Avian Response to Old-growth Maintenance Logging in the Swan River State Forest, Montana

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Abstract:

Old-growth maintenance silvicultural treatment is a tool implemented to retain old-growth forest attributes, remove shade-intolerant trees, and create canopy gaps. Our objectives were to examine how these treatments affect avian diversity and density. We used a Before-After/Control-Impact Pairs study design by pairing old-growth stands proposed for harvest with nearby untreated stands, based on their pre-treatment forest structure and composition similarity. Logging reduced basal area by 40 percent ($P < 0.05$), overstory canopy cover by 31 percent ($P < 0.05$), and the density of trees >42 cm dbh **(**$P < 0.05$). No major changes in bird species composition or diversity were detected. Only the relative densities of evening grosbeaks changed (58% reduction in density, $P < 0.05$), likely due to the removal of insect-infested trees. All old-growth associated bird species continued to occupy treatment stands under the landscape conditions we observed. We did not evaluate avian survival or reproductive success, which would provide beneficial metrics for further interpretation of the potential effects of old-growth maintenance treatments.

Key Words: old-growth, logging, avian diversity, species density, biodiversity, BACIP

Introduction

The impact of logging on old-growth forests and wildlife, and maintenance of this important forest age class on the landscape have long been a concern in the northwestern United States (Franklin et al. 1981, Harris 1984, Ruggiero et al. 1991, Bart and Forsman 1992, Hunter 1999). Increasingly, partial logging treatments to meet ecological objectives are implemented to balance the need to generate revenue, while also providing a steady, long-term timber supply (Gustafsson et al. 2012). Partial logging encompasses a variety of silvicultural treatments that retain a greater density of trees than traditional regeneration treatments such as clear cut and seed tree treatments. Such treatments are often selected to help retain biological diversity and to avoid adverse impacts to forest communities associated with regeneration treatments (Rosenvald and Lohmus 2008, Gustafsson et al. 2012).

Old-growth maintenance silvicultural treatments are one of the partial logging treatments that the Montana Department of Natural Resources and Conservation (DNRC) implements to retain old-growth attributes, while also removing encroaching shade-tolerant tree species (e.g., grand fir {*Abies grandis*}). These treatments create small canopy gaps to encourage the regeneration of shade-intolerant tree species (e.g., western larch {*Larix occidentalis*} and ponderosa pine {*Pinus ponderosa*}). Old-growth forests in the Northern Rockies were shaped by periodic disturbance, such as wildfire (Pfister et al. 1977, Green et al. 1992). Hence, old-growth maintenance treatments are intended to imitate vegetation-altering effects of low to moderate-intensity fires (Bauhus et al. 2009, Larson et al. 2012). Harvest prescriptions are designed to meet or exceed old-growth definitions reported by Green et al. (1992), which specify minimum criteria for the number of trees of a given diameter, basal area, and age based on forest cover type and habitat type groups. However, these old-growth maintenance treatments still remove or alter old-growth forest attributes, such as the density of large live trees, coarse woody debris, snags, the amount of decadence, multistoried tree canopy, basal area, and crown cover, which may affect habitat quality and use by old-growth associated wildlife.

Effects of partial harvest of mature timber stands on birds vary due to differences in silvicultural treatments applied and local forest conditions. Some communities increased in species diversity while others decreased (Bakermans et al. 2012, Kendrick et al. 2015, Twedt and Somershoe 2009, Vanderwel et al. 2007). Overall, ground foragers and flycatchers tend to benefit from logging mature and old-growth stands while foliage gleaners and cavity nesters are negatively impacted (Tobalske et al. 1991, Beese and Bryant 1999, Vanderwel et al. 2007, Vanderwel et al. 2009). No avian species associated with old-growth are federally listed as Endangered or Threatened in Montana; however, some species do have moderate Conservation Concern Scores (CCS, see Apendix 1) or are declining regionally (Partners in Flight 2019). Some old-growth associated species, such as brown creepers (*Certhia americana*; moderate CCS) are especially sensitive to partial harvests with densities declining 50 percent when 30 to 40 percent of basal area is removed (Vanderwel et al. 2007, D'Astous and Villard 2012). In northwest Montana, researchers have not found large differences in avian community composition when comparing logged and unlogged dry Douglas-fir (*Pseudotsuga menziesii*) and western larch old-growth forest types (Hoffland 1995, Hutto et al. 2014). However, a restoration treatment appropriate for dry stands with frequent low-intensity burns was examined in those studies, whereas old-growth maintenance treatments applied in more mesic stands may produce different results.

We investigated the impact of old-growth maintenance treatments in mesic forest types found in the Swan Valley, Montana. We collected data on bird communities because they reflect the abundance and diversity of coexisting species and provide a cost-effective way to assess ecological community change (Hutto 1998). Our objectives were to examine how old-growth maintenance treatments affect avian diversity and the density of individual bird species, particularly old-growth associated species. Our null hypothesis was that old-growth maintenance treatments have no impact on bird species diversity or density. We also summarize post-logging changes to forest stand attributes so that our results can be compared to those of other studies.

Study Area

We conducted this study in the 22,787-ha Swan River State Forest, which is in a forested landscape surrounded by Flathead National Forest lands 16 km south of Swan Lake, MT (Fig. 1). Montana DNRC removes approximately 6.8 million board feet (MMBF) from the Swan River State Forest annually. Our study was conducted in the Scout Lake Multiple Timber Sales Project Area which involved the removal of 20.4 MMBF of timber (approximately 5,100 log truck loads) from 813 ha over a 4-year period (DNRC 2012). This logging operation occurred around the midpoint of the 6-year time frame of our study and involved multiple timber sale contracts. We selected old-growth timber stands below 1,200 m elevation consisting primarily of western larch and Douglas-fir with grand fir understories for monitoring. Old-growth maintenance treatments are infrequently applied, and we studied all available stands within the study area that were proposed for these treatment types during the time frame of the study.

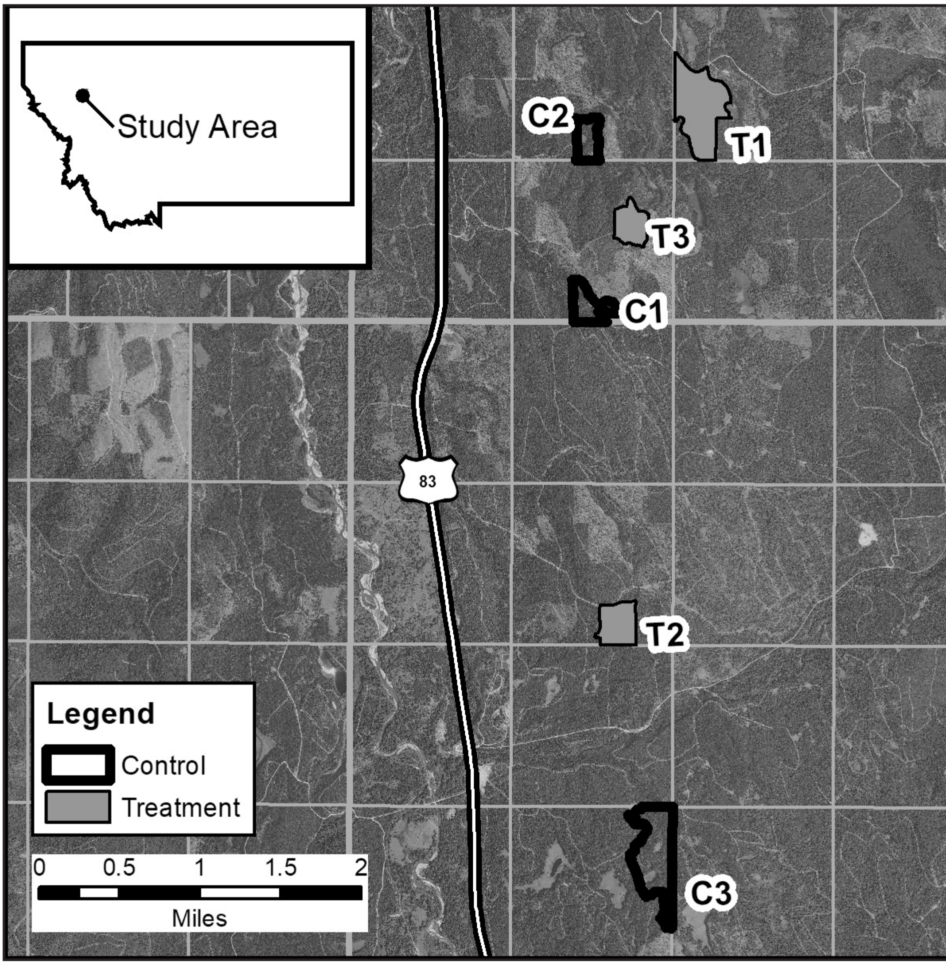

Figure 1. Location of six BACI study stands in the Swan River State Forest, Montana. C = control, T = treatment. Paired stands are assigned the same number.

Methods

Stand Sampling Design

We used a Before-After/Control-Impact Pairs (BACIP) experimental study design and paired three old-growth stands proposed for harvest (treatment) with three untreated old-growth stands (control) (Fig. 1, Stewart-Oaten et al. 1986). All study stands met old-growth definitions of Green et al. (1992). Treatment stands were selected by foresters to meet project objectives including generating revenue, reducing fuel loads, and improving forest health (DNRC 2012). We paired treatment stands with control stands based on their similarity regarding forest type, density of mature trees, density of all conifers, and dominant conifer species in the understory. When more than one match for a treatment stand was identified based on these criteria, control stands were selected randomly. Our pairing of control and treatment stands was intended to reduce the possibility that initial differences in vegetation parameters such as habitat type or conifer density might contribute to the differences in the bird species parameters we would be assessing. Additionally, treatment stands were logged under different timber sale contracts that were executed in different years, but the Before-After sampling period was the same for all control and treatment pairs, thus reducing the potential influence of weather-related factors. The distance between control and treatment stands ranged from 1.7 km to 5.6 km ($\bar{X}$ = 3.9, SD = 2.0) and the size of control and treatment stands ranged from 9 to 37 hectares ($\bar{X}$ = 19, SD = 12). The sizes of the treatment stands varied, and the corresponding control stands were not equal in size to their counterparts.

Bird Surveys

Point counts were conducted twice per summer between 15 June and 12 July 2012 to 2017 (Thompson 2002). Point counts began approximately 15 min before sunrise and ended by 1000 hrs. Point counts were conducted by a sole observer standing at a fixed point recording all bird species detected by sight or sound for 10 min. Distances from the observer to the bird were estimated to provide the necessary parameter for approximating a density value for each species (Buckland et al. 2015). Survey points were located within each stand using the ArcGIS (9.3.1) random point generator tool and were at least 250 m apart and 100 m from stand edges (ESRI 2009). The number of points within a survey stand varied according to size of the stand and ranged from two to seven per stand ($\bar{X}$ = 5, N = 22 control points, N = 24 treatment points).

At least 2 years of pre-harvest and 2 years of post-harvest bird survey data were collected in each control-treatment pair. The amount of pre- and post-harvest data collected varies depending on the year the treatment stand was logged (control/treatment one = 2 years pre-harvest, 3 years post-harvest; control/treatment two = 3 years pre- and post-harvest; control/treatment three = 4 years pre-harvest, 2 years post-harvest). Data from treatment stand one in the summer of 2014 when logging was incomplete in this stand was excluded from analysis.

Vegetation Surveys

Vegetation parameters were measured in control stands and treatment stands before and after logging to provide information on how old-growth maintenance treatments affected stand attributes and to estimate differences between control and treatment stands. Ten vegetation plots were randomly placed within each survey stand. Overstory canopy cover was estimated using a GRS densiometer with 10 readings taken every 15 m between vegetation plots. Basal area of trees >2 m tall was estimated in variable plots with a Relaskop, and tree species, dbh, and status (live or dead) was recorded. Trees per ha ≤2 m tall were counted in fixed 1/100-ha plots and categorized according to species and height class. We visually estimated the percentage ground cover of shrubs and grasses, the presence and abundance of conifer seedlings, hardwoods, coarse woody debris, moss, litter, rock, and bare soil within the 1/100-ha sampling plots and recorded the 10 dominant understory plant species. Coarse woody debris was sampled along a 15 m transect from plot center on a random azimuth obtained using a random number generator (Haahr 2012). Diameters of sound and decayed coarse woody debris >8 cm were recorded where they intersected transect lines (Brown 1974).

Data Analysis

We truncated our bird observations at 150 m (approximately 10% of observations were eliminated) to reduce the impact of birds located outside of the study stands on diversity estimates. Data were analyzed using R version 3.2.3 statistical software (R Core Team, 2015). The Shannon diversity index (*H*) (Shannon 1948), which accounts for species richness (*S*) and the relative abundance of each bird species, was calculated using the Vegan package in R (Oksanen et al. 2017). We used bootstrapping to calculate confidence intervals (Gardener 2014).

We calculated the density of bird species within each study stand before and after logging for species with at least 50 total detections. We selected the best detection function model for each bird species using the Program R Distance package (Miller 2017) according to the variable radius protocols described in Miller et al. (2017). Detection functions are corrective equations that account for differences in detectability among species including how loud and often birds sing, as well as their behavior. Logging removes vegetation and may increase detectability of birds because they may be easier to see and hear in a logged stand. We tested logging status (logged or unlogged) as a potential covariate in our models and selected detectability models based on Akaike's Information Criterion (AIC) (Akaike 1987). All models <2 AIC units greater than the best model were considered plausible models. Effect size is described in terms of relative density as indicated by the BACIP contrast, which represents the change in species density in treatment stands relative to the change in species density in paired control stands following logging. We also report the percent increase or decrease in relative density (BACIP contrast/pre-treatment density in treatment stands).

We used the Encounter Rate (ER, birds per point count) to assess impacts on brown creepers and pacific wrens (*Troglodytes pacificus*), which are of interest but had too few detections to estimate densities using detection functions. ER does not provide information on relative abundance differences among species and does not allow for analysis of covariates but does provide information on how observations increased or decreased post-harvest.

Vegetation characteristics of control plots and treatment plots pre- and post-harvest were summarized with descriptive statistics. T-tests (two-tailed) were used to test for differences in bird density in paired treatment stands and control stands post-harvest, encounter rates, and vegetation characteristics of treatment stands pre- and post-harvest. We used a modified version of the T-test to compare *H* in study stands before and after harvest (Gardener 2014, Hutcheson 1970). We accepted $P \leq 0.05$ as indication of difference and provide discussion of results with marginal significance $0.05 < P < 0.10$.

Results

Species Diversity

We observed 64 bird species and 5,331 individuals (Appendix A). H increased post-harvest in one control stand (control two, $P = 0.01$), but did not change post-harvest in treatment stands or the other control stands (control one, $P = 0.47$; control three, $P = 0.67$; treatment one, $P = 0.91$; treatment two, $P = 0.64$ treatment three, $P = 0.16$) (Fig. 2) . Fourteen common bird species such

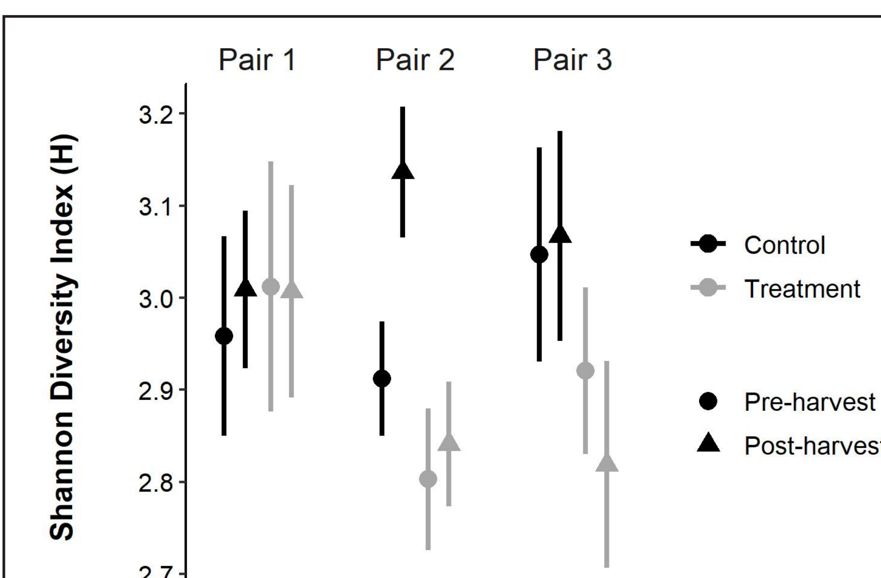

Figure 2. Shannon Diversity Indices (H) for control (black) and treatment (gray) stands pre- and post-harvest with 95% confidence intervals obtained by bootstrapping. Control stands were considered post-harvest based on if the paired treatment stand had been harvested. Higher values indicate higher species diversity.

as American robins (*Turdus migratorius*), common ravens (*Corvus corax*), and northern flickers (*Colaptes auratus*) were only observed in the post-harvest period in control stand two, influencing the increase in species diversity. Comparatively, new species detections in the post-harvest period ranged from 3 to 11 in the other study stands.

Species Density

We applied species-specific detection functions and estimated the densities of 22 species with ≥50 observations. Logging did not impact bird detection probability for those 22 species in our models. Relative densities of evening grosbeaks (*Coccothraustes vespertinus*) decreased 58% ($P < 0.05$), following old-growth harvest (see BACIP Contrast values, Table 1). Overall, a large shift in bird community composition did not occur and the density of the most common species did not appreciably differ following harvest (see *P*-values for bolded species, Table 1). Old-growth associated bird species continued using treated stands post-harvest, but no significant change was detected (Fig. 3, Table 1).

Brown creepers and pacific wrens also continued using treated stands post-harvest but no change in ER was detected (brown creeper: ER BACIP contrast = -0.14, P = 0.34; pacific wren ER BACIP contrast = -0.11, P = 0.28).

Stand Characteristics

Approximately 40 percent of live-tree basal area was removed by old-growth maintenance treatments, and canopy cover of mature trees declined from 59 percent to 41 percent (Table 2). Snags per hectare also declined from 37 to 13 per ha, although the average diameter increased, indicating that large snags were retained according to harvest prescriptions. Trees per ha ≤2 m tall decreased by 32 percent and coarse woody debris (tons per ha) decreased by 26 percent. Stand averages for the canopy cover of mature trees, basal area of green trees, trees/ha >2 m tall and >42 cm dbh, Douglas-fir trees ≤2 m tall, and the ground cover of coarse-woody debris and moss were reduced in treatment stands ($P < 0.05$; Table 2). Overall, common understory shrub, forb, and grass species did not change post-harvest although prince's pine (*Chimaphila umbellata*), which is associated with old-growth forests and sheltered stands (Freedman 1983), decreased following harvest. Example photographs depicting control stands and managed stands pre- and post-harvest are displayed in Fig.4.

Discussion

We reject our null hypothesis that old-growth maintenance treatments have no impact on bird communities considering that the relative densities of evening grosbeaks decreased following harvest. However, we did not observe large changes in species diversity, the composition of bird communities, or species density. Species diversity increased in control stand two post-harvest (Fig. 2), but surprisingly no change was detected in treatment stands. The increase in diversity in control stand two was caused by fourteen common bird species using this stand only in the post-harvest period. We believe that logging that occurred in two mature stands within 500 m of this stand may have displaced these birds into control stand two causing these results.

We did not detect a large shift in community species composition between harvested and unharvested old-growth stands. Townsend's solitaires (*Myadestes townsendi*), yellow warbler (*Setophaga petechia*), and western wood-pewee (*Contopus sordidulus*) were only detected in logged stands, however there were only five observations of these birds (Appendix A). Vegetation data suggest that sufficient vegetative structure and other favorable habitat attributes were retained in the old-growth maintenance treatments to prevent a dramatic alteration in bird species composition. Average overstory canopy cover in post-harvest treatment stands in our study was 41 percent. Previous research suggests that bird species occurrence or density does not change until canopy cover drops below 40 percent (Sallabanks et al. 2006).

Table 1. Density of birds/ha in control and treatment stands (± SE) before and after logging. BACIP contrast indicates relative density increase (+) or decrease (-) post-harvest in treatment stands in comparison to control stands. The percent change is calculated as BACIP contrast in density as a percentage of densities observed in treatment stands before logging (**P < 0.05, *P < 0.10). Abundant species are bolded.

Species >	CCS[1]	Control-Pre (N = 72)		Control-Post (N = 54)		Treatment-Pre (N=64)		Treatment-Post (N=66)		BACIP	%	P
50 Detections[1]		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Contrast	Change	
Pileated woodpecker, *Drycopus pileatus*[OGA]	7	0.0013	0.0006	0.0010	0.0003	0.0007	0.0005	0.0011	0.0003	0.0007	93%	0.068*
Hammond's flycatcher, *Empidonax hammondii*[OGA]	10	0.2386	0.0747	0.2099	0.1063	0.0423	0.0292	0.0873	0.0447	0.0737	174%	0.550
Cassin's vireo, *Vireo cassinii*	10	0.0169	0.0129	0.0432	0.0106	0.0173	0.0004	0.0343	0.0083	-0.0094	-54%	0.714
Canada jay, *Perisoreus canadensis*[OGA]	9	0.0106	0.0040	0.0100	0.0035	0.0071	0.0036	0.0058	0.0029	-0.0007	-10%	0.934
Black-capped chickadee, *Poecile atricapillus*	7	0.1195	0.0460	0.1574	0.0316	0.1254	0.0347	0.1125	0.0307	-0.0508	-40%	0.106
Mountain chickadee, *Poecile gambeli*	10	0.0323	0.0071	0.0502	0.0080	0.0523	0.0273	0.0713	0.0379	0.0010	2%	0.987
Chestnut-backed chickadee, *Poecile sclateri*	13	0.1577	0.0546	0.1787	0.0279	0.2436	0.0653	0.1804	0.0375	-0.0842	-35%	0.455
Red-breasted nuthatch, *Sitta canadensis*	6	0.0695	0.0118	0.0747	0.0093	0.0722	0.0157	0.0773	0.0089	0.0000	0%	1.000
Golden-crowned kinglet, *Regulus satrapa*[OGA]	**8**	**0.3358**	**0.0745**	**0.3530**	**0.0563**	**0.4224**	**0.0565**	**0.3079**	**0.0279**	**-0.1317**	**-31%**	**0.091***

Table 1. (Continued)

Species >	CCS[1]	Control-Pre (N = 72)		Control-Post (N = 54)		Treatment-Pre (N=64)		Treatment-Post (N=66)		BACIP	%	P
50 Detections[1]		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Contrast	Change	
Ruby-crowned kinglet, *Regulus calendula*	6	0.0294	0.0171	0.0330	0.0055	0.0223	0.0023	0.0277	0.0182	0.0018	8%	0.895
Swainson's thrush, *Catharus ustulatus*[OGA]	**10**	**0.2340**	**0.0457**	**0.2770**	**0.0186**	**0.2614**	**0.0211**	**0.3223**	**0.0099**	**0.0179**	**7%**	**0.790**
American robin, *Turdus migratorius*	5	0.0425	0.0207	0.0322	0.0134	0.0241	0.0017	0.0216	0.0046	0.0078	32%	0.713
Orange-crowned warbler, *Oreothlypis celata*	9	0.0115	0.0049	0.0086	0.0046	0.0144	0.0034	0.0281	0.0100	0.0166	115%	0.248
MacGillivray's warbler, *Geothlypis tolmiei*	12	0.0216	0.0073	0.0273	0.0073	0.0170	0.0104	0.0157	0.0035	-0.0070	-41%	0.602
Yellow-rumped warbler, *Setophaga coronata*	6	0.0400	0.0093	0.0734	0.0247	0.0483	0.0048	0.0800	0.0052	-0.0018	-4%	0.939
Townsend's warbler, *Setophaga townsendi*[OGA]	11	0.0723	0.0144	0.0732	0.0035	0.0960	0.0247	0.0541	0.0200	-0.0428	-45%	0.177
Chipping sparrow, *Spizella passerine*	**8**	**0.6998**	**0.0470**	**0.8316**	**0.0387**	**0.5528**	**0.0306**	**0.8815**	**0.0636**	**0.1970**	**29%**	**0.395**
Dark-eyed junco, *Junco hyemalis*	**8**	**0.1555**	**0.0204**	**0.2131**	**0.0298**	**0.1359**	**0.0141**	**0.2725**	**0.0149**	**0.0790**	**58%**	**0.061***
Western tanager, *Piranga ludoviciana*	9	0.0868	0.0169	0.0785	0.0069	0.1047	0.0110	0.1083	0.0118	0.0118	11%	0.606

Table 1. (Continued)

Species >	CCS[1]	Control-Pre (N = 72)		Control-Post (N = 54)		Treatment-Pre (N=64)		Treatment-Post (N=66)		BACIP	%	P
50 Detections[1]		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Contrast	Change	
Red crossbill, *Loxia curvirostra*	8	0.0361	0.0099	0.0314	0.0088	0.0180	0.0030	0.0223	0.0064	0.0090	50%	0.265
Pine siskin, *Spinus pinus*[OGA]	10	0.1311	0.0365	0.1294	0.0236	0.1616	0.0323	0.1358	0.0089	-0.0636	-15%	0.516
Evening grosbeak, *Coccothraustes vespertinus*	13	0.0923	0.0157	0.1080	0.0352	0.1095	0.0181	0.0616	0.0119	-0.0242	-58%	0.034**

[1] Species status as old-growth associates (Hejl and Woods 1991 and Hejl and Paige 1994) labeled OGA.

[2] CCS = Conservation Concern Scores (Panjabi et al. 2019, Partners in Flight 2019). CCS ≥8 = moderate concern, CCS ≥14 = high concern

Comparison of the density of species with >50 detections pre- and post-harvest indicated that flycatcher and ground foraging bird densities slightly increased in harvested stands while foliage gleaners typically decreased, although results were not significant. These data are consistent with results from other researchers (Beese and Bryant 1999, Vanderwel et al. 2007, Vanderwel et al. 2009). We detected a decline in density in only one species, evening grosbeaks. This species is irruptive with large flocks often following outbreaks of insects, especially spruce budworm (*Choristoneura fumiferana*) (Bonter and Harvey 2008). Logging prescriptions often focus on removal of disease and insect-infested trees to promote stand health, and it is likely that insect foods were reduced in logged stands. Typically, evening grosbeaks are not found in greater densities in old-growth stands and are not considered an old-growth associated species; however, they are found in mature forest (Bonter and Harvey 2008).

At a marginal significance level ($0.05 < P \leq 0.10$), we found pileated woodpecker and dark-eyed junco densities increased, while golden-crowned kinglet densities decreased (Table 1). The increase in pileated woodpecker density was small, but consistent across treated stands. In similar Montana studies, pileated woodpeckers continued to use logged stands (Brewer et al. 2008) and were more common in partially cut stands than uncut stands (Hutto and Young 2002). Thus, pileated woodpeckers appear to be somewhat tolerant of silvicultural treatments that retain ample large trees, snags and western larch trees with heart rot (McClelland and McClelland 1999). Reductions of mature coniferous canopy cover that occurred during our study on nearby non-study stands may also

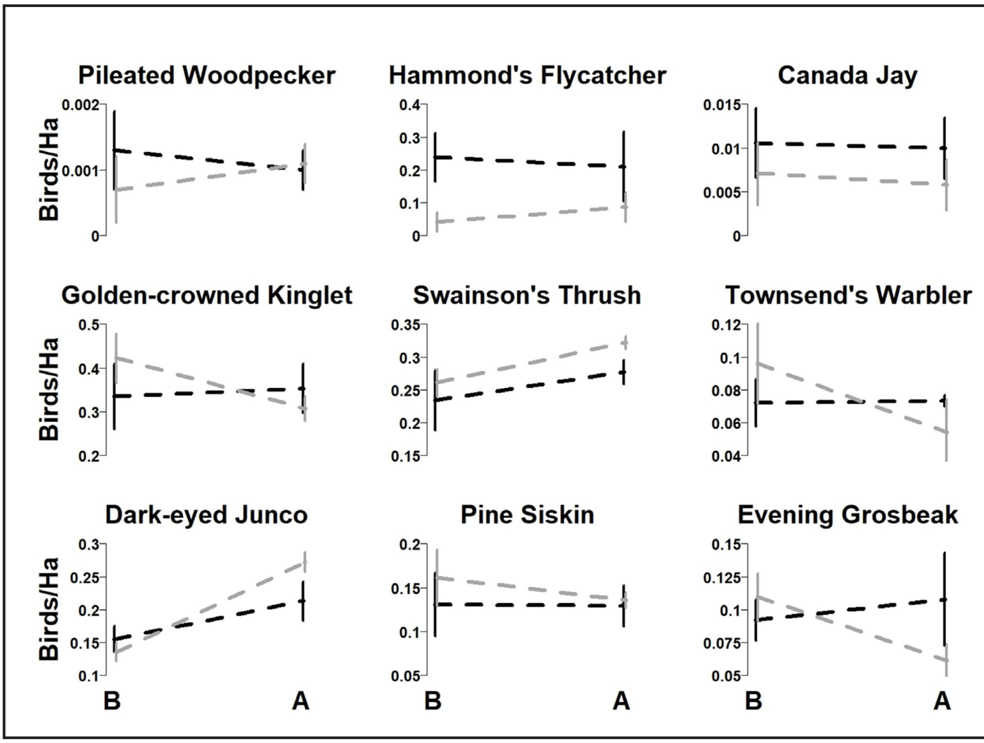

Figure 3. Densities of birds per ha in control (black) and logged (grey) stands before (B) and after (A) harvest (± SE). All species depicted are old-growth associates except for evening grosbeaks and dark-eyed juncos which are included because their densities changed significantly (evening grosbeak, P = 0.034; dark-eyed junco P = 0.061).

have influenced pileated woodpecker selection of old-growth stands that received maintenance treatments that occurred during our study. Dark-eyed juncos are ground feeders that will forage in logging slash (Nolan et al. 2002), which may explain density increases post-harvest in our study. Golden-crowned kinglets glean small insects and spiders from the tips of conifer branches and are associated with dense, old-growth forests (Swanson et al. 2012). Researchers have observed that golden-crowned kinglets are sensitive to logging with negative impacts observed even with 70 percent to 75 percent tree retention (Harrison et al. 2005, Vanderwel et al. 2007, Vanderwel et al. 2009), as compared to the 60 percent mature tree retention in the stands we studied, which may explain the post-treatment decreases we observed in this kinglet species.

Old-growth associated species continued using logged stands post-harvest with some species increasing (pileated woodpecker, Hammond’s flycatcher, Swainson’s thrush) and others decreasing (Canada jay, golden-crowned kinglet, Townsend’s warbler, Pacific wren, brown creeper); however, these results were not significant at the $\alpha = 0.05$ level (Table 1). Of these species, population trends overall of golden-crowned kinglets, Townsend’s warblers, and Swainson’s thrush in the Northern Rockies Bird Conservation Region indicate declines of ≥15 percent from 1970-2017 (Partners in Flight 2019).

We acknowledge that we were unable to assess how the survival and reproductive success of birds may have been affected by their use of logged stands, as compared to unlogged stands for breeding habitat. Additionally, we are unable to ascertain if the results we observed will continue to occur as trends, or if some of these results are one-time occurrences. Given that maintenance of biodiversity of forest ecosystems and the population status of old-growth associated species are likely

Table 2. Stand characteristics in Control and Treatment stands logged with an old-growth maintenance treatement pre- and post-harvest (*P < 0.05).

Stand Characteristic`	Control Mean	Control SE	Treatment Pre-harvest Mean	Treatment Pre-harvest SE	Treatment Post-Harvest Mean	Treatment Post-Harvest SE
Canopy Cover Percent						
(Mature Trees ≥23 cm dbh)	51.7	0.9	59.0	6.1	41.0*	2.6
Basal Area Snags >2 m Tall, m^2/ha	3.7	0.5	4.3	2.0	1.7	0.8
Basal Area Green Trees >2 m Tall, m^2/ha	28.8	1.1	33.1	4.7	19.9*	2.7
Total Trees ≤2 m Tall/ha	1,235.5	275.2	1,606.2	605.8	1,087.2	197.7
CWD Metric Tons/ha	35.6	3.7	40.1	6.9	29.5	6.2
Snags/ha >23 cm dbh	32.1	4.9	37.1	14.9	13.2	6.4
Trees/ha >2 m Tall by Size Class						
≤10 cm dbh	94.5	68.0	350.3	74.7	184.6	96.8
10-20 cm dbh	206.2	44.4	238.0	20.0	158.2	48.0
21-41 cm dbh	124.2	13.8	129.1	23.3	53.2	3.2
42-52 cm dbh	23.6	4.8	42.7	11.5	27.4*	10.0
≥53 cm dbh	32.9	5.8	30.5	5.9	22.2*	4.9
Trees/ha >2 m Tall by Species						
Western Larch	49.3	7.7	97.4	48.9	83.8	49.8
Douglas-fir	113.1	35.8	228.7	54.1	95.0	30.8
Grand Fir	209.9	155.5	305.6	154.7	146.5	87.0
Engelmann Spruce	58.9	15.1	88.8	61.2	59.3	41.7
Lodgepole	21.5	14.6	27.3	27.3	31.1	25.7
Total Trees ≤2 m Tall/ha by Species						
Douglas-fir	345.9	107.7	56.7	10.7	271.8	65.4
Grand Fir	716.6	285.0	149.7	70.6	617.8*	130.8
Engelmann Spruce	98.8	49.4	52.6	28.3	65.9	43.6
Ground Cover Percent						
Shrub	16.3	4.2	20.8	4.0	21.4	1.2
Forb	21.5	0.7	6.4	0.2	12.9	2.3
Grass	13.1	4.1	24.8	1.3	20.8	4.3
Conifer Seedling	4.2	2.3	3.4	0.5	2.6	0.4
Hardwood <2 m	1.1	0.5	0.0	0.0	1.6	1.2
Rock	0.3	0.1	0.2	0.2	0.3	0.2
Bare Soil	0.8	0.4	1.1	0.8	1.6	0.9
CWD	10.9	0.9	4.3	0.7	8.2*	1.2
Moss	2.7	1.7	8.9	1.9	2.2*	0.4
Litter	29.0	6.6	30.0	2.3	29.2	1.9

to remain issues of concern, additional research investigating the underlying causes for the changes in population trends and the reproductive success of birds in logged stands would be useful.

Management Implications

We found that habitat generalist and old-growth associated birds continued to occupy old-growth maintenance logging treatment stands after harvest in the mesic forest communities we examined. This suggests that light to moderate intensity harvest of old-growth forests, with attention to retaining large trees, snags, large pieces of coarse woody debris, and a multi-storied canopy structure may be compatible with providing habitat conditions usable by many bird species. A decline in density was only

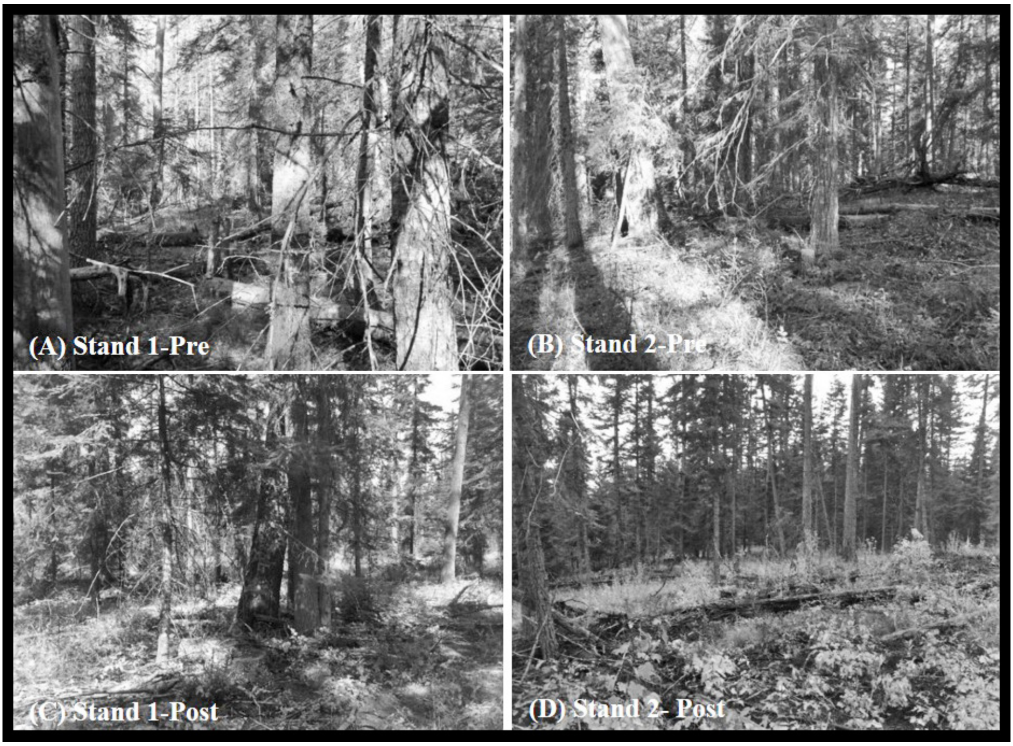

Figure 4. Repeat photographs in two vegetation plots pre- and post-harvest. The two photographs on the left (A, C) show a typical decrease in stand density post-harvest. The two photographs on the right show an example of one of the 0.4 to 0.8 ha cut patches designed to increase larch regeneration and stand variability as a part of old-growth maintenance logging prescriptions (B, D).

detected for evening grosbeaks, an irruptive species that feeds on insects such as spruce budworm.

Old-growth maintenance treatments, such as those examined in our study maintained high levels of forest structural diversity, as well as diverse bird communities. Forest communities with high structural diversity have long been known to support greater levels of biodiversity (Harris 1984, Hunter 1999). We believe the treatments we studied may provide a tool for forest managers to maintain bird species diversity, promote sustainability of old-growth forests, while continuing to provide revenue generation from forest products in working forest landscapes.

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APPENDIX A. Counts of 64 bird species by year.

Species	CCS[1]	2012	2013	2014	2015	2016	2017	Grand Total
Canada goose *Branta canadensis*	5					1		1
Mallard *Anas platyrhynchos*	7					2	2	4
Northern goshawk *Accipiter gentilis*	10		1	1			2	4
Red-tailed hawk *Buteo jamaicensis*	6	4	1		1	1		7
Ruffed grouse *Bonasa umbellus*	8				1			1
Sora *Porzana carolina*	9				1			1
Sandhill crane *Antigone canadensis*	8		2			2		4
Wilson's snipe *Gallinago delicata*	9						3	3
Rufous hummingbird *Selasphorus rufus*	14				1			1
Williamson's sapsucker *Sphyrapicus thyroideus*	12		1	4	2	4	4	15
Red-napped sapsucker *Sphyrapicus nuchalis*	9		3	3	11	12	9	38
Downy woodpecker *Picoides pubescens*	7			2	4		1	7
Hairy woodpecker *Picoides villosus*	6	1	4	1	6	3	5	20
American three-toed woodpecker *Picoides dorsalis*	8	2			1			3
Northern flicker *Colaptes auratus*	9		1	2	8	2	2	15
Pileated woodpecker *Dryocopus pileatus*	7	8	10	10	8	8	15	59
Olive-sided flycatcher *Contopus cooperi*	13	4		1	2	4	3	14
Western wood-pewee *Contopus sordidulus*	12						1	1
Hammond's flycatcher *Empidonax hammondii*	10	11	13	15	17	11	13	80
Dusky flycatcher Empidonax oberholseri	11		4	2	1	1	3	11
Cassin's vireo *Vireo cassinii*	9	4	9	11	13	20	17	74
Warbling vireo *Vireo gilvus*	8	4	8	1	3	3	2	21

Appendix A. Continued

Species	CCS[1]	2012	2013	2014	2015	2016	2017	Grand Total
Red-eyed vireo	6		1	1		1	2	5
Vireo olivaceus								
Canada jay								
Perisoreus canadensis	8	10	16	17	15	22	11	91
Common raven								
Corvus corax	6	14	8	6	17	15	8	68
Tree swallow								
Tachycineta bicolor	10			2			1	3
Black-capped chickadee								
Poecile atricapilla	7	13	27	14	19	28	13	114
Mountain chickadee								
Poecile gambeli	11	10	7	18	5	28	33	101
Chesnut-backed chickadee								
Poecile rufescens	12	19	27	18	34	36	27	161
Red-breasted nuthatch								
Sitta canadensis	6	44	28	44	43	53	56	268
Brown creeper								
Certhia americana	8	3	7	10	10	3	11	44
Pacific wren								
Troglodytes pacificus	11	6	9	8	1	12	2	38
Golden-crowned kinlget								
Regulus satrapa	8	46	29	72	49	82	54	332
Ruby-crowned kinglet								
Regulus calendula	6	16	16	34	30	10	27	133
Mountain bluebird								
Sialia currucoides	11			1				1
Townsend's solitaire								
Myadestes townsendi	10				2	1		3
Swainson's thrush								
Catharus ustulatus	10	116	139	147	141	168	151	862
American robin								
Turdus migratorius	5	24	37	12	24	19	21	137
Varied thrush								
Ixoreus naevius	12	5			1			6
Cedar waxwing								
Bombycilla cedrorum	6		2	2	14	8	18	44
Orange-crowned warbler								
Oreothlypis celata	9	9	7	14	13	12	14	69
Nashville warbler								
Oreothlypis ruficapilla	9		1					1
Yellow warbler								
Setophaga petechia	8					1		1
Yellow-rumped warbler								
Setophaga coronata	6	13	18	27	39	28	48	173

Appendix A. Continued

Species	CCS[1]	2012	2013	2014	2015	2016	2017	Grand Total
Townend's warbler								
Setophaga townsendi	12	34	43	49	39	26	42	233
American redstart								
Setophaga ruticilla	10				1	3	5	9
Northern waterthrush								
Parkesia noveboracensis	8		2	3		1	1	7
MacGillivray's warbler								
Geothlypis tolmiei	12	12	5	9	10	13	11	60
Common yellowthroat								
Geothlypis trichas	9		4	5	6	10	6	31
Wilson's warbler								
Cardellina pusilla	10	8	3		1	3		15
Western tanager								
Piranga ludoviciana	9	47	68	71	72	68	53	379
Chipping sparrow								
Spizella passerina	9	54	71	59	64	94	82	424
Song sparrow								
Melospiza melodia	8	1		1		3		5
Lincoln's sparrow								
Melospiza lincolnii	7				3			3
Dark-eyed junco								
Junco hyemalis	8	32	49	63	66	62	77	349
Black-headed grosbeak								
Pheucticus melanocephalus	9	7	3	5	2	2	1	20
Lazuli bunting								
Passerina amoena	9		6	4		1		11
Red-winged blackbird								
Agelaius phoeniceus	8			3	1			4
Brown-headed cowbird								
Molothrus ater	7		1	1	1	9	1	13
Pine grosbeak								
Pinicola enucleator	10		1					1
Cassin's finch								
Haemorhous cassinii	13	1						1
Red crossbill								
Loxia curvirostra	8	46	4	37	19	10	48	164
Pine siskin								
Spinus pinus	10	131	39	4	105	92	56	427
Evening grosebeak								
Coccothraustes vespertinus	13	40	22	20	19	17	18	136
Grand Total		**799**	**757**	**834**	**946**	**1,015**	**980**	**5,331**

[1] CCS = Conservation Concern Scores (Panjabi et al. 2019, Partners in Flight 2019). CCS ≥8 = moderate concern, CCS ≥14 = high concern.