Reprinted from Wildlife Society Bulletin
Volume 28, Number 3, Fall 2000

Forest management strategy, spatial heterogeneity, and winter birds in Washington

Bruce A. Haveri and Andrew B. Carey

Abstract Ecological management of second-growth forest holds great promise for conservation of biodiversity, yet little experimental evidence exists to compare alternative management approaches. Wintering birds are one of several groups of species most likely to be influenced by forest management activities. We compared species richness and proportion of stand area used over time by wintering birds in 16 second-growth Douglas-fir (*Pseudotsuga menziesii*) stands to determine the effects of management strategy and experimental variable-density thinnings. Management strategies were retaining legacies (large live, dead, and fallen trees from the previous old-growth stand) with long rotations and managing for high-quality timber with multiple thinnings and removal of defective trees. Experimental thinnings were designed to reduce inter-tree competition and monopolization of light, moisture, and nutrients by trees at the expense of other growth forms; reproduce the within-stand spatial heterogeneity found in old-growth forests; and accelerate development of habitat breadth. Proportion of area used and species richness increased with experimental thinnings. Two of the 8 most common winter species increased their use of experimentally thinned stands. No species exhibited greater use of unthinned, competitive-exclusion-stage stands over thinned stands. Variable-density thinnings, in conjunction with other conservation measures (legacy retention, decadence management, and long rotations), should provide habitat for abundant and diverse birds.

Key words biodiversity, birds, conservation, forest management, Pacific Northwest, silviculture, variable-density thinning, Washington, winter

Conserving biodiversity will be more effective if it includes intentional management of multiple-use forest ecosystems in addition to maintaining natural reserves (Carey and Curtis 1996, Carey et al. 1999*b*). One area of special concern is maintaining winter-resident bird communities in second-growth forests (Manuwal and Huff 1987, Carey 1989, Huff et al. 1991, DeSante et al. 1998). Winter is a critical season not only for resident bird species in the Pacific Northwest but also for small mammals (Merritt 1984, Buchanan et al. 1990, Carey 1991) and other wildlife. Low temperatures and increased precipitation create thermally stressful environments. Winter increased precipitation create thermally stressful environments. Winter weather influences foraging strategies (Grubb 1975) and habitat selection (Anderson 1972, Morrison et al. 1986). Availability of food, roost sites, and thermal cover become crucial to survival (Huff et al. 1991; Carey et al. 1991, 1992, 1997). Winter, survival influences size of breeding populations and thus probability of persistence (Fretwell 1972, DeSante et al. 1998).

Previous studies of bird communities in Pacific Northwest Douglas-fir (*Pseudotsuga menziesii*) forests compared differences in bird species richness

Authors' address: Pacific Northwest Research Station, United States Department of Agriculture Forest Service, 3625 93rd Ave. SW, Olympia, WA 98512, USA; e-mail address for Carey: acarey@fs.fed.us.

and abundance among early, mid-, and late-seral stands (Manuwal and Huff 1987, Carey et al. 1991, Gilbert and Allwine 1991, Huff et al. 1991). Old, structurally complex stands supported more diverse and abundant bird populations than young stands of simple structure; most differences in avian populations between old and young stands were in overwintering resident bird species.

Currently, 2 general forest management strategies are being used to conserve or restore biodiversity in managed forests (see Carey 2000 for a review): 1) management with legacy retention (conserving biological components from the previous forest, including, but not limited to, soil organic matter, litter, large snags, coarse woody debris, and live trees) and no intermediate treatments and 2) management with commercial thinnings to produce high-quality timber and to stimulate understory development as a way to mimic old-growth vegetation structure. In the latter strategy, thinning is systematic and emphasizes even tree spacing. A new alternative emphasizes legacy retention and variable-density thinning to accelerate processes of forest ecosystem development-while allowing for extraction of wood products from the forest (Carey 1995; Carey and Johnson 1995; Carey and Curtis 1996; Carey et al. 1999*a*,*b*). Variable-density thinning is designed to produce plant community spatial heterogeneity characteristic of late seral forests (Carey et al. 1999*a*,*c*).

Our study was part of the Forest Ecosystem Study (FES), an experiment designed to accelerate development of late-seral characteristics in second-growth Douglas-fir forests (Carey et al. 1999*c*). Our objectives were to examine 1) effects of management strategy (managed with legacies vs. managed with multiple commercial thinnings) and 2) effects of variable-density thinning under each management strategy on bird species abundance, bird species richness, and consistency and completeness of stand use by birds in winter.

Methods

Study area

The FES was conducted on the 6,000-ha Rainier Training Area of Ft. Lewis Military Reservation in Thurston County, Washington (Carey et al. 1999*c*). We chose 4 large management compartments based on homogeneity, history of treatment, and isolation from old-growth forests to be used as blocks within a randomized blocks experiment. Two compartments had been harvested *circa* 1937 and are hereafter referred to as legacy stands. Numerous large live trees, large snags, and fallen trees were retained at harvest (legacy management); no further management, other than protection, was undertaken. Douglas-fir regenerated naturally into dense (598-642 stems/ha) stands of small (43-cm-dbh) trees, with numerous tall stumps (>48/ha), large snags (4/ha), and large, live old-growth trees (3/ha). The legacy stands had 5-10% cover of coarse woody debris, 2-4% cover of recently fallen trees that died from suppression or root-rot (*Phellinus weirii*), and sparse cover (17-19%) of salal (*Gaultheria shallon*). The other 2 compartments (hereafter referred to as thinned stands) had been clearcut *circa* 1927 and commercially thinned twice with salvage of merchantable dead trees before stand age of 65 years. The naturally regenerated, even-aged Douglas-fir stands were well-stocked (224-236 stems/ha) with large (58- to 63-cm-dbh) trees, had a dense understory of shrubs (primarily *G. shallon*) and ferns (primarily *Polystichum munitum* and *Pteridium aquifolium),*but few (< 1/ha) snags and large live trees and little coarse woody debris (2-3% cover).

We demarcated 4 13-ha stands within each management compartment (a total of 16 stands) and laid out 8 by 8 grids with 40-m intervals in the center of each stand. The grid served as a template to apply experimental treatments and to sample bird communities. Two randomly selected stands in each block (compartment) were treated with variable-density thinning (VDT); the remaining stands served as controls. VDT consisted of 3 thinning intensities applied randomly to the 0.16-ha (40 x 40-m) cells composing each grid; the remaining 80-m borders of the treated stands were thinned lightly (Figure 1).

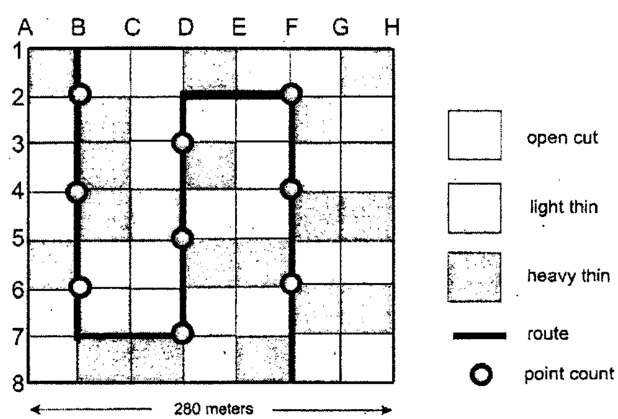

Figure 1. Example of VDT stand with random assignment of 3 thinning intensities, systematic location of point-count stations, and route of observer travel. Locations of point-count stations in control stands were identical.

A root-rot (open thinning) treatment was applied to pockets of root-rot (*Phelinus wierii*) infestation and randomly assigned cells (where root rot was not apparent) to cover 15% of the grid. This sub-treatment removed all low-vigor trees out to 10 m from the pocket, but retained all apparently healthy trees (with an average retention of about 40 trees/ha or a relative density of about 2). We used Curtis' (1982) relative density (RD) to measure inter-tree competition and as a guide to thinning. We assigned randomly light (RD 6) and heavy (RD 4) thinnings to the remaining cells in a 1-2:1 ratio (Carey et al. 1999*c*), equivalent to retaining an average of 309 trees/ha and 185 trees/ha, respectively, in an "average" 30- to 50-year-old stand of 10- to 50cm-dbh trees (Carey and Curtis 1996). We designed the ratio and scale of application of the various thinning intensities to reduce inter-tree competition to free up light, moisture, and nutrients to develop a spatially heterogeneous understory of diverse vegetation site types (great habitat breadth) similar to that found in old-growth forests (Carey 1995; Carey et al. 1999*a*,*c*). Loggers completed the variable-density thinnings in spring 1993.

Bird counts

We counted birds at 9 point-count stations/stand, systematically located at grid markers; all stations were at least 80 m apart and at least 80 m from the edge of the stand (Figure 1). In 1996, we randomly selected and surveyed one VDT and one control stand from each block (a total of 8 stands). In 1997 and 1998, we surveyed all 16 stands. We began counting birds 2 minutes after arrival at a station to allow for normal resumption of bird activity. We recorded all birds seen or heard during the subsequent 8 minutes (Manuwal and Carey 1991). We counted individual birds only once. To reduce observer bias we used the same observers all 3 years and systematically rotated observers among stands. We made counts in January and February during daylight hours. We did not survey during foggy, rainy, or snowy conditions, or when wind was >24 km/hr. During 1996, we surveyed 6 stands 3 times each and 2 stands twice each. In 1997 and 1998, we visited all 16 stands 4 times.

Data and analysis

We recorded station number, 4-letter code for each species detected (Gustafson et al. 1997), number of individuals of each species in each of 4 distance categories (<20 m from the station, 20-40 m, > 40 m, and flyovers), initial detection cue (visual or aural), and field notes. We do not present data here on species whose use of the area could not be determined (flyovers) or on species detected < 2 winters. We included species, including common ravens (*Corvus corax*) and red-tailed hawks (*Buteo jamaicensis*), that we commonly saw flying over the study area only if we also saw those species on perches or roosts in the stand.

We present actual counts to facilitate comparison with other studies. However, our initial examination of count data revealed deviations from the normal distribution. As expected for winter surveys (Manuwal and Huff 1987, Manuwal and Carey 1991), counts were very variable day-to-day and year-to-year and were confounded by flocking behavior (observations were not independent) and traveling birds. As in most studies of avian abundance, such point-count data may not adequately represent species density (Verner 1985) and do not meet the assumptions of most statistical procedures. Nevertheless, for heuristic purposes, we compared abundances between treatments using 95% confidence intervals about means (0±2 SE) for 1997 and 1998 based on 4 observations/treatment/year for the 8 species with frequencies of detection >5%.

Our experiment emphasized spatial heterogeneity to promote biocomplexity, including bird diversity. Great variances in mean abundances obscured the degrees to which stands were used fully spatially—i.e., means based on high counts at a few points were indistinguishable from means based on moderate counts at each point. We developed an index of use based on consistency and completeness of use of sample points within stands (but see Saab 1999 for caveats). Reducing data to presence-absence values can do much to eliminate extraneous variation, albeit at a cost of some loss in information (Verner 1985, Carey et al. 1991, Manuwal and Carey 1991). We assigned values based on presence (1) or absence (0) for each species at each point sampled and calculated mean value/visit/point (sum of values/number of visits) to derive a use value for each point. Point-use values were then averaged over the number of points/stand to determine stand-use rates. Calculated stand-use rates approximated normal distributions and use of means invoked the central limit theorem that assures normality. We assumed equal probability of detection between forests and between VDT and control stands. We tested our assumption by analysis of variance with general linear models (SPSS 1997) to detect distance-by-treatment interactions; we found no interaction for most species.

We used data only from control stands in our analysis of effects of management strategy on birds. We used data from all stands in our analysis of experimental treatments in relation to management strategy. We used data from all 3 winters to compare species richness among treatments and strategies. Because sampling effort was low in 1996, we only used data from 1997 to 1998 to examine stand use by the 8 most common winter species (frequency of detection >5%). We conducted multiple factor (split-plot or 2-way) analyses of variance with both management-strategy and experimental manipulation data sets on numbers of species and stand-use rates to examine effects of strategy, year, VDT, and their interaction on species richness and stand use. We designated strategy, year, and treatment as fixed factors, year as the split-plot factor in time, and strategy and treatment as split-plot factors in space. When we found significant interaction effects, we used Bonferroni's pair-wise multiple comparison test to determine which means differed ($P<0.05$). For response variables without significant interaction effects, we pooled data and conducted one-way ANOVAs to test main effects for statistical significance. We calculated confidence intervals from control-stand data to compare effects of strategy, but results are reported as means ± 1 standard error (0± SE). We report all statistical analyses at $\alpha=0.05$ and we used SPSS 8.0 software (SPSS Inc. 1997) for all analyses.

Results

Over 3 winters, we made 1,350 visits to 144 count stations in 16 stands. We recorded

Table 1. Number of birds detected more than one winter, and number of species detected in control (unthinned) and VDT (variable-density thinning) stands (n=16) of 60- to 70-year-old Douglas-fir managed with legacy retention (legacy) and commercial thinning (thinned) in the Puget Trough, Washington, 1996-98.

	1996				1997				1998			
	Legacy		Thinned		Legacy		Thinned		Legacy		Thinned	
Bird Species	Control	VDT	Control	VDT	Control	VDT	Control	VDT	Control	VDT	Control	VDT
Regulus satrapa	129	89	131	111	310	407	465	393	412	552	439	282
Troglodytes troglodytes	22	28	64	53	124	171	184	193	116	149	159	149
Poecile atricapillus	25	21	17	80	69	17	25	47	16	13	12	24
Poecile rufescens	6	17	25	8	23	20	39	21	5	42	23	18
Ixoreus naevius	34	71	39	7	19	31	17	19	2	4	2	0
Sitta canadensis	10	19	29	28	22	12	35	29	1	2	1	0
Melospiza melodia	1	0	20	65	1	3	8	29	0	1	10	44
Certhia americana	4	4	2	3	22	21	26	22	20	12	22	23
Perisoreus canadensis	8	6	15	11	14	15	16	15	16	15	14	5
Regulus calendula	0	0	10	11	1	4	29	21	0	12	25	20
Juncus hyemalis	2	18	60	41	0	5	1	1	0	0	0	1
Carduelis pinus	22	3	50	36	0	6	0	0	0	0	0	0
Corvus corax	5	3	3	1	10	6	6	7	5	3	8	14
Picoides villosus	2	4	4	3	7	8	4	4	8	8	8	5
Cyanocitta stelleri	0	1	4	14	2	1	5	9	0	0	1	4
Dryocopus pileatus	1	4	1	3	4	1	5	7	1	1	2	3
Vireo huttoni	5	0	3	2	6	2	3	2	1	1	1	3
Turdus migratorius	1	0	1	2	5	3	3	3	0	0	6	2
Picoides pubescens	5	0	0	1	3	3	1	1	3	4	1	2
Pipilo erythrophthalmus	1	0	7	7	0	0	1	1	0	0	2	1
Buteo jamaicensis	0	0	2	3	0	2	3	2	0	2	1	1
Colaptes auratus	0	3	8	0	0	1	0	1	0	0	0	1
Sphyrapicus ruber	0	0	0	1	2	4	1	5	0	1	0	0
Corvus brachyrhynchos	2	2	2	0	0	1	1	1	0	0	0	1
Glaucidium gnoma	0	0	2	2	2	2	1	0	0	0	0	1
Accipiter striatus	0	1	2	1	0	0	1	0	0	0	0	0
Dendroica townsendi	0	0	1	0	0	0	0	0	0	0	0	4
Aegolius acadicus	1	0	0	0	0	0	0	0	0	0	1	0
Total	286	294	502	494	646	746	880	833	606	822	738	608
# of Species	20	17	25	24	19	24	24	23	13	17	20	22

birds representing 28 species (Table 1). We record-ed 1.4 times more birds in thinned controls than in legacy controls and 1.2 times more birds in legacy VDT than in legacy controls; we counted approximately equal numbers in thinned VDT and thinned controls. Eight species accounted for 88% of all detections and included golden-crowned kinglet (*Regulus satrapa*), winter wren (*Troglodytes troglodytes*), black-capped chickadee (*Poecile atricapillus*), chestnut-backed chickadee (*P. rufescens*), varied thrush (*Ixoreus naevius*), red-breasted nuthatch (*Sitta canadensis*), song sparrow (*Melospiza melodia*), and brown creeper (*Certhia americana*). Abundance estimates from count data indicated that in 1997 no species differed between treatments within a management strategy, whereas in 1998 we did not detect song sparrows in control stands of the legacy forest and we did not detect red-breasted nuthatches or varied thrushes in VDT stands of the thinned forest. We found other species in all 16 stands, including gray jay (*Perisoreus canadensis*), common raven, hairy woodpecker (*Picoides villosus*), and pileated woodpecker (*Dryocopus pileatus*). In 1996, we counted 111 pine siskins (*Carduelis pinus*) and 121 Oregon juncos (*Junco hyemalis*); however, we recorded only 6 and 7 in 1997 and 0 and 1 in 1998, respectively.

Table 2. Means (±1 SE in parentheses) for species richness (number of species), bird community use rates (28 species pooled), and individual species use rates for 8 common species in control (unthinned) and VDT (variable-density thinning) stands (n=16) of 60- to 70-year-old Douglas-fir managed with legacy retention (legacy) and commercial thinning (thinned) inthe Puget Trough, Washington, 1997–98. Symbol (‡) indicates significant difference (P<0.05) between control and VDTstands based on analysis of variance.

	1997				1998			
	Legacy		Thinned		Legacy		Thinned	
Response measure	Control	VDT	Control	VDT	Control	VDT	Control	VDT
Species richness [a]	12.75 (0.85)	15.75 (0.48)	15.25 (0.95	16.50 (0.65)	9.50 (0.65)	12.00 (0.58)	13.75 (1.11)	13.75 (0.48)
Bird community use	1.92 (0.09)	1.89 (0.10)	2.19 (0.09)	2.20 (0.15)	1.15 (0.05)	1.40 (0.11)	1.53 (0.07)	1.69 (0.12)
Troglodytes troglodytes	0.60‡ (0.05)	0.71‡ (0.03)	0.76 (0.07)	0.82 (0.01)	0.56‡ (0.04)	0.69‡ (0.04)	0.71 (0.02)	0.73 (0.03)
Regulus satrapa	0.35 (0.07)	0.36 (0.05)	0.37‡ (0.02)	0.24‡ (0.03)	0.24 (0.03)	0.23 (0.03)	0.23‡ (0.03)	0.17‡ (0.03)
Certhia americana	0.15 (0.02)	0.13 (0.03)	0.16 (0.03)	0.14 (0.02)	0.13 (0.01)	0.07 (0.02)	0.12 (0.01)	0.14 (0.02)
Sitta canadensis [b]	0.15 (0.03)	0.07 (0.01)	0.21 (0.03)	0.19 (0.04)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)
Melospiza melodia	0.01 (0.01)	0.01 (0.01)	0.06‡ (0.03)	0.16‡ (0.02)	0.00 (0.00)	0.01 (0.01)	0.07‡ (0.02)	0.24‡ (0.05)
Poecile atricapillus	0.19 (0.04)	0.08 (0.03)	0.10 (0.03)	0.12 (0.04)	0.04 (0.02)	0.04 (0.02)	0.05 (0.01)	0.06 (0.02)
Ixoreus naevius	0.10 (0.02)	0.16 (0.05)	0.11 (0.02)	0.10 (0.03)	0.01 (0.01)	0.03 (0.01)	0.01 (0.01)	0.00 (0.00)
Poecile rufescens	0.06 (0.02)	0.06 (0.01)	0.08 (0.01)	0.04 (0.01)	0.02 (0.01)	0.10 (0.03)	0.06 (0.02)	0.04 (0.02)

[a] Year-by-treatment interaction in legacy ($F_{2,14}$=5.1, P=0.021)
[b] Year-by-treatment interaction in legacy ($F_{1,12}$=5.5, P=0.036)

Species richness

Thinned control stands had more species (16.2±1.4) than legacy controls (12.2±1.0) on average across years ($F_{1,18}$=5.8, P=0.03). Species richness differed between strategies without significant year-by-forest interaction (Figure 2). Differences in richness among years, however, was greater than differences in richness between strategies. Species richness in 1996 (19.8±2.3) was greater ($F_{2,17}$=9.8, P=0.001) than in 1997 (14.0±0.8) or 1998 (11.6±1.0), despite low sampling effort in 1996. Mean number of species ranged from 16.5 to 9.5 in legacy stands and from 23 to 13.8 in thinned stands.

Legacy stands had year-by-treatment (VDT) interaction ($F_{2,14}$=5.1, P=0.02) for species richness; fewer species were lost in VDT stands between high and low richness years. Stands from both strategies had significant year effects on species richness (legacy: $F_{2,14}$ = 10.6, P = 0.002; thinned: $F_{2,14}$=24.5, $P \leq 0.001$; Figure 3; Table 2). However, thinned stands did not have significant year-by-treatment interaction ($F_{2,14}$=0.7, P=0.54). Thus, inter-annual fluctuation in mean number of species was less in VDT when applied to legacy stands (controls: 9.5 - 16.5 species, VDT: 12.0-15.8 species) but not when applied to thinned stands. There were no differences in species richness between VDT and controls in thinned stands. Species richness in thinned stands was greater ($F_{2,17}$ =27.1, $P \leq 0.001$) in

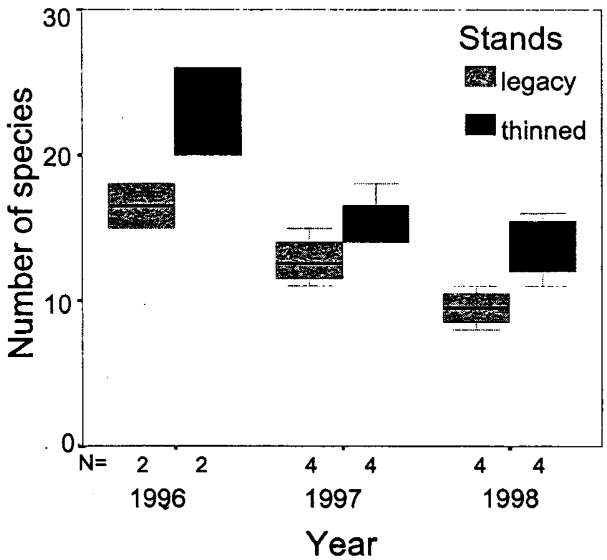

Figure 2. Differences in species richness between 60- to 70-year-old Douglas-fir stands managed with legacies and commercial thinning in the Puget Trough, Washington, 1996-98. Boxplots represent control stands in each forest and suggest that commercially thinned stands consistently supported more species than competitive-exclusion stage stands managed only with legacy retention.

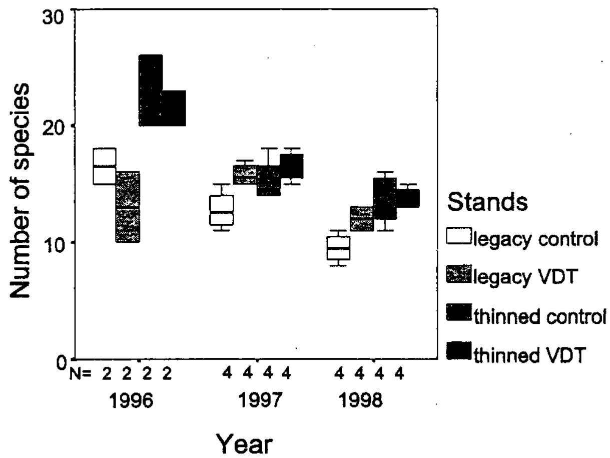

Figure 3. Differences in species richness between unthinned (control) and variable-density thinning (VDT) stands of 60- to 70-year-old Douglas-fir managed with legacy retention (legacy) and commercial thinning (thinned) in the Puget Trough, Washington, 1996-98. Results suggest that VDT in the legacy stands may have helped maintain avian community diversity during a period of general decline.

1996 (22.2±1.4) than in either 1997 (15.9±0.6) or 1998 (13.8±0.6). Inter-annual fluctuation in mean number of species was only slightly greater in control stands (13.8-23.0) than in VDT stands (13.8-21.5). Thus, VDT had little effect when applied to stands previously conventionally thinned twice.

Use of stands in time and space

None of the 8 common species exhibited year-by-strategy interactions on use rates. Song sparrows made greater use ($F_{1,14}$=15.44, P=0.002) of thinned stands (0.06±0.01) than legacy stands (0.003 ± 0.003). Winter wrens also used more ($F_{1,14}$ =9.48, P =0.008) of thinned stands (0.74±0.03) than legacy stands (0.58 ± 0.03). We did not find differences in use between strategies for the 6 other common species.

Red-breasted nuthatches exhibited year-by-treatment interaction ($F_{1,12}$ = 5.54, P = 0.04) in use of legacy stands, whereas no species showed year-by-treatment interactions in use of thinned stands. Winter wrens used more ($F_{1,14}$ = 8.48, P = 0.01) of legacy VDT stands (0.70 ± 0.02) than legacy control stands (0-58 ± 0.03), but did not differ between thinned VDT and thinned controls. Golden-crowned kinglets made greater use ($F_{1,14}$ = 6.07, P = 0.027) of thinned controls (0.30 ± 0.03) than thinned VDT (0.20 ± 0.02), whereas song sparrows made greater use ($F_{1,14}$ = 17.72, P = 0.001) of thinned VDT (0.20 ± 0.03) than controls (0.06 ± 0.01). Song sparrows appeared to use more of legacy VDT than legacy controls, but their numbers were too low to produce a statistically significant difference. We found no other differences in use of VDT and control stands by the common species.

Discussion

Scope and limitations

Our study was limited in scope to 3 winters and 16 second-growth Douglas-fir stands in the Puget Trough of Washington. Factors operating beyond the scale of our study (i.e., landscape or regional population trends) may have influenced our results. Projected full effects of VDT on understory and midstory development requires ≥ 20 years of response (Carey et al. 1999*c*); our study was limited to ≤ 5 years following experimental treatment. The composition and abundance of winter bird communities in our experimentally treated stands may continue to change as plant communities continue to respond to the thinning.

None of our stands supported populations of woodpeckers (Picidae) dense enough to be sampled effectively with our methods, a common problem in avian community studies (Verner 1985, Manuwal and Carey 1991, see papers in Ruggiero et

Legacy retention holds snags and coarse woody debris in the forest, but passive management allows rapid canopy closure, a long competitive exclusion stage, and little understory development.

The black-capped chickadee, a common winter bird in lowland Washington.

al. 1991). We did not attempt to sample nocturnal birds such as owls. We did not encounter the seed-eating birds, red crossbills (*Loxia curvirostra*) and white-winged crossbills (*L. leucoptera*), reported by Huff et al. (1991) to be associated with old-growth in winter and that putatively would benefit from seed production by large, live, old trees in the legacy forest. Legacy management is often aimed at woodpeckers, other cavity-using birds, owls, and raptors. Nevertheless, our sampling was more intensive and included more species than other recent studies (Hagar et al. 1996, Chambers et al. 1997) of winter bird communities in the Pacific Northwest.

Strategies

Thinning as a forest management strategy produced stands that supported more winter birds and more species of winter birds than legacy retention. We were somewhat surprised by this result because legacy retention is often implemented with the expressed purpose of providing habitat for overwintering, cavity-using, birds (5 of the 8 most common species and 12 of the 28 species recorded) and conventional thinning often results in reduced decadence in overstory trees and thus reduced utility to cavity users. However, we found limited use of large, old snags by cavity-using wildlife in the legacy stands (Carey et al. 1997), presumably because these snags were well-decayed and cavity-using birds in the Pacific Northwest prefer moderately decayed large conifer snags (Carey et al. 1991, Lundquist and Mariani 1991). We observed significant use by cavity-nesting birds and mammals of suppressed deciduous trees in the thinned forest (deciduous trees that occupied the site at the same time as the Douglas-fir and were maintained by conventional thinning, but that were eventually overtopped by Douglas-fir; Carey et al. 1997). Hagar et al. (1996) also compared commercially thinned and unthinned stands (40- to 55-yearold Douglas-fir in Oregon) and found no difference in abundance of winter birds and only marginally greater species richness in thinned stands. We, however, counted more birds and found more species overall than Hagar et al. (1996). Two species, winter wrens and song sparrows, clearly exhibited greater use of thinned stands than of legacy stands.

Manipulation of spatial heterogeneity

Our VDT treatment had immediate effects on the bird communities in the legacy stands despite insufficient time for full understory response to reduced and variable canopy density. VDT reduced interannual fluctuations in species richness in legacy stands. Species richness was greater in 2 of 3 years in legacy VDT stands compared to legacy controls, 2 years in which overall richness was least. The mechanisms of this action are not clear, but could include understory development (with concomitant foliage, fruit, seed, and associated insect production), changed microclimates (patches of direct sunlight and sun flecks that might help raise local temperatures with-out increasing wind-flow), and increased vigor of overstory trees. Experimental VDT had less effect on diversity in the thinned stands, suggesting that thinning in general has positive effects on winter bird communities and that the spatial component of VDT had not yet had an effect. Only time will tell whether VDT will lead to increased habitat breadth and midstory development, as postulated, and whether these 2 changes in forest structure will positively affect the winter bird community.

Thinning brings light into the forest, helping the development of midstory and understory forest layers, which support many small bird and mammal communities. Variable-density thinning helps delay canopy reclosure, delaying competitive exclusion.

Species patterns

No species common in winter preferred unthinned legacy stands. The most common species, the winter wren (20% of all birds counted and present at nearly 70% of count stations), made greater use of VDT legacy stands than legacy controls. Winter wrens are understory-gleaning insectivores that often nest in cavities in fallen trees (Ehrlich et al. 1988). Their low use of legacy controls may reflect the limited forb, fern, and shrub cover, which may have limited foraging substrate and prey availability. VDT increased understory vegetation in the legacy stands, which already had large fallen trees, increasing the quality of the environment for winter wrens. Chambers and McComb (1997) detected no differences among 4 treatment types (uncut controls, small-patch group selection 2-story, and modified clear-cut) for wintering winter wrens in 80- to 120-year-old Douglas-fir forest in the Oregon Coast Ranges. Perhaps understory vegetation and coarse woody debris were abundant in all their stands. Use of legacy stands by red-breasted nuthatches declined between 1997 and 1998, but the decline was less severe in VDT stands.

Golden-crowned kinglets made greatest use of the thinned control stands. Golden-crowned kinglets are foliage-gleaning insectivores that move through the forest canopy in flocks (Ehrlich et al. 1988). They were typically encountered as foraging flocks moving through the canopy and accounted for nearly half of all individual birds detected in our study. Use rates of golden-crowned kinglets in thinned controls were comparable to rates across legacy stands, suggesting the kinglets may have been avoiding canopies with reduced density due to multiple thinnings (2 conventional + 1 VDT). Song sparrows are understory-gleaning insectivores (Ehrlich et al. 1988) and demonstrated a strong positive response to VDT even in the previously thinned forest. Their pattern of occurrence among stands likely reflects the degree of understory development. Their use of conventionally thinned stands and VDT thinned stands was likely a response to dense understory vegetation. This contrasts with Chambers and McComb's (1997) report of no detectable short-term (3-5 years after harvest) difference among 4 treatment types for winter song sparrows in the Coast Ranges of Oregon. We would have expected understory vegetation to have responded strongly to their heavy overstory removal and song sparrows to have increased concomitantly.

High annual variation in bird populations is common (e.g., Huff et al. 1991) and has been linked to great annual variances in environmental conditions (Smith 1984) and survivorship (DeSante et al. 1998). During our study, several species varied widely between years and many species declined from 1996 to 1998. The decline of some species, such as pine siskins, may be weather-related in part. Our survey in 1997 commenced 2 weeks after a severe ice storm when many tree tops and upper-canopy seed-bearing branches were broken. This event likely reduced available food and may have contributed to mortality or emigration by pine siskins.

Management implications

Silviculture can enhance abundance and diversity of winter birds. Variable-density thinning can shorten or preclude the competitive-exclusion stage and accelerate the development of understory and midstory structure in overstocked closed-canopy forests to create conditions which support more diverse and abundant wintering bird communities. Only 6 years after application, VDT legacy stands approached the same attractiveness to birds as long-term (10-15 years) commercially thinned forest; VDT is a valuable adjunct to legacy retention. Although con-tinued research is needed to evaluate the long-term effects on resident birds, variable-density thinning holds promise as a valuable tool to manage for bio-diversity and multiple forest values (Carey et al. 19996, Carey 2000). Variable-density thinning also may be viable economically for many management applications (Lippke et al. 1996, Carey et al. 1999*b*). Cavity-excavating birds, often used as management indicator species, were rare even in the presence of substantial legacy trees and suppression mortality, suggesting that more information is needed on how to manage decadence in second-growth stands.

Acknowledgments. Funding was provided by the Pacific Northwest Research Station, United States Department of Agriculture Forest Service. We thank the United States Department of the Army, Fort Lewis, for its cooperation and support. We especially thank G. Braden and S. Brewster for their professional assistance in the field. E. D. Ford provided statistical advice and, along with J. C. Hagar, D. A. Manuwal, and C. M. Raley, provided valuable comments on an early draft of this manuscript.

Literature cited

ANDERSON, S. H. 1972. Seasonal variations in forest birds of western Oregon. Northwest Science 46:194-206.

BUCHANAN, J. B., R W. LUNDQUIST, AND K B. AUBRY 1990. Winter populations of Douglas' squirrels in different-aged Douglas-fir forests. Journal of Wildlife Management 54:577-581.

CAREY, A B. 1989. Wildlife associated with old-growth forests of the Pacific Northwest. Natural Areas Journal 9:151-162.

CAREY A. B. 1991. The biology of arboreal rodents in Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-276.

CAREY A. B. 1995. Sciurids in Pacific Northwest managed and old-growth forests. Ecological Applications 5:648-661.

CAREY A. B. 2000. Effects of new forest management strategies on squirrel populations. Ecological Applications 10:248-257.

CAREY A B., AND R O. CURTIS. 1996. Conservation of biodiversity: a useful paradigm for ecosystem management. Wildlife Society Bulletin 24:610-620.

CAREY, A. B., M. M. HARDT, S. P. HORTON, AND B. L. BISWELL. 1991 Spring bird communities in the Oregon Coast Range. Pages 122-142 in Ruggiero L. F., K B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-285

CAREY A B., S. P. HORTON, AND B. L BLSWELL. 1992. Northern spotted owls: influence of prey base and landscape character. Ecological Monographs 62:223-250.

CAREY A B., AND M. L. JOHNSON. 1995. Small mammals in managed, naturally young, and old-growth forests. Ecological Applications 5:336-352.

CAREY, A B., J. KERSHNER, B. BISWELL, AND L D. DE TOLEDO. 1999*a*. Ecological scale and forest development: squirrels, dietary fungi, and vascular plants in managed and unmanaged forests. Wildlife Monographs 142:1-71.

CAREY, A B., B. R LIPPKE, AND J. SESSIONS. 1999*b*. Intentional systems management: managing forests for biodiversity. Journal of Sustainable Forestry 9 (3/4):83-125.

CAREY, A B., D. R THYSELL, AND A W. BRODIE. 1999*c*. The forest ecosystem study: background, rationale, implementation, baseline conditions, and silvicultural assessment. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-457.

CAREY, A B., T. M. WILSON, C. C. MAGUIRE, AND B. L BISWELL. 1997. Dens of northern flying squirrels in the Pacific Northwest. Journal of Wildlife Management 61:684-699.

CHAMBERS, C. L., AND W. C. MCCOMB. 1997. Effects of silvicultural treatments on wintering bird communities in the Oregon coast range. Northwest Science 71: 29-304.

CURTIS, R O. 1982. A simple index of stand density for Douglasfir. Forest Science 28:92-94.

DESANTE, D. F., D. R O'GRADY K M. BURTON, P. VELEZ, D. FROEHLICH, E. E. FEUSS, H. SMITH, AND E. D. RUHLEN. 1998. The Monitoring Avian Productivity and Survivorship (MAPS) Program sixth and seventh annual report (1995 and 1996). Bird Populations 4:69-122.

EHRLICH, P. R, D. S. DOBKIN, AND D. WHEYE. 1988. Birder's Handbook: A Field Guide to the Natural History of North American Birds. Simon and Schuster, New York, New York, USA.

FRETWEL, S. D. 1972. Populations in a seasonal environment. Monographs in Population Biology Number 5. Princeton University, Princeton, New Jersey, USA.

GILBERT, F. F., AND R ALLWINE. 1991. Spring bird communities in the Oregon Cascade Range. Pages 145-157 *in* Ruggiero L. F., K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-285.

GRUBS, T. C., JR. 1975. Weather-dependent foraging behavior of some birds wintering in a deciduous woodland. Condor 77:175-182.

GUSTAFSON, M. E., J. HILDENBRAND, AND L. METRAS. 1997. The North American Bird Banders Manual. (Electronic version) Version 1.0.

HAGAR, J. C., W. C. MCCOMB, AND W. H. EMMINGHAM. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildlife Society Bulletin 24:353-66.

HUFF M. H., D. A MANUWAL, AND J. A PUTERA. 1991. Winter bird communities in the southern Washington Cascade Range. Pages 207-218 *in* Ruggiero L. F., K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-285.

LIPPKE, B. R, J. SESSIONS, AND A B. CAREY. 1996. Economic analysis of forest landscape management alternatives. Center for International Trade in Forest Products Special Publication, CINTRAFOR SP2 1. University of Washington, Seattle, USA.

LUNDQUIST, R W., AND J. M. MARLANI. 1991. Nesting habitat and abundance of snag-dependent birds in southern Washington Cascade Range. Pages 221-240 *in* Ruggiero L. F., K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-285.

MANUWAL, D. A., AND M. H. HUFF. 1987. Spring and winter bird populations in a Douglas-fir forest sere. Journal of Wildlife Management 51:586-595.

MANUWAL, D. A., AND A. B. CAREY 1991. Methods for measuring populations of small, diurnal forest birds. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR-278.

MERRITT, J. F., EDITOR. 1984. Winter ecology of small mammals. Special Publication 10, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.

MORRISON, M. L., K A WITH, AND L C. TIMOSSI. 1986. The structure of a forest bird community during winter and summer. Wilson Bulletin 98:214-230.

RUGGIERO L F., K B. AUBRY A B. CAREY, AND M. H. HUFF, technical coordinators. 1991. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Department of Agriculture Forest Service, General Technical Report PNW-GTR 285.

SAAB, V. 1999. Importance of spatial scale to habitat use by breeding birds in riparian forests: a hierarchical analysis. Ecological Applications 9:135-151.

SMITH, P. G. R 1984. Observer and annual variation in winter bird population studies. Wilson Bulletin 96:561-574.

SPSS, INC. 1997. SPSS for Windows, Release 8.0. SPSS, Chicago, Illinois, USA.

VERNER, J. 1985. Assessment of counting techniques. Current Ornithology 2:247-302.

Bruce A. Haveri received his B.S. in environmental science from Evergreen State College in Olympia, Washington. Bruce has been lead biologist for avian studies on the Ecological Foundations of Biodiversity Research Team since 1996 and is an avid birder. ***Andrew B. Carey*** received his B.S. in forestry and wildlife and his M.S. in wildlife management from Virginia Tech and his Ph.D. in zoology and entomology from Colorado State University. He has been studying old-growth, naturally young, and managed forests in the Pacific Northwest since 1982 and currently leads the Ecological Foundations of Biodiversity Research Team.

Associate editor: *Thompson*