Effects of Variable-Retention Treatments on Numbers of Singing Small Passerine Birds in Pacific Northwest Forests

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EFFECTS OF VARIABLE-RETENTION TREATMENTS ON NUMBERS OF SINGING SMALL PASSERINE BIRDS IN PACIFIC NORTHWEST FORESTS

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ABSTRACT—Forest birds are sensitive to habitat change and may be suitable for measuring responses to retention forestry. I present the short-term effects of 6 treatments in a 6 block randomized design experiment on 15 breeding small bird species in mature Douglas-fir (*Pseudotsuga menziesii*) forests in western Washington and Oregon, 1994–2001. The 13-ha treatment stands contained aggregated (A) green-tree retentions of 100, 75, 40 and 15%, and a dispersed tree distribution pattern (D) of 40 and 15% retention. I compared numbers of entire singing bird territories (abundances) mapped inside sampling plots in post- (2-y $\bar{x}$) and pre-treatments (1 y). Species richness significantly declined in both 15% treatments. In the 15%D treatment, significantly lower richness and lower species similarity were less than A treatments with $\geq$40% retention, and significantly lower species diversity was less than the other treatments. The size of decline of abundances of canopy-associated species (summed members) increased with successively lower tree retention; the cavity-nesting species declined with lower snag retention in treatments $\leq$40% retention; and there was no response for species associated with understory vegetation, but medians of the percentage change in abundance of understory species were negative in cut treatments. There was no detectable difference in treatment effects between tree distribution cut patterns. Greater amounts of tree retention helped maintain composition and abundance better than less retention, and overall the variety of treatments maintained all species. For maintaining richness, similarity, and diversity, the 15%A and 40%D treatments were transitional between the A treatments $\geq$40% retention, where these community parameters were maintained, and 15%D, which did not maintain natural diversity or species persistence.

Key words: bird communities, Brown Creeper, cavity nest, Chestnut-backed Chickadee, Dark-eyed Junco, DEMO, Douglas-fir, forest management, Hermit Warbler, Oregon, Pacific Wren, *Pseudotsuga menziesii*, Townsend's Warbler, Washington

Retention forestry strives to maintain natural biodiversity and manage risk of defaunation (Franklin and others 1997; Lindenmayer and Franklin 2002; Gustafsson and others 2012). The Demonstration of Ecosystem Management Options Study (DEMO) is a long-term retention experiment initiated in the 1990s to understand treatment effects of retention and cut pattern on an array of flora and fauna components in mature Douglas-fir (*Pseudotsuga menziesii*) forests in western Washington and Oregon (Halpern and Raphael 1999). The Short-term treatment responses of vertebrate fauna have been published for communities of salamanders and small mammals (Erickson and West 2003; Maguire and others 2005; Gitzen and others 2007; Holloway and others 2011; Wilk and others 2015), but not bird communities. Responses of passerine bird species are of particular interest because they are sensitive responders to habitat change (Wu and others 2018), which may make them suitable indicators for measuring the outcomes of variable tree retention (Rosenvald and Lõhmus 2008). Nearly 2 decades have passed since initial treatments were completed, during which time wood demand from the growing human population has increasingly subsumed forests (Alig and Plantinga 2004; Nowak and Walton 2005; Nowak and others 2005), and climate change has heightened concerns about effects on forest resources (van Mantgem and others 2009; Fettig and others 2013). Presentation of short-term effects lacking hitherto is fundamental and necessary to help identify initial post-treatment response thresholds for maintaining bird communities to better inform and help advance management of Pacific Northwest forests.

The DEMO hypotheses addressed a triad of bird groups (identified by superscripts 1, 2, and 3 below) positing: (1) that short-term abundances of canopy-dwelling birds[1] and birds associated with understory vegetation[2] would decline with decreasing levels of tree retention; (2) among nesting cavity-dependent species[3] (subgroup of the canopy group), declines would occur from losses of snags in treatments $\leq$40% retention; and (3) aggregation of tree retention (versus dispersed) would lessen the effects

(Lehmkuhl and others 1999). The objective here is to address these hypotheses by describing treatment effects on the triad of bird groups.

Six randomized blocks on federal and state lands west of the Cascade Range crest represented the upland physiography of mature (65–170 y-old) sub-climax Douglas-fir forests. Three blocks are in the Cascade Range and 1 is in the Black Hills, southwestern Washington; and 2 are in the Cascade Range of southwestern Oregon (Aubry and others 2009). Each block had 13-ha treatment unit stands of basal area retention (tree retention) of continuous aggregated (A) no-tree removal controls (100%A); low removal 75%A retained basal area, with 3 logged circular 1-ha patches; medium removal 40%A retained in 5 not cut 1-ha circle A patches evenly spaced within the treatment unit; high removal 15%A retained in 2 not cut 1-ha diagonally spaced circle A patches; and 40 and 15% treatments in a dispersed cut pattern (D) of evenly distributed dominant and co-dominant trees (USDA FS 2014).

Singing territories were spot-mapped from 4 point-count sampling circle station centers per unit (75-m radius) spaced ≥160 m apart, each visited 6 times evenly spaced between late April and mid-July. This was done to capture breeding phenology and to delineate territory perimeters during 1 y pre-treatment (hereafter Pre) and 2 consecutive treatment years, ending 1–3 y after the completion of logging (hereafter Post) in 2001 (Lehmkuhl and others 1999; Aubry and others 2007). Statistical independence of treatments was maintained by constraining the response variable to the number of mapped entire territories contained inside sampling circles (excluding partial territories), resulting in species with small territories, which lends the analysis to the stand-scale space (Manuwal and Manuwal 2002) in breeding season time; and since entire territories were de facto abundances, detection probabilities were not warranted (Siegel 2009).

I used error bar overlap rules for confidence intervals (95% CI) to estimate *P*-values between Post (2-y $\bar{x}$) and Pre, and across treatments, and to show the precision of estimates, effect sizes, and the uncertainty with interpretation of results (Cumming 2009; Fidler and Loftus 2009). Error bar proportional overlap of 0.59 has an approximate *P*-value of 0.05, and *P* gets smaller as overlap decreases (see Cumming 2009: Fig. 1).

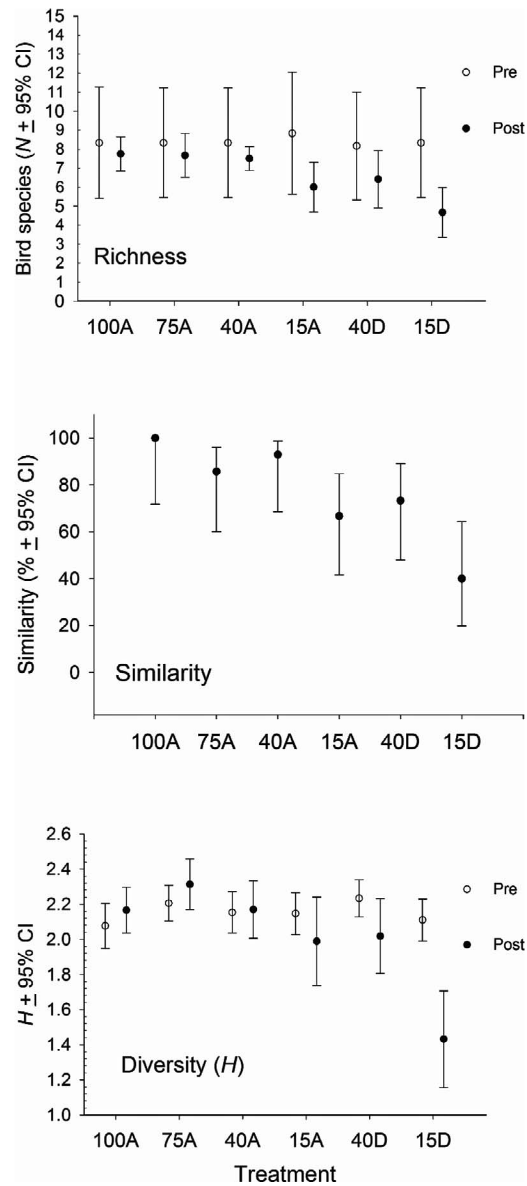

FIGURE 1. Bird species richness (top), similarity (species in common with Pre [%]; center), and alpha diversity (Shannon-Weiner *H*, bottom) by treatment and sampling period (Pre-, Post-treatment). Horizontal axis shows percentages of tree retention and distribution pattern (A = aggregated; D = dispersed).

For percentages, I used integers to compute CIs and estimate *P*, and the error bars are highly asymmetrical when *P* is closer to 0 or 100% (Cumming 2012). I used Gardiner (2018) for CIs for alpha diversity (Shannon-Weiner). I show *P*-

TABLE 1. Post-treatment summary of forest feature measurements ($\bar{x} \pm s\bar{x}$, $n = 6$ [*$n = 5$]), subdivided by treatment (tree retention % and pattern; A = aggregated, D = dispersed). Across rows, treatment values with the same letters are similar and different letters indicate statistical differences among treatments ($P \leq 0.05$).

Category	100%A	75%A	40%A	15%A	40%D	15%D
Canopy cover (%)*	81.7 ± 2.1a	55.1 ± 1.7b	55.1 ± 2.2b	27.4 ± 1.4d	46.7 ± 3.1c	22.9 ± 1.7d
Tree density (n/ha)	559 ± 159a	557 ± 204a	243 ± 93ab	121 ± 19bc	193 ± 66b	80 ± 21c
QMD [a] (cm)	45.3 ± 6.7ab	40.2 ± 6.2ab	45.6 ± 6.7ab	50.3 ± 5.6a	36.4 ± 4.0b	47.1 ± 5.2ab
Wood debris cover, new (%)	0.0 ± 0.0a	19.9 ± 0.8b	49.9 ± 1.6c	74.1 ± 3.2d	70.7 ± 4.1d	79.5 ± 4.0d
Tall shrub cover (%)	13.2 ± 4.1a	24.4 ± 9.6a	21.1 ± 11.6a	11.7 ± 6.2a	13.5 ± 6.0a	11.7 ± 6.2a
Herb/low shrub cover (%)	33.9 ± 8.1a	32.8 ± 6.0a	19.9 ± 1.5b	13.4 ± 3.9b	22.5 ± 3.7ab	14.7 ± 2.8b
Snags/ha	54.8 ± 20.2a	46.6 ± 11.8a	25.8 ± 4.5b	25.3 ± 4.2b	21.3 ± 6.7b	16.5 ± 3.0b
Snag dia. breast ht. (cm)	47.5 ± 4.6a	49.4 ± 2.4a	53.9 ± 2.8ab	56.6 ± 3.2ab	54.4 ± 3.3ab	58.2 ± 2.5b

[a] Tree quadratic mean diameter (QMD) is a measure of central tendency compared to the arithmetic mean; assigns greater weight to larger trees, and is always ≥ arithmetic mean; in timber cruising used to estimate the standing volume of timber because it has the practical advantage of being directly related to basal area, which in turn is directly related to volume (from Wikipedia, accessed 9 Nov 2018).

values where CI or $s\bar{x}$ (standard error) are not in figures or tables (note: supporting supplemental figures and tables are available from the author). Unless specified (for example, "on average"), terms such as "increase", "decline", "different", or use of the symbols > or < imply statistical significance. "Summed abundance" refers to the total of territories of all species in a group, and "median of change in abundance" refers to the geographic middle of ordered percentages change in abundance of all species within a group (% $\bar{x}$ in table). Species richness in this study is simply the number of different species and does not take into account their abundances or relative abundance distributions. Similarity (Jaccard method) compares the number of species in common with Pre. Diversity accounts for both abundance and evenness of the species present.

Treatments differed in measured amounts of forest attributes except for tall shrub cover (Table 1). In the 40% treatments, aggregation of trees maintained canopy cover better than dispersed trees, where wood debris cover was greater. Snag density was less than half that of the controls in treatments ≤40% retention.

There were 15 species of passerine birds (Table 2) in 9 families, and initially 12 or 13 species were observed in treatments. Post species richness declined in both 15% treatments (A and D, Fig. 1). In 15%D, richness and similarity were less than in the A treatments with ≥40% retention, and species diversity was less than in all of the other treatments, which indicated that numbers of territories were less evenly distributed among the bird species. This was influenced primarily by Dark-eyed Juncos (scientific names in Table 2) that exhibited up to more than a 6-fold ($P \leq\leq 0.001$) increase in percentage composition of territories (composition) in cut treatments and up to more than a 2-fold ($P << 0.001$) increase in numbers of territories (abundance).

Initial composition and abundance of the canopy group (species listed in Table 2) was greater than the understory group (species listed in Table 2), but in Post understory group composition amounts in 15% treatments exceeded canopy group amounts (opposing patterns in Fig. 2 top L and R, Fig. 3), and only the composition of the cavity-nesting subgroup of the canopy group was reduced in the 15%D treatments (Fig. 2 center column; cavity-nesting species listed in Table 2). In treatments ≤40% retention, the effect size on canopy species was greater than effect size on cavity and understory groups (Fig. 2 and Fig. 3, bottom row panels). Overall territories were reduced by about half, and numbers in treatments were < controls, but no species was extirpated from the study (Table 2, Table 3).

In controls, 5 species made up 74–76% of the Pre–Post territory composition: Hermit/Townsend's Warbler (HT Warbler 32–26%); Golden-crowned Kinglet (GC Kinglet 14–17%); Junco (10–15%); Pacific Wren (P Wren 10–9%); and Brown Creeper (Creeper 8–9%). In Post 75 and 40% A treatments, compositions of the 5 main species respectively, were Junco 22*> and 27%*>, HT Warbler 17 and 20%*<, P Wren 13 and 10%, GC Kinglet 9 and 9%, and Creeper 7 and 8% (*indicates that percentage composition is significantly different, $P \leq 0.05$, and is either greater than [>] or less than [<] Pre). In Post 15%A, the 5 main species were Junco (41%*>), HT Warbler (12%*<), and P Wren (12%), with

TABLE 2. Total composition (%) of passerine bird territories summed across treatments in pre- and post-treatment periods. Statistically different 95% CIs are in brackets.

Species	Pre- $n = 1158$	Post- $n\ \bar{x} = 608$ [b]
CANOPY SPECIES		
Pacific-slope Flycatcher, *Empidonax difficilis*†	6.5 [5.2–8.0]	3.1 [2.0–4.8] [c]
Townsend's Solitaire, *Myadestes townsendi*	0.2 [0.0–0.6]	3.9 [2.7–5.8] [d]
Hammond's Flycatcher, *E. hammondii*†	1.0	1.9
Hermit/Townsend's Warbler, *Setophaga occidentalis/S. townsendii*), or hybrid†[a]	30.3 [27.7–33.0]	17.3 [14.5–20.5] [d]
Golden-crowned Kinglet, *Regulus satrapa*	12.3 [10.6–14.4]	8.7 [6.7–11.2] [e]
Chestnut-backed Chickadee, *Poecile rufescens**	6.8	4.9
Brown Creeper, *Certhia americana**	7.5	7.2
Red-breasted Nuthatch, *Sitta canadensis**	7.0	6.1
Canopy group	71.7 [69.0–74.2]	53.1 [49.2–57.1] [d]
Cavity-nesting subgroup*	21.3	18.3
UNDERSTORY VEGETATION SPECIES		
Dark-eyed Junco, *Junco hyemalis*	9.8 [8.2–11.6]	29.4 [26.0–33.2] [d]
Pacific Wren, *Troglodytes pacificus*	10.6	11.3
Hermit Thrush, *Catharus guttatus*†	3.8 [2.8–5.1]	1.2 [0.6–2.4] [c]
Varied Thrush, *Ixoreus naevius*	2.8 [2.0–4.0]	1.1 [0.6–2.4] [e]
House Wren, *T. aedon*†	0.0 [0.0–0.3]	2.0 [1.1–3.4] [d]
Swainson's Thrush, *Catharus ustulatus*†	0.6	1.2
MacGillivray's Warbler, *Geothlypis tolmei*†	0.7	0.8
Understory vegetation group	28.3 [25.8–31.0]	47.0 [43.1–51.0] [d]

* Cavity-nesting species.
† Neotropical migrant (Torgersen and others 1995; Birds of North America 2018).
[a] Treated as 1 species.
[b] $\bar{x}$ of post-treatment years 1 ($n = 605$) and 2 ($n = 611$).
[c] $P \leq 0.01$.
[d] $P << 0.001$.
[e] $P \leq 0.05$.

House Wren (H Wren, 8%*>) and Red-breasted Nuthatch (RB Nuthatch, 7%) replacing Creeper (3%) and GC Kinglet (2%*<). In Post D treatments, the 5 main species were present in 40%D: Junco (38%*>); HT Warbler (13%*<); P Wren (11%); Creeper (10%); and GC Kinglet (6%). In 15%D, Junco (57%*>), P Wren (16%), and HT Warbler (4%*<) remained in the top 5, and Townsend's Solitaire (Solitaire, 9%*>), Chestnut-backed Chickadee (CB Chickadee, 4%), and RB Nuthatch (4%) were added. In all, 9 species (60%) made up the top 5 species percentage composition across treatments.

Although different in Pre, Post abundances between canopy and understory groups did not differ in cut treatments (Fig. 3), and cut pattern had no detectable effect on any group (Fig. 3). Canopy group abundance declined with successively lower retention, which supported that group hypothesis, and treatments ≤40% were < controls (Fig. 3, left column panels). Four species of this group declined in 75%A, 5 species each declined in 40%A and 15%A, 5 species declined in 40%D, and 7 species declined in 15%D (compare with overall totals in Table 3); The canopy species Solitaire increased/colonized treatments (all $P \leq 0.05$). The understory group did not show a response to treatments based on average abundances, which did not support the group hypothesis. However, medians of abundance change of group member species were negative (compare Table 3 medians to Fig.3). Only 1 species declined in the 75%A, 2 species each declined in 40 and 15%A, and 3 species each declined in the D treatments, but abundances of a few species also increased in treatments ($P \leq 0.05$, see below).

Abundances in the cavity group were possibly influenced by the removal of unsafe snags in treated areas, which potentially would have provided nesting holes (Table 1). Abundances declined in treatments ≤40% retention, which supported the group hypothesis, and 15% treatments were < controls (Fig. 3, center column panels). The Creeper and CB Chickadee declined in all cut treatments ($P \leq 0.05$), and the RB Nuthatch declined in D treatments ($P \leq 0.01$).

The number of species that declined in abundance increased with successively lower tree retention, and 15%D had the fewest species

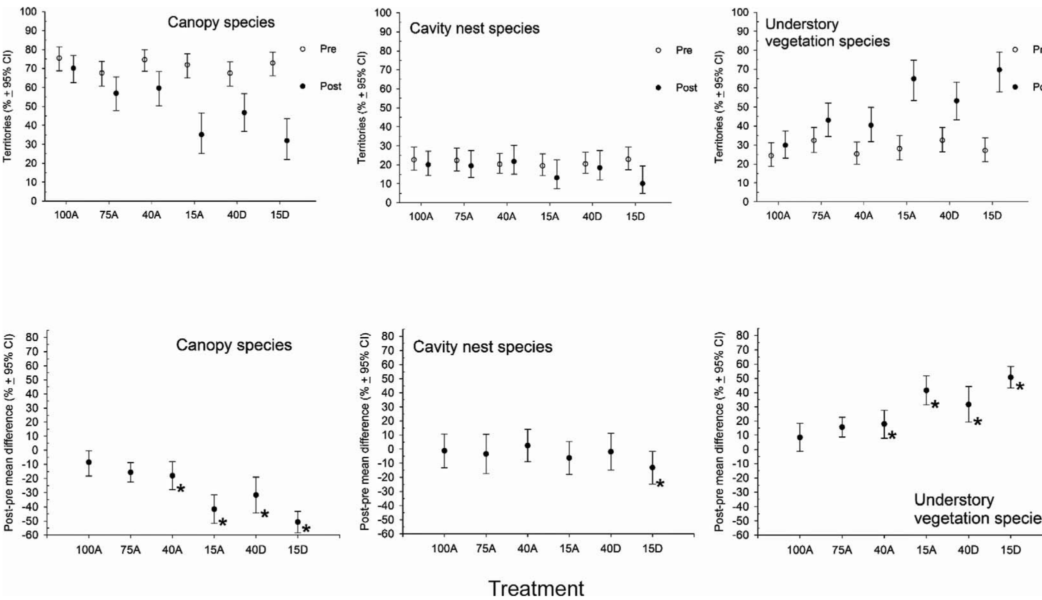

FIGURE 2. Pre- and post- treatment percentage composition (top graphs) and post-treatment change (bottom graphs) in number of singing territories of canopy-dwelling, cavity-nesting, and understory vegetation small bird groups ($\bar{x}$, 95% CI). Asterisks in bottom graphs indicate statistical differences that are associated with paired bars in top graphs. Graph panels are scaled for across row comparisons. Horizontal axis shows treatment tree retention percentage and pattern (A = aggregated, D = dispersed).

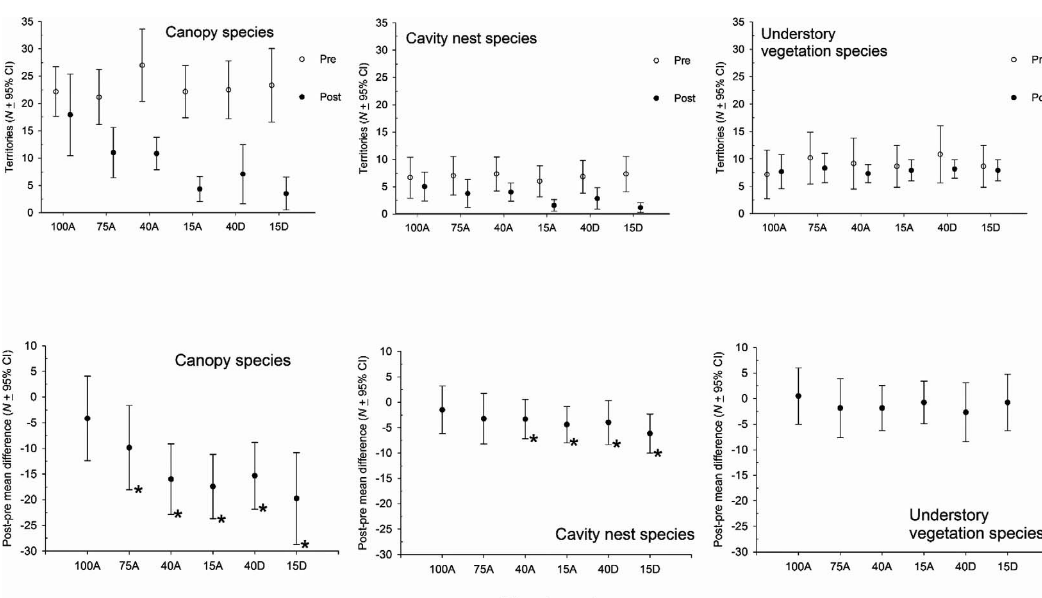

FIGURE 3. Pre- and post-treatment abundance (top row) and post-treatment change (bottom graphs) of singing territories of canopy-dwelling, cavity-nesting, and understory vegetation small bird groups ($\bar{x}$, 95% CI). Asterisks in bottom graphs indicate statistical differences that are associated with paired bars in top graphs. Graph panels are scaled for across row comparisons. Horizontal axis shows treatment tree retention percentage and pattern (A = aggregated; D = dispersed).

TABLE 3. Post-treatment change in number of territories of species within groups (% $\bar{x}$ [median]), with status change among all bird species in the DEMO Study ($n = 15$), subdivided by treatment (tree retention % and pattern; A = aggregated, D = dispersed). Across rows, treatment values with the same letters are similar and different letters indicate statistical differences among treatments ($P \leq 0.05$).

Category	100%A	75%A	40%A	15%A	40%D	15%D
TERRITORY ABUNDANCE CHANGE (% $\bar{x}$) [a]						
Canopy dwelling	–17.8	–55.3	–48.1	–75.8	–72.4	–91.3
Cavity nesting (subgroup)	–24.9	–56.2	–42.9	–68.3	–67.8	–83.2
Understory vegetation	25.0	–9.4	–17.7	–59.4	–94.0	–78.1
Total	0.0	–50.0	–40.0	–66.0	–77.0	–86.8
(Post-*N*/Pre-*N*) ×100 (95% CI)	82–92a	55–68b	44–57c	33–47cd	39–53cd	30–43d
Species present (*N*) [b]	13a	14a	14a	13a	13a	8b
COMPOSITION (CHANGE IN TERRITORY PERCENTAGE COMPOSITION, SPECIES *N*) [c]						
Decreased	0a	0a	1a	2a	2a	2a
Increased	0a	2a	2a	3a	2a	3a
Not changed	15a	13a	12a	10b	11b	10b
ABUNDANCE (CHANGE IN TERRITORY ABUNDANCE, SPECIES *N*) [c]						
Decreased	0a	5b	7bc	7bc	9bc	11c
Increased	0a	2ab	2ab	4b	3ab	3ab
Not changed	15a	8b	6b	4bc	3bc	1c
Extirpated [d]	0a	0a	0a	3ab	2ab	6b
Colonized [e]	0a	2a	1a	3a	2a	2a

[a] Medians were negative values but CIs were broad (not significant) in several cases and were not computable across all treatments due to small samples ($n \leq 5$).
[b] Significance based on integer (x) as a proportion: x species/15 total species.
[c] Significance based on integer (x) as a proportion: x species/species present in pre-treatment.
[d] Recorded in pre-, but not in post-treatment.
[e] First recorded in post-treatment.

(Table 3). Species that declined in all cut treatments included the Creeper and the Hermit Thrush (H Thrush) ($P \leq 0.05$), and the timber-foliage insectivores, HT Warbler ($P \leq 0.01$), GC Kinglet ($P \leq 0.05$), and CB Chickadee (above) (as a foraging guild, $P << 0.001$). The Varied Thrush (V Thrush) declined in treatments ≤40% ($P \leq 0.05$), and the Pacific-slope Flycatcher (PS Flycatcher) declined in 40%A and in both 15% treatments ($P \leq 0.01$). The Hammond's Flycatcher (H Flycatcher) declined in 15%D ($P \leq 0.05$). The MacGillivray's Warbler (M Warbler, $P \leq 0.05$), like RB Nuthatch (above), declined in D treatments. The Swainson's Thrush (S Thrush) declined in 40%D ($P \leq 0.05$), and the P Wren declined in 15%D ($P \leq 0.05$).

A small number of species in cut treatments increased in abundance (Table 3); whereas, in the higher retention A units, more species did not change in abundance than in other treatments, exemplified by the H Flycatcher, P Wren (above), and RB Nuthatch (above). The air-insectivore H Flycatcher, PS Flycatcher, and Solitaire as a foraging guild, did not decline in cut treatments because Solitaire increases ($P \leq 0.05$) and H Flycatcher average increases offset PS Flycatcher losses (above; also see Table 2). Juncos increased in 40%D and 15% treatments ($P \leq 0.05$), H Wrens colonized treatments ≤40% retention ($P \leq 0.05$), and S Thrushes increased in 75%A and 15%A ($P \leq 0.05$).

Canopy species abundances were reduced in the green-tree removal treatments and cavity-nester abundances were reduced in treatments with snag removal in cut areas, but the impacts to the understory group ≤3 y after treatments seemed to lessen relative to the presence of wood debris and ground cover. A review of several stand-level studies of coastal coniferous forests in the region reported similar group responses in habitat fragments (see Manuwal and Manuwal 2002). In DEMO, not all species declined in all treatments, but medians of abundance change reflected negative effects across the groups (Table 3), which supported the triad group hypothesis, whereas summed abundances only supported the hypothesis for canopy-dwellers and cavity-nesters (Fig. 2).

Most of the species may be common across young, mature, and old-growth stands in Douglas-fir forests in the region (see Carey and others 1991; Huff and Raley 1991; Manuwal 1991). DEMO treatments appeared to influence shifts in abundance of some species, and decreases and extirpations exceeded increases and colonizations, especially in high canopy removal and dispersed treatments (Table 3). For example, PS Flycatchers and GC Kinglets reached maximum abundance in old-growth forest and were extirpated or nearly so from 15% treatments, whereas Juncos were abundant and increased in all stand ages (Carey and others 1991; Manuwal 1991). H Thrushes were nearly extirpated from the 15%D stands, and were most abundant in young to mature stands (Carey and others 1991; Manuwal 1991). In contrast, Solitaires (all cut treatments) and H Wrens ($\leq$ 40%) prefer open canopies (see Hejl and others 1995; Bowen 1997; Gaines and others 2007; Waterhouse and Armleder 2007), and colonized the 15% treatments.

The understory group responses were influenced by sensitivity to pattern of habitat disturbance by species of low abundance and the influx of Juncos. For example, M Warblers are generally abundant in stands $\geq$30% retention (Gaines and others 2007), but in the 40%D treatment (and 15%D) they declined. S Thrushes occur in all stand ages and along forest edges (Mack and Yong 2000; Brand and George 2001; Manuwal and Manuwal 2002), and declined in 1 D treatment, but colonized the low and high removal A treatments. The more common P Wren declines with losses of old forest nesting structures (Hejl and Kroodsma 2016), but is highly adaptable in creating and using nest sites (Toews and Irwin 2012), and only declined in the highest removal D treatments. Junco nest sites are also highly variable, and numbers increase with post-logging cover by low plants (Nolan and others 2002), as would occur in the D and high removal treatments. Increases of plants and insects in treatments (Halpern and others 2005; Halaj and others 2009) likely created better conditions for the low understory-herbivore-insectivore Junco (see Nolan and others 2002; Kroll and others 2012), also reported in other studies in the region to increase after high tree removal (Vega 1993; Steventon and others 1998; Chambers and others 1999; Waterhouse and Armleder 2007).

Abundance of cavity-nesting birds in the Pacific Northwest is influenced by number and size of snags (Mannan and others 1980; Zarnowitz and Manuwal 1985), which likely limited abundances because declines occurred where snag densities declined, and snag average relative size in all treatments was small (Table 1, Fig. 3). Snag cavities used by small birds begin to occur naturally in Douglas-fir forests at about 75 y, and by 200 y (Cline and others 1980) densities average about 4 times greater (Mannan and others 1980: range by species = 3–6 times greater). Since stand ages in this study ranged from 65–170 y, treatment units probably initially provided about the same range of available snag cavities, but 2 blocks with 65–80 y-old stands would have had very small numbers of snag cavities. Snag sizes were small in DEMO, when compared to the size of snags used by cavity-nesting small birds. For example, snags used by the semi-cavity nesting ("slots" between trunk and loose bark) Creeper ($\bar{x}$ = 58.8, $s\bar{x}$ = 6.3 cm dbh) in the western Cascades, Washington were > 100%A and > 75%A in DEMO ($P < 0.05$), and the true hole-nesting RB Nuthatch ($\bar{x}$ = 71.1, $s\bar{x}$ = 7.2 cm dbh; $P < 0.05$) and CB Chickadee ($\bar{x}$ = 94.0 cm, $s\bar{x}$ = 7.8 cm dbh; $P << 0.001$) were > all treatments (see Lundquist and Mariani 1991). In western Oregon, snags used by the RB Nuthatch ($\bar{x}$ = 118, range = 74–185 cm dbh) and CB Chickadee ($\bar{x}$ = 103, range = 53–160 cm dbh) were, on average, much > DEMO (see Mannan and others 1980) (compare with Table 1).

Aggregation treatments $\geq$75% retention may provide enough interior forest for longer-term habitat of cavity-nesting species (see Kroodsma 1984; Nelson 1989; Gyug and Bennett 1996; this study). At lower retentions, cavity-nester abundances were lower, and cavity nest use was not different between aggregated patch and dispersed tree distribution patterns in this region (Chambers and others 1997; Walter and Maguire 2005; Arnett and others 2010; inferred from this study). Larger, older trees form natural snags for nesting (Cline and others 1980; Mannan and others 1980; Zarnowitz and Manuwal 1985) and provide larger amounts of arthropods than smaller trees (Poulin and others 2013), which benefits these small, mostly bark or timber-foliage cavity-dependent avian insectivores. Retaining patches of mature large diameter trees with snags and creation of green snags are practical habitat management approaches for these species (Chambers and others 1997; Mayrhofer 2006; Linden and others 2012). Dominant/co-dominant green-tree snags were created in DEMO to replace "unsafe" decayed snags in cut areas (Aubry and others 1999), but because new hard snags take up to 5 y to be naturally excavated for nesting (Chambers and others 1997), a short-term approach could include systematic placement of nest boxes for small cavity-dependent species to replace the snag cavities lost in treatments (see McComb and Noble 1981).

Responses of all species to treatments in this study were generally consistent with current knowledge in species accounts (Birds of North America 2018). Eight species are Neotropical migrants (Table 2), the Hermit Warbler is on watch and concern lists (USDI FWS 2018), and the resident CB Chickadee is a species of continental importance (Rosenberg and others 2016). However, asynchrony of sampling years in some blocks may have possibly influenced some of the results if this study, and population natural fluctuation may also influence responses as McGarigal and McComb (1995) posited for P Wrens and CB Chickadees in the Oregon Coast Range.

Mapped entire territories of small passerine birds helped identify stand-scale treatment effects by maintaining the independence of treatments. Larger-bodied species often have larger territories (see Schoener 1968; McComb and Lindenmeyer 1999; Elchuk and Wiebe 2003), which can be problematic in stand-scale analysis and because they may occur in more than 1 treatment. For example, studies with non-mapping abundance estimation methods across a more diverse bird fauna in western Washington and Oregon, which included the larger, wider-ranging passerine corvids and picids, did not detect stand-level (10–12+ ha) differences in species richness between experimental clear-cut and tree-retention stands, nor between size of clearcut or mature forest (Vega 1993; Chambers and others 1999; Manuwal and Manuwal 2002).

DEMO scientists surmised that about 70% retention of large trees would lessen declines or losses of bird species, and a variety of treatments would be needed to maintain habitat for different species (Lehmkuhl and others 1999) because larger patches of retained trees offer greater amounts and diversity of food, cover, and other beneficial resources available to many species (Linden and others 2012). Greater tree retention helped maintain composition and abundance better than less retention, and the variety of treatments did not extirpate any species overall. Species richness, similarity, and diversity indices were similar to the controls across all treatments except 15%D, but richness and similarity in 15%D treatments were also similar to the richness and similarity in the 15%A and 40%D treatments. This suggests that for maintaining short-term small passerine bird community integrity, the 15%A and 40%D treatments were transitional between the A treatments ≥40% retention, where these community parameters were maintained, and 15%D, which did not maintain natural diversity or species persistence.

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