BIODIVERSITY AND SPECIES COMPOSITION BETWEEN HARDWOOD RETENTION FOREST TREATMENTS

BY

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ABSTRACT

A diverse landscape can support a more diverse range of species and allow for more complex community structures. In forested habitats, openings and changes in tree composition allow for a higher species richness due to the greater chance of niche occupancy. We used recorded bird songs and used trail cameras to determine the differences in species richness and community composition between 2 altered habitats and a control habitat in a mixed-stand forest in the John Prince Research Forest, BC, Canada. The altered habitats included a clear cut and a hardwood-retention patch. We made these comparisons using a rarefaction curve and found that the highest Shannon and species diversity was in the control, or unharvested forest. The hardwood retention patch had significantly lower diversity than the forest but was significantly higher than the clear cut diversity estimates. While looking at species composition, we found that there were forest-adapted species who were using the hardwood-retention patch in addition to the control. This suggests that the retention patch, while creating a diversity buffer on the control, is adding novel habitat to increase the overall diversity of the landscape. This method of forest harvesting may allow for retaining diversity while still making a profit from logging. Further research should be conducted to determine the value of this novel habitat at different spatial scales to understand the impacts that it may have on a larger dimension.

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Table of Contents

Contents

List of Tables

List of Figures

Introduction

For forest habitats to support a diverse community of birds, the habitat structure needs to be somewhat heterogenous; having a mixture of standing live and dead trees, coniferous and deciduous tree species, fallen trees, shrubs, and grassy openings creates more niche options that can be occupied by different, unique species (Hobson and Bayne 2000). Some bird species in such a community would be considered generalists and occupy a variety of different microhabitats within the larger forest, while others are considered specialists, and are found only in specific microhabitats (Mahon et al 2016). Those forests which have the highest heterogeneity in their physical structure should support the highest avian diversity. Old growth forests, for example, provide an array of microhabitats created when large, mature trees fall, leaving gaps in the canopy that provide structural variance to the habitat (Andersson et al 2004). When forests face natural disturbances, the communities of birds living within them will shift as the forests go through various successional phases on route to returning to old growth stands (Mahon et al 2016).

Natural forest disturbances occur through fire, flooding, insect outbreaks and wind events. But with the invasion of humankind into the natural world, there has been an increase of anthropogenic disturbances associated with natural resource extraction and development. Both natural and anthropogenic disturbances will disrupt the habitat, creating potential opportunities for new species (Väisänen et al 1986), but also removing habitat options for others. With the removal of trees from a forested landscape, wildlife that depends on such trees for nesting, breeding, or feeding will not likely be retained (Linden and Roloff 2018). Species associated more commonly with open or early-succession habitats, however, may colonize these open patches (Väisänen et al 1986). Species that rely on standing trees for cavity nests and feeding, such as woodpeckers, may only occupy disturbance patches that either retain some standing deadwood, or reoccupy these patches once they sufficiently revegetate (Tremblay et al 2018). How the habitat rebounds following the disturbance (either naturally or through management) may also change the wildlife community. For example, traditional forest harvesting (i.e. complete patch removal of trees, or clear cut logging) is often followed by replantation with monoculture stands of commercially sought seedlings. The monoculture, even-aged forest stands which this practice creates typically decreases the diversity of species settling in these stands compared to the original forest or naturally regenerated forests (Castaño-Villa et al 2019). Species' may also be limited in their ability to move through these monoculture habitats, restricting transit between remnant forest patches, as is seen with the Ovenbird, *Seiurus aurocapilla,* and spruce plantations (Villard and Hache 2012). By comparison, disturbances created through forest fires may open similar-sized patches to forest harvesting, but some standing deadwood may remain and the forest regenerates in classic succession order, eventually ending up as a mixed stand. Studies suggest the vertebrate community will return to its original state faster in such naturally disturbed forests compared to clear cut/replanted forests (Charchuk and Bayne 2018).

Size, shape, scale, and severity of the disturbance are also factors that affect the wildlife community in post-disturbance habitats (Redlich et al 2018) and may also interact with the initial cause of the disturbance - whether natural or human-induced. Species diversity may be relatively high in areas with many small patches of disturbance intermixed among larger tracks of mature forest; such a mosaic of habitats can provide sufficient edge to attract new species to compensate for loss of some species that prefer continuous forest (Redlich et al 2018, Leston et al 2018).

Species composition may also shift over time, transitioning from an initial increase in edge-associated species post-disturbance, to habitat specialists as the habitat ages. Following large fires, it may take up to 30 years for some species of the bird community to return to the area (Hobson and Schieck 1999). After clear cut logging followed by monoculture replantation, however, the original bird community may never fully return (Thorn et al 2018), suggesting that the nature of the disturbance can impact the ability of the community to rebound. One means of managing this is to employ harvesting techniques that better resemble natural disturbances, such as variable-retention harvesting. This technique retains a proportion of the standing live and dead trees and creates vertical structure and vegetative diversity to the regenerating landscape. Techniques such as this are useful for retaining diversity, as many species prefer a natural disturbance to an unnatural one (Kardynal et al 2009). Even though the composition of the bird communities that occur in the harvested areas may be fluid during the transition back to mature forest, the number of species within the area (species diversity) may remain similar by creating a mix of attracted and retained generalist species (Fourcade et al 2018). Thus, techniques in resource extraction that attempt to mimic natural disturbances in species retention/attraction will need to consider both species diversity and species composition in post-disturbance monitoring.

In central British Columbia, timber harvest is the largest source of anthropogenic disturbance to forest ecosystems. Variable–retention harvesting that removes commercially valuable trees (typically conifer species in central BC) while retaining a portion of the trees (typically non-commercial deciduous) is being tested in the region as a means of managing wildlife diversity and composition over the larger forested landscape. With standing trees still available, even if in lower stem density, forest-adapted bird and mammal species may continue to use these patches for supplementary foraging/nesting more than their use of clear cuts (Lencinas et al 2018).

Further, open-habitat adapted species may also be attracted to these lower-density patches (Fourcade et al 2018). Different types of retention harvesting will attract different species (Grodsky et al 2016). Harvesting younger trees and leaving the mature “veteran” trees will allow cavity nesters, raptors, and insectivorous birds and mammals to use this habitat post-harvest (Franklin et al 2019, Perry et al 2018, Rodgers and Koper 2017). Harvesting coniferous trees and leaving deciduous species will allow woodpeckers and herbivores to utilize a mixed-age stand of deciduous species (Lencinas et al 2018). When monitoring a community post-disturbance, there may be little overall change in measures of species diversity, as retention patches may lose some habitat specialists but gain some habitat generalist species (Rosenvald and Lõhmus 2007, Lance and Phinney 2001). Therefore, to test the effectiveness of this management technique to facilitate transitions back to initial states, it is important to compare both the species richness *and* composition of variable-retention sites against traditional clear cut harvesting.

In this paper, we compare the species diversity and composition of the avian communities between experimental clear cut forests and neighbouring deciduous (hardwood) retention patches in mixed-wood, sub-boreal forest ecosystem of central British Columbia. Our primary objective was to determine if species diversity was higher or lower in retention patches compared to similar-sized clear cut forests and neighbouring communities of unaffected mature forest (control). Our secondary objective was to determine if there is evidence that forest species were using the retention patches. Our prediction was that the patches would increase species richness by providing novel habitat, and species who often prefer forested habitats would utilize the hardwood retention patches more than they would utilize a clear cut.

Methods

Study Area

The study was conducted in the John Prince Research Forest, located approximately 25km north of Fort St. James, BC (54.669432°N, 124.414230°W)   We conducted the work on five recently-harvested blocks (within the last 10 years) where part of the block was clear cut and another was selectively-harvested. Selectively-harvested sites removed commercial conifer species (White X Engleman's Spruce *Picea glauca x englemannii*, Douglas Fir *Pseudotsuga menziesii* and Lodgepole Pine *Pinus contorta*) but retained much of the non-commercial hardwoods (primarily Trembling Aspen, *Populus tremuloides*, and Paper Birch, *Betula papyrifera*). Blocks were approximately 75ha in size, with 90% of the block in clear cut and 10% selective retention.   For our study, we designated an area of the clear cut of similar size and proximity to the surrounding forest as our clear cut treatment to compare to the selective-retention patch (Retention treatment). Within each of the five blocks, we placed a remote-sensed trail camera (Bushnell Trophy Cam HD, 2014 v.119676C) and an autonomous recording unit (ARU) (SM4, Wildlife Acoustics) in the center of the treatment (Clear cut or Retention), as well as one in the neighbouring unharvested forest as a control (Forest treatment).

Plot Preparation

In 2018, we conducted sound detection tests to determine the range of the sound detection of the ARU. A Northern Cardinal song was played at 75dB (at 1m) using a Logitech X100 Bluetooth speaker from increasing distances (25m, 50m, 75m & 100m) on all sides of the ARUs at every plot.   As Northern Cardinals are not found within the study area, they were easily distinguished from native singers in recordings.   Further, their songs include broad frequency sweeps that cover much of the range of bird song in the region.   These recordings were then analysed using

Kaleidoscope software (v.5, Wildlife Acoustics) to determine the distance that songs were visible in spectrograms and could be recognised by auto-detection software, as well as sufficiently audible in recordings for trained observers to detect them. This indicated that the functional range of the ARU was approximately 75 to 100m for passerine song.

We chose a mature tree at the center of each treatment plot within the block and mounted both the ARU (2.5m above ground) and the trail camera (1.5m ag). The ARU held two available SD card slots, into which we inserted a 32GB (primary) and an 8GB (backup) card. Trail cameras were equipped with 8GB SD cards. The mounting tree was chosen such that the detection radius of the ARU (approximately 100m) fell within the treatment type, and did not overlap the detection radius of the ARUs in the other treatments within the same block (at least twice the detection distance from another ARU, and on average 250m from the closest other ARU in the same block). If the plot center did not have any mature trees within it, a pole was erected at the plot center. The ARU was mounted to the tree using cables and fastened with clamps, and a small tree-climbing ladder was used to access the ARU. The trail camera was placed near the base of the same tree, and vegetation and brush in front of the camera was cleared to deter wind and shadows from triggering the camera. A small sample of bait (1 tablespoon of peanut butter) was placed 2.5 meters in front of the camera to draw animals into the camera and was replenished with every camera check visit.

We collected data from May 25th to July 15th in both 2018 and 2019. We returned once every 2 weeks to change the SD storage cards and replace batteries at all the sites. This schedule was established by trials in 2018 and ensured in 2019 that ARUs and trail cameras had typically not filled their drives before they were replaced. Extensive wildfires in the region impeded sampling in 2018, which accounts for some of the disparity in the dataset.

Vegetation measurements were taken at each treatment plot. These measurements include: the amount of coarse woody debris; shrub cover; the number of mature stems; and stem density. Shrub cover was assessed using a cover pole at 15 m in each of the cardinal directions from the plot center. Coarse woody debris was counted on a 15 m transect in each of the cardinal directions. Mature stems (>17.5 cm DBH) were counted within a 11.28 m radius plot.

ARU Settings

In 2018, the ARU's were set to record for 2 hours centered on dawn and dusk. During analysis of the first year's data, we found the peak period of song activity occurred within the hour centered at dawn (30min either side), or nearer to the end of recordings, so in 2019 we set ARUs to record for an hour centered on dawn. From these recordings, we selected 30 min of dawn singing (centered on dawn) from every third day throughout the date range, and enumerated all species audible in the recordings. If these recordings fell on a day of high wind or storms, we would select the next day with audible conditions as a substitute; likewise if the 30min window centered on dawn had low-audibility conditions for the start or end of the recording, we shifted the time back or forward to conduct the 30 minute inventory during more audible conditions. This method gave more flexibility in usable recording days.

The recordings were transcribed in 5 min intervals, assisted with the use of spectrographic software (Kaleidoscope, Wildlife Acoustics). A trained observer identified the presence of each species detected within the five-minute blocks, aided by reference vocalizations of local species (from personal recordings or sound archives, such as Xeno-canto or the Macaulay Library of Natural Sounds, Cornell University).

To independently classify the habitat associations of the species identified in this study, we provided a species list to a group of five ornithologists, and asked them to categorized the species as to whether their breeding habitat was characterized by either mature forest, early-seral habitat, or open country habitat. This assessment was done using the habitat descriptions from individual species accounts on Bird of North America Online (www.birdnas.org), where the reviewers were provided with some key words associated with each habitat type to use in classification. For example, these included descriptors like: "old-growth", "mature deciduous woodlands" for our Mature Forest category; "edge", "shrub", "forest openings", "young forest stands" for our Early-seral category; and, "open", "grasslands", "fields"for Open category. Reviewers made classifications without reference to which treatment types the species had been detected in, nor how often they had been detected.

Trail Camera Footage

The motion-trigger for trail cameras were set at a medium sensitivity and recorded 15 second videos when activated. A species was noted if it appeared on camera for just one frame. To avoid overestimating species occurrences, an animal would need to be off camera for at least 15 minutes before being counted again as a new individual. Camera trapping effort was measured by noting the days when the camera was functional and noting the days when the camera was unable to record footage (dead battery, full card, other). Within a block, the data on species detections was scaled to the camera in any one treatment that filled up first – for example, if one camera filled its memory card prior to being replaced, all other detections by cameras in other treatments within the same block were constrained to the same time period as the one that filled early. All video files were scored by the same individual. This data was compiled for comparison using Microsoft Excel.

Data Analysis

Number of detections per species were compiled for ARU and camera data and analysed separately. We used the package iNEXT (Chao et al. 2014, Hsieh et al. 2020) in R (v. 3.5.3. 2019, R Development Team) to Interpolate/Extrapolate Species Richness and Shannon Diversity estimates of samples by treatment type for comparison.

Results

Habitat Attributes of Treatments

The Forest treatments had the highest number of standing mature trees among the three treatments (av 28.6 ± 6.6SD/plot), compared to the Retention treatment (av 7.8 ± 2.7/plot) and the Clear cut treatment (av 0.2 ± 0.07/plot). Among the trees that were in the plots, the Forest treatment had a mixed composition of deciduous (24%) and coniferous trees (76%), while the Retention was dominated by deciduous trees (95%). There was only one tree found in all the Clear cut sites, and it was a deciduous tree.

Avian Diversity, Species Richness and Species Composition between Treatments

Analysis of the 2018 Shannon Diversity (Fig 1A) and Species Richness (Fig 1B) suggest that sampling was inadequate in these years to accurately assess biodiversity, as the number of individuals sampled (dot on lines) falls below the slope asymptotes. By contrast, the ARU data from 2019 had observed values (Fig 1C &D) that fall on the asymptotes of the interpolation/extrapolation curves – this suggests that the sampling was adequate to estimate true values for both species richness and species diversity using this data, so we restricted interpretations to the 2019 dataset.

The Shannon Diversity indices of the 2019 ARU data showed clear distinctions between all three treatments (Fig 1C). The Forest treatment had a higher Shannon Diversity index than the other two treatments; the interpolation curve (solid line) and confidence intervals fall significantly above the curves for both the Clear cut and Retention treatment for all levels of subsampling. Further, the Retention treatment's curve also fell above the curve and outside the confidence intervals of the Clear cut treatment, indicating it had an intermediate species diversity.

The species richness indices of the 2019 ARU data had more overlap of the 95%CI surrounding the interpolation/extrapolation curves. However, the observed Species Richness for the Clear cut (Fig 1D) falls outside the 95%CI of the interpolation curve of the Forest treatment, which indicates the species richness is significantly lower for the Clear cut compared to the Forest treatment when controlling for the number of individuals sampled. By comparison, the observed Species Richness for the Retention site does not fall outside the 95% CI of the Forest curve, suggesting that the two treatments can not be considered different. Indeed, the Retention treatments appear to fall in between both Forest and Clear cut treatments, with the observed values of each of these falling within the 95% confidence intervals of the Retention treatment when controlling for the number of individuals sampled.

To examine species composition, we compared the number of detections of each species in each treatment (Fig 2). There was an overall difference in the species detections across the treatment sites (X^2= 534.6, df=88, p=<0.0001). Several species contributed disproportionately to this treatment difference: Killdeer, Common Nighthawk, and Orange-crowned Warbler were detected exclusively in the Clear cut sites, and were found in this treatment type at higher values than expected by chance, and significantly less than expected by chance in Forested sites. Similarly, White-throated Sparrow, Dark-eyed Juncos, Alder Flycatchers and Willow Flycatchers were all detected significantly more in Clear cut sites and significantly less in Forest sites than expected by chance. These species were independently categorized as being primarily associated with either Open (Killdeer and Common Nighthawk) or Early-seral Forests (Orange-crowned Warblers, Dark-eyed Junco, White-throated Sparrow, Alder & Willow Flycatchers) (Appendix 1).

Cedar Waxwings, Tennessee Warblers, Western Wood Pewee, Yellow-bellied Sapsucker, and Yellow-rumped Warblers were found significantly more in Retention sites than expected by chance and were less likely to be found in Forest sites than expected by chance. All but Yellow-rumped Warblers were independently classified by observers as being associated with Early-seral forests (Appendix 1); Yellow-rumped Warblers were classified as Mature Forest associated, but were noted as preferring mature forest with significant deciduous component, which might attract them to the Retention sites. Black-capped chickadees were independently classified as Early-seral, but also secondarily classified as a Mature Forest species, and all detections in this study were split between Retention and Forest sites. Interesting, several other species also had a large proportion of detections in Retention sites, such as Lincoln's Sparrow, and Wilson's Warblers, all of which were also independently classified as associated with Early-seral habitats.

Varied Thrush, Hermit Thrush, Brown creepers, Pacific Wrens, Ruby-crowned Kinglets and Golden-crowned Kinglets were all found in significantly more in Forested sites than expected by chance, and less than expected by chance in Clear cuts and Retention sites (Fig 2). All these species were independently categorized as being primarily Mature Forest species (Appendix 1). Northern Pygmy Owls (another Mature Forest species) were also exclusively detected in Forest sites but were detected in such low number of recordings that they did not contribute as significantly to the differences.

Diversity, Species Richness and Species Composition between Treatments from Camera Traps

Species Richness and Diversity estimates from camera data was assess from 2019 results, due to the ARU data suggesting that 2018 was under-sampled. Camera results were not as defined as ARU data; the highest Shannon Diversity estimates were in the Retention treatments, but the observed diversity (points on lines) for all three sites fell within the 95% confidence estimates for the other two treatment types when accounting for the number of individuals sampled (Fig 3A). Therefore, we can't conclude that the camera traps detected differences in diversity between treatments. The same is true of species richness, which was highest in the Clear cut but again all observed values for the three treatments fell within the confidence ranges of the other treatments (Fig 3B).

Species composition, though, did differ between treatments, as the number of occurrences of species detections differed among treatments (X^2=83.6, df=38, P<0.001). Many of the bird species were found more often in the Clear cut sites than expected by chance, including Cedar Waxwings and Dark-eyed Juncos, both of which were classified independently as associated with Early-seral habitat (Appendix 1). Medium-sized mammals were found most often in the Retention sites, including Pine Marten and Striped Skunks. The Forest sites had the largest mammal found on the cameras, a grizzly bear.

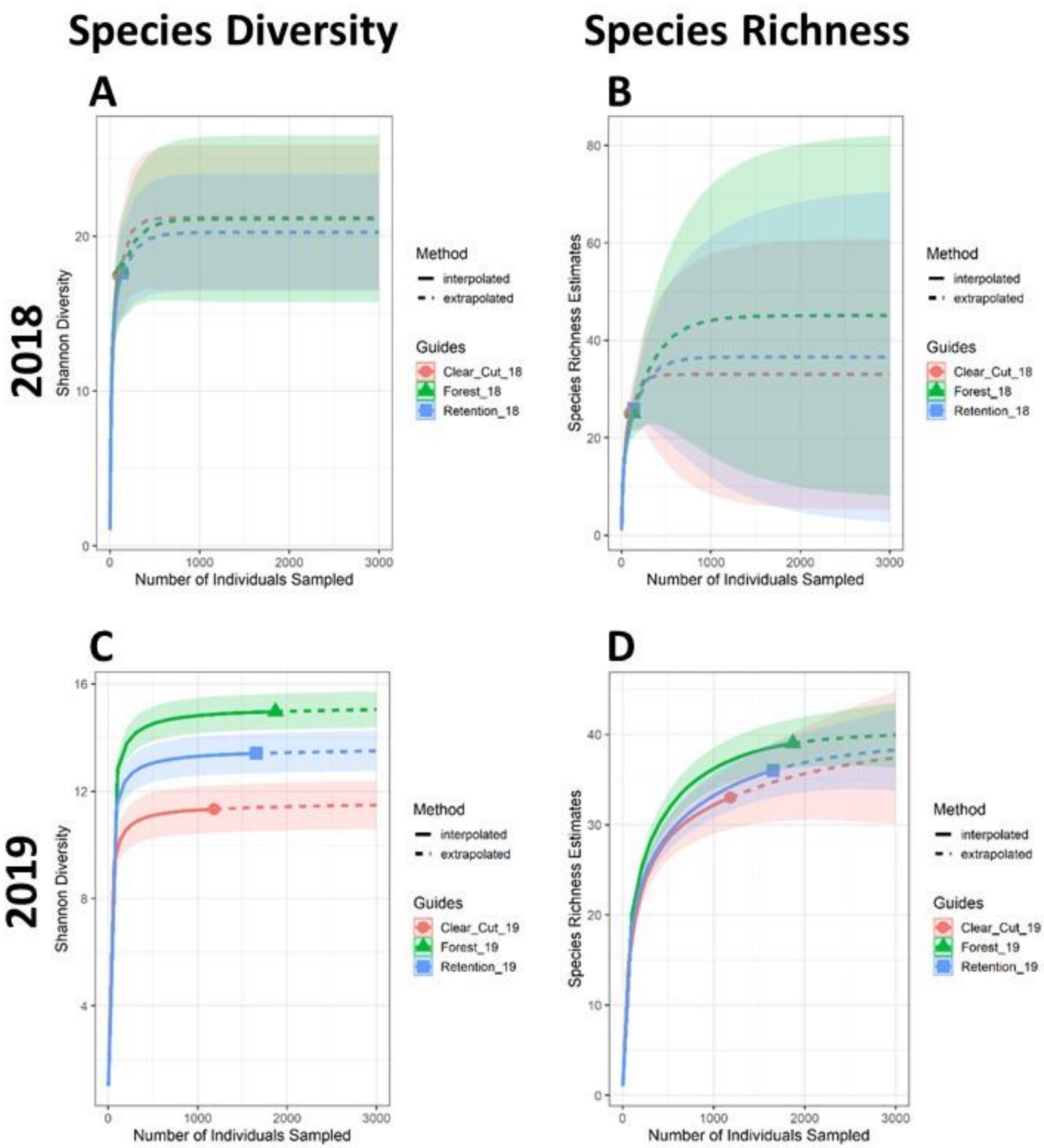

Figure 1: Shannon Diversity (A & C) and Species Richness (B & D) of bird detections in 2018 & 2019 by treatment. Points on the line indicate the actual measured value for the number of individuals sampled at each site. Solid lines are the back-interpolated estimates of Shannon Diversity or Species Richness at different smaller values of individuals sampled, and dashed lines are extrapolations of values if additional individuals had been sampled. Shaded areas are 95% Confidence intervals for the interpolated/extrapolated values.

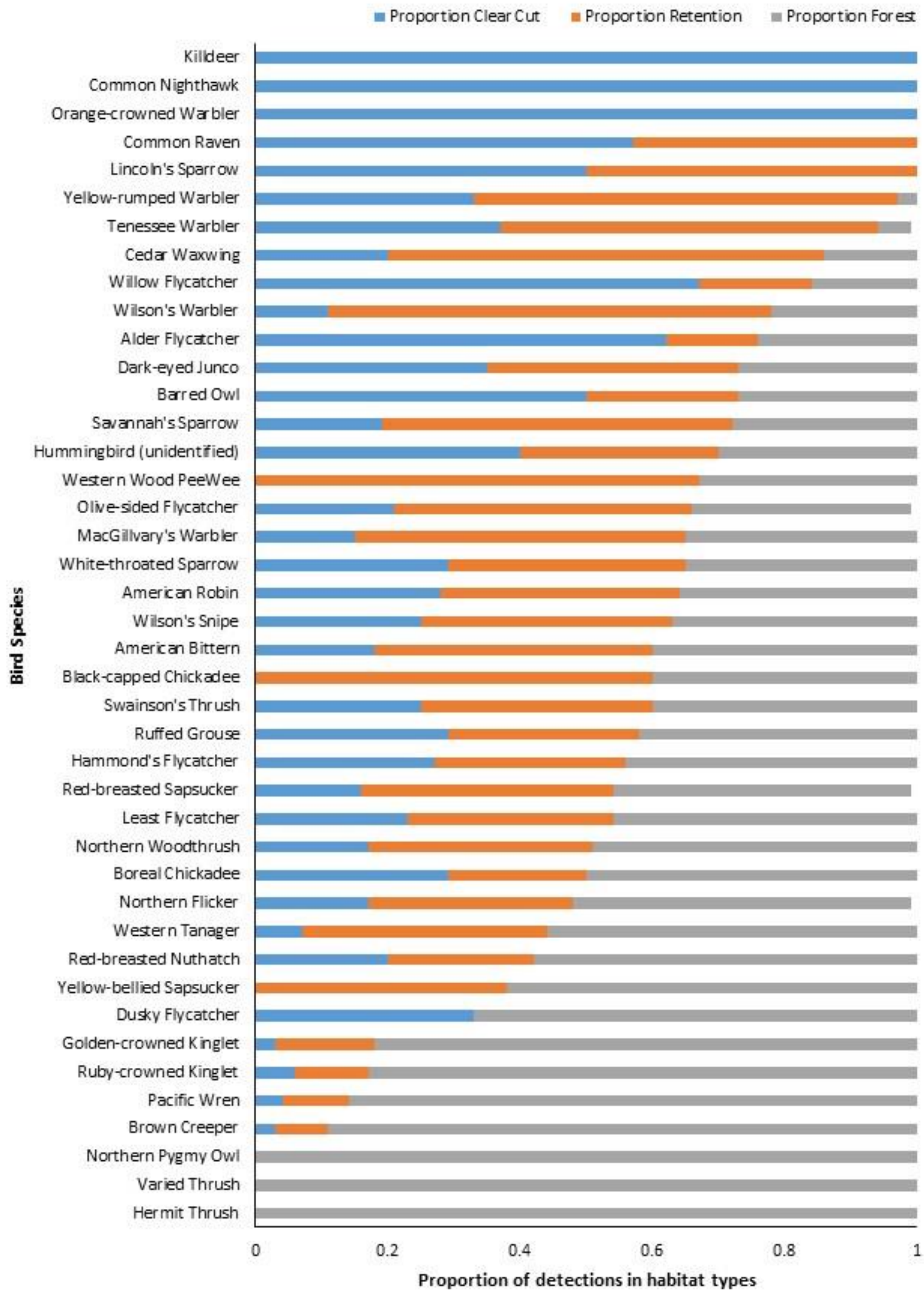

Figure 2: Proportions of each listed species detected on Autonomous Recording Units in the three treatment types: Forests, Clear cut and Retention sites.

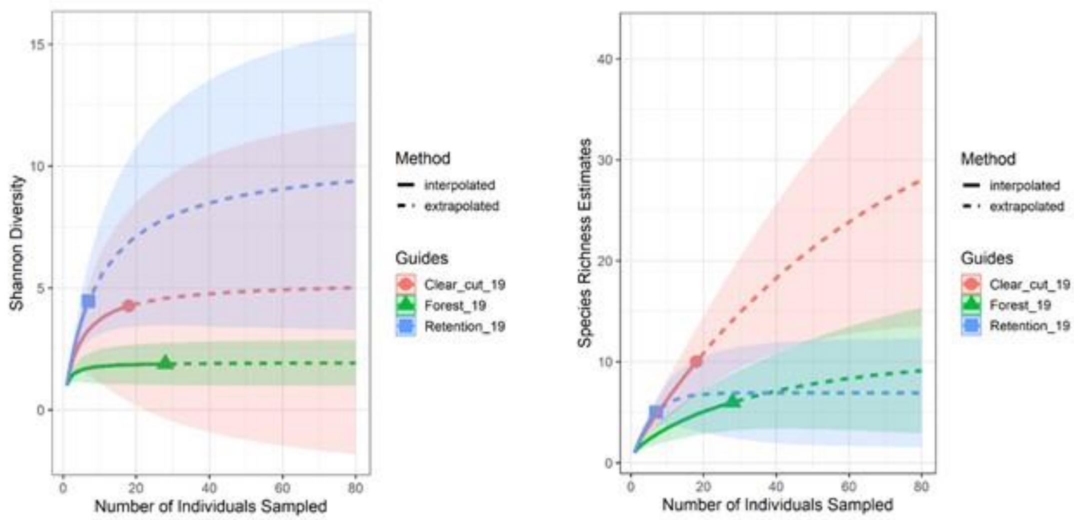

Figure 3: Shannon Diversity (A) and Species Richness (B) of camera-trap sampled individuals in 2019 by treatment. Points on the line indicate the actual measured value for the number of individuals sampled at each site. Solid lines are the back-interpolated estimates of Shannon Diversity or Species Richness at different smaller values of individuals sampled, and dashed lines are extrapolations of values if additional individuals had been sampled. Shaded areas are 95% Confidence intervals for the interpolated/extrapolated values.

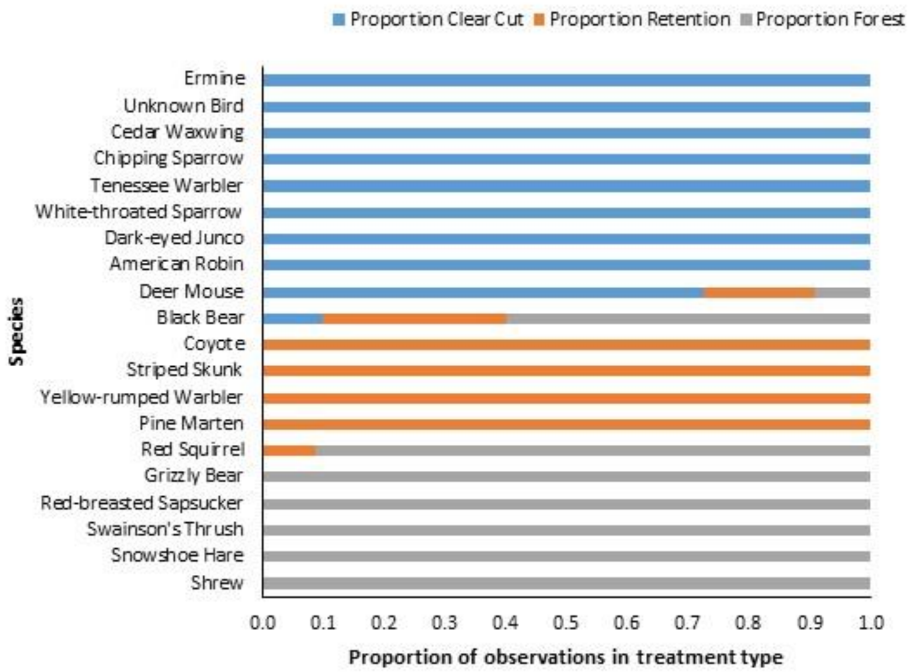

Figure 4: Proportions of each listed species detected on Camera Traps in the three treatment types in 2019: Forests, Clear cut and Retention sites.

Discussion

Diversity

Our data suggests that Retention treatments dominated by deciduous species created a softer edge between the Forest and Clear cut treatments. Several species that were independently classified as "Mature Forest" associated were detected primarily in Forest sites, but also used Retention sites secondarily. Many other species were detected almost equally in the Forest and Retention sites, but less in the Clear cut sites. Thus, species associated primarily with forests may be able to use Retention sites as a habitat buffer, while the selective-retention of deciduous trees may also create potentially novel habitat that attracts Early-seral associated species (e.g. Tennessee Warblers and Western Wood Peewees) that contribute to increasing the overall diversity of the landscape. Although the retention itself did not have the highest species diversity, it may contribute to increasing the overall diversity when considering all three Treatment types collectively.

We found that the highest Shannon diversity index occured in the Forest treatment and lowest in the Clear cut treatments, with the Retention sites being intermediate. When observing the habitat differences between these sites, the Forest sites had double the number of mature stems, and a higher variety in tree species. This could account for the higher bird diversity, as there is a more diverse forest community that can support a more diverse bird community (Väisänen et al 1986). The Forest sites also had a higher species richness than the Clear cut sites, but interestingly the species richness in Forests was not not significantly different from the Retention treatment – this further suggest the Retention treatments could serve as a buffer to minimize the overall loss of species from the region.

The lowest Shannon diversity index was found in the Clear cut treatment, which also had the lowest vertical vegetation structure available. Without this important vertical structure, there is little habitat available to most forest-dependent birds characteristic of the local ecosystem. This vertical structure is used as perches for foraging or singing, or provides nesting sites for non-ground nesting species (Laughlin et al 2013). Without this structure, many species will not spend extensive time in these spaces, and could account for the lower species richness and diversity in these sites. Most of the species detected in these areas were either Open habitat or Early-seral Forest associated species. More vertical structure can support more forest-dependent species, as vertical niche differentiation occurs (Laughlin et al 2013), which also supports the utility of integrating in selective-retention patches in logging management.

While the retention did not increase the biodiversity within its specific site, it did contribute to increasing the overall landscape-level diversity. This is due to several species being significantly more likely to be found in this treatment type than in either Forest or Clear cut sites. By providing this buffer to the clear cut, the retention has created a softer boundary between the harvested and unharvested parts of the forest. Species utilizing the forest and the clear cut primarily were both found using the retention, so it has created a space where overlap between these species may occur.

The differences were less clear in the camera data, this could be due to the smaller sample size. While the Forest had the lowest species richness, the Retention was still found between the two other treatments. Surprisingly, the Clear cut was found to have the highest diversity using camera data, which was mostly due to greater detection of birds. This result ist opposite the effect from ARU data, but the differences in diversity between habitat types are also less clear on the camera data. While the Retention had fewer species, it did attract different species that were not found in either the Clear cut or the Forest sites, such as Pine Marten and Striped Skunks. This could indicate that the Retention is increasing the overall diversity of the landscape by providing alternate habitats for species that would not commonly be found in a clear cut.

Species Composition

There were many species found exclusively in the control, these include: Hermit Thrush, Pygmy Owl, and the Varied Thrush. Other species found primarily in the control, but occasionally in the retention include: Brown Creeper, Ruby-crowned Kinglet, Golden-crowned Kinglet, and Pacific Wren. Most of these species are associated with mature coniferous forests and are rarely found in habitats other than that (Schieck and Hobson 2000). Our own independent classifiers categorized all as “Mature Forest” associated species. The camera data also showed many species observed exclusively in the Forest sites, including: Grizzly Bear, Red-breasted Sapsucker, and Shrew. This highlights the importance of maintain a significant portion of the landscape in mature forest, as these species might otherwise be lost.

While there were no species found exclusively in the Retention treatment, we did find some species which had 50% or more of their detections in the Retention sites. Many of these species were classified independently as early-seral stage preferred species, which includes habitat very similar to edge habitat. Edge habitats are described as an interface between two adjacent and opposing habitats, such as the transition between forests and large openings (Boesing et al 2018), which is represented by our Retention plots. These early-seral species will use both the open and forested aspects of the edge for different daily activities, including foraging and nesting. The retention site in this study may have helped make this transition less highly contrasted, extending the valued aspects of vertical structure and foraging availability for these species. While the Retention sites were still considered “forested”, stem densities of mature trees in these sites were only half that of Forest sites. This type of buffer effect may change the edge-effect dynamic of this forest, making this softer edge more accessible for both forest-associated species and clear cut associated species, while potentially generating novel habitat for other species that aren't associated with edge, mature mixed forest, or open country.

There were several species found exclusively in the clear cut which were associated with open-country habitats in the independent assessments. Species using open-country habitats are usually foraging (aerial predators and insectivores, as well as seed-eating species) or nesting (ground nesting birds) (Fourcade et al 2018). These species were found less often in the Retention sites, compared to species who were classified as being associated with forest habitats. This may suggest that the retention is a more important habitat component for forest-dwelling species than for open-country species, and further studies could be conducted to determine the importance of retention habitats.

The results of our study are similar to many other studies conducted on bird communities around the world. Väisänen et al (1986) found that the removal of mature forests in Finland reduced the number of forest-dependent species but increased the overall diversity by the addition of other species in the new habitat created. Many other studies have noted the general decrease in biodiversity found in clear cuts, especially clear cuts that are replanted as a monoculture stand (Rosenvald and Lõhmus 2007, Väisänen et al 1986, Perry et al 2018, Linden and Roloff 2013). Linden and Roloff (2013) looked at a different kind of selective-retention than our study, specifically snags, downed trees, and younger green trees. They found that the retention of certain habitat elements increased the biodiversity in the forest that they were studying. Many studies have found that numerous bird species benefit from other specific habitat elements such as perches (Rodgers and Koper 2017) and legacy trees (Mazurek and Zielinski 2004) when left after a harvest or disturbance. Lance and Phinney (2001) also compared clear cut, partial retention and forest patches in the central-interior of BC on diversity of birds, and similarly found the lowest avian diversity in clear cuts, while the retention and forest sites had similar diversity. This almost parallels the findings in our study, although the Retention sites in our study did not have as high of diversity as the Forest sites. Lindenmayer et al. (2018) observed the effects of harvesting and fire on bird diversity, and found the highest diversity was in the least disturbed sites, equivalent to our control Forest sites, but also suggested that retention patches are very effective to better maintain diversity when harvesting timber.

Selective-retention harvesting not only maintains better diversity in the short-term, as our study shows, but also has the advantage of faster recovery of the habitat to a level near its original diversity. Schieck and Song (2007) have estimated that post-disturbance (fire), it may take up to 70 years for mature-forest adapted bird species to return to the area. Similar delays may be expected with complete forest removal by clear cut harvesting. Integration of selective-harvesting and retention of mature non-commercial deciduous trees, such as our retention sites, may expedite the return of forest-adapted species, and it would be of interest to continue tracking our sites over time to see if this is the case.

Other studies have found that clear cuts do partially increase the overall diversity of a site by contributing new species associated with open habitat. Maintaining small cutblocks may help contribute to overall diversity, and all the species we encountered in these sites were native to the region. Integration of clear cuts and retention sites to management does have utility, particularly if designing the clear cuts in a manner that allows them to be quickly reoccupied (Vitz and Rodewald 2006), such as smaller sized clear cuts.

There was less evidence suggesting that these retention patches were as beneficial for mammals. Demarais et al. (2017) suggests that longer studies (>5 years) need to be conducted on the effect of harvest techniques on mammal usage of habitat, and also suggested conducting work over a larger area than was available for our studies. This suggests that an expansion of this project could better reflect the impact of retention harvesting on mammal species in the area.

Using two different methods of determining diversity and community composition shows an interesting difference in diversity. The camera traps did catch a variety of birds, but many species were not captured by this method, therefore the ARU is a more reliable method to determine the diversity or community composition of birds in a habitat. But the ARU was unable to capture the presence of any silent animals in the habitat, which includes all the mammals in this study. Each method captures a different, yet important, aspect of the habitat and its users.

Management Suggestions

Although the retention treatment did not have the greatest diversity or species richness, the diversification of habitats at this scale allow for an increase in overall landscape level diversity. Removal of all trees clearly leads to a decrease in diversity, as many species depend on the vertical structure and canopy cover as vital habitat features. Using this retention treatment as a way of harvesting merchantable timber while maintaining diversity and significant habitat structure could be a solution to combat the decline of biodiversity in British Columbian forests. Despite approximately half of the mature trees being removed from the landscape, the diversity remained very close to that of the control. If coniferous trees were the target species of the harvest, which they often are in British Columbia, then leaving the remainder of the stand appears to be very beneficial to the local bird communities. There is also evidence that suggests smaller clear cuts are more beneficial for forest-adapted species, as they are more likely to utilize a small opening compared to a larger opening (Vitz and Rodewald 2006). This suggests that smaller clear cuts, in combination with the retention patches around the edges, may be the most economical method to harvest and maintain diversity. In a time when climate change threatens the forestry industry, making harvest changes such as this may have long-term positive impacts on the wildlife within the harvested forest. Climate change is also threatening bird species and their habitats (Stralberg et al 2015), so making as many changes to harvesting that will benefit these species is necessary to maintain healthy populations in the future.

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Appendix Table 1. **Total number of detections of bird species by ARU according to site and year**.

Species	Clear cut 2018	Retention 2018	Forest 2018	Clear cut 2019	Retention 2019	Forest 2019	Total
White-throated Sparrow	11	15	13	210	258	257	764
American Robin	11	14	9	194	251	253	732
Swainson's Thrush	8	13	12	168	238	274	713
Dark-eyed Junco	11	15	7	207	224	159	623
Least Flycatcher	4	12	10	121	161	242	550
Wilson's Snipe	2	3	3	62	95	91	256
Northern Flicker	7	8	10	25	49	84	183
Northern Waterthrush	6	9	10	23	49	76	173
Red-breasted Sapsucker	1	3	1	20	47	58	130
Golden-crowned Kinglet	1	5	11	2	11	80	110
Tenessee Warbler	0	0	0	35	54	5	94
Pacific Wren	3	6	7	0	1	54	71
Olive-sided Flycatcher	4	5	5	10	25	17	66
American Bittern	2	1	1	8	22	21	55
Red-breasted Nuthatch	6	9	8	3	1	19	46
Cedar Waxwing	0	0	0	9	29	6	44
Savannah's Sparrow	0	2	0	8	21	12	43
Hammond's Flycatcher	2	0	0	9	12	18	41
Western Tanager	0	0	0	3	15	23	41
Brown Creeper	0	2	2	1	1	34	40
MacGillvary's Warbler	0	1	1	6	19	13	40
Yellow-rumped Warbler	0	0	0	12	23	1	36
Barred Owl	0	0	1	13	6	6	26
Alder Flycatcher	3	1	2	10	2	3	21
Hummingbird (unidentified)	2	2	1	6	4	5	20
Ruby-crowned Kinglet	1	1	6	0	1	9	18
Common Loon	2	4	1	1	6	3	17
Varied Thrush	0	0	1	0	0	15	16
Boreal Chickadee	0	0	0	4	3	7	14
Ruffed Grouse	0	0	0	4	4	6	14
Yellow-bellied Sapsucker	0	3	5	0	2	3	13
Western Wood PeeWee	0	0	0	0	6	3	9
Wilson's Warbler	1	0	0	0	6	2	9

Canada Goose	1	0	0	2	3	2	8
Common Raven	1	1	0	3	2	0	7
Willow Flycatcher	0	1	1	4	0	0	6
Black-capped Chickadee	0	1	0	0	2	2	5
Hermit Thrush	0	0	1	0	0	4	5
Dusky Flycatcher	1	0	0	0	0	2	3
Sandhill Crane	0	0	0	1	1	1	3
Lincoln's Sparrow	1	1	0	0	0	0	2
Common Nighthawk	0	0	0	1	0	0	1
Killdeer	0	0	0	1	0	0	1
Northern Pygmy Owl	0	0	0	0	0	1	1
Orange-crowned Warbler	1	0	0	0	0	0	1

Appendix Table 2. Habitat associations of species in the study

Species	Habitat Association
White-throated Sparrow	Early-seral forest
American Robin	Early-seral forest
Swainson's Thrush	Mature Forest
Dark-eyed Junco	Early-seral forest
Least Flycatcher	Early-seral forest
Northern Flickers	Early-seral forest
Northern Waterthrush	Mature Forest
Red-breasted Sapsucker	Mature Forest
Golden-crowned Kinglet	Mature Forest
Tennessee Warbler	Early-seral forest
Pacific Wren	Mature Forest
Olive-sided Flycatcher	Early-seral forest
Red-breasted Nuthatch	Mature Forest
Cedar Waxwing	Early-seral forest
Savannah Sparrow	Open
Hammond's Flycatcher	Mature Forest
Western Tanager	Mature Forest
Brown Creeper	Mature Forest
MacGillivray's Warbler	Early-seral forest
Yellow-rumped Warbler	Mature Forest
Alder Flycatcher	Early-seral forest
Ruby-crowned Kinglet	Mature Forest
Varied Thrush	Mature Forest
Boreal Chickadee	Mature Forest
Yellow-bellied Sapsucker	Early-seral forest
Western Wood-Pewee	Early-seral forest
Wilson's Warbler	Early-seral forest
Black-capped Chickadee	Early-seral forest
Hermit Thrush	Mature Forest
Dusky Flycatcher	Early-seral forest
Lincoln's Sparrow	Early-seral forest
Orange-crowned Warbler	Early-seral forest

Appendix Table 3. Total number of detections of species by trail camera

Species	Clear cut 2018	Retention 2018	Forest 2018	Clear cut 2019	Retention 2019	Forest 2019	Total
American Robin	0	1	1	1	1	19	23
Red Squirrel	1	1	3	0	6	75	86
Shrew	0	0	0	0	0	13	13
Deer Mouse	0	0	1	15	4	46	66
Snowshoe Hare	0	0	1	0	0	15	16
Black Bear	0	3	4	1	1	6	15
Swainson's Thrush	0	1	0	0	0	14	15
Dark-eyed Junco	1	1	0	1	0	4	7
Bat	0	0	0	0	0	1	1
Pine Marten	0	0	1	0	1	0	2
Yellow-rumped Warbler	0	0	0	0	1	0	1
Red-breasted Sapsucker	0	0	0	0	2	1	3
White-throated Sparrow	0	0	0	1	0	0	1
Tenessee Warbler	0	0	0	1	0	0	1
Chipping Sparrow	0	0	0	1	0	0	1
Cedar Waxwing	0	0	0	1	0	0	1
Unknown Bird	0	0	0	2	0	3	5
Flying Squirrel	0	0	0	0	0	1	1
Ruffed Grouse	0	1	0	0	0	3	4
Canadian Lynx	0	0	0	0	0	2	2
Ermine	0	0	0	1	0	0	1
Striped Skunk	0	0	0	0	1	0	1
Grizzly Bear	0	1	1	0	0	0	2
Moose	0	0	2	0	0	0	2
Elk	0	0	6	0	0	0	6
Woodchuck	1	0	2	0	0	0	3
Coyote	0	1	0	0	0	0	1