

For the Birds:
*The Effects of Wildfire on Bird Diversity
In Rocky Mountain National Park*

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Abstract

Wildfire plays a large role in the ecology of Rocky Mountain National Park. As threats of wildfire have increased over the past decades, it is important to understand how both wildfire and prescribed burning influence the species within the park. In my study I wanted to see how wildfire and the prescribed burning program in Rocky Mountain National Park influence bird diversity.

The results show that 5 species had statistically significant correlations with wildfire and 10 species had significant correlations with prescribed burning. 5 species in the study were only observed in non-burned areas, 6 of the species were only observed in prescribed burn areas, and 9 of the species were only observed in areas affected by wildfire. On a broader level I was able to show that an ideal environment for Rocky Mountain National Park's bird diversity is one that is made of a variety of burned and non-burned forests of all varieties. Overall, the key to bird species diversity within the park is a heterogeneous environment, but one in which prescribed burning should not play a large role.

Introduction

Rocky Mountain National Park is home to a reported 270 species of birds (National Park Service 2016), all of which are impacted in some way or another by fire. Over the years, Rocky Mountain National park has seen many fires, both controlled and wild, and therefore the ecology of the birds is heavily shaped by the fire ecosystem.

The park itself is located in north central Colorado and holds within its borders about 265,828 acres of land (Lewelling 2012). It is home to a diverse array of ecosystems as it has elevations ranging from 7,630 feet to 14,259 feet. Almost 60% of the park is covered in forests of which include Lodgepole pine, Ponderosa pine, and Douglas fir communities in the lower regions of the park. Above 9,500 feet these give way to stands of Engelman spruce and subalpine fir. It is also home to a very fragile alpine tundra ecosystem (Lewelling 2012). RMNP also contains many streams that carve the beautiful park and feed into both the Colorado River and the Cache la Poudre (Lewelling 2012). Though the species in the park are well known, it is yet to be uncovered how fires and fire management affect the distribution of the over 270 birds throughout the park.

The ecology of the forest changes quickly after a fire, with both plants and bird communities overturning rapidly (Saab et al. 2007). Pre-fire conditions such as vegetation type, canopy cover, and climate affect the processes by which foraging and nesting sites are created, but unless the original conditions support fire dependent species a turnover of species is inevitable (Kotliar et al. 2002). The effects of fire on individual specimens of plants are well known and fairly predictable: buds and foliage at the crown of the tree can be burned, the roots can be over heated and die, and the trunk of the tree can be heated to the point where the vascular cambium is destroyed (Agee 1993). There can also be many

negative effects on the soil including changes to the composition in layers of the soil. These can suppress the regrowth of forests for many years after the original fire.

When wildfire destroys a forest region it causes a change in soil wettability depending on the severity of the fire. This repellency can cause damage by way of increased runoff that can lead to massive erosion (Doerr et al. 2006). A study observing the effects of soil wettability and repellency combined with lab tests of soil at different fire temperatures determined the mechanism by which this phenomenon occurs. According to the hypothesis by L.F. Debano, organic matter accumulates on the ground surface after a fire—when this organic matter and the mineral soil dry they create a water repellent layer of soil (Debano 2000). Right after a fire, this layer is found running parallel to the mineral soil surface and a few centimeters below it. It is of varied thickness and may be spread unevenly throughout the ground (Debano 2000).

During a fire, there is a massive heat gradient caused both by the combustion of organic material as well as the transfer of heat throughout the ground. Temperature of a wildfire can reach up to 1000°C at the canopy and 850°C where the soil meets the burning organic matter, however just five centimeters below the surface of the soil it will rarely break 150°C because of the insulating abilities of dry soil (Debano et al. 1973). The heat vaporizes organic substances and they move down through the soil along the heat gradient until they reach a point cool enough for them to condense. Water repellent layers elsewhere in the soil may also become intensified due to heating (Debano 2000). As this layer moves deeper the above layer is more subject to landslides and erosion as well as flooding (Debano 2000). This is because water cannot penetrate the organic repellent layer. This erosion plays a disastrous role in the well being of the ecology of the forest. Despite this organic layer and the disastrous impacts, it can have on the soil in a forest secondary succession is inevitable.

Succession is a complicated process and is not yet totally understood. In 1916 Frederick Clements predicted a system in which there were orderly stages leading to the climax vegetation—he believed that discrete groups of species would take over and eventually create unfavorable conditions for themselves allowing for the next discrete group to come in and take their place (Baker 2009 p. 82). In 1917 Henry Gleason challenged Frederick Clements views of succession. He believed that succession did not happen in discrete groups, but rather that species would succeed independently of one another (Baker 2009 p. 83). More recently a broader framework for succession has appeared which takes into consideration species physiology and life history. Pickett, Collins, and Armesto took the frameworks laid out by previous modelers of succession, mostly Clements, and constructed a hierarchical framework that tries to take into account all factors and notes that providing an overarching framework for all situations is highly ineffective (Pickett, Collins, Armesto 1987). This framework contains the following hierarchy: First it tries to answer the question of what causes succession? This can be answered rather easily and is site specific. Generally, the answer to this question is either open sites become available, species area available at different numbers at a site, or species have different evolved capabilities to deal with one another or a site (Pickett, Collins, Armesto 1987). Second, the hierarchy tries to answer the question “What interactions, processes or conditions contribute to the general causes of succession?” The answer to this question encompasses a broad array of ecological phenomena that are specific to a given case (Pickett, Collins, Armesto 1987). Finally, on the hierarchy is the site specific factors and behaviors that determine how a specific case of succession turns out and it is these factors and behaviors that allow for the multitude of successional results that we see in nature (Pickett, Collins, Armesto 1987). The model of succession is highly specific to

each particular situation and so there is no one rule that all succession patterns must follow.

Despite the complicated nature of succession, it is understood that post-fire succession begins immediately after a fire and generally follows a simplified framework. The opening up of forest land after a fire allows other plants to either move into the area or it allows for secondary succession species to become more prevalent in that area. It is debated whether plant diversity becomes greater throughout succession or falls off, but it turns out that the process depends on many variables such as type of community, geographic location, and the circumstances of the succession (Shoemaker et al. 1998). After a fire in the Rocky Mountains, resprouters tend to dominate in the first one to five years in both Lodgepole pine forests, Douglas fir forests and sagebrush at 74%, 71%, and 77% respectively (Baker 2009 p. 82). In those first few years however, seed bank species struggle immensely with one, three, and zero species showing up in those first five years in each respective habitat (Baker 2009 p. 82). Off site seed dispersal species also show up in the first five years however they too struggle and are varied with only four, one, and three species sprouting in each respective habitat (Baker 2009 p. 82). It is expected that resprouters dominate after fire due to the fact that many shrubs, forbs, and graminoids have the ability to resprout (Baker 2009 p. 82). Although many times fire can lead to new species taking over an area there are also examples forests that depend on fire to survive.

In 1987, Robert W. Mutch hypothesized that in species that depend on fire characteristics have developed to make them more flammable to perpetuate burning and fire dependent communities (Mutch 1970). It is a fact that in some fire dependent plant communities, plants burn more readily than non-fire-dependent communities when both communities are in close proximity with one another (Mutch 1970). In the Rocky

Mountains most regions are in some state of succession following a past fire and due to the variation in these stages at different places it is understood that past fires did not completely burn over and destroy the landscapes (Habeck and Mutch 1973). The reason is that the places where these fires burn are generally in specific communities where the plant type favors burning because it provides a competitive advantage—this can be seen in Ponderosa pine communities, Savannah woodland communities, and certain grassland communities (Habeck and Mutch 1973).

In the event of a wildfire, whether the community supports and depends on fires or the pre-existing community does not depend on fire, a variety of interesting things happen in regards to the bird ecology. When trees are damaged by small fires they can be inhabited by bark beetles, which can in turn be consumed by specific types of birds (Baker 2009 p. 82). In fires that leave either logs, standing dead trees, or heavily damaged trees the resulting environment is perfect for wood-boring and bark-boring beetles (Werner 2002). The beetles come quickly as they are heavily attracted to the burned areas, it is found that some species of beetles, including *Melanophila* have special pits on their exoskeleton that house infrared detectors and help them seek out these burned areas (Agee 1993). They can come from tens of kilometers away and concentrate heavily in the newly burned area (Baker 2009 p. 102). These beetles are an essential food source for many species of woodpecker (Saab et al. 2007). As the beetles swarm to post-fire areas woodpeckers follow suite to take advantage the abundance of nutrients. Some of the most notable beetle seeking woodpeckers include the Black-backed Woodpecker and the Three-toed Woodpecker, but other more common (and less specialized) woodpeckers can also be found in post-burn areas such as the Hairy Woodpecker, the Downy Woodpecker and Northern Flickers (Baker 2009 p. 102). For some birds, wildfires are a great advantage. They provide many areas ideal for the certain food sources and therefore some

birds find a niche in the newly burned areas. For other species the new abundance of food in burned areas is not just a happy occurrence, it is what they consistently depend on for survival.

In many cases, species that thrive in these newly burned areas such as the Black-backed Woodpecker and many other insect eating birds have trouble foraging for food and shelter in other types of habitats—they have evolved to specialize in post burn forests (Hutto 1995). The Black-backed Woodpecker is one of the most reliant birds on freshly burned forests. They rely on the larvae of the wood-boring beetle specifically of the family Buprestidae and Cerambycidae (Dixon and Saab 2000). They also use the burned trees as shelter as Black-backed Woodpeckers inhabit standing dead Lodgepole pine, Ponderosa, and many other tree species after a fire (Dixon and Saab 2000). Often times forests are managed to inhibit large fires that result in the increase in these fire dependent species. Fire management has negatively impacted the Black-backed Woodpecker as the number of high intensity wildfires that support beetle outbreaks and subsequent Black-backed Woodpecker inhabitation have gone down (Dixon and Saab 2000).

More generally, stand replacement fires are associated with insect outbreaks that result in many birds occupying the areas for food supplies not just Black-backed Woodpeckers (Kotliar et al. 2002). The first couple of years after fire the densities of beetle foraging birds increase significantly, but within 2-4 years these birds decrease as the beetle population decreases (Saab et al. 2007). This changeover, however, depends heavily on severity of the fire. Birds that are seen to have mixed responses to fires actually respond according to the degree of the wildfire. A study in Montana showed that almost twice as many bird species increased significantly than decreased in response to fire (Smucker 2005). To the average person stand replacement fires are seen as devastating to the forest. They kill trees, displace species, and often times leave an “eyesore”, but these

are only the immediate effects—people fail to understand that these fires can have a positive effect for years and years after their occurrence. There are ecological nuances that allow for species that would not otherwise inhabit a region to thrive and sometimes fire management can get in the way of that.

When fires are less severe (i.e. they are not stand replacement fires) plant response, and therefore bug and bird responses, are different. Smaller fires can lead to quick regrowth of plant life and as a result dispersal of seeds and abundance of flowers and an increase in insects other than beetles (Saab et al. 2007). This leads to an increase in seed eating birds, aerial insectivores and nectar eating birds (Kotliar et al. 2002). Overall the response of birds to fires varies across species and across fire severities. Naturally, most fires negatively affect some birds, but quite a few are positively impacted. Birds that make their living in the foliage of trees such as Chickadees and Kinglets prefer unburned forests whereas shrub nesting species nest in mixed-severity burn sites—ground nesters such as the Spotted Towhee prefer mixed-severity to high-severity burn sites where ground vegetation rapidly regrows (Kotliar et al. 2002). Birds such as the White-headed Woodpecker that eat the seeds of pine cones or Nuthatches and Creepers that search for insects riddled among the bark of live trees positively respond to low-severity to medium-severity burns as they provide decayed trees for nesting but still maintain the live trees that they rely on for food (Kotliar et al. 2002).

In summation, all types of birds respond differently to different degrees of fire, but each of these types of fires is natural to certain habitats. Fires can provide ideal habitats for certain species of birds and an abundance of burn sizes and types are critical to maintain habitats and resources for many native birds (Kotliar et al. 2002). This means that the human response to wildfire is critical. All fire and fire management has an affect on bird populations; therefore, it is crucial that fire management is properly monitored

and that fires are not stopped all together. By taking away fire, humans are taking away the native species that rely on it. As the threat of wildfire in the United States and the world increases it becomes ever more important for us to understand how wildfires can both hurt and help an environment.

Fire activity in the United States has increased markedly since the 1980's as temperatures have increased and snow melts earlier in the spring (Westerling 2006). Every year, hundreds of homes are burned and big wildfires are reported on the national news, resulting in more attention and more calls for legislative and administrative action (Westerling 2006). There are a few stances on why there has been an increase in wildfires in the past few decades: climate change and fire management.

Those who take the management stance believe that the "Forest regrowth after extensive logging beginning in the late 19th century, combined with an absence of extensive fires, promoted forest structure changes and biomass accumulation, which now reduce the effectiveness of fire suppression and increase the size of wildfires and total area burned" (Westerling 2009). This idea is in contention with the decrease in Black-backed Woodpeckers due to management, but every circumstance is and the two ideas are not mutually exclusive.

On the other hand, the stance on climate states that the changing moisture conditions, warmer temperatures, and increases in droughts have lead to more wildfire activity (Westerling 2009). Regardless of the cause of the increase in fire, it is wildly accepted that in the future anthropogenic climate change will further increase wildfire events in the future (Marlon 2009). During the last interglacial-glacial transition there was an increase in burned biomass and periods of rapid climate change 13.9, 13.2, and 11.7 ka that resulted in a large increase in fire as documented by charcoal data (Marlon

2009). With an impending increase in wildfires there will naturally be an equal response in terms of fire management.

Right now, the protocol for fire management in Rocky Mountain National Park abides by a three level hierarchical framework. The first goal is to provide for the safety of the public as well as the safety of the employees (Lewelling 2012). The next goal is to provide protection for communities, infrastructure, and natural and cultural resources with the park. The final goal is to restore and maintain fire-adapted ecosystems (Lewelling 2012). It is my worry that a lack of stand-replacement fires due to fire management will result in a loss of bird species in Rocky Mountain National Park. As of now, no study has been done to determine how wildfires and fire management directly affect the diversity and distribution of birds across Rocky Mountain National Park. Hopefully this project will provide insight into how species are distributed throughout fire stricken areas and why these species pop up in one place or another. Ultimately I will determine four things: 1). The species diversity of birds and numbers of each species in burned, non-burned, a prescribed burned transects in Rocky Mountain National Park, 2). The causes of these differences and whether the differences are statistically significant, 3). Which type of habitat leads to the greatest species richness, and 4). Whether or not the current fire management policy in Rocky Mountain National Park does a good job of maintaining the diversity of birds throughout the park. Wildfires and prescribed burns have a huge impact on landscapes and therefore should have a huge impact on bird species and diversity. It is of the utmost importance that these impacts are investigated.

Methods

Study Site

This study was conducted in June and July at Rocky Mountain National Park in Estes Park, Colorado. Rocky Mountain National Park is located on the Front Range of the Rocky Mountains, in north central Colorado (Lewelling 2012). The park ranges in altitude from about 7,630 feet up to a height of 14,259 feet, but the data was collected at altitudes ranging from 7871 feet to 8833. In June, the park averages a high of 73° F and a low of 41° F with precipitation of 1.76 inches. In July the temperature increases to an average high of 78° F and an average low of 46° F and 2.21 inches of precipitation (National Park Services 2016). It is important to note that the summer of 2015 was an exceptionally wet one for Colorado, with Estes Park receiving 3.14 inches of rain in May (May averages 2.02), 1.22 inches in June, and 2.72 inches in July according to the Estes Park weather website. Though the precipitation for June was lower than average, the aggregate for the season was notably higher.

The field site consisted of six transects all located in the montane ecosystem on the south eastern side of the park. *Pinus Ponderosa* known colloquially as the Ponderosa Pine is the dominant tree in the environment, appearing heavily on the Southern facing slopes where moisture is lost to the sun. On the northern facing slopes where moisture is more readily available, Ponderosa Pines are interspersed with Douglas Fir (*Psuedotsuga menziesii*), Lodgepole Pine (*Pinus contorta*), and Engelmann Spruce (*Picea engelmannii*) (National Park Service 2016). During my study I categorized this habitat as mixed forest. Large herbivores residing in the study site include bighorn sheep (*Odis canadensis*), Elk (*Cervus canadensis*), Moose (*Alces alces*), and Mule Deer (*Odocoileus*

heminous). Large carnivores in the site include Black bear (*Ursus americanus*), Coyote (*Canus latrans*), and Mountain Lion (*Puma concolor*) (National Park Service 2016).

Table 1. Study Sites

Study Area	Burn Status	Habitat
Cub Lake	Burned	Ponderosa
Hollowell Park	Non-burned	Ponderosa
Horseshoe Park	Non-burned	Mixed
Moraine Park Burn	Prescribed Burn	Mixed
Upper Beaver Meadows	Prescribed Burn	Ponderosa
Upper Cub Lake	Burned	Mixed

Table 2. Cub Lake

Point Count	Altitude	Location
1	8162'	40°21.032' N, 105°37.194' W
2	8267'	40°21.037' N, 105° 37.218' W
3	8316'	40°21.169' N, 105°37.245' W
4	8195'	40°20.997' N, 105°37.490' W
5	8232'	40°21.098' N, 105°37.543' W
6	8254'	40°20.981' N, 105°37.756' W
7	8273'	40°20.907' N, 105°37.851' W
8	8298'	40°20.954' N, 105°38.109' W

Table 3. Hollowell Park

Point Count	Altitude	Location
1	8346'	40°20.487' N, 105°36.239' W
2	8019'	40°20.434' N, 105°36.350' W
3	8258'	40°20.483' N, 105°36.487' W
4	8378'	40°20.516' N, 105°36.558' W
5	8502'	40°20.585' N, 105°36.624' W
6	8516'	40°20.583' N, 105°36.760' W
7	8543'	40°20.546' N, 105°36.818' W
8	8519'	40°20.458' N, 105°36.807' W

Table 4. Horseshoe Park

Point Count	Altitude	Location
1	8375'	40°24.050' N, 105°37.710' W
2	8548'	40°24.024' N, 105°37.805' W
3	8683'	40°24.992' N, 105°37.906' W
4	8816'	40°24.950' N, 105°37.926' W
5	8579'	40°24.120' N, 105°37.809' W
6	8624'	40°24.158' N, 105°37.890' W
7	8681'	40°24.024' N, 105°37.805' W
8	8642'	40°24.173' N, 105°37.956' W

Table 5. Moraine Park

Point Count	Altitude	Location
1	7,932'	40°20.869' N, 105°34.581' W
2	7,890'	40°20.888' N, 105°34.485' W
3	7,871'	40°20.953' N, 105°34.446' W
4	7,886'	40°20.984' N, 105°34.544' W
5	7,894'	40°20.929' N, 105°34.595' W
6	7,915'	40°20.801' N, 105°34.675' W
7	7,917'	40°20.816' N, 105°34.622' W
8	7,887'	40°20.821' N, 105°34.562' W

Table 6. Upper Beaver Meadows

Point Count	Altitude	Location
1	8354'	40°22.200' N, 105°35.773' W
2	8407'	40°22.331' N, 105°35.810' W
3	8448'	40°22.387' N, 105°35.854' W
4	8453'	40°22.465' N, 105°35.901' W
5	8507'	40°22.492' N, 105°35.018' W
6	8347'	40°22.315' N, 105°35.875' W
7	8372'	40°22.365' N, 105°35.939' W
8	8371'	40°22.422' N, 105°35.983' W

Table 7. Upper Cub Lake

Point Count	Altitude	Location
1	8303'	40°20.817' N, 105°38.309' W
2	8526'	40°20.741' N, 105°38.397' W
3	8681'	40°20.688' N, 105°38.472' W
4	8761'	40°20.659' N, 105°38.554' W
5	8663'	40°20.700' N, 105°38.664' W
6	8667'	40°20.749' N, 105°38.769' W
7	8734'	40°20.786' N, 105°38.829' W
8	8833'	40°20.762' N, 105°38.961' W

Though the park itself is home to some 270 species of birds (including those that migrate through), this study included 56 species. The most abundant species in the survey was the Broad-tailed Hummingbird, other notables included the William's Sapsucker and the Rufous Hummingbird.

The study was conducted along transects in areas affected by the Fern lake fire of 2012, areas that were subject to prescribed burning, and areas that have been unaffected by fires for the last century. Approximately 3 years after the fires, the fire ridden survey areas were mostly absent of foliage in the canopies and in many areas the understory has yet to return. In areas with prescribed burning, the understory was also relatively bare, however the canopy retained normal levels of density. In each habitat, I tried to maintain a similar altitude and keep the forest make up the same. Though all plots were in the montane ecosystem, some were dominated by Ponderosa Pine while some maintained a healthy mix of tree species.

Bird Observations

Observations were made over a 6-week period using point transect method based on techniques described in *Bird Ecology and Conservation: A Handbook of Techniques* (Sutherland et al 2004). Overall, 6 areas were surveyed consisting of 2 that had been affected by the Fern lake fire of 2012, 2 that had been part of the Rocky Mountain National Park prescribed burning program, and 2 that had been unaffected by burns in recent history. Along each transect 8 points were selected approximately 200 meters apart from one another to avoid overlap in the bird counts. Some points varied up to 30 meters in any direction along the transect due environmental hazards such as steep gradients, cliffs, and heavy streams. I tried to stay as far away as possible from both trails and roads. The counts took place in the early morning, from 6:30 am to 9:30 am when the bird activity was highest and temperatures were relatively cool. Each point within each of the transects was observed for 15 minutes and for a total of 5 times throughout the 6-week observation period. In all, each of the 48 points was observed for a total of 75 minutes, each transect was observed for 600 minutes, and the total observation time was 3,600

minutes. During the survey, all birds observed were identified along with their distance from the transect point using a range finder and their cardinal direction with the use of a compass.

Vegetation Survey

The canopy density was measured using a spherical densitometer. At each point in the transects, a reference tree was found (either a dominant or co-dominant tree). The measurements were taken just outside the crown of the reference tree so that the estimation did not include the crown of the reference tree. Around each reference tree, I took four total measurements one to the North, one to the South, one to the East, and one to the West of the reference tree according to proper spherical densitometer protocol (Lemmon 1956). At each site, the dominant tree type was also noted—either mixed forest or Ponderosa Pine.

To calculate foliage height diversity (FHD), I broke the vegetation down into three height ranges: Ground (0-0.5 meters), Shrub (0.05-5 meters), Tress (5> meters). At each point along the transect I walked 25 meters in each cardinal direction and noted the presence or absence of each of the height ranges every 5 meters. Using this information, I calculated the percentage of each of the height ranges for each of the points along the transect and applied the equation from the Shannon Weiner diversity index (SWD) to determine the foliage height diversity.

Altitude

I used a handheld GPS in order to determine the altitude at each bird counting point along all of the transects.

Analysis

The first step in my analysis was to break the species down into their foraging guilds according to scientific publication (De Graaf et al. 1985). Next, using the species counts from each of the points on the transect I calculated the Shannon Weiner diversity index (SWD) for bird species at each transect. I used multiple regressions to determine if there were any correlations between the burn status, habitat type, altitude, canopy cover, foliage height diversity and bird diversity in the form of SWD and species richness. I also used a multiple regression to determine if canopy cover and FHD were correlated with the other environmental conditions (burn status, habitat type, and altitude). Because I considered burn status to be a categorical variable and assigned it three levels (non-burned, prescribed burn, and burned), I dummy coded the variable into two parts: first, subscribed burn or not to which I assigned a 1 or 0 respectively and second, burned or not, to which I also assigned a 1 or 0 respectively.

The data I collected on the occurrence of birds and guilds along the transects was count data and not normally distributed, therefore I could not use a normal multiple regression to determine how the species and guilds were correlated with the aforementioned environmental factors. Instead, I used a generalized linear model assuming a Poisson distribution otherwise known as a Poisson regression. I ran the Poisson regression for all 56 bird species and all 10 guilds observed in the study. I used the R statistical package to run all of my models (R Core Team 2015), the Stargazer package to make my tables (Hlavac 2015), and ggplot2 (Wickham 2009) to make all figures.

Discussion

In order to create a theoretical distribution of bird species for each of the combinations of burn status and habitat type in my study, I randomly sampled point counts from my data and added all of the birds attributed to each randomly selected point count to a new data set. I did this for different combinations of burned and non-burned and Ponderosa and mixed forest. In all there were 9 combinations of burn status and habitat type. Each of the specific habitat types, burned mixed forest, burned Ponderosa forest, non-burned mixed forest, non-burned Ponderosa forest, were assigned a number 1-4 respectively and each of these habitats had 40 unique point counts.

For theoretical distributions of a single habitat type (burned mixed forest, burned Ponderosa forest, non-burned mixed forest, non-burned Ponderosa forest) I sampled the birds of 1000 randomly selected point counts with replacement and added them to a new data set. For theoretical distributions of two habitat types I sampled the birds of 500 randomly selected point counts from each of the two habitat types with replacement and bound them into a new data set. For the theoretical distribution of all habitat types I sampled the birds of 250 randomly selected point counts from each of the four habitat types with replacement and bound them into a new data set. By breaking it down this fashion, I equalized the effort among the habitat types so that each habitat within a theoretical distribution was uniformly represented. Because each of the new data sets were all made up of different numbers of birds I converted the bird counts of each of the 9 new data sets into species frequencies and created unique histograms for each of these new data sets. The histograms represent a theoretical distribution of bird species in 0% burned 0% Ponderosa forest (100% mixed forest), 0% burned 100% Ponderosa forest (0% mixed forest), 100% burned 0% Ponderosa forest (100% mixed forest), 100% burned 100% Ponderosa forest (0% mixed forest), 50% burned 0% Ponderosa forest (100% mixed

forest), 50% burned 100% Ponderosa forest (0% mixed forest), 0% burned 50% Ponderosa forest (50% mixed forest), 100% burned 50 % Ponderosa forest (50% mixed forest), and finally 50% burned 50% Ponderosa forest (50% mixed forest). In order to take into account more environmental factors i.e. altitude, I broke the habitats down into low altitude and high altitude where possible. I used the R in order to created the randomized theoretical distributions (R Core Team 2015) and ggplot2 to make

With theoretical distributions in hand, I used Microsoft Excel to created a three-dimensional surface plot comparing percent burned forest, percent Ponderosa forest, and species richness, I then applied to the same concept to bird abundance, and finally made a three-dimensional scatterplot with each of the bird species frequencies in relation to percent forest burned and percent Ponderosa using plot.ly (Plotly Technologies Inc. 2015).

Results

During the course of the study 1440 individuals made up of 56 different species of bird were observed across 6 distinct habitats and 48 survey points. The most abundant bird during the study was the Broad-tailed Hummingbird, followed by the American Robin, Chipping Sparrow, Violet-green Swallow, and the American Crow (Appendix 1). Of burned, non-burned, and prescribed burn plots, both burned and non-burned contained a total of 36 species each while prescribed burn plots contained 34 species.

Table 8. Bird Abundance by Guild

Guild	Abundance by Burn Status			Total Abundance
	Burned	Non-Burned	Prescribed Burn	
Carnivore	2	0	7	9
Granivore	0	1	8	9
Granivore/Herbivore	1	0	0	1
Herbivore	0	4	0	4
Insectivore	129	135	81	345
Insectivore/Frugivore	30	8	5	43
Insectivore/Granivore	7	6	19	32
Omnivore	174	234	152	560
Omnivore/Granivore	81	74	122	277
Omnivore/Insectivore	55	41	64	160
Totals	479	503	458	1,440

Note: where slashes occur, the guild before the slash denotes non-breeding feeding tendencies while the guild after the slash denotes breeding feeding tendencies

6 species were only observed in non-burned transects, 5 were only observed in prescribed burn transects, and 9 species were only observed in burned transects (Appendix 1). Granivores with herbivorous breeding tendencies were observed exclusively in burned transects whereas herbivores were observed only in non-burned areas.

Multiple Regressions

Within the multiple regressions, which included altitude, canopy cover, and FHD, SWD and Species Richness were both significantly correlated ($p < 0.05$) with altitude in prescribed burn Ponderosa forests. There was 0.006 ($R^2 = 0.725$) increase in SWD per foot and a 0.029 ($R^2 = 0.832$) increase in species richness per foot (Appendix 2 A). Figures 1 A and 1B show the correlations between only altitude and SWD, and only altitude and species richness respectively. Though the R^2 values are lower, the correlations are significant to a much lower P-values.

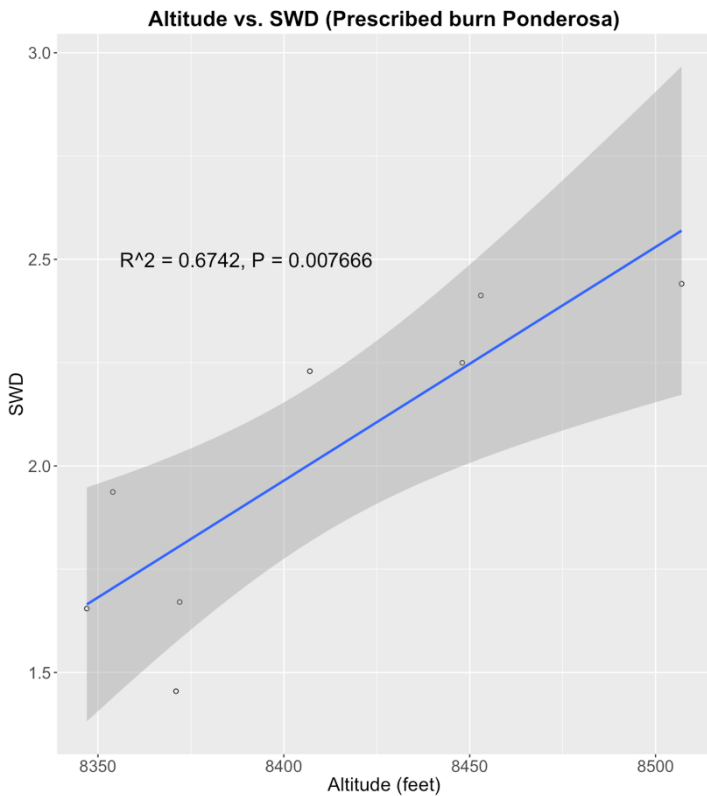


Figure 1 A. Correlation between Altitude and SWD with 95% confidence region

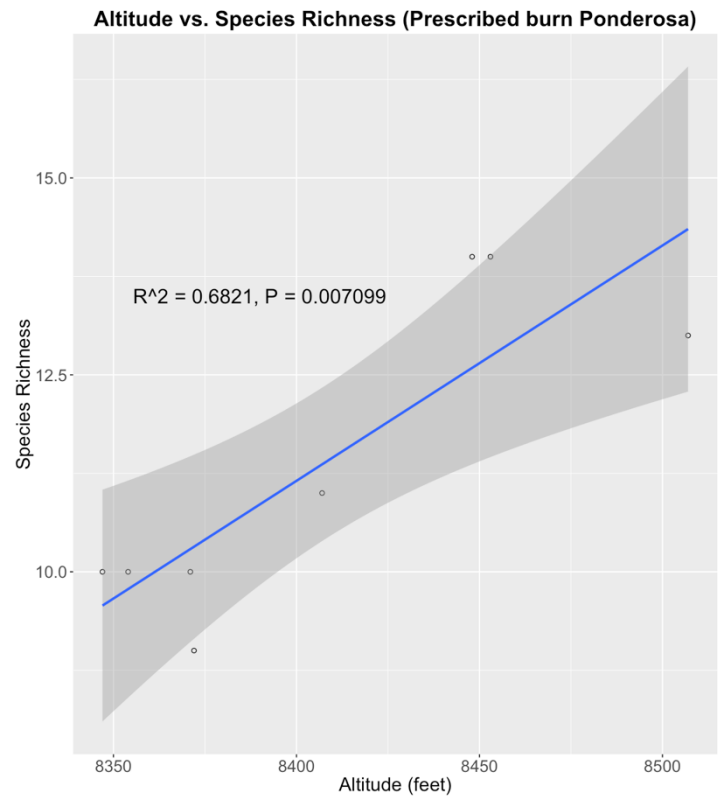


Figure 1 B. Correlation between Altitude and Species Richness with 95% confidence region

Within Foliage height diversity and canopy cover were both significantly correlated with burn status of the transects ($p < 0.01$), with burns resulting in a decrease of 0.207 FHD and a decrease of 25.9% canopy cover in burned areas (Appendix 2 B). Due to the nature of the data (either non-burned or burned) the R^2 are relatively low, but the P-values are very small and a strong correlation appears to exist.

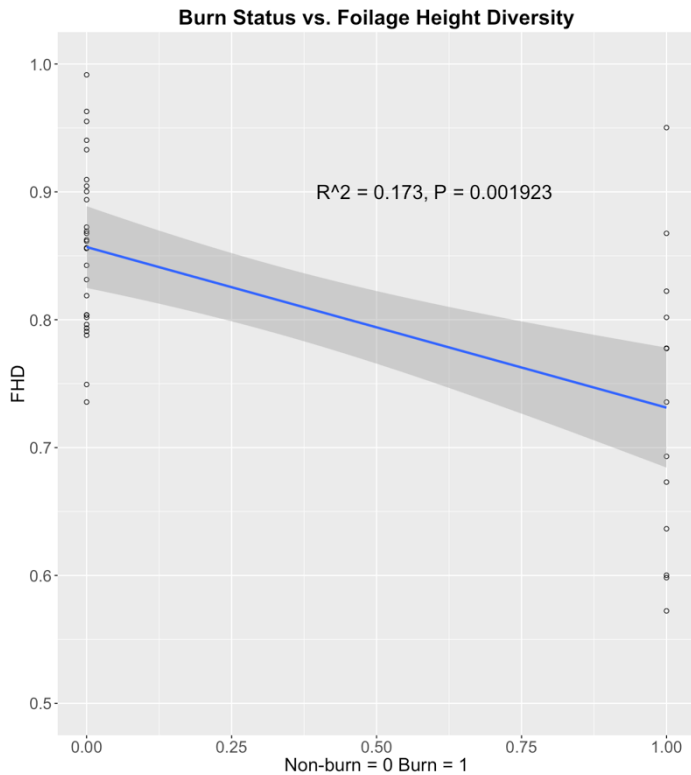


Figure 2 A. Correlation between Burn Status and FHD with 95% confidence region

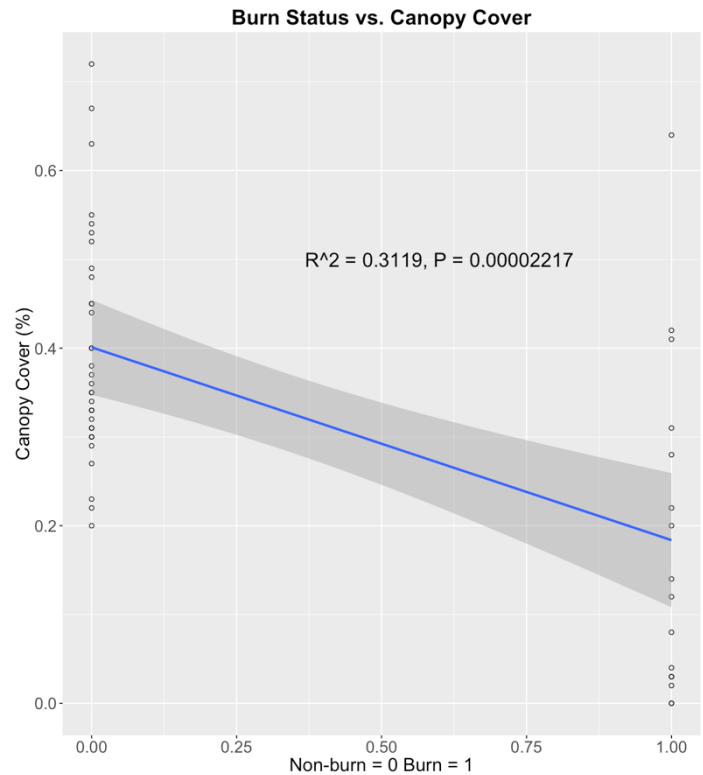


Figure 2 B. Correlation between Burn Status and Canopy Cover with 95% confidence region.

Poisson Regressions

The Poisson Regressions revealed that in all, 27 species and 8 guilds had significant ($p < 0.05$) correlations to at least one of the environmental factors measured in the study. Carnivores had a significant positive correlation with altitude ($p < 0.05$; Appendix 3 A). Granivores had a significantly positive correlation to canopy cover ($p < 0.05$; Appendix 3 A). Insectivores had a significantly positive correlation with altitude

($p < 0.01$) but a significantly negative correlation with canopy cover ($p < 0.05$; Appendix 3 A). Insectivores with breeding frugivorous behaviors had significantly positive correlations to both wildfire ($p < 0.01$) and Ponderosa forests ($p < 0.05$; Appendix 3 A). Insectivores with breeding granivorous tendencies were positively correlated with both wildfires and canopy cover ($p < 0.001$; Appendix 3 B). Omnivores had significant negative correlations to wildfires, prescribed burns, Ponderosa forests, and altitude ($p < 0.01$; Appendix 3 B). Omnivores with breeding granivorous tendencies had significantly negative correlations to both Ponderosa forest and altitude ($p < 0.01$; Appendix 3 B). Omnivores with breeding insectivorous tendencies had positive and significant correlations to wildfire, prescribed burns, and altitude ($p < 0.01$; Appendix 3B).

Apart from the specific feeding guilds, 27 species of bird were significantly correlated with one environmental factor or another. American Crows had statistically significant negative correlations with both prescribed burns ($p < 0.05$) and altitude ($p < 0.001$) and they had significantly positive correlations with both Ponderosa forests and canopy cover ($p < 0.001$; Appendix 4 A). American Robins had a significantly negative correlation to both prescribed burns and Ponderosa forests ($p < 0.05$) as well as altitude ($p < 0.001$), but were positively correlated with FHD ($p < 0.001$; Appendix 4 A). Black-billed Magpies were positively correlated with prescribed burns ($p < 0.05$) but were negatively correlated with FHD ($p < 0.001$; Appendix 4 A). Broad-tailed Hummingbirds were negatively correlated with Ponderosa forests ($p < 0.01$; Appendix 4 A).

Brown Creepers were negatively correlated with both altitude ($p < 0.01$) and canopy cover ($p < 0.05$; Appendix 4 B). Chipping Sparrows were negatively impacted by both habitat and altitude to a significant level ($p < 0.01$; Appendix 4 B).

Common Ravens were negatively correlated with altitude and positively correlated with FHD to a significant level ($p < 0.01$; Appendix 4 B). Dark-eyed Juncos were negatively correlated with altitude to a significant level ($p < 0.01$). Downy Woodpeckers were positively correlated with wildfires to a significant level ($p < 0.01$; Appendix 4 C). Green-tailed Towhees were negatively correlated with prescribed burns, Ponderosa forests, and FHD ($p < 0.01$; Appendix 4 C). Hairy Woodpeckers were positively significantly correlated with burns ($p < 0.05$) and Ponderosa forests ($p < 0.01$). House Wrens were positively impacted by both prescribed burns and altitude to a significant level ($p < 0.01$). Mountain Bluebirds were positively correlated with altitude to a significant level ($p < 0.01$; Appendix 4 D). Mountain Chickadees were negatively correlated with Ponderosa forests and positively correlated to altitude to a significant level ($p < 0.01$; Appendix 4 D). Northern Flickers were negatively correlated with altitude to a significant level ($p < 0.01$; Appendix 4 D). Olive-sided Flycatchers had significant negative correlations to both wildfires burned ($p < 0.05$) and prescribed burned ($p < 0.01$; Appendix 4 D). Pygmy Nuthatches were positively correlated with prescribed burns to a significant level ($p < 0.05$; Appendix 4 E). Red-breasted Nuthatches were positively correlated with FHD to a statistically significant level ($p < 0.05$; Appendix 4 E). Redwinged Blackbirds were negatively correlated with canopy cover ($p < 0.05$; Appendix 4 E). Rufous Hummingbirds had positive significant correlations to both prescribed burns and FHD ($p < 0.05$; Appendix 4 E). Steller's Jay had significantly negative correlations to both Ponderosa forests and FHD ($p < 0.01$). Three-toed Woodpeckers were negatively correlated to FHD to a significant degree ($p < 0.05$; Appendix 4 E). Townsend Solitaires were positively and significantly correlated with altitude ($p < 0.01$; Appendix 4 E). Violet Green Swallows were negatively correlated with correlated with canopy cover ($p < 0.05$) and positively correlated with FHD ($p < 0.01$; Appendix 4 E). Warbling Vireos are

positively correlated with canopy cover in a significant manner ($p < 0.05$; Appendix 4 G). Yellow Warblers were negatively correlated to prescribed burns ($p < 0.05$) and as well as altitude ($p < 0.01$; Appendix 4 G). Yellow-Rumped Warblers were significantly correlated with prescribed burns and altitude ($p < 0.05$; Appendix 4 G).

Discussion

The clearly shows that not all birds are equally distributed between habitats and not all birds respond the same way to either wildfire or prescribed burning. 3 guilds and 4 species were significantly positively correlated with wildfires, and some were observed only in wildfires. 1 guild was significantly negatively correlated with wildfire along with 1 species. 1 guild and 5 species were significantly positively correlated with prescribed burning, but 1 guild and 5 species were also significantly negatively correlated with prescribed burning. 1 guild was significantly positively correlated with Ponderosa forests along with with 3 species and 2 guilds were significantly negatively correlated with Ponderosa forests along with 6 species. Altitude had many significant correlations in either direction and so did both FHD and canopy cover.

Although correlations do not imply causation, it is likely that both wildfire and prescribed burning play a big role in the distribution of some species. While some birds thrive in freshly burned forestland, some are not found in burned regions at all, and others were seen most frequently in prescribed burn areas. More so, while some species of bird make their living in the nicely spaced Ponderosa forest slopes others prefer the denser mixed forests. While a much more thorough exploration of the park might give better insight into the true bird species distribution in the park, the data collected in this study allows us to make the conclusion that a heterogeneous habitat allows for the greatest species diversity. This should play a huge role in the application of prescribed burning both in Rocky Mountain National Park and beyond, interestingly enough while it could prevent wildfires, and therefore decrease diversity in the park, it also creates its own habitat, which in turn should theoretically add diversity.

Theoretical Species Distributions

I used the data that I collected in the study to create a series of theoretical bird species distributions in different combinations of burned or non-burned and Ponderosa forest and mixed forest. For simplicity sake, and because only wildfire had a significant correlation with either FHD or canopy cover, I assumed that any given environment would have a range of FHD and canopy cover and that they would naturally be included in the model.

The distributions show not only which bird species would be present given a certain combination of environments, but also the relative frequencies at which the species should occur. In doing so I found that the greatest distribution of species will occur when all four habitats are present. According to several iterations of my model, while a park containing only non-burned Ponderosa forests might contain only 28 species (Appendix 5 A I) and a park with only non-burned mixed forest might contain only 24 species (Appendix 5 A II), a park containing both non-burned Ponderosa and mixed forest might contain 37 species (Appendix 5 C I). A park containing just burned Ponderosa forest might contain 23 species (Appendix 5 B I) and a park containing just burned mixed forest might contain 30 species (Appendix 5 A III), but a park with totally burned Ponderosa and mixed forest could contain 40 species (Appendix 5 C II). A park containing burned and non-burned Ponderosa forests could carry 38 species (Appendix 5 B III) and a park containing burned and non-burned mixed forests could carry 39 species (Appendix 5 B II), a park that contained both burned and non-burned Ponderosa and mixed forests could host 51 species (Appendix 5 C III).

Table 9. Species Richness and Total Bird Abundance in Varied Habitats

Species Richness					Bird Abundance				
Percent Ponderosa					Percent Ponderosa				
0% 50% 100%					0% 50% 100%				
Percent Burned	0%	24	37	28	0%	5184.3	6289.2	7449.5	
	50%	39	51	37	50%	6053.7	6120.8	6263	
	100%	30	40	23	100%	6900.4	5983.3	5099.8	

I wanted to add another wrinkle into the model and determine how much of a role altitude played in the theoretical distribution of species. Unfortunately, most of my data was collected in a pretty narrow range of altitude and splitting the data between low altitude and high altitude resulted in certain combinations of habitat being left out the model. Therefore, I selected the habitat with the greatest range of altitude, which was 0% burned and 100% Ponderosa forest, and split it between low altitude (<8,500') and high altitude (>8,500'). According to the model, there was once again a difference in the number of bird species occupying each habitat. Low altitude 0% burned and 100% Ponderosa returned 26 species (Fig. 3 A), while high altitude 0% burned 100% Ponderosa returned only 16 species (Fig. 3 B). When ran with both high and low altitude 0% burned 100% Ponderosa forest, the model returned 27 species (Fig. 3 C).

Though the nature of the process by which I produced these distributions was random and running the model multiple times returns slightly different results, it will always tell us the same thing; a heterogeneous environment results in the greatest species richness.

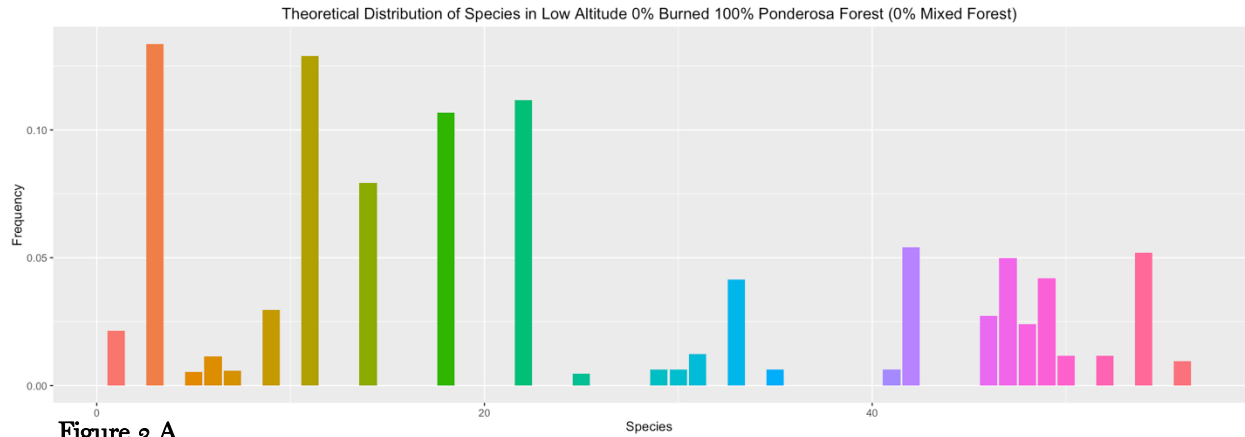


Figure 3 A

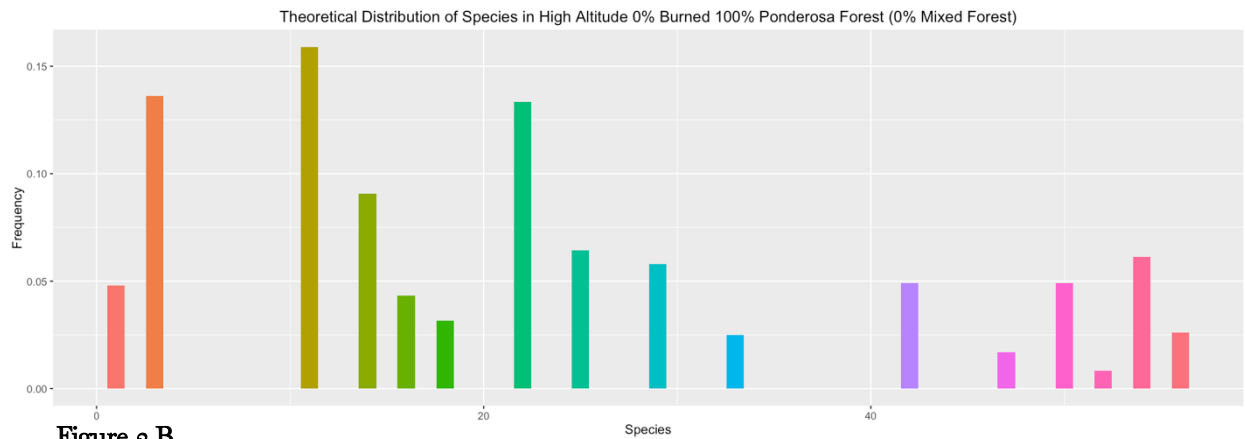


Figure 3 B

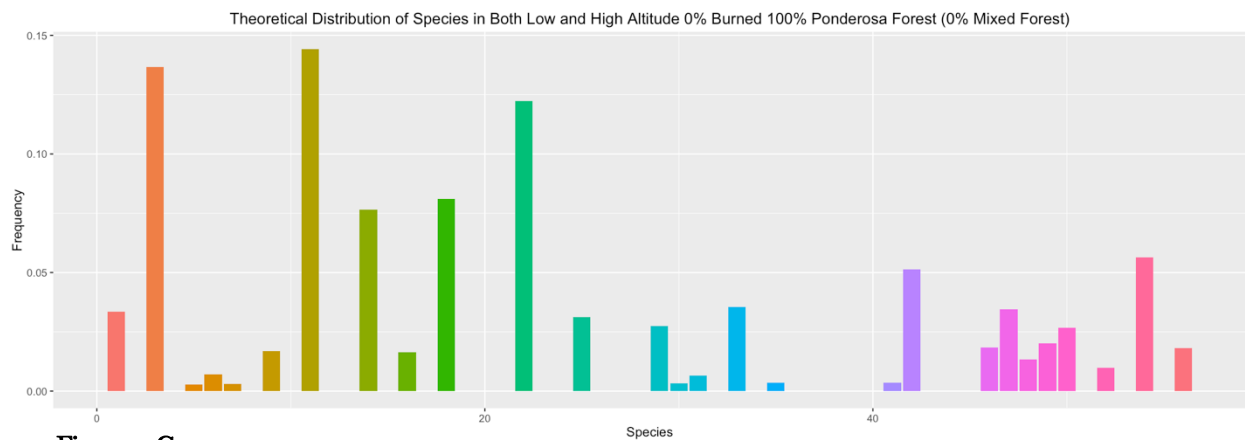
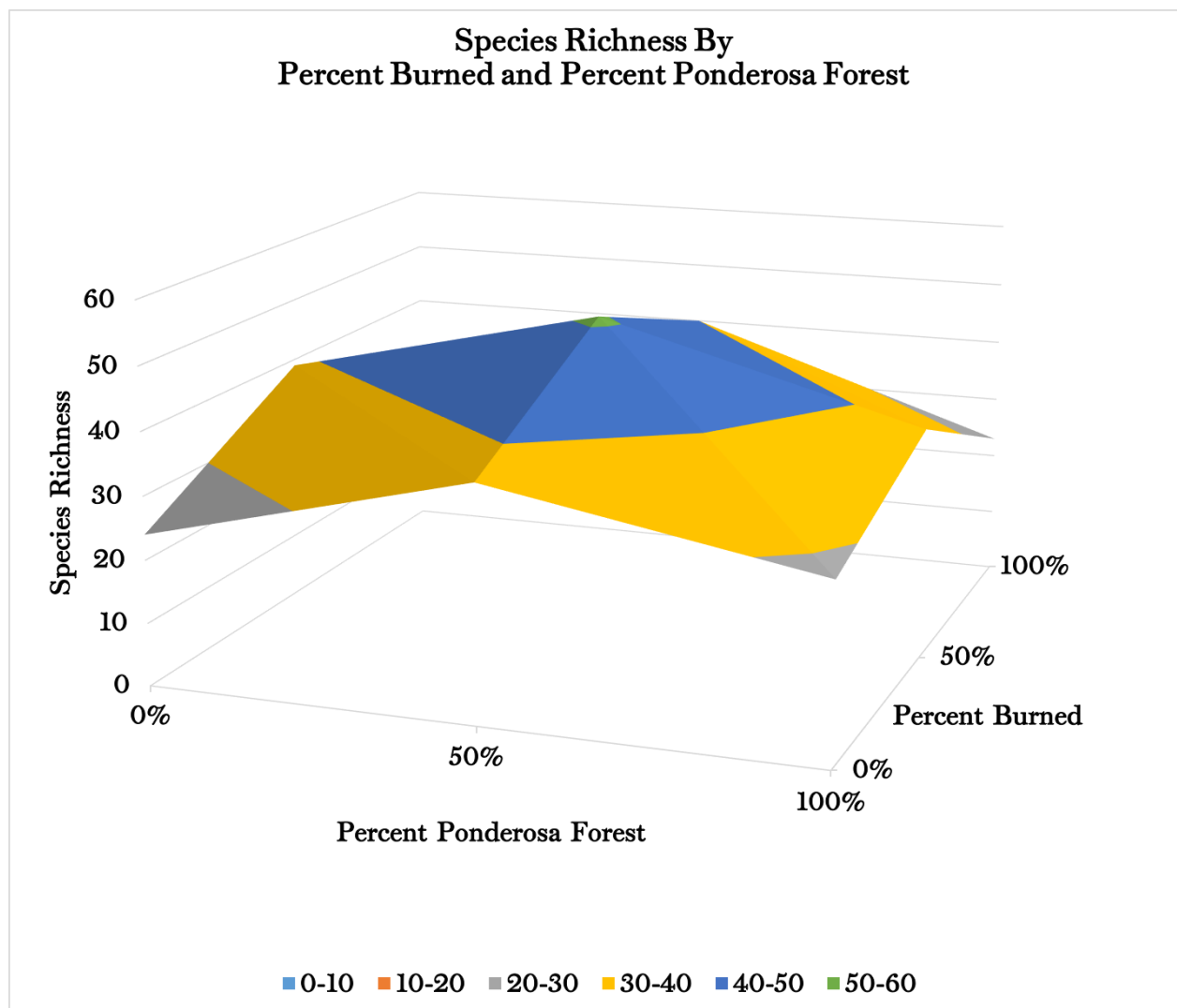


Figure 3 C



Species Richness Landscape Model

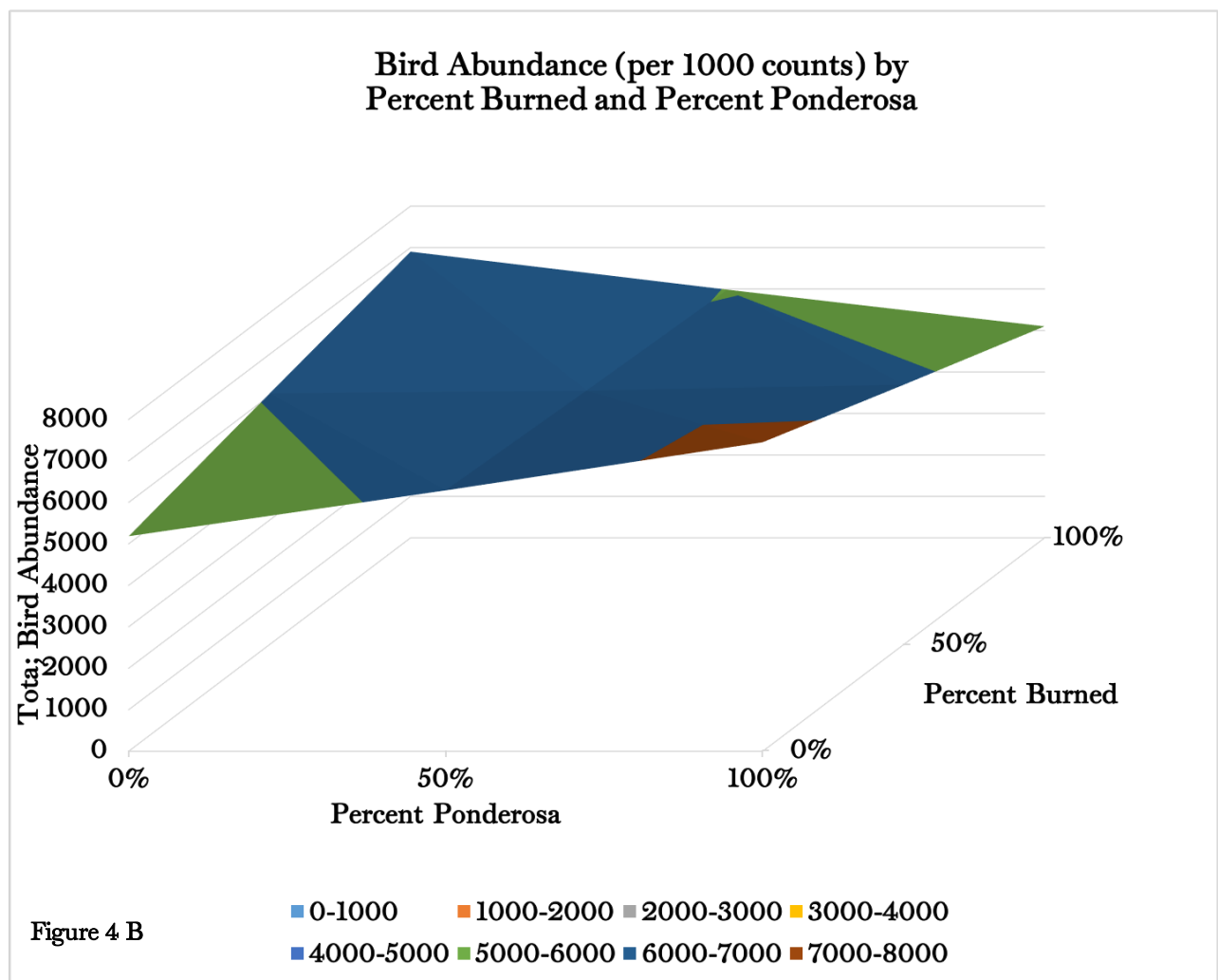
Using the results of my theoretical distributions I was able to create a model for the species richness in varied landscapes based on Table 8. Like the theoretical distributions in varied landscapes, it shows how species are spread along a varied landscape, but rather than showing which species inhabit a landscape it shows how many species occupy a landscape. The model shows how many bird species would theoretically occupy a forest given percentages of burned forest and percentages of ponderosa forests. It is quite easy to tell from the figure that as habitats become more and more varied, the



species richness goes up. In this model, it peaks when 50% of the forest is burned and 50% of the forest is made up of Ponderosa Pine.

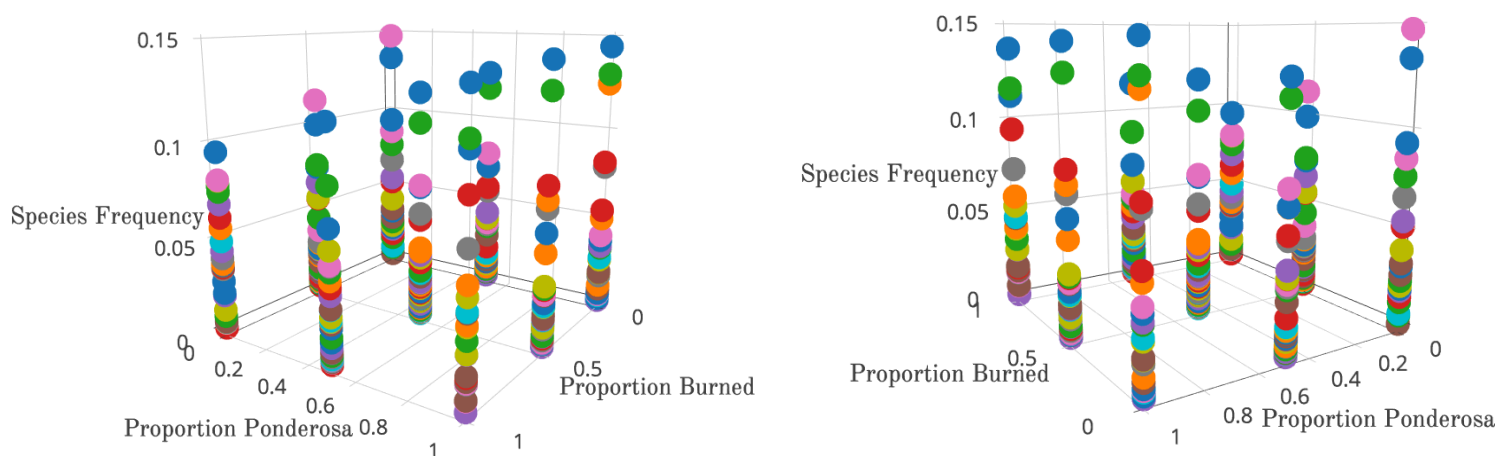
Bird Abundance Landscape Model

In order to see how a varied landscape impacts bird abundances, I applied the same processes to create a model that shows bird abundance in response to various burn and habitat conditions. Unlike the species richness model, this model shows that a homogenous landscape is favorable for this metric and peaks at 0% burned and 100%



Ponderosa forest. In this circumstance, and environment with lots of homogeneity results results in a high abundance at the cost of certain species.

Figure 5. The Distribution of Individual Species by Percent Burned and Percent Ponderosa



- | | | | |
|-----------------------------|-----------------------|--------------------------|---------------------------|
| ● American Crow | ● Clark's Nutcracker | ● Mountain Chickadee | ● Three-toed Woodpecker |
| ● American Pitpit | ● Common Raven | ● Mourning Dove | ● Townsend Solitaire |
| ● American Robin | ● Cooper's Hawk | ● Northern Flicker | ● Tree Swallow |
| ● American Tree Sparrow | ● Dark-eyed Junco | ● Northern Harrier | ● Vesper Sparrow |
| ● Ash-Throated Flycatcher | ● Downy Woodpecker | ● Olive-Sided Flycatcher | ● Violet Green Swallow |
| ● Black and White Warbler | ● Dusky Flycatcher | ● Pine Grosbeak | ● Warbling Vireo |
| ● Black-Billed Magpie | ● Dusky Grouse | ● Pine Siskin | ● Western Tanager |
| ● Black-Chinned Hummingbird | | ● Pygmy Nuthatch | ● Western Wood Pewee |
| ● Black-Headed Grosbeak | ● Green-Tailed Towhee | ● Red-Breasted Nuthatch | ● White-Breasted Nuthatch |
| ● Brewer's Blackbird | ● Gray Flycatcher | ● Red-Tailed Hawk | ● White-Crowned Sparrow |
| ● Broad-Tailed Hummingbird | ● Hairy Woodpecker | ● Redwinged Blackbird | ● William's Sapsucker |
| ● Brown Creeper | ● House Wren | ● Rufous Crowned Sparrow | ● Wilson's Warbler |
| ● Canyon Wren | ● Lincoln's Sparrow | ● Rufous Hummingbird | ● Yellow Warbler |
| ● Chipping Sparrow | ● Mallard | ● Steller's Jay | ● Yellow-Rumped Warbler |
| | ● Mountain Bluebird | | |

Conclusion

While it is impossible to say just how much wildfire will affect Rocky Mountain National Park and the rest of our environment in the future, it is important to note that it is a very natural part of RMNP's landscape. Without it some bird species would likely disappear all together. Though the need to protect communities around National Parks is very important, restricting wildfires through the use of prescribed burning techniques could destroy the bird diversity within the park in the long run. Though, it appears that prescribed burning can add diversity in it's own right it is not nearly as big of a factor in adding diversity as wildfire and it is not part of the natural order of Rocky Mountain National Park. Prescribed burning should be used as little as possible and in only the direst of circumstances. A park that is made up of a mixture of both burned and non-burned Ponderosa and mixed forests will have the most diversity.

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Appendix

Appendix 1. Bird Abundance by Species and Guild

Bird	Scientific Name	Burned	Non Burned	Prescribed Burn	Total Abundance
Carnivore		2	0	7	9
Granivore		0	1	8	9
Granivore/Herbivore		1	0	0	1
Herbivore		0	4	0	4
Insectivore		129	135	81	345
Insectivore/Frugivore		30	8	5	43
Insectivore/Granivore		7	6	19	32
Omnivore		174	234	152	560
Omnivore/Granivore		81	74	122	277
Omnivore/Insectivore		55	41	64	160
American Crow	Corvus brachyrhynchos	33	38	27	98
American Pitpit	Anthus rubescens	1	0	0	1
American Robin	Turdus migratorius	41	56	40	137
American Tree Sparrow	Spizella arborea	0	0	4	4
Ash-Throated Flycatcher	Myiarchus cinerascens	0	1	0	1
Black and White Warbler	Mniotilta varia	0	2	0	2
Black-Billed Magpie	Pica hudsonia	0	18	14	32
Black-Chinned Hummingbird	Archilochus alexandri	5	0	0	5
Black-Headed Grosbeak	Pheucticus melancephalus	0	5	0	5
Brewer's Blackbird	Euphagus cyanocephalus	10	0	0	10
Broad-Tailed Hummingbird	Selasphorus platycercus	52	63	44	159
Brown Creeper	Certhia americana	15	0	0	15
Canyon Wren	Catherpus mexicanus	0	2	1	3
Chipping Sparrow	Spizella passerina	19	28	61	108

Clark's Nutcracker	Nucifraga columbiana	0	1	0	1
Common Raven	Corvus corax	10	12	15	37
Cooper's Hawk	Accipiter cooperii	1	0	1	2
Dark-eyed Junco	Junco hyemalis	23	27	37	87
Downy Woodpecker	Picoides pubescens	27	4	0	31
Dusky Flycatcher	Empidonax oberholseri	1	0	0	1
Dusky Grouse	Dendragapus obscurus	0	4	0	4
Green-Tailed Towhee	Pipilo chlorurus	0	37	14	51
Gray Flycatcher	Empidonax wrightii	3	1	1	5
Hairy Woodpecker	Leuconotopicus villosus	20	10	0	30
House Wren	Troglodytes aedon	18	20	25	63
Lincoln's Sparrow	Melospiza lincolnii	1	5	0	6
Mallard	Anas platyrhynchos	1	0	0	1
Mountain Bluebird	Sialia currocoides	10	0	11	21
Mountain Chickadee	Poecile gambeli	11	16	19	46
Mourning Dove	Zeniada macroura	0	1	4	5
Northern Flicker	Colaptes auratus	8	2	6	16
Northern Harrier	Circus cyaneus	2	0	0	2
Olive-Sided Flycatcher	Contopus cooperi	6	15	3	24
Pine Grosbeak	Pinicola enucleator	0	0	13	13
Pine Siskin	Carduelis pinus	17	1	1	19
Pygmy Nuthatch	Sitta pygmaea	1	1	8	10
Red-Breasted Nuthatch	Sitta canadensis	0	0	6	6
Red-Tailed Hawk	Buteo jamaicensis	0	0	6	6
Redwinged Blackbird	Agelaius phoeniceus	12	0	0	12
Rufous Crowned Sparrow	Aimophila ruficeps	0	0	1	1
Rufous Hummingbird	Selasphorus rufus	6	5	7	18
Steller's Jay	Cyanocitta stelleri	22	15	12	49
Three-toed Woodpecker	Picoudes dorsalis	21	0	0	21

Townsend Solitaire	Myadestes townsendi	10	0	1	11
Tree Swallow	Tachycineta bicolor	3	4	5	12
Vesper Sparrow	Poocetes gramineus	3	5	0	8
Violet Green Swallow	Tachycineta thalassina	25	41	33	99
Warbling Vireo	Vireo gilvus	1	17	1	19
Western Tanager	Piranga ludoviciana	0	7	0	7
Western Wood Pewee	Contopus sordidulus	13	9	7	29
White-Breasted Nuthatch	Sitta carolinensis	7	6	14	27
White-Crowned Sparrow	Zonotrichia leucophrys	0	3	1	4
William's Sapsucker	Sphyrapicus thyroideus	2	0	0	2
Wilson's Warbler	Cardellina pusilla	0	8	0	8
Yellow Warbler	Setophaga petechia	5	8	2	15
Yellow-Rumped Warbler	Setophaga coronata	13	5	13	31
Total		479	503	458	1,440

Appendix 2 A. Multiple Regressions for SWD and Species Richness

	<i>Dependent variable:</i>	
	SWD (1)	Species Richness (2)
Altitude	0.006** (0.002)	0.029** (0.008)
Canopy Cover	0.029 (0.945)	2.825 (3.883)
FHD	0.382 (1.586)	-9.770 (6.517)
Constant	-44.987* (16.343)	-226.371** (67.135)
Observations	8	8
R ²	0.725	0.832
Adjusted R ²	0.519	0.706
Residual Std. Error (df = 4)	0.263	1.081
F Statistic (df = 3; 4)	3.517	6.611**
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01	

Appendix 2 B. Multiple Regressions for FHD and Canopy Cover

	<i>Dependent variable:</i>	
	FHD (1)	Canopy Cover (2)
Prescribe	-0.077 (0.065)	-0.076 (0.062)
Burn	-0.207*** (0.055)	-0.259*** (0.053)
Habitat	0.040 (0.045)	-0.053 (0.043)
Altitude	0.0001 (0.0001)	0.00003 (0.0001)
Constant	0.269 (0.844)	0.246 (0.810)
Observations	48	48
R ²	0.277	0.387
Adjusted R ²	0.209	0.330
Residual Std. Error (df = 43)	0.154	0.148
F Statistic (df = 4; 43)	4.109***	6.780***
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01	

Appendix 3 A. Poisson Regressions by Guild

	<i>Dependent variable:</i>			
	Carnivore (1)	Granivore (2)	Insectivore (3)	Insectivore/Frugivore (4)
Burn	15.625 (2,748.426)	-18.296 (2,763.288)	-0.289 (0.193)	1.898*** (0.651)
Prescribe	29.571 (2,748.431)	1.220 (1.189)	-0.038 (0.167)	0.030 (0.762)
Habitat	7.018* (3.919)	-2.164 (1.496)	0.093 (0.119)	0.866** (0.435)
Altitude	0.016** (0.007)	-0.002 (0.003)	0.002*** (0.0003)	0.0004 (0.001)
Canopy Cover	-3.289 (5.194)	7.587** (3.393)	-0.986** (0.414)	1.058 (1.223)
FHD	3.167 (4.153)	-3.655 (5.914)	0.198 (0.313)	0.779 (0.791)
Constant	-164.001 (2,749.193)	16.743 (26.077)	-11.181*** (2.278)	-6.248 (7.386)
Observations	48	48	48	48
Log Likelihood	-18.005	-14.923	-193.196	-62.033
Akaike Inf. Crit.	50.010	43.846	400.392	138.065
<i>Note:</i>	*p<0.1 **p<0.05 ***p<0.01			

Appendix 3 B. Poisson Regressions by Guild

	<i>Dependent variable:</i>			
	Insectivore/ Granivore (1)	Omnivore (2)	Omnivore/ Granivore (3)	Omnivore/ Insectivore (4)
Burn	9.141 ^{***} (3.030)	-0.450 ^{***} (0.127)	0.060 (0.202)	0.824 ^{***} (0.296)
Prescribe	4.304 (3.022)	-0.680 ^{***} (0.123)	-0.009 (0.179)	1.157 ^{***} (0.249)
Habitat	25.700 (3,022.519)	-0.385 ^{***} (0.090)	-0.419 ^{***} (0.140)	-0.018 (0.183)
Altitude	-0.004 (0.002)	-0.001 ^{***} (0.0002)	-0.002 ^{***} (0.0003)	0.002 ^{***} (0.0004)
Canopy Cover	15.407 ^{***} (4.682)	0.062 (0.310)	-0.396 (0.487)	1.078 [*] (0.568)
FHD	4.761 (2.963)	-0.545 [*] (0.327)	0.942 (0.630)	0.542 (0.558)
Constant	-6.239 (3,022.612)	9.414 ^{***} (1.674)	17.204 ^{***} (2.326)	-15.245 ^{***} (3.188)
Observations	48	48	48	48
Log Likelihood	-28.670	-135.928	-130.593	-122.849
Akaike Inf. Crit.	71.339	285.855	275.186	259.697

Note: * p<0.1 ** p<0.05 *** p<0.01

Appendix 4 A. Poisson Regressions by Species

	<i>Dependent variable:</i>			
	American Crow (1)	American Robin (2)	Black-Billed Magpie (3)	Broad-Tailed Hummingbird (4)
Burn	0.240 (0.336)	-0.165 (0.271)	-20.858 (2,367.747)	-0.029 (0.240)
Prescribe	-0.744** (0.373)	-0.581** (0.253)	1.616** (0.775)	-0.343 (0.224)
Habitat	0.626*** (0.230)	-0.470** (0.197)	1.179* (0.605)	-0.487*** (0.174)
Altitude	-0.001*** (0.001)	-0.001*** (0.0004)	0.002 (0.001)	-0.0003 (0.0004)
Canopy Cover	2.130*** (0.674)	-0.912 (0.665)	-4.290* (2.518)	0.066 (0.559)
FHD	-0.460 (0.764)	2.595*** (0.952)	9.442*** (3.502)	0.928 (0.719)
Constant	11.749*** (4.309)	11.873*** (3.230)	-26.496** (11.413)	2.861 (3.122)
Observations	48	48	48	48
Log Likelihood	-95.816	-95.406	-37.806	-97.847
Akaike Inf. Crit.	205.632	204.812	89.612	209.694
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01			

Appendix 4 B. Poisson Regression by Species

	<i>Dependent variable:</i>			
	Brown Creeper (1)	Chipping Sparrow (2)	Common Raven (3)	Dark-eyed Junco (4)
Burn	9.785 (13,300.910)	-0.195 (0.399)	0.255 (0.653)	-0.470 (0.363)
Prescribe	-14.078 (16,981.920)	0.268 (0.279)	-0.684 (0.629)	-0.503 (0.334)
Habitat	25.063 (6,213.903)	-1.110 ^{***} (0.273)	0.599 (0.416)	-0.084 (0.238)
Altitude	-0.012 ^{***} (0.004)	-0.004 ^{***} (0.001)	-0.003 ^{***} (0.001)	-0.002 ^{***} (0.001)
Canopy Cover	-29.673 ^{**} (12.317)	1.330 (0.913)	3.763 ^{***} (1.174)	0.787 (0.847)
FHD	-1.056 [*] (0.606)	1.818 (1.433)	-0.326 (1.863)	-1.327 (0.912)
Constant	68.455 (14,680.890)	29.125 ^{***} (4.417)	23.581 ^{***} (7.515)	19.395 ^{***} (4.384)
Observations	48	48	48	48
Log Likelihood	-10.232	-86.628	-53.268	-95.881
Akaike Inf. Crit.	34.464	187.256	120.535	205.762
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01			

Appendix 4 C. Poisson Regression by Species

<i>Dependent variable:</i>				
	Downy Woodpecker (1)	Green-Tailed Towhee (2)	Hairy Woodpecker (3)	House Wren (4)
Burn	3.150 ^{***} (1.110)	-24.260 (2,236.939)	2.285 ^{**} (1.057)	-0.326 (0.503)
Prescribe	-18.265 (1,951.975)	-1.108 ^{***} (0.368)	-16.959 (2,077.713)	0.983 ^{***} (0.357)
Habitat	2.953 ^{***} (0.727)	-2.502 ^{***} (0.835)	2.319 ^{***} (0.894)	-0.237 (0.306)
Altitude	-0.002 [*] (0.001)	0.0001 (0.001)	0.001 (0.001)	0.003 ^{***} (0.001)
Canopy Cover	2.436 (1.962)	-3.656 (2.301)	3.143 [*] (1.887)	-0.633 (1.001)
FHD	0.675 (0.853)	-8.911 ^{***} (3.413)	0.376 (0.828)	-0.351 (0.739)
Constant	12.979 (10.577)	9.836 (10.345)	-15.129 (12.117)	-26.163 ^{***} (5.908)
Observations	48	48	48	48
Log Likelihood	-34.559	-40.824	-39.174	-89.911
Akaike Inf. Crit.	83.117	95.648	92.348	193.821
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01			

Appendix 4 D. Poisson Regressions by Species

	<i>Dependent variable:</i>			
	Mountain Bluebird (1)	Mountain Chickadee (2)	Northern Flicker (3)	Olive-Sided Flycatcher (4)
Burn	17.612 (1,887.345)	0.350 (0.509)	1.921 (1.261)	-1.410** (0.642)
Prescribe	19.672 (1,887.344)	0.601 (0.390)	-0.312 (1.355)	-1.867*** (0.693)
Habitat	-0.527 (1.053)	-1.156*** (0.430)	-0.795 (1.182)	-0.923* (0.513)
Altitude	0.005*** (0.002)	0.003*** (0.001)	-0.008*** (0.002)	-0.001 (0.001)
Canopy Cover	-2.928 (2.822)	2.100** (0.979)	3.009 (1.845)	0.690 (1.679)
FHD	2.954* (1.748)	0.296 (1.397)	1.987 (3.716)	-2.382 (1.641)
Constant	-62.458 (1,887.397)	-24.607*** (8.571)	57.817*** (19.251)	6.872 (9.834)
Observations	48	48	48	48
Log Likelihood	-30.775	-73.201	-29.764	-41.936
Akaike Inf. Crit.	75.550	160.401	73.528	97.873
<i>Note:</i>	* p<0.1 ** p<0.05 *** p<0.01			

Appendix 4 E. Poisson Regressions by Species

<i>Dependent variable:</i>				
	Pygmy Nuthatch (1)	Red-Breasted Nuthatch (2)	Redwinged Blackbird (3)	Rufous Hummingbird (4)
Burn	0.704 (1.845)	-2.440 (13,405.280)	19.502 (6,719.894)	1.253 (1.208)
Prescribe	3.009** (1.426)	13.684 (8,883.759)	-1.901 (11,747.520)	1.930** (0.888)
Habitat	-0.139 (1.029)	12.300 (8,396.437)	-1.513 (1.935)	-0.360 (0.773)
Altitude	0.002 (0.002)	-0.018 (0.054)	-0.005 (0.004)	0.003* (0.002)
Canopy Cover	0.676 (2.934)	-9.835 (29.762)	-7.657** (3.012)	0.576 (2.165)
FHD	2.401 (4.171)	35.731** (18.030)	-0.227 (2.536)	7.317** (3.134)
Constant	-23.121 (17.022)	90.212 (12,198.820)	25.057 (6,719.990)	-31.814** (12.796)
Observations	48	48	48	48
Log Likelihood	-24.560	-6.024	-10.946	-34.545
Akaike Inf. Crit.	63.120	26.047	35.893	83.091

Note: * p<0.1 ** p<0.05 *** p<0.01

Appendix 4 D. Poisson Regressions by Species

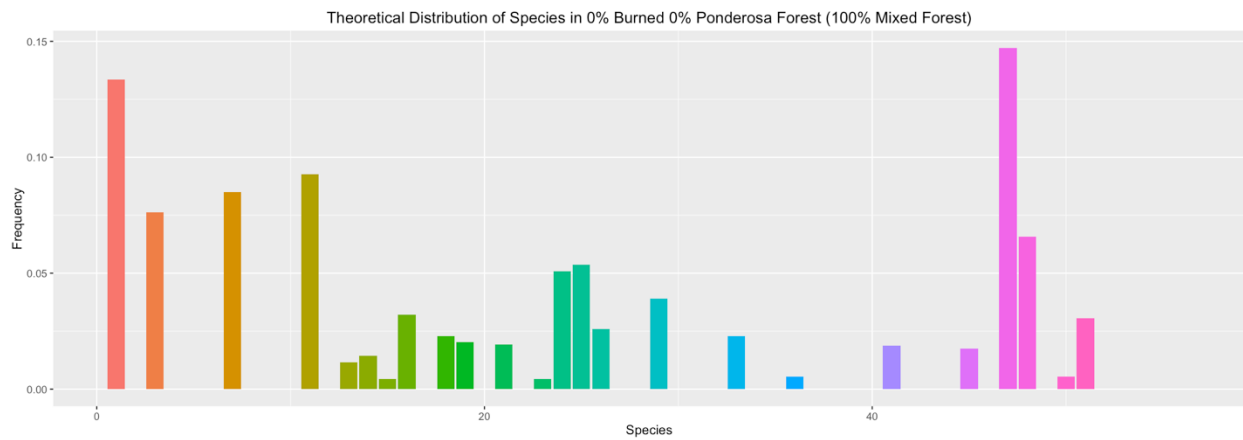
<i>Dependent variable:</i>				
	Steller's Jay (1)	Three-toed Woodpecker (2)	Townsend Solitaire (3)	Violet Green Swallow (4)
Burn	0.243 (0.463)	26.859 (7,689.517)	25.931 (2,510.147)	-0.545 (0.452)
Prescribe	-0.205 (0.404)	3.525 (10,761.010)	25.362 (2,510.147)	0.383 (0.301)
Habitat	-2.301*** (0.627)	24.271 (3,880.526)	5.487 (3.632)	0.049 (0.245)
Altitude	0.003** (0.001)	0.001 (0.003)	0.008*** (0.003)	0.001 (0.001)
Canopy Cover	1.086 (1.006)	10.333 (8.499)	12.353 (7.954)	-1.895** (0.894)
FHD	-3.060*** (0.819)	-1.750** (0.709)	0.135 (1.294)	5.115*** (1.247)
Constant	-25.357** (11.918)	-58.835 (8,613.244)	-102.029 (2,510.347)	-8.185* (4.193)
Observations	48	48	48	48
Log Likelihood	-68.132	-16.131	-18.677	-113.565
Akaike Inf. Crit.	150.264	46.261	51.354	241.129

Note: * p<0.1 ** p<0.05 *** p<0.01

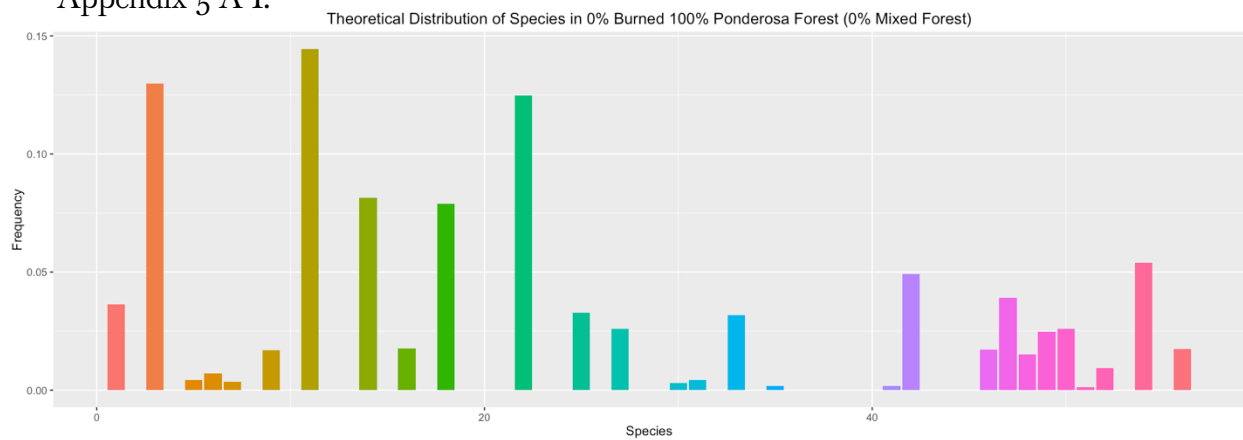
Appendix 4 G. Poisson Regressions by Species

	<i>Dependent variable:</i>		
	Warbling Vireo (1)	Yellow Warbler (2)	Yellow Rumped Warbler (3)
Burn	-0.779 (1.228)	-0.561 (0.888)	1.247 [*] (0.666)
Prescribe	-1.843 (1.128)	-3.172 ^{**} (1.417)	1.441 ^{**} (0.592)
Habitat	-0.678 (0.978)	0.077 (0.876)	-0.562 (0.473)
Altitude	0.0001 (0.002)	-0.005 ^{***} (0.002)	0.002 ^{**} (0.001)
Canopy Cover	4.793 ^{**} (2.109)	-2.387 (2.385)	1.466 (1.246)
FHD	5.668 (3.868)	2.848 (3.054)	-1.011 (0.974)
Constant	-8.428 (14.366)	38.712 ^{***} (13.187)	-21.058 ^{**} (8.298)
Observations	48	48	48
Log Likelihood	-27.681	-34.611	-60.428
Akaike Inf. Crit.	69.363	83.223	134.855

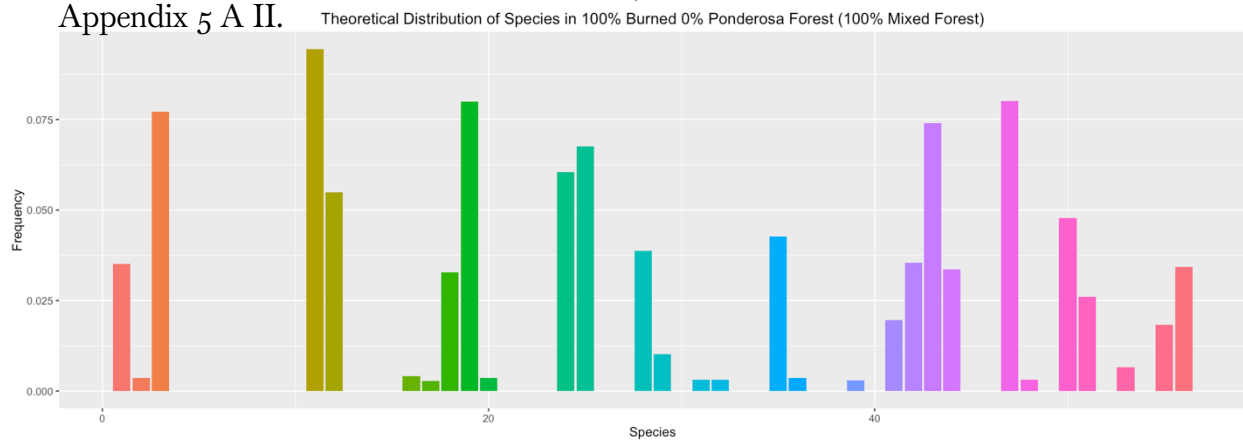
Note: * p<0.1 ** p<0.05 *** p<0.01



Appendix 5 A I.

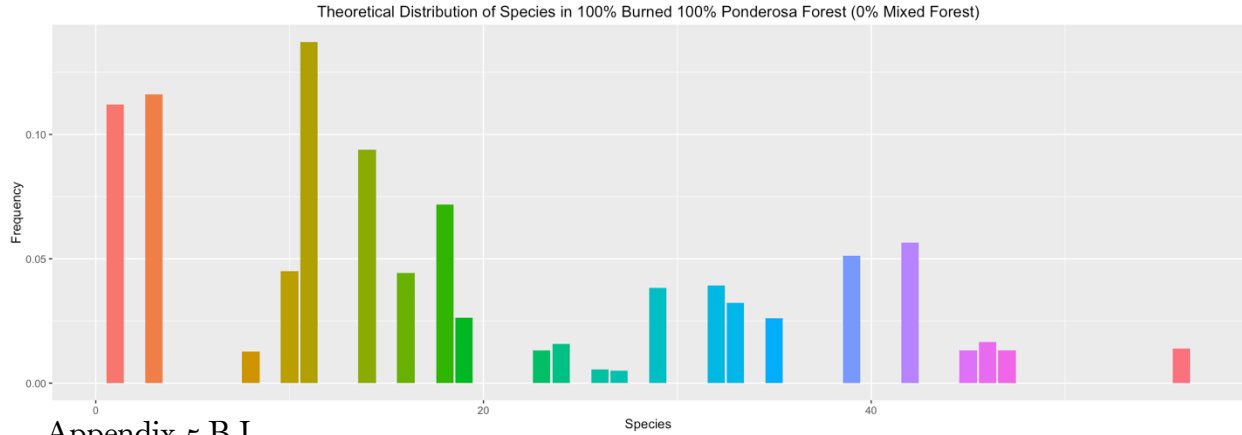


Appendix 5 A II.

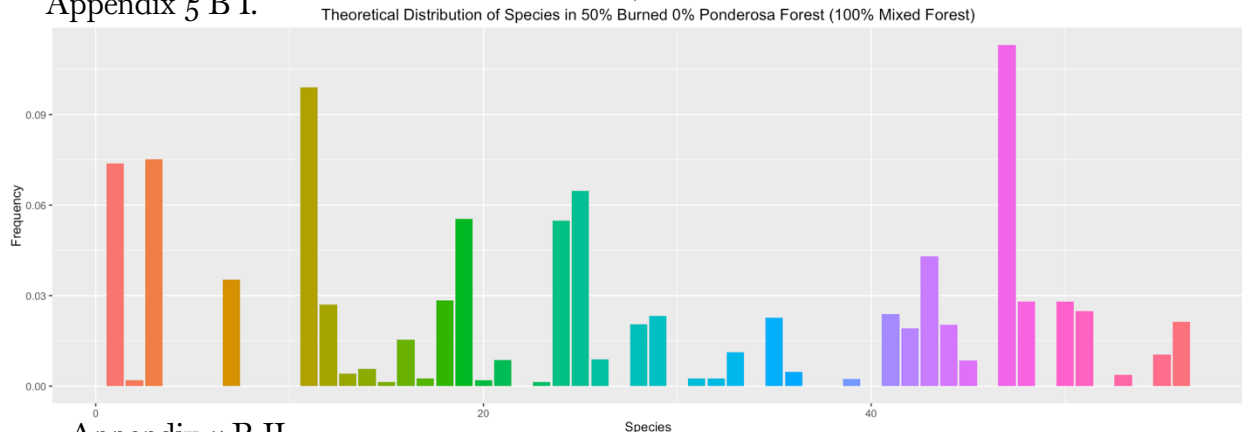


Appendix 5 A III.

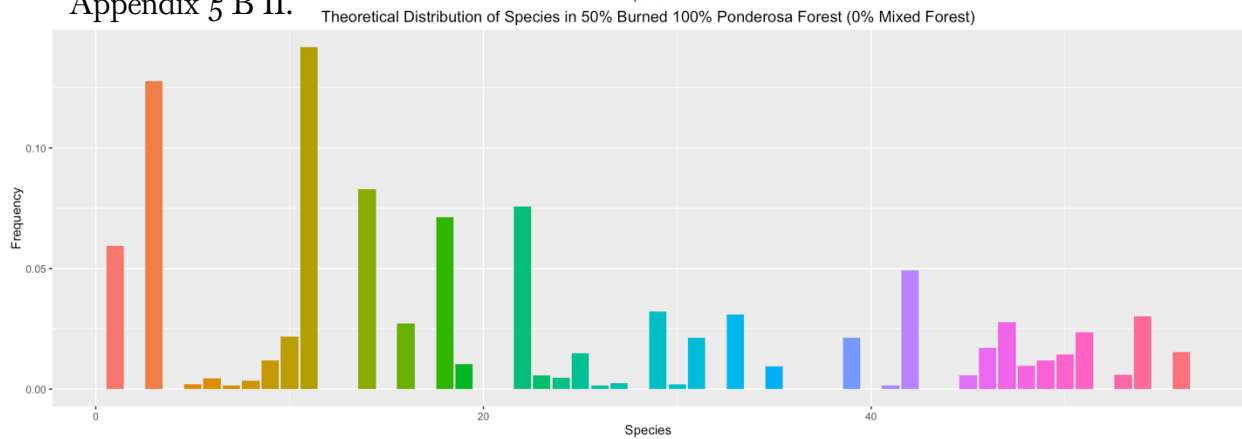
American Crow	Canyon Wren	House Wren	Red-Breasted Nuthatch	Western Tanager
American Pipit	Chipping Sparrow	Lincoln's Sparrow	Red-Tailed Hawk	Western Wood Pewee
American Robin	Clark's Nutcracker	Mallard	Redwinged Blackbird	White-Breasted Nuthatch
American Tree Sparrow	Common Raven	Mountain Bluebird	Rufous Crowned Sparrow	White-Crowned Sparrow
Ash-Throated Flycatcher	Cooper's Hawk	Mountain Chickadee	Rufous Hummingbird	William's Sapsucker
Black and White Warbler	Dark-eyed Junco	Mourning Dove	Steller's Jay	Wilson's Warbler
Black-Billed Magpie	Downy Woodpecker	Northern Flicker	Three-toed Woodpecker	Yellow Warbler
Black-Chinned Hummingbird	Dusky Flycatcher	Northern Harrier	Townsend Solitaire	Yellow-Rumped Warbler
Black-Headed Grosbeak	Dusky Grouse	Olive-Sided Flycatcher	Tree Swallow	
Brewer's Blackbird	Gray Flycatcher	Pine Grosbeak	Vesper Sparrow	
Broad-Tailed Hummingbird	Green-Tailed Towhee	Pine Siskin	Violet Green Swallow	
Brown Creeper	Hairy Woodpecker	Pygmy Nuthatch	Warbling Vireo	



Appendix 5 B I.

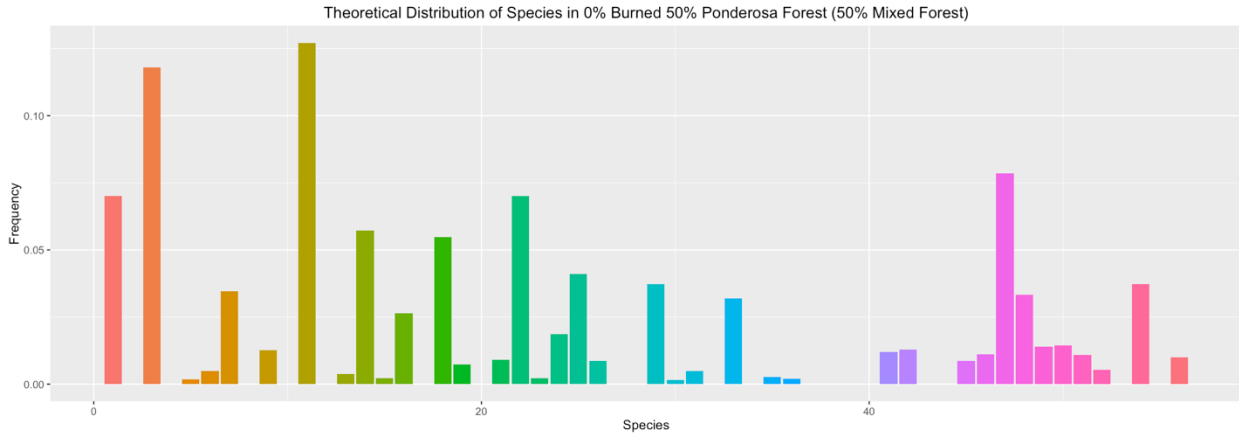


Appendix 5 B II.

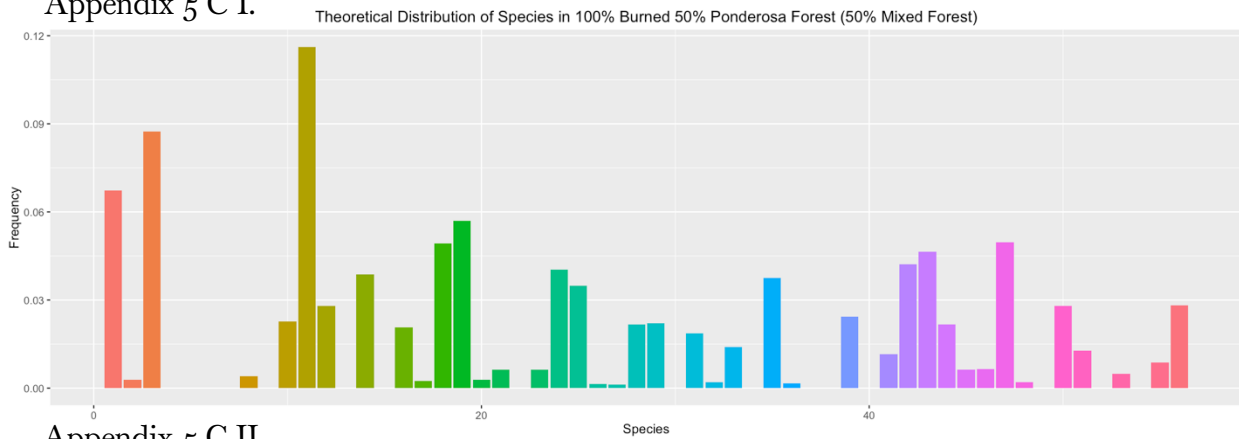


Appendix 5 B III.

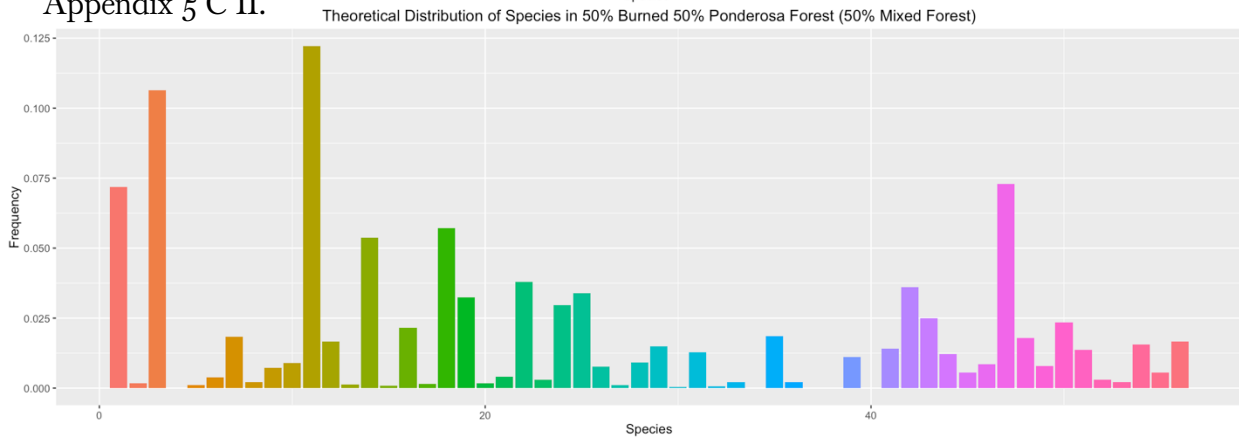




Appendix 5 C I.



Appendix 5 C II.



Appendix 5 D III.

American Crow	Canyon Wren	House Wren	Red-Breasted Nuthatch	Western Tanager
American Pipit	Chipping Sparrow	Lincoln's Sparrow	Red-Tailed Hawk	Western Wood Pewee
American Robin	Clark's Nutcracker	Mallard	Redwinged Blackbird	White-Breasted Nuthatch
American Tree Sparrow	Common Raven	Mountain Bluebird	Rufous Crowned Sparrow	White-Crowned Sparrow
Ash-Throated Flycatcher	Cooper's Hawk	Mountain Chickadee	Rufous Hummingbird	William's Sapsucker
Black and White Warbler	Dark-eyed Junco	Mourning Dove	Steller's Jay	Wilson's Warbler
Black-Billed Magpie	Downy Woodpecker	Northern Flicker	Three-toed Woodpecker	Yellow Warbler
Black-Chinned Hummingbird	Dusky Flycatcher	Northern Harrier	Townsend Solitaire	Yellow-Rumped Warbler
Black-Headed Grosbeak	Dusky Grouse	Olive-Sided Flycatcher	Tree Swallow	
Brewer's Blackbird	Gray Flycatcher	Pine Grosbeak	Vesper Sparrow	
Broad-Tailed Hummingbird	Green-Tailed Towhee	Pine Siskin	Violet Green Swallow	
Brown Creeper	Hairy Woodpecker	Pygmy Nuthatch	Warbling Vireo	

Appendix 6. Example of code used to run simulations of habitat types

```
df1 <- df[df$Habitat.Number.Assignment == 1, ]
newdata1 <- NULL
for (i in 1:1000) {
  data.samp <- df1[!is.na(df1$Point.Count.Number.Assignment) &
    df1$Point.Count.Number.Assignment == sample(1:40, 1, replace =
TRUE), ]
  newdata1 <- rbind(newdata1, data.samp)
  print(i)
}

df6 <- data.frame(table(newdata1$Bird))
```

This paper represents my own work in accordance with University regulations.