	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	5	5	
Bushtit	BUSH	---	---	---	---	---	W	---	---	---	0	1	
Cassin's Finch	CAFI	---	---	---	---	---	---	---	F	---	1	0	
Cassin's Vireo	CAVI	---	---	F	---	---	---	---	---	---	1	0	
Cedar Waxwing	CEDW	F	---	---	---	---	---	---	---	---	1	0	
Common Raven	CORA	F,W	W	---	---	F	F	F	F	F,W	4	3	
Dark-eyed Junco	DEJU	F	F	F,W	F,W	F,W	F	F	F,W	F,W	5	3	
Evening Grosbeak	EVGR	F	---	---	---	F	---	---	---	F	3	0	
Fox Sparrow	FOSP	F	---	---	F	---	---	F	F	F	4	0	
Golden-crowned Kinglet	GCKI	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	5	5	
Hairy Woodpecker	HAWO	---	F	F	F	W	F,W	F,W	F	F,W	4	3	
House Wren	HOWR	---	---	---	---	F	---	---	F	---	2	0	
Lesser Goldfinch	LEGO	---	F	---	F	---	---	F	F	---	4	0	
MacGillivray's Warbler	MGWA	F	---	---	---	---	---	---	---	F	2	0	
Mountain Bluebird	MOBL	---	---	---	---	---	---	---	F	---	1	0	
Mountain Chickadee	MOCH	F,W	F	F	F	F	F,W	F	F,W	F,W	5	3	
Mountain Quail	MOQU	---	---	---	---	F	F	---	---	F	3	0	
Nashville Warbler	NAWA	F	---	---	F	---	F	F	F	F	4	0	
Northern Flicker	NOFL	F	---	---	F,W	F	F,W	F	F,W	F,W	4	3	

Northern Pygmy Owl	NOPO	F	---	F	F	---	---	---	---	W	3	1
Olive-sided Flycatcher	OSFL	---	---	---	---	---	---	---	---	F	1	0
Pacific Wren	PAWR	F,W	W	W	---	---	W	---	F,W	W	2	4
Pileated Woodpecker	PIWO	W	W	F,W	W	W	F	F	---	---	2	3
Pine Grosbeak	PIGR	---	---	---	---	---	F	---	---	---	1	0
Pine Siskin	PISI	---	F	---	---	F	F	F	F	---	4	0
Purple Finch	PUFI	W	F	W	F	---	F	F,W	F	---	4	3
Red-breasted Nuthatch	RBNU	F,W	F,W	F,W	W	F	F,W	F,W	F	F,W	5	5
Red-breasted Sapsucker	RBSA	---	---	---	---	---	---	---	---	F,W	1	1
Red-tailed Hawk	RTHA	---	---	---	---	---	---	---	---	W	0	1
Ruby-crowned Kinglet	RCKI	F	F	W	F,W	F,W	F,W	F,W	F,W	F	5	4
Spotted Towhee	SPTO	---	---	---	---	---	---	---	F	F	1	0
Steller's Jay	STJA	F,W	F	F	F,W	F	F	F	F,W	F,W	5	3
Townsend's Solitaire	TOSO	F,W	F	F,W	F	---	F	F	F,W	F	5	3
Violet-green Swallow	VGSW	---	F	---	---	---	---	F	---	---	2	0
Western Bluebird	WEBL	F,W	F,W	F	F	F	F	F	F,W	F	5	3
Western Tanager	WETA	---	F	---	---	F	F	F	---	---	3	0
Western Wood-Pewee	WEWP	---	---	---	---	---	---	F	F	---	2	0
White-breasted Nuthatch	WBNU	F,W	W	---	---	---	---	---	F	---	2	2
White-headed Woodpecker	WHWO	F,W	F	F	F,W	F,W	F,W	F,W	F,W	F,W	5	4
Williamson's Sapsucker	WISA	---	---	---	---	---	---	---	---	F	1	0
Wilson's Warbler	WIWA	F	---	---	F	---	---	---	---	---	2	0
Yellow-rumped Warbler	YRWA	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	F,W	5	5

Table 5. Poisson Regression with fixed parameter richness estimates for all detections for categories compared between seasons. All categorical factors (predictor variable) were modeled and the best models from stepAIC results were used. Individual Sites: linear relationship between factors and season, and estimated total number of species. Fire histories: linear relationship between factors and seasons, and estimated total number of species. Time Since Fire and Total Number of Prescribed Fires: linear relationship between factors and season, and estimated total number of species. For every unit change in the predictor variable, the difference in the logs of the expected counts will change by the value of the regression coefficient (estimated beta ( $\beta$ )), holding other variables in the model constant.

Parameter Estimates					
Factor	Category	Estimate (log scale)	AIC	Std. Error	p-value
Season	(Intercept) fall	2.57346		0.05315	-----
	winter	-0.87886		0.09812	< 2e-16 ***
	(Intercept) Old Growth Site (OG) in fall	2.68121	275.6	0.13022	-----
	Old Growth Site (OG) in winter	1.80235			
Individual Sites	Prescribed Fire site (PF)	-0.01626		0.15597	0.917
	Rough Fire Site (RF)	-0.27699		0.16361	0.0905 .
	Rough Prescribed Site (RP)	0.09237		0.15324	0.5466
	Second Generation Site (SG)	-0.35437		0.1662	0.0330 *
Fire History Categories	(Intercept) Sites in fall with fire history (RP, RF, PF)	2.29559	275	0.16437	-----
	Sites in winter with fire history (RP, RF, PF)	1.41673			
	Sites with no fire history (OG, SG)	0.16382		0.18138	0.36643
	Sites with wildfire history (RF, RP)	0.10863		0.1247	0.38366
	Sites with prescribed fire history (PF, RP)	0.36936		0.13413	0.00589 **
Time Since Fire and Total Number of Prescribed Fires Categories	(Intercept) Sites in fall with no time since fire (OG, SG)	2.44895	275.8	0.0689	-----
	Sites in winter with no time since fire (OG, SG)	1.57009			
	Sites with 2 years since fire (RP, RF)	-0.002309		0.009968	0.81684
	Sites with at least 1 prescribed fire	0.120364		0.043218	0.00535 **

Signif. codes: p-value < 0.01 = \*\*  
p-value < 0.05 = \*  
p-value < 0.1 = .

FIGURES

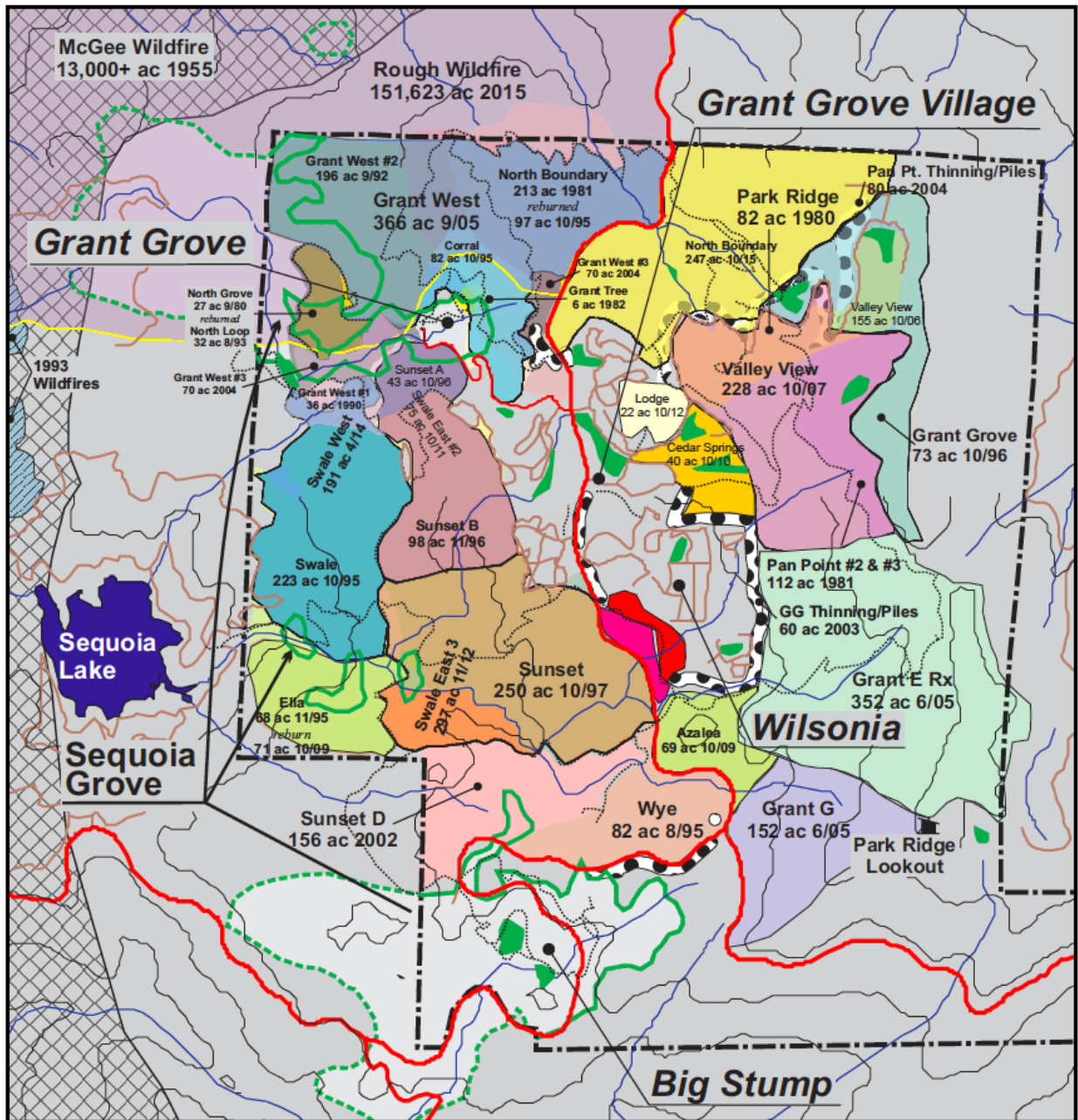


Figure 1. Grant Grove peninsula fire history (Sequoia and Kings Canyon National Parks, 2017).



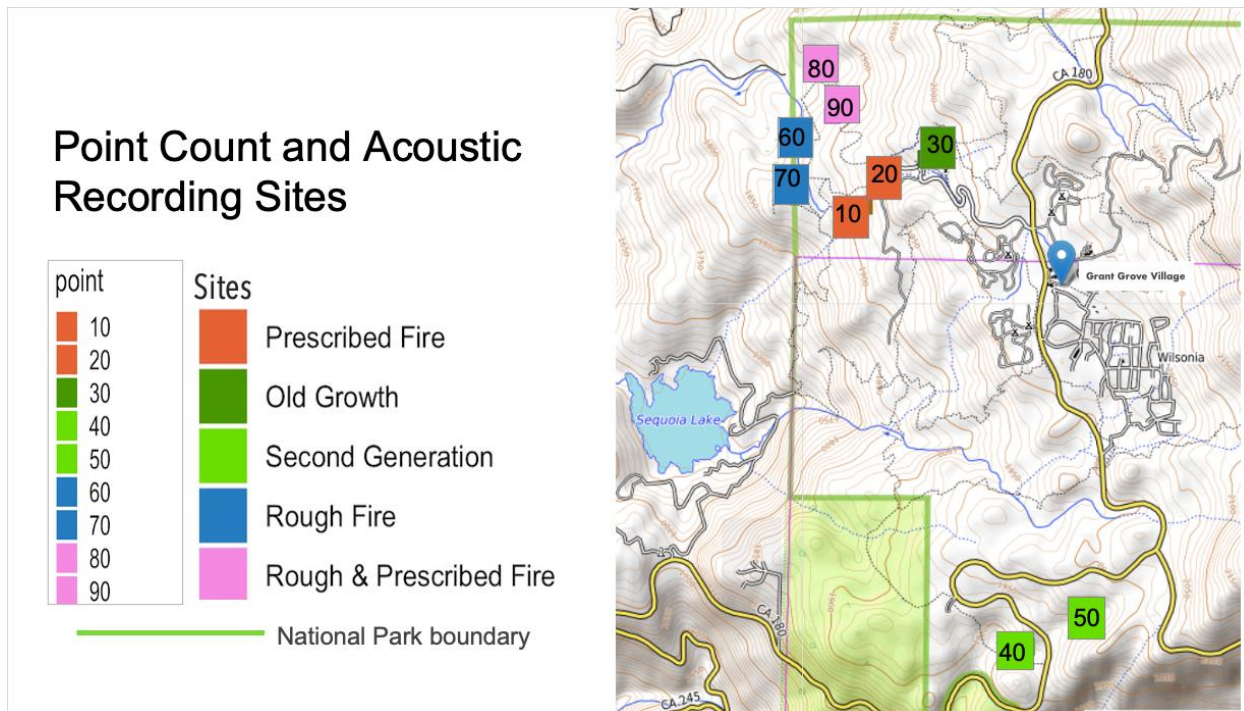


Figure 2. The 9 ARU points (identified by their ARU number) are at sites with different fire histories within the Grant Grove peninsula.



Figure 3. ARU 50, July 27, 2017. SEKI installed a SM3BAT Song Meter at each point in each site with microphone and standardized height across all sites.



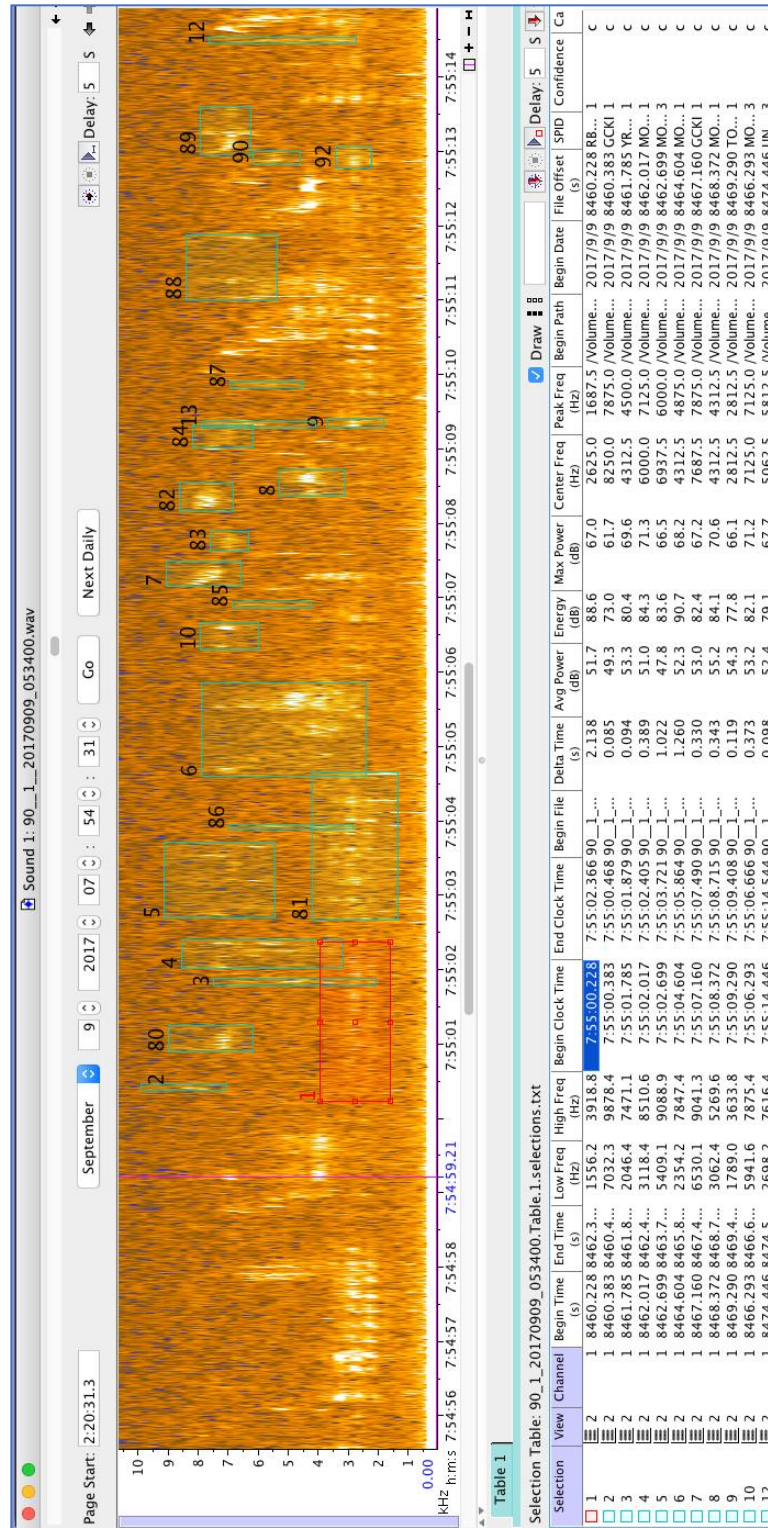
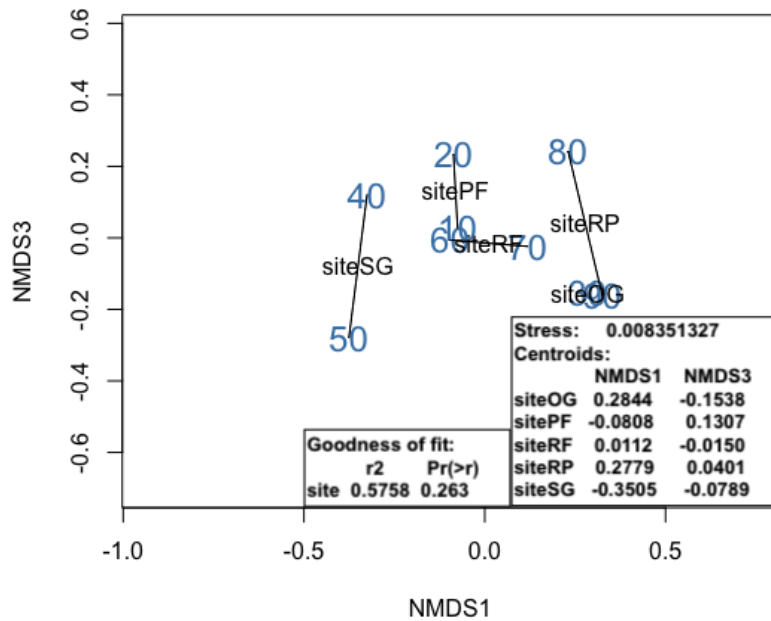


Figure 4. Raven Pro sample window showing spectrogram and data table from ARU 90 (Rough and Prescribed Fire site), September 9, 2017 survey.

### Fall Surveys Species Composition Ordination and Sites



### Winter Surveys Species Composition Ordination and Sites

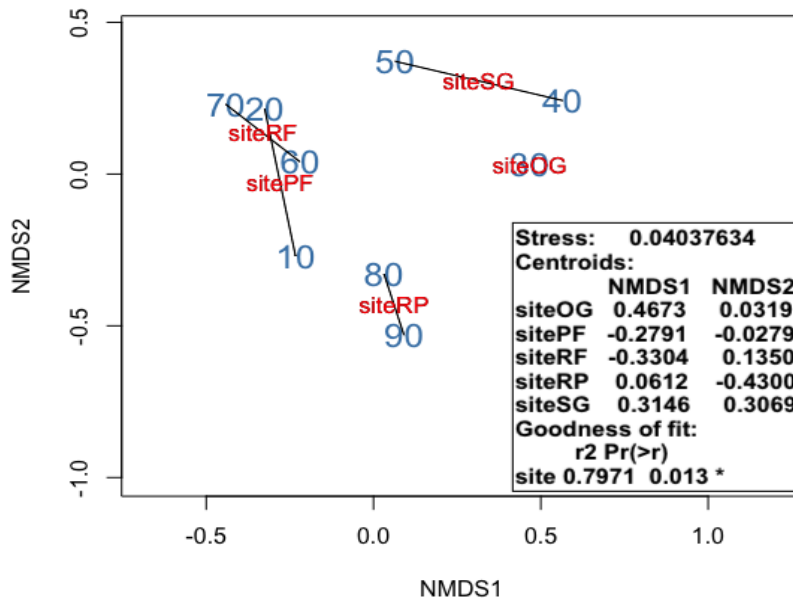
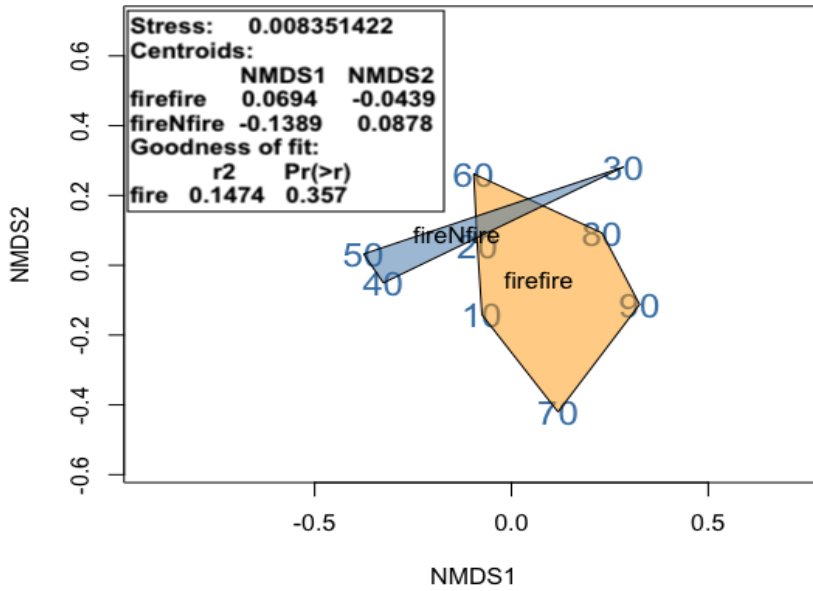


Figure 5. NMDS ordination of ranked dissimilarity (Bray-Curtis) in fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of site, where siteOG = Old Growth Site, sitePF = Prescribed Fire Site, siteRF = Rough Fire Site, siteRP = Rough Prescribed Site, siteSG = Second Generation Site. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit site category and associated p-value (red =  $p \leq 0.05$ ).

**Fall Surveys Species Composition Ordination and Combined Fire History**



**Winter Surveys Species Composition Ordination and Combined Fire History**

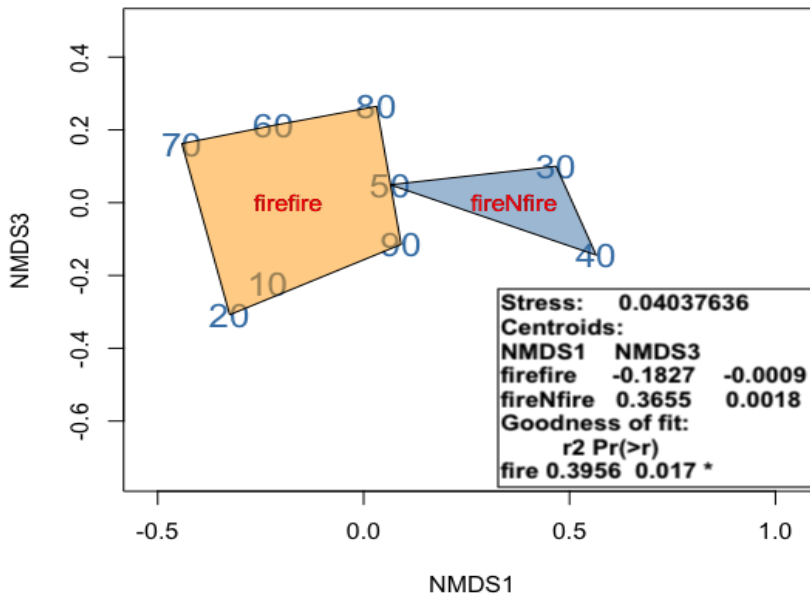
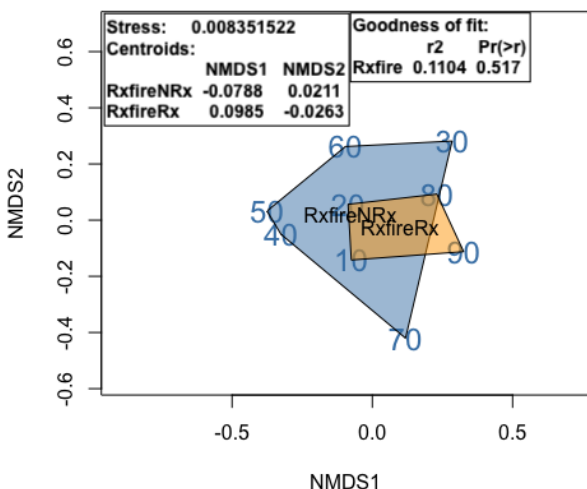
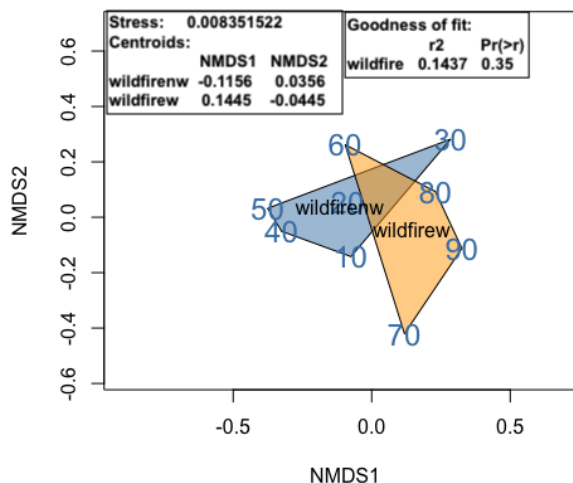


Figure 6. NMDS ordination of ranked dissimilarity (Bray-Curtis) in fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of combined fire history, where fireNfire = no fire history, and firefire = fire history. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

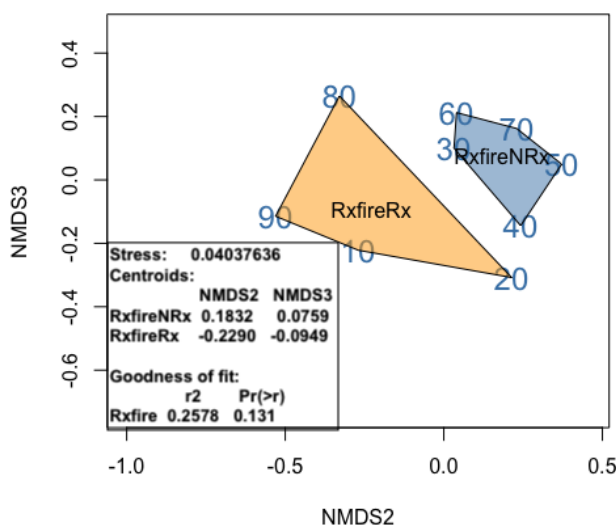
Fall Surveys Species Composition Ordination and Prescribed Fire History



Fall Surveys Species Composition Ordination and Wildfire History



Winter Surveys Species Composition Ordination and Prescribed Fire



Winter Species Composition Pairwise Dissimilarity Ordination with Wildfire History

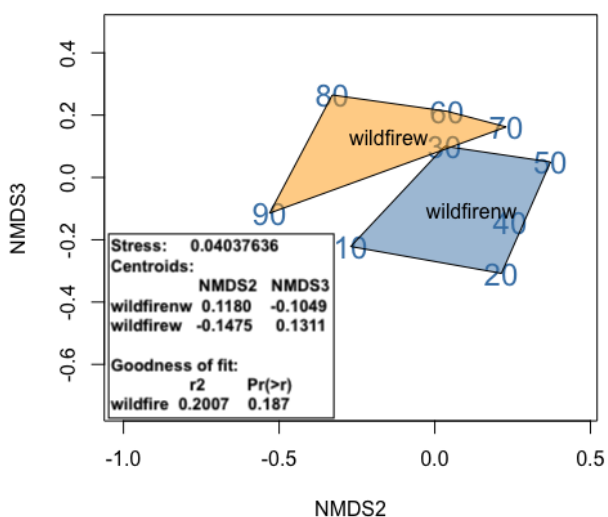
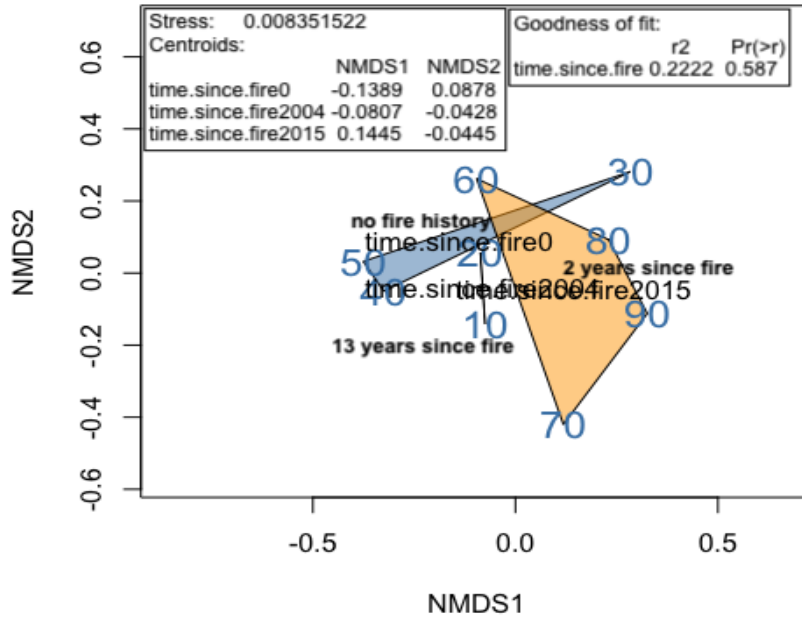


Figure 7. NMDS ordination of ranked dissimilarity (Bray-Curtis) in fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of prescribed fire history and wildfire history, where RxfireNRx = no prescribed fire history, RxfireRx = prescribed fire history, wildfirew = no wildfire history, and wildfirew = wildfire history. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

Fall Surveys Species Composition Ordination and Time Since Fire



Winter Surveys Species Composition Ordination and Time Since Fire

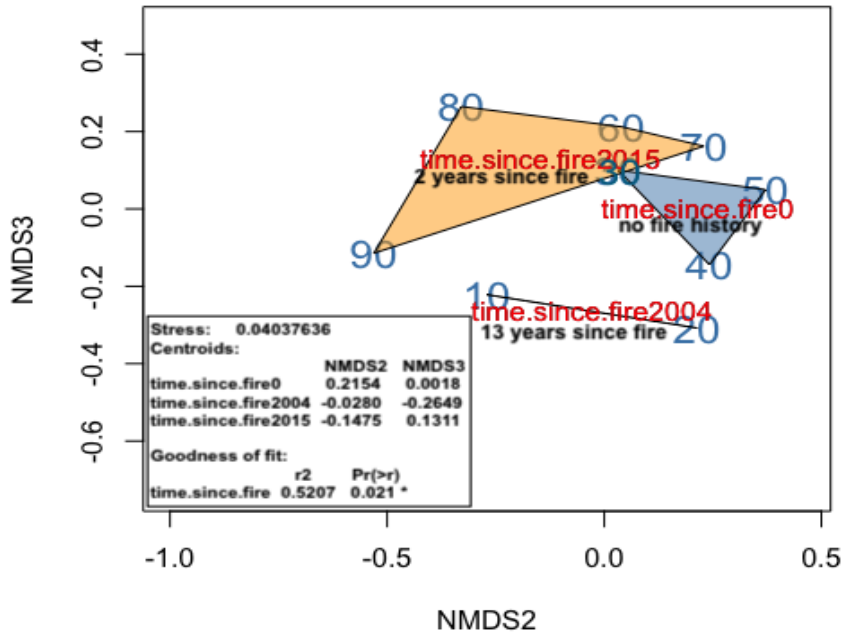
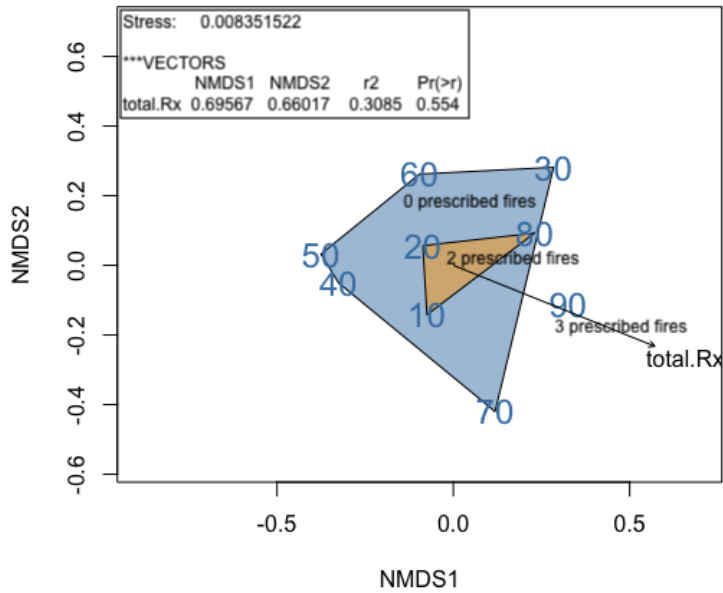


Figure 8. NMDS ordination of ranked dissimilarity (Bray-Curtis) in winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of time since most recent fire, where time.since.fire0 = no fire history, time.since.fire2004 = 13 years since fire, and time.since.fire2015 = 2 years since fire. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

Fall Surveys Species Composition Ordination and Total Prescribed Fires



Winter Surveys Species Composition Ordination and Total Prescribed Fires

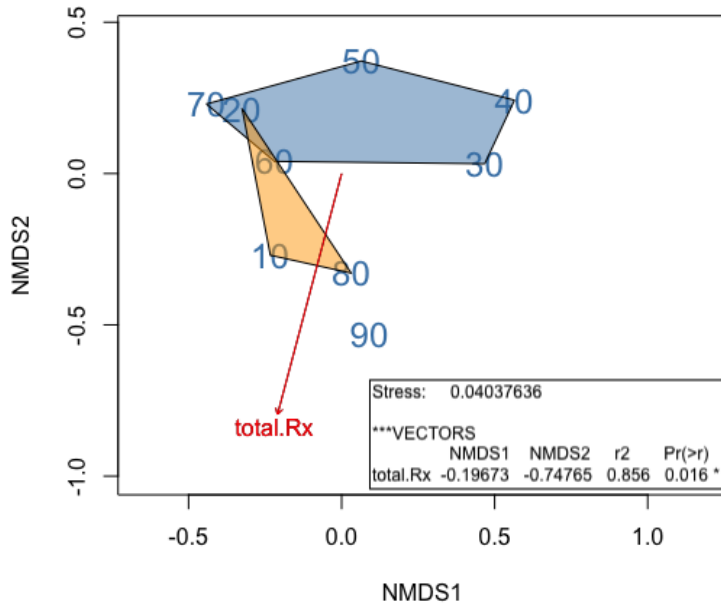


Figure 9. NMDS ordination of ranked dissimilarity (Bray-Curtis) in fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of total number of prescribed fires, where total.Rx vector indicates the direction of greater prescribed fire history and maximal correlation. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).



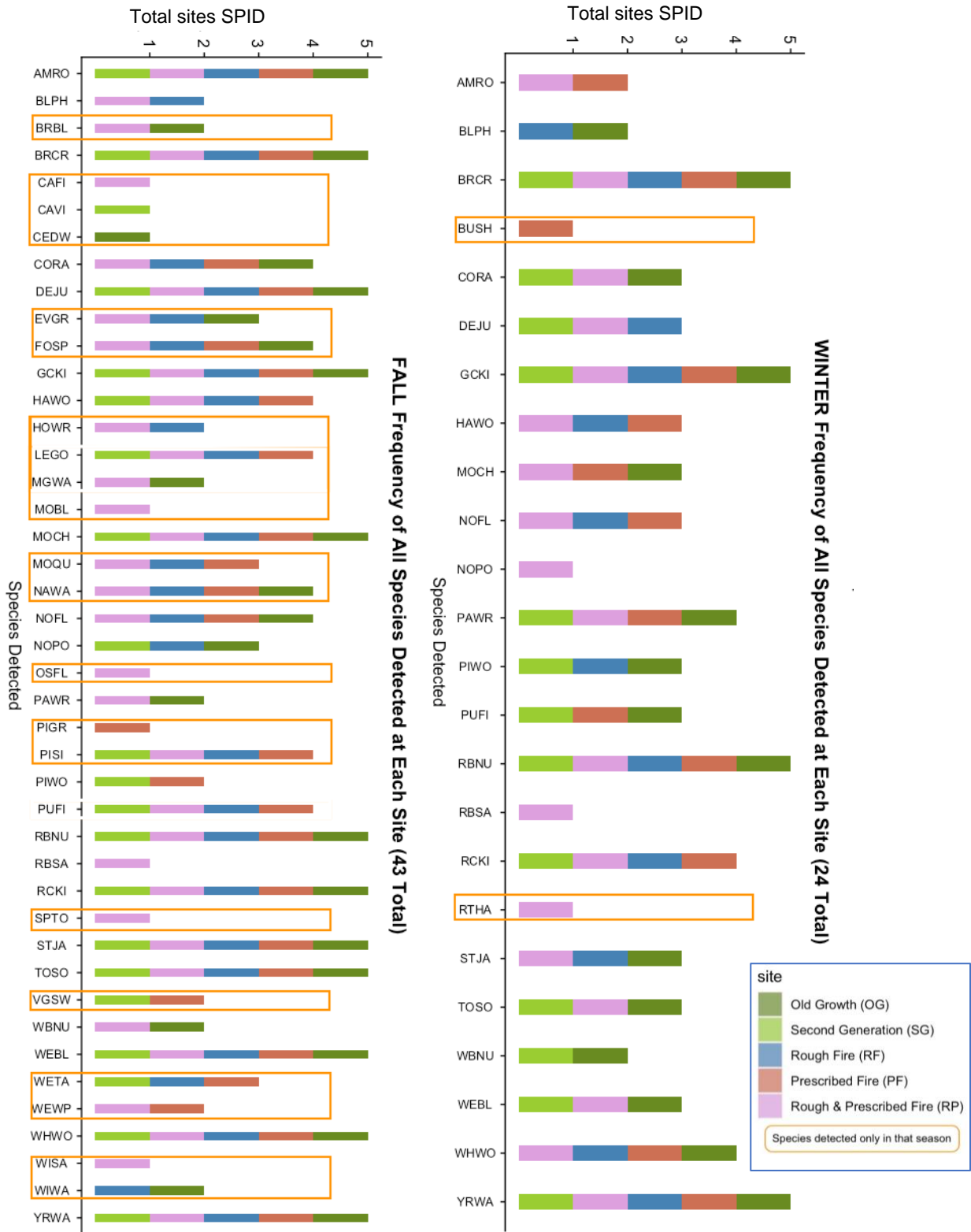


Figure 10. Frequency of all species detected by site in fall and winter.

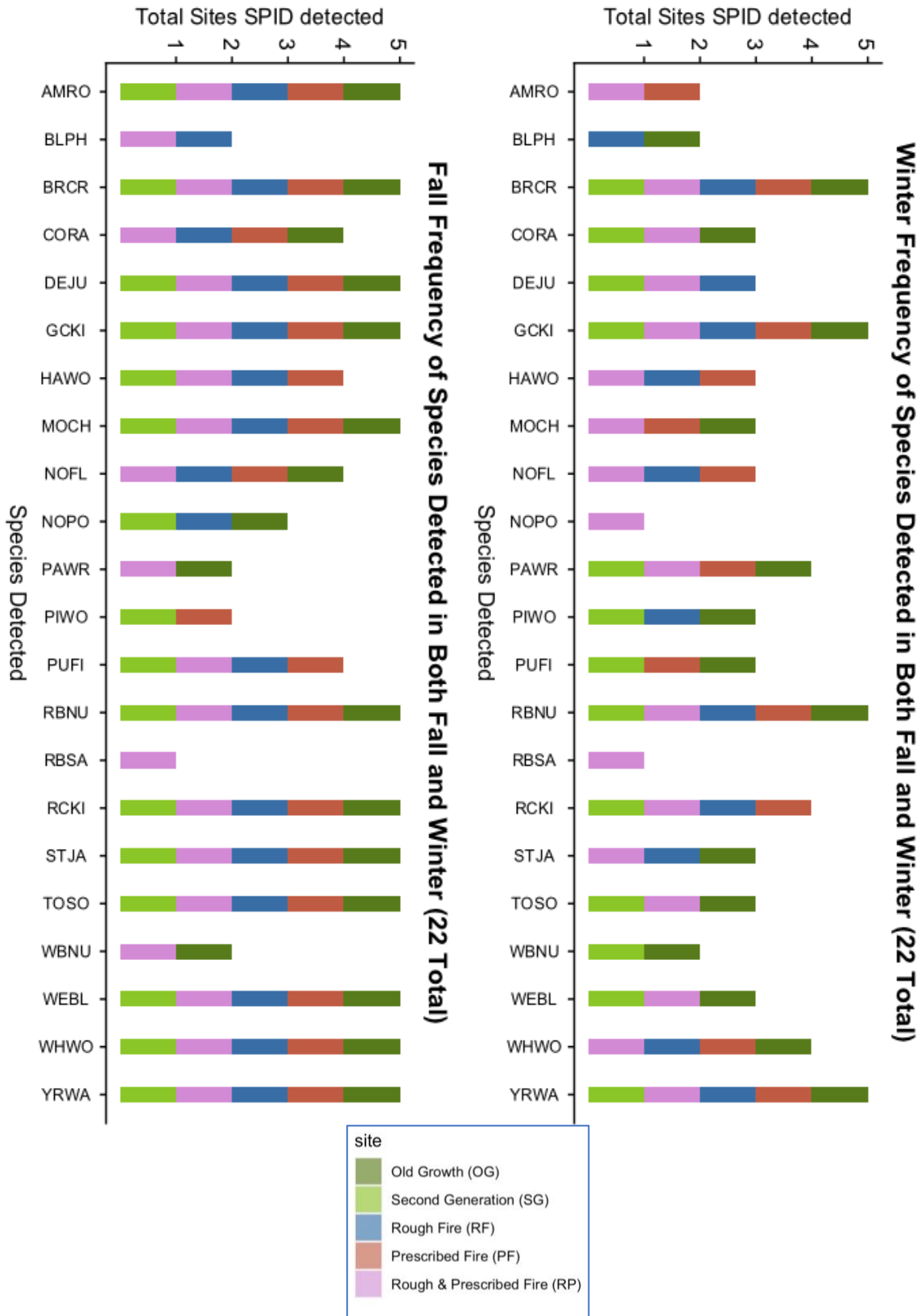


Figure 11. Frequency of 22 species detected by site in both fall and winter.



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**Appendix A: Sequoia National Park Rough Fire Soundscapes Study Plan and Acoustic Sampling Protocol**

## Rough Fire Soundscapes Study Plan

### Site Selection and Details

All study sites are in the Grant Grove peninsula in Kings Canyon National Park. They are separated by fire history, and within the peninsula, are located in two general areas located 1.8 miles apart from each other-Grant Grove and Big Stump. The latter area was included to accommodate site selection requirements for the No Rough-No Prescribed fire category.

#### Site Requirements

Sites were selected using buffer analysis and random point generation in ArcMap. Site requirements are:

1. Within Sequoia Tree vegetation associations
2. 190 ft. from the fire history boundary
3. 75 ft. from a hiking trail
4. 125 ft. from a road
5. 350 ft. from a meadow or fen
6. 800 ft. from another site of any category

#### Site Names

*O'Hearn Master's Project naming convention of Acoustic Recording points at each site.*

Site Code/Number	Treatment
NRYP10	No Rough-Yes Prescribed
NRYP20	No Rough-Yes Prescribed
NRNP30	No Rough-No Prescribed
NRNP40	No Rough-No Prescribed
NRNP50	No Rough-No Prescribed
YRNP60	Yes Rough-No Prescribed
YRNP70	Yes Rough-No Prescribed
YRYP80	Yes Rough-Yes Prescribed
YRYP90	Yes Rough-Yes Prescribed

Point	Site Name	Fire History
10	Prescribed Fire	Prescribed fire ONLY
20	Prescribed Fire	Prescribed fire ONLY
30	Old Growth	No Fire*
40	Second Generation	No Fire
50	Second Generation	No Fire
60	Rough Fire	Rough Fire ONLY
70	Rough Fire	Rough Fire ONLY
80	Rough & Prescribed Fire	Rough & Prescribed Fire
90	Rough & Prescribed Fire	Rough & Prescribed Fire

### Site Visits

#### General Site Information

At each site, an SM3BAT songmeter (Model SM3, Wildlife Acoustics Inc., Concord, MA; firmware version; 1.3.1) will be installed recording ultrasonic and acoustic sounds. Sampling rate of 48 kHz and 16 bits using the right channel with a gain of 35 dB. Programs will be adjusted throughout the season to accommodate diel patterns. Microphone heights and songmeter installations will be standardized across all sites. The songmeter installation will act as a centroid for the site, from which all other plot surveys will be derived. All data will be recorded on a tablet or smart phone using the ArcCollector application.

*Recording Schedule (PDT) Until Nov 5<sup>th</sup>, then below*

Frequency: Every Day  
sunrise -1:00 to sunrise +3:00 (4 hr) then sunset -1:30 to sunset -0:01 (1.5 hr)  
Sampling Frequency: 45kHz  
Gain: 35db

#### *Recording Schedule (PST)*

Frequency: Every Day\*  
sunrise -1:00 to sunrise +3:00 (4 hr) then sunset -1:30 to sunset -0:01 (1.5 hr)  
Sampling Frequency: 45kHz  
Gain: 35db

\*NOT accurate AFTER NOV 7<sup>th</sup>, after Nov 7 2017 some ARUs recorded unintentionally intermittently and irregularly.

North America: **PST** is currently not observed because locations are on summer time / daylight saving time and are observing **PDT**. Currently has same time zone offset as **PST** (UTC -8) but different time zone name. Pacific Standard Time (**PST**) is 8 hours behind Coordinated Universal Time (UTC).

#### *Weekly Site Visits-1/week*

Each week, all songmeters will be visited to swap out batteries (D-cell), and memory cards (128 Gb SDXC). Memory cards are labeled by site number (10, 20...), and go into the respective unit in slot 1.

#### *Insect Traps-1/month*

- Changed monthly, or longer depending on collections
- Enter data in insect trap log in arc collector
- Label insect traps with the # ID of the songmeter (10, 20, 30...)
- Set at 10 ft above ground, reduced visibility....counter balance, etc.
- Label insect trap with ID, date of deployment and retrieval

#### *Temperature Sensors-1/month*

- 2 iButtons will be deployed at each site to record temperature every 30 m
- Low temperature: 1 meter up on a tree.
  - Use even numbers for iButton codes (10, 20, 30...)
- High temperature: 3-5 meters up on a tree.
  - Use odd numbers for iButton codes (11, 21, 31...)
- All iButtons and will be auto-deployed and downloaded using R code

#### *Bird Survey-1-2/month*

- Bird observations will be made by sight and sound at each songmeter
- An experienced avian point counter will record the date/time, species, life stage, direction, and estimated distance on paper
- Each observation will be recorded later in ArcCollector

#### *Wildlife Survey-1/month*

- Once a month while the songmeters are recording, wildlife surveys will be entered into the Wildlife Sound Log in ArcCollector

*Anthro Log-opportunistically*

- If an observer is at the site while the songmeters are recording, opportunistically record all human-derived sounds

*Vegetation Surveys*

- The SEKI Fire Ecology program will be collecting vegetation data and burn severity at each site.
- 3 random points within a 150 ft buffer of the songmeter were generated.
- 2 of the 3 locations will be surveyed

**Raven Selection SEKI Acoustic Protocol (sent from Megan McKenna)**

<b>Daytime</b>	<b>Night time</b>
<b>Acoustic (0-12 kHz)</b>	<b>Ultrasonic (16-192 kHz)</b>
<b>SM?_0_201?</b>	<b>SM?_1_201?</b>
30 mins*3 after sunrise	Triggered from 30 mins
30 mins*3 around sunset	after sunset to sunrise
5 mins every 30 mins	

**Raven Instructions:**

- 1) Open Raven Pro and click yes on warning box
- 2) File-> open sound files, navigate to a folder, select a subset of recordings (Start with ~3 days)
- 3) From the Windows Preset drop down menu select “BirdsPiceance” preset
- 4) Highlight “page sound” (or Raven will crash)
- 5) In the “Date/Time” tab, click “Use clock time axis label” and “File name template” and in the box, delete the prefix (e.g. P010832SMA\_0\_ ...don’t mess with the <yyyy><ll><dd>\_<hh><mm><ss> part). Make sure the date and time are correctly displayed below. Make sure to get this right before you open or start working with the files.
- 6) Hit OK
- 7) Right click on table, chose DETOacoustics preset
- 8) \*\*Save the table after a few selections (save to the folder with the recordings you are working with

**Reopening a selection table with associated recordings:**

- 1) Open Raven Pro and click yes on warning box
- 2) File-> open sound selection table, navigate to a folder, open selection table
- 3) Follow steps 3-6 above

**Task 1: Get familiar with bird calls in the acoustic data (0-12 kHz). (Complete)**

- 1) Scan through spectrograms
- 2) For each new bird call you observe, draw a box around it, hit enter and put the four letter species code in “Notes” (e.g. Mountain bluebird = MOBL)

- 3) In the “CommonBirdSpecies” spreadsheet, note down the species name and site where you heard it
- 4) Once you’ve scanned through a few of the sites recordings, note whether the species is VC = very common (hearing them all the time); C = common (pretty common); O = occasional (you hear them once and a while); or R = rare (you hear them once or twice)
- 5) If the call is loud and clear, “save sound 1 as” and save the sound to the “call library” folder
- 6) Make a power point presentation with the name of each bird found in recordings, a brief description, a screen-shot of its song spectrogram, and an example of its song or call.

**Task 2:** Convert wav files to calibrated sound levels in spreadsheets (**Complete**)

- 1) Open the “batch\_PAMGUIDE\_NV SPL\_V7.r” file
- 2) Set your working directory to a month’s worth of recordings (e.g. "H:\Acoustic\_Day\2015\_MayJuneJuly ")  
Note: the drive may change depending which USB port you have the hard drive plugged into, so note the “H:\” part of the name
- 3) Identify only the subfolders (e.g. all folder names start with “SM”, so WAVDirs[grep("SM", WAVDirs)])
- 4) Set the file extension name (2 possible formats: "0\_%Y%m%d\_%H%M%S\_000.wav")
- 5) Set the directory that contains the PAM guide files
- 6) Set the calibration parameters
- 7) Run a test file (“Part 1”) and check “t” to make sure timestamps are correct
- 8) Run Part 2 (Note: could take a few days)

**Task 3:** Species richness in subsamples of recordings

- 1) In Raven open all the files in a “SPLITFILES” folder within the monthly folder
- 2) Follow steps 3-6 in “Raven Instructions” except open with Piceance\_Splitfile preset
- 3) Right click on table, chose PiceanceBirds preset\*\*
- 4) Select each sound and put the four letter code in the “Notes” section
- 5) If you come across an anthropogenic sound, use the listening lab code scheme (e.g. 1 for aircraft, 2 for vehicle, etc)
- 6) \*\*Save the selection table after a few selections (save to the “SpeciesRichness” folder)
- 7) The filename of the selection table should include the songmeter name and dates (e.g. SMA\_20150520\_20150620)
- 8) Throw away rainy/windy days. (Note date in ‘Rainy dates’ column in the ‘SpeciesRichnessSubsamples’ tab of the “Analysis Metadata” spreadsheet)
- 9) For multiple calls... select whole call ‘bout’, list how many individual calls (eg. SPTO\_5).
- 10) Save unknowns to folder... (eg. UNK\_A1)
- 11) OFFICIAL NOTE FORMAT: spp(4 letter code)\_# of calls\_q (if quiet)
  - a. If UNK: UNK\_Further Classification (A,B,C,D, etc...)\_# of calls\_q (if quiet)
  - b. If UNK flycatcher: UNKFL(#)\_# of calls\_q (if quiet)
- 12) Do not ID calls under 40 dB

**Task 4:** Save anthropogenic noise

- 1) During the “species richness” analysis, draw a box around any anthropogenic sounds encountered (note: id the call in the selection table as per usual, step 5 above)
- 2) Save the sound in the “AnthropogenicSounds” folder
- 3) ID the sound with an identifier, the site, date, and time (e.g. Vehiclepass\_SMA\_20150529\_0730)
- 4) Save a maximum of 2 of each unique anthropogenic sounds per site (e.g. only 2 car passes, 2 rig sounds etc. at site SMA)

**Task 5:** Create daily spectrograms

- 1) Open “AMT”
- 2) Open “data plotter”
- 3) File -> “Open files” and navigate to an NVSPL folder within a song meter folder
- 4) Click “select all”
- 5) Under “Spectrogram options” make sure only “Display title” is ticked
- 6) Under “Spectrogram weighting” click “A-weighted”
- 7) Hit start
- 8) Find files in “My Documents” -> “Toolbox output” -> “Plots”

Move these files to a folder on the “Piceance bats” hard drive with the song meter name (e.g. in the “Analysis” -> “spectrograms” -> “MayJune” -> “SMA” folder)

**Appendix B: Point Count and Manual Acoustic Recording Supplemental Methods  
Protocols**







## **Manual ARU Count Protocols**

### **Acoustic Recording Unit (ARU) Recording Sampling Protocol:**

1. The acoustic recording units (ARUs) recorded daily for 4 hours across the dawn chorus (sunrise -1:00 to sunrise +3:00), and 1.5 hours at dusk (sunset -1:30 to sunset -0:01) (Appendix A).
2. Initial ARU count surveys followed a protocol of every 15-20 days for a 3-day window beginning August 21, 2017 coinciding with point count period 5. Due to recording malfunctions and errors described later, ARU sampling surveys followed a monthly period beginning September 9, 2017.
3. Each ARU point was sampled on the same day when complete recordings for that day are available. If they are not available, then the nearest day with recordings from the missing point will be used.
4. A randomly selected 10-minute survey window was sampled from the recording.

### **ARU Survey Protocol:**

1. Each of 9 points were surveyed 6 times (3 times during September - November and 3 times during December – February) producing 60 minutes surveyed per point, and a total of 540 minutes (9 hours) surveyed.
2. Each survey period began with a different point such that each point was rotate between being the first, middle, and last point to be surveyed.
3. All surveys were conducted using Raven Pro 1.5.0 Sound Analysis Software Pro (Figure 4, main document).
4. In Raven wav file (ex: 10\_\_1\_\_201708212017\_0051800.wav) for point that is to be surveyed is opened.
5. In Raven, SEKI preset protocols were used (Appendix A)
6. Data measurement columns needed were added: SPID, Confidence, Call.Song, Noise, Comments
7. Save the selection table as “All Files” to the original wav file folder, labeling same as wav file name, **\*\*MINUS\*\*** the double lines (\_ vs \_\_, this caused problems in R). Save workspace for easier opening after first time.
8. Navigate to randomly generated 10-minute sample time between Sunrise and 2 hours post sunrise and listen for 30 seconds or a minute leading up to survey time to warm up listening.
9. During a 10-minute survey the first of each new sound (not previously detected) was selected and distinguished as an identifiable species or unknown (Figure 4, main document).
10. Each sound was noted by species alpha code for first and second of each new sound, unless unknown:
  - a. The first time sounds were selected, they were given a confidence ranking: (1) extremely confident the sound is identified correctly; (2) somewhat confident,

some referencing and listening practice is needed; (3) not confident or likely unidentifiable.

- b. All detections identified to species with a 2 ranking were revisited after review and given a 1 or 3 ranking.
  - c. All detections identified as unknown (UNK) were returned to for further research ultimately identifying either to species with a confidence ranking of 1 or 2 or remaining marked as UNK.
  - d. Upon final review, unknown detections were ranked to distinguish a sound I believe is identifiable with more expertise or with more time (UNK1), should this effort be used in future studies, or as an unidentifiable sound (UNK3).
  - e. All sounds identified with a confidence ranking of 2 or as UNK were investigated using other samples from the recordings, live site recordings, online resources (Macaulay Library, Nature Instruct, Xeno-Canto), and experts. All sounds confidently identified were changed to confidence 1, those that are deemed able to be identified with more time and expertise are left as UNK1 with confidence ranking=3, and all those that are deemed un-identifiable are changed to UNK3 with confidence ranking=3.
11. Sound detected was noted as a c (call note) or s (song). Identifiable woodpecker drumming was noted as song. If individual calls in a 'bout' or a series (like RBNU often), note in comments.
  12. Only species sounds detected with a confidence ranking 1, and only the first detection of each unique species were used in analysis. NOTE: that often several calls for one SPID are selected for learning, examples, and confidence building.
  13. Noise was noted for each survey similarly to how it was noted in the point count protocol with modifications accommodating aspects unique to a recorded sound: (1) no background noise; (2) slight, probably vocalizing birds were not missed; (3) moderate, may have missed high and/or low pitched and/or distant calls, typically due to light rain, light or intermittent breeze, trickling water, vehicles, and/or voices; (4) substantial, detection was reduced, typically due to heavy rain, wind, insects sitting on microphone, and so on; (5) loud, likely leading only to detection of close and loud calls.
    - a. If the noise ranking was 4 or greater at any time during a 10-minute survey, the survey was abandoned and the next, subsequent 10-minute sample from that day with noise ranking below 4 was surveyed. If there was no such recording available, the next closest day was sampled.
  14. Comment Column: Use comment section for anecdotal notes and resource investigation comments such as confidence ranking resource support, and noise ranking
  15. Sounds detected that are under either Avg Power of 40 dB (from protocol Megan sent) or Energy of 70 dB are NOT selected.

**Appendix C: Tables and Figures for Richness of 22 Species Detected in Both Fall and Winter and Second Generation Site Contrast**

## TABLES

*Table 1. Poisson Regression with fixed parameter richness estimates for 22 species detected in both seasons for categories compared between seasons. All categorical factors (predictor variable) were modeled and the best models from stepAIC results were used. Individual Sites: linear relationship between factors and season, and estimated total number of species. Fire histories: linear relationship between factors and seasons, and estimated total number of species. Time Since Fire and Total Number of Prescribed Fires: linear relationship between factors and season, and estimated total number of species. For every unit change in the predictor variable, the difference in the logs of the expected counts will change by the value of the regression coefficient (estimated beta ( $\beta$ )), holding other variables in the model constant.*

Parameter Estimates for 22 Species Detected in Both Seasons					
Factor	Category	Estimate (log scale)	AIC	Std. Error	p-value
Season	(Intercept) fall	2.3979	265.09	0.05803	-----
	winter	-0.72392		0.10154	1.01e-12 ***
	(Intercept) Old Growth Site (OG) in fall	2.51341	265.17	0.13886	-----
	Old Growth Site (OG) in winter	1.78949			
Individual Sites	Prescribed Fire site (PF)	-0.01835		0.16565	0.9118
	Rough Fire Site (RF)	-0.25783		0.17305	0.1362
	Rough Prescribed Site (RP)	0.00905		0.1649	0.9562
	Second Generation Site (SG)	-0.29376		0.17429	0.0919 .
Fire History Categories	(Intercept) Sites in fall with fire history (RP, RF, PF)	2.22818	262.3	0.17644	-----
	Sites in winter with fire history (RP, RF, PF)	1.50426			
	Sites with no fire history (OG, SG)	0.09926		0.19321	0.6074
	Sites with wildfire history (RF, RP)	0.0274		0.13516	0.8394
	Sites with prescribed fire history (PF, RP)	0.26688		0.14413	0.0641 .
Time Since Fire and Total Number of Prescribed Fires Categories	(Intercept) Sites in fall with no time since fire (OG, SG)	2.303731	262.5	0.075638	-----
	Sites in winter with no time since fire (OG, SG)	1.579812			
	Sites with 2 years since fire (RP, RF)	0.001435		0.010736	0.8936
	Sites with at least 1 prescribed fire	0.083625		0.046999	0.0752 .

Signif. codes: p-value < 0.01 = \*\*  
p-value < 0.05 = \*  
p-value < 0.1 = .

Table 2. Poisson Regression with fixed parameter richness estimates for all detections for categories compared between seasons. Sites and season (predictor variable) were modeled in contrast to the Second Generation site and the best model from stepAIC.

Parameter Estimates for All Species Detected					
Factor	Category	Estimate (log scale)	AIC	Std. Error	p-value
Season	(Intercept) fall	2.57346	283	0.05315	-----
	winter	-0.87886		0.09812	< 2e-16 ***
Individual Sites	(Intercept) Second Generation Site (SG) in fall	1.981	275.6	0.10721	-----
	Second generation Site (SG) in winter	1.10214			
	Old Growth Site (OG) in winter	0.35437		0.1662	0.03299 *
	Prescribed Fire site (PF)	0.33811		0.14032	.01597 *
	Rough Fire Site (RF)	0.07739		0.14877	0.60294
	Rough Prescribed Site (RP)	0.44675		0.13729	0.00114 **

Signif. codes: p-value < 0.01 = \*\*  
p-value < 0.05 = \*  
p-value < 0.1 = .

## FIGURES

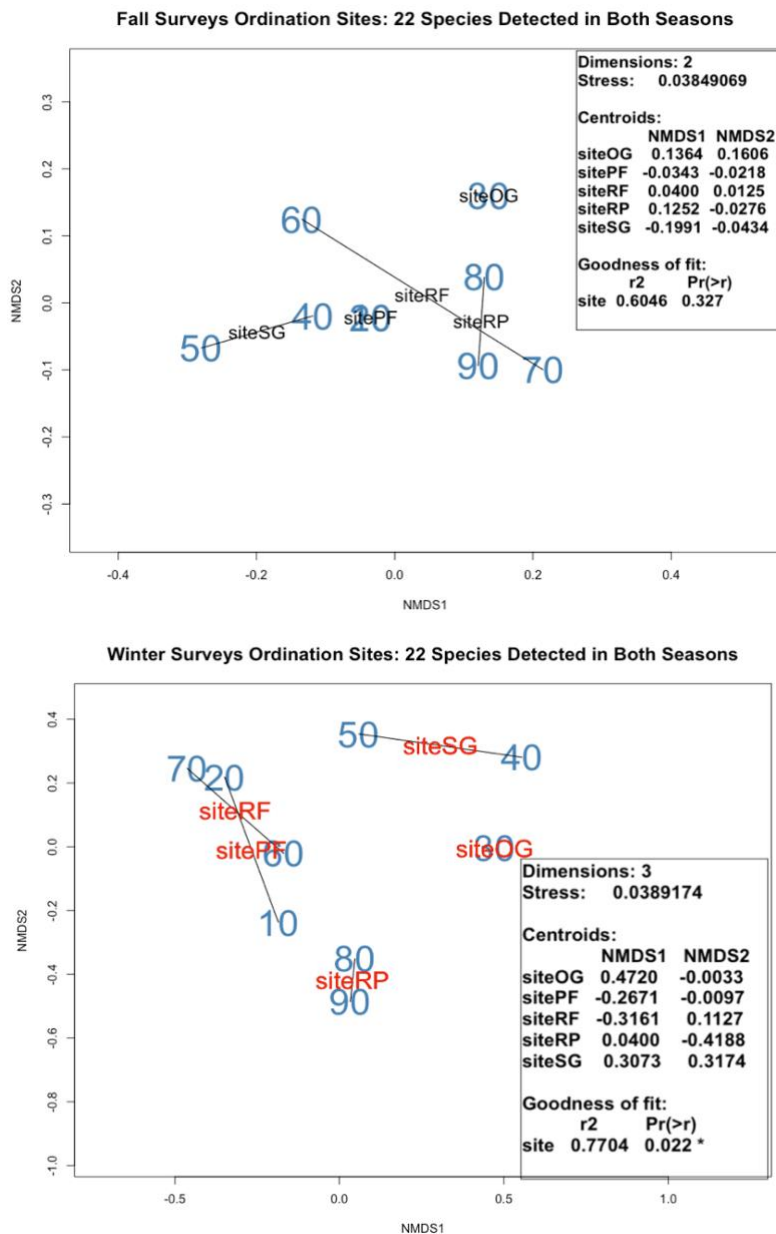


Figure 1. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of site, where siteOG = Old Growth Site, sitePF = Prescribed Fire Site, siteRF = Rough Fire Site, siteRP = Rough Prescribed Site, siteSG = Second Generation Site. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit site category and associated p-value (red =  $p \leq 0.05$ ).

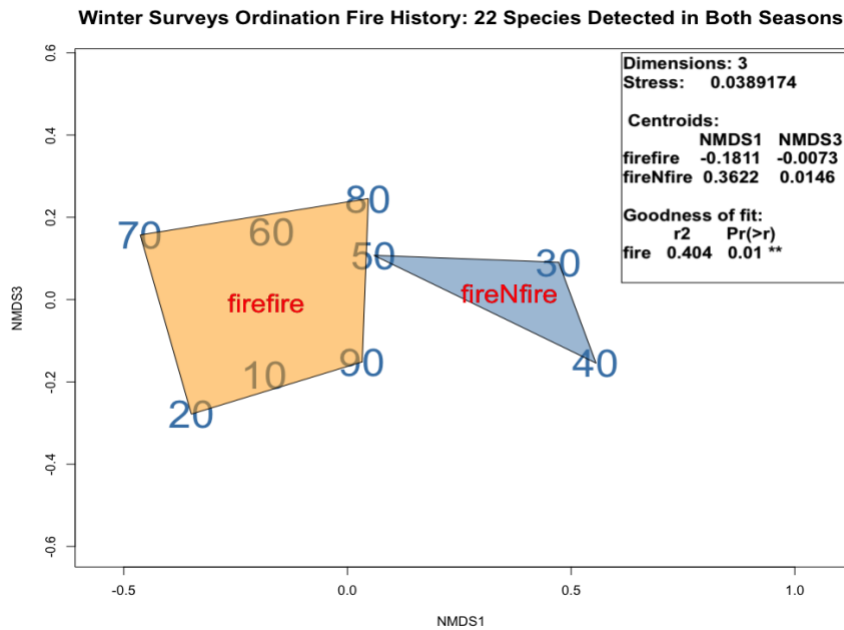
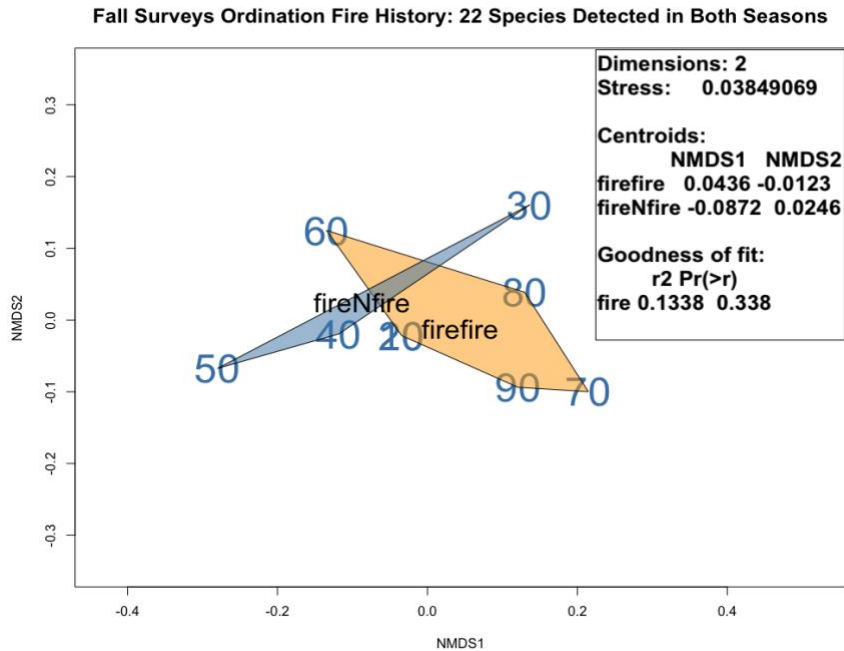


Figure 2. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of combined fire history, where fireNfire = no fire history, and firefire = fire history. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).



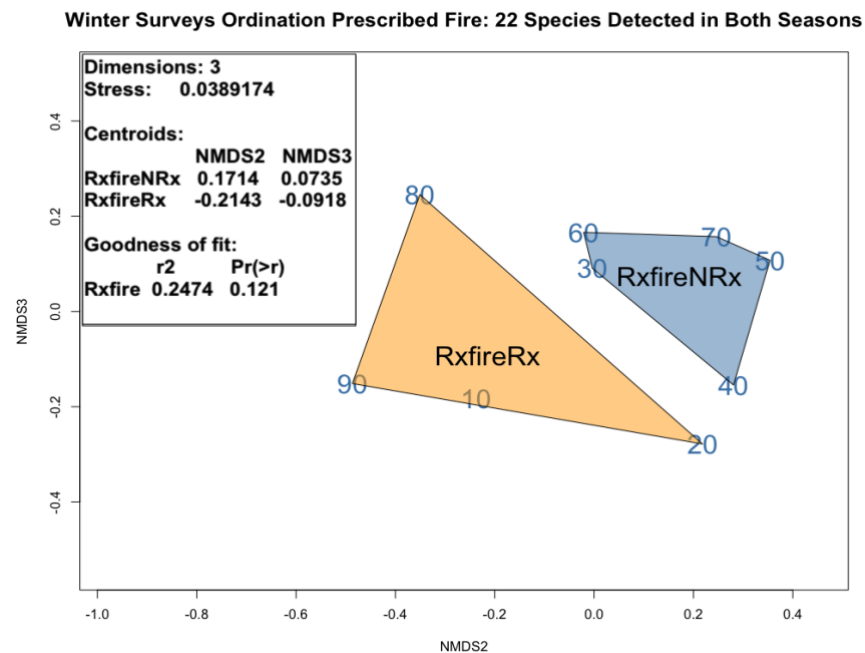
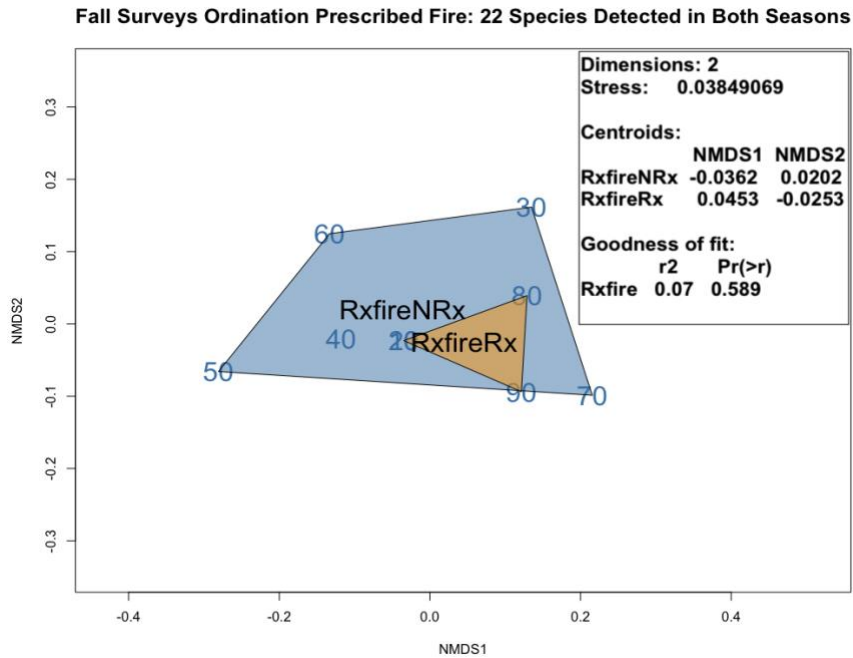


Figure 3. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of prescribed fire history, where RxfireNRx = no prescribed fire history and RxfireRx = prescribed fire history. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

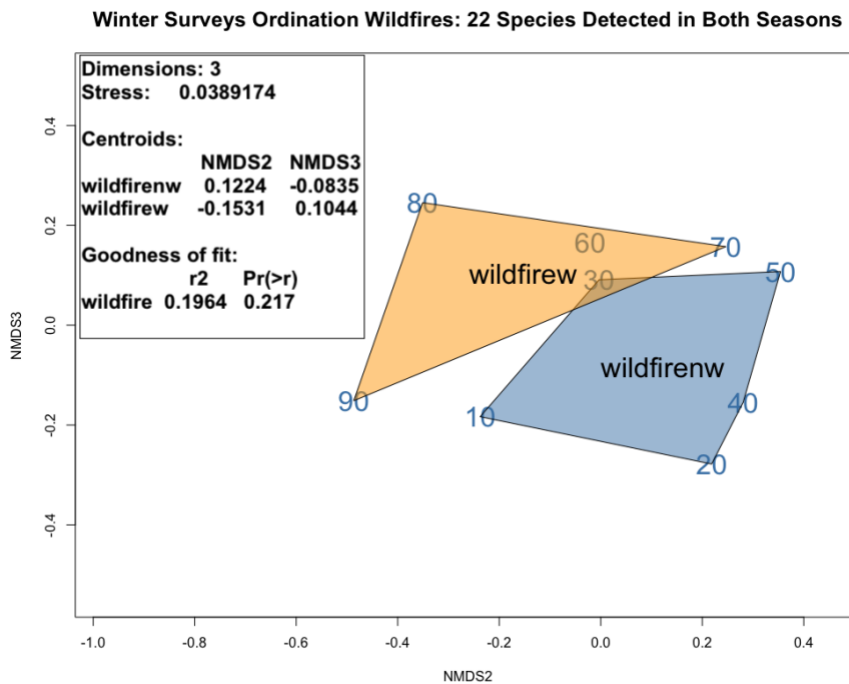
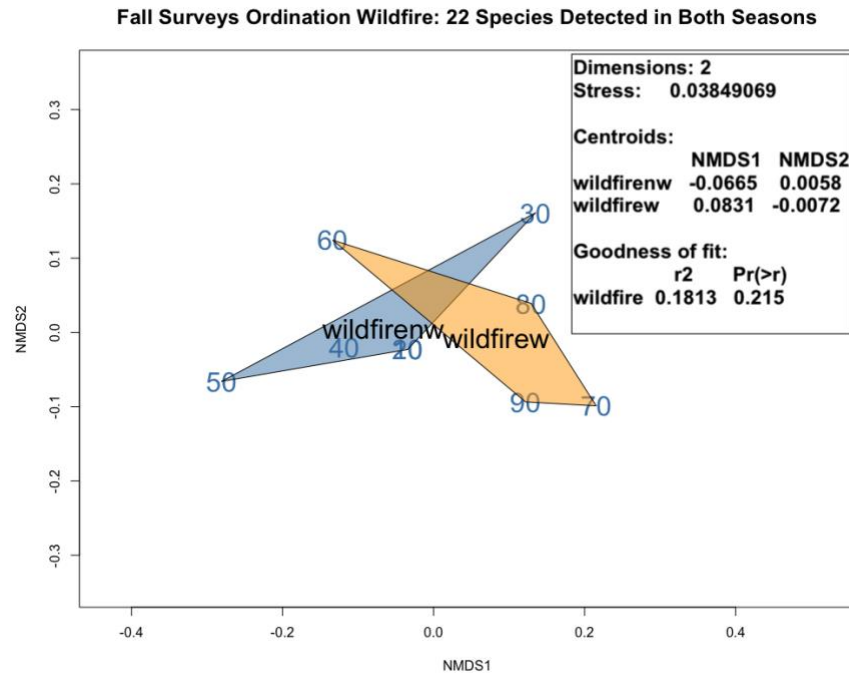
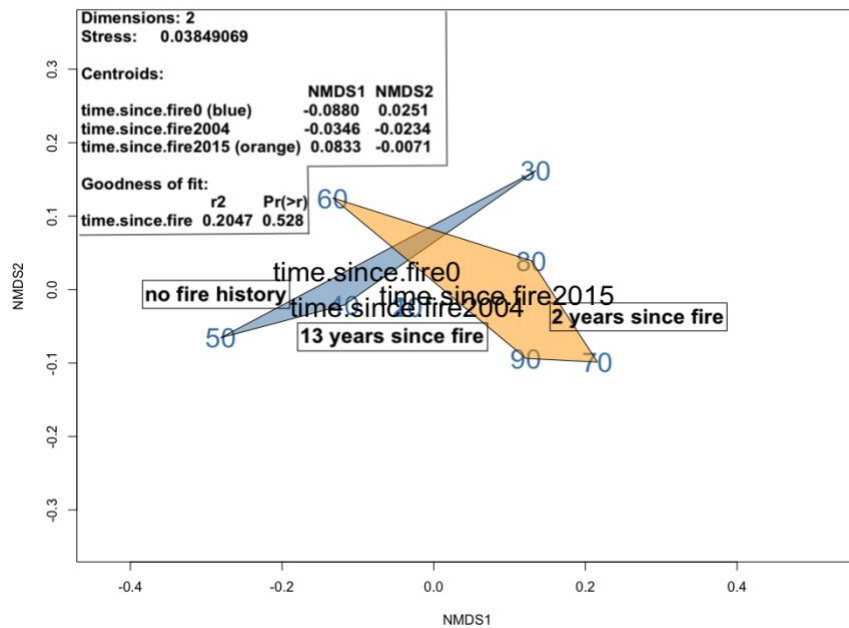


Figure 4. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of wildfire history, where wildfirew = no wildfire history, and wildfire = wildfire history. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

Fall Surveys Ordination Time Since Fire: 22 Species Detected in Both Seasons



Winter Surveys Ordination Time Since Fire: 22 Species Detected in Both Seasons

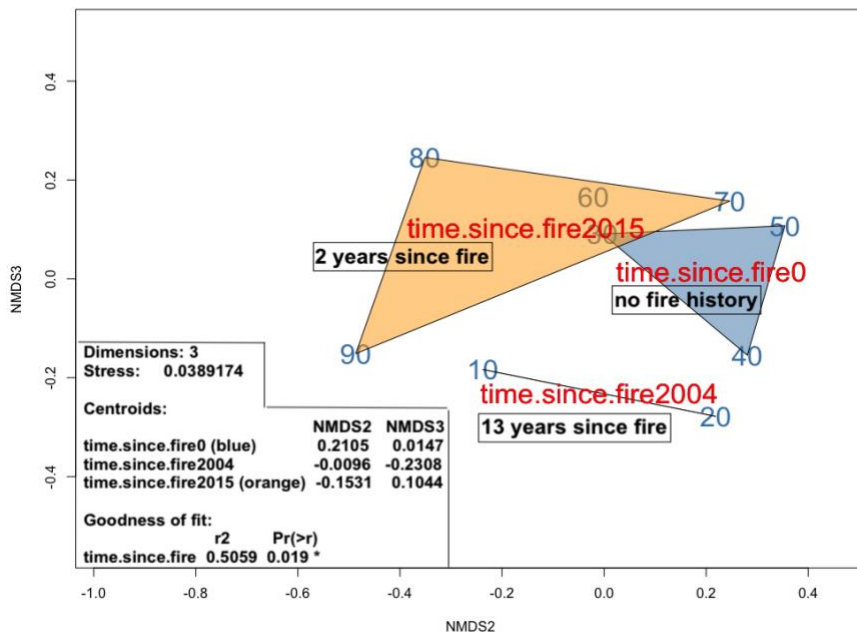


Figure 5. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of time since most recent fire, where time.since.fire0 = no fire history, time.since.fire2004 = 13 years since fire, and time.since.fire2015 = 2 years since fire. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated p-value (red =  $p \leq 0.05$ ).

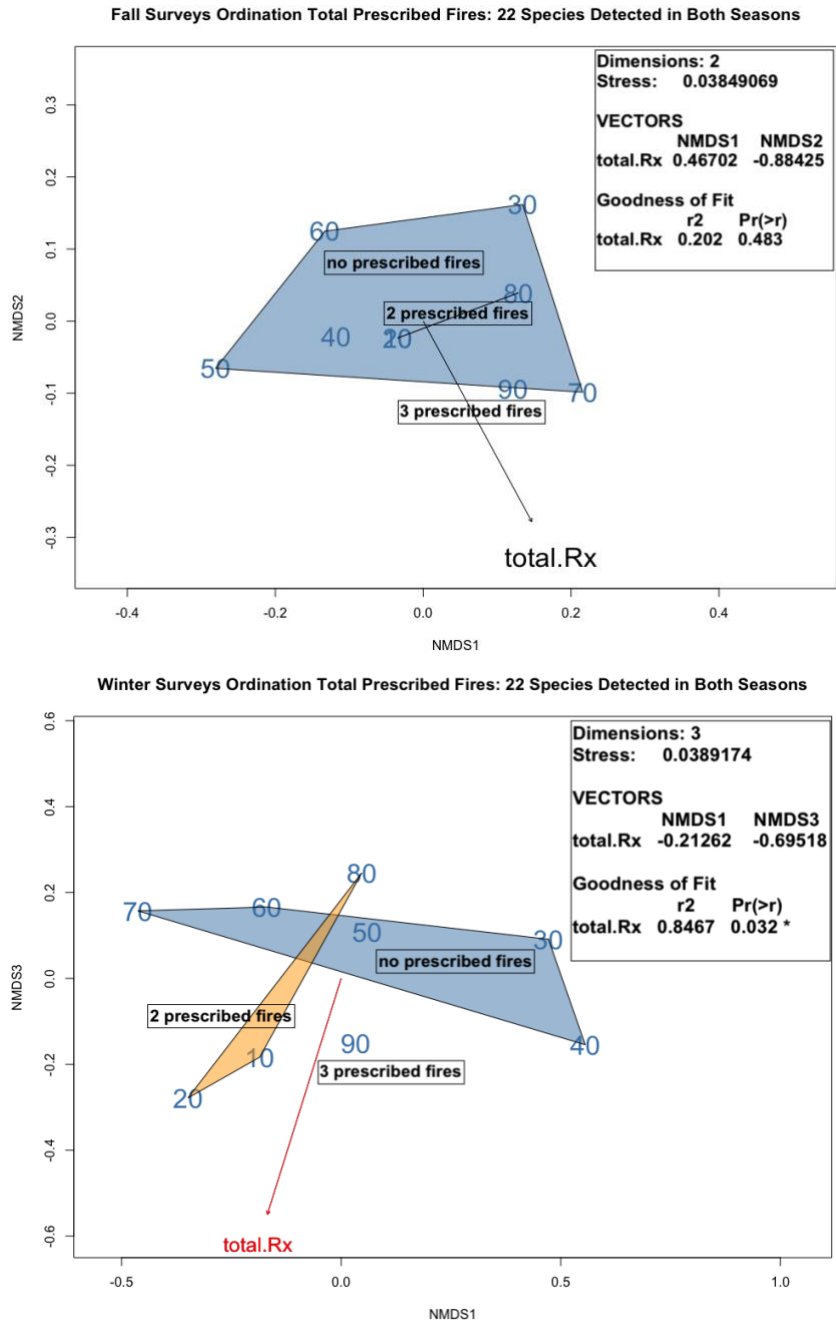


Figure 6. NMDS ordination of ranked dissimilarity (Bray-Curtis) of 22 species detected in both fall and winter bird species composition at 9 points with envfit category test for composition and category correlation. Lines are polygons linking categories of total number of prescribed fires, where total.Rx vector indicates the direction of greater prescribed fire history and maximal correlation. Numbers are points where species were detected: 10-20 = Prescribed Fire (PF), 30 = Old Growth (OG), 40-50 = Second Generation (SG), 60-70 = Rough Fire (RF), 80-90 = Rough & Prescribed Fire (RP) sites. Labels indicate correlations with envfit fire history category and associated  $p$ -value (red =  $p \leq 0.05$ ).