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Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon

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Abstract We compared abundance and diversity of breeding and winter birds between commercially thinned and unthinned 40- to 55-year-old Douglas-fir (*Pseudotsuga menziesii*) stands in the Oregon Coast Ranges. Abundance of breeding birds was greater in thinned stands. Bird species richness was correlated with habitat patchiness and densities of hardwoods, snags, and conifers. During the breeding season, Hammond's flycatchers (*Empidonax hammondii*), hairy woodpeckers (*Picoides villosus*), red-breasted nuthatches (*Sitta canadensis*), dark-eyed juncos (*Junco hyemalis*), warbling vireos (*Vireo gilvus*), and evening grosbeaks (*Coccothraustes vespertinus*) were more abundant in thinned than unthinned stands. Pacific-slope flycatchers (*Empidonax difficilis*) were more abundant in unthinned stands. Golden-crowned kinglets (*Regulus satrapa*), gray jays (*Perisoreus canadensis*), and black-throated gray warblers (*Dendroica nigrescens*) were more abundant in unthinned than thinned stands, but these patterns were inconsistent between seasons, regions, or years. Stand-scale habitat features were associated with the abundance of 18 bird species.

Key words avian-habitat, forest-management, habitat-management, silviculture, USA

In the temperate coniferous forests of the Pacific Northwest, both structural and animal diversity are lowest in the closed sapling-pole-sawtimber successional stage (Brown 1985:30). The dense canopies of young (40- to 80-year-old) stands suppress understory layers of vegetation because they allow little penetration of light (Oliver and Larson 1990:146–147). Forests regenerating after a natural disturbance (e.g., fire) may retain some features from the previous stand such as large overstory trees and large woody debris, which contribute to spatial heterogeneity (Spies and Franklin 1991). However, managed plantations typically lack residual features and therefore are structurally simple (Hansen et al. 1991). Low animal diversity in young, closed-canopy forests may be related to a lack of vegetational complexity resulting from the low structural diversity (Hunter 1990:187–192).

The combination of clearcut harvesting and short (<100 years) rotations in western Oregon over the past several decades has resulted in a shift from landscapes dominated by structurally complex late successional forests, to ones dominated by relatively homogenous young plantations (Hansen et al. 1991). For wildlife species associated with structural features characteristic of old-growth forests and naturally regenerated young stands (e.g., large trees and snags), this shift may represent a loss of habitat. Land managers interested in maintaining biodiversity and mitigating the loss of old-growth habitat are seeking tools for managing young forests to provide habitat for all native wildlife species associated with forests (McComb et al. 1993). Commercial thinning may be one such tool because it may enhance vertical diversity within a forest stand (Hunter 1990:227-230), which may in turn increase wildlife species diversity, particularly for birds (Thomas et al. 1975:276, Langelier and Garton 1986).

The use of commercial thinning has increased in western Oregon (Sessions 1990:8) as timber has be-

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come more valuable and clearcutting has been restricted on federally managed lands (S. Laam, Oregon Dep. For., Philomath, Oreg., pers. commun.). In 1993, 116,011 ha (286,664 acres) were commercially thinned in western Oregon forests (Bourhill 1994), and commercial thinning is currently practiced at a steady annual rate of about 10,000 acres/year on State lands (L. Jones, Oregon Dep. For., Salem, pers. commun.). Specific thinning practices also have been proposed as a means of improving habitat for old-growth associated wildlife species in young plantations (McComb et al. 1993). Although commercial thinning may be a useful tool for increasing stand-level structural complexity and for moving stands more rapidly toward old-growth-like habitat, few quantitative data exist for predicting the effects of commercial thinning on wildlife and wildlife habitat.

Our objectives were to compare bird abundance and community composition between commercially thinned and unthinned young (40- to 55-year-old) stands of Douglas-fir (*Pseudotsuga menziesii*) in western Oregon, and to identify habitat features associated with bird abundance in these young stands.

Study area

Study sites were in 2 regions: (1) the northern Oregon Coast Range between 45° 45' and 45° 35' latitude in the Tillamook State Forest (TSF), Tillamook and Washington Counties and (2) the central Oregon Coast Ranges (CCR) between 44° 37' and 44° 22' latitude in Benton and Lincoln Counties. Both sites were in the western hemlock (*Tsuga heterophylla*) forest zone of the Oregon Coast Ranges (Franklin and Dyrness 1988:70–93). Douglas-fir dominated all stands. Western hemlock, western redcedar (*Thuja plicata*), and true firs (*Abies* spp.) were rare but present in some stands. Common understory shrubs included salal (*Gaultheria shallon*), dwarf Oregon-grape (*Berberis nervosa*), and vine maple (*Acer circinatum*).

The structure and composition of the TSF is largely a product of several conflagrations which occurred between 1933 and 1945 and burned approximately 143,670 ha of forest land (Oregon Dep. For. 1983). Since the fires occurred, the forest has naturally regenerated or been planted uniformly under the management of the Oregon Department of Forestry. Clearcut harvesting and commercial thinning began in 1983 (Oregon Dep. For. 1983), introducing the first discontinuities into an otherwise large, even-aged, homogenous tract of Douglas-fir dominated forest. This landscape differs from that of the CCR, which is a mosaic of different age classes of forest created by various management practices of multiple owners.

Methods

Study site selection

We chose 4 commercially thinned and 4 unthinned stands in each of the 2 regions (16 total stands). Thinned stands were defined by the thinning boundary, as determined by the land owner. Unthinned stands were delineated by boundaries with stands (>3 ha) of vegetation that differed in condition (e.g., seral stage) or plant community composition as defined in Brown (1985:19–31). Thinned and unthinned stands were paired based on similarity in elevation, aspect, and vegetation association. Stands were 40–55 years old, dominated by Douglas-fir overstories, and 65–510 ha in size. The wide range in stand sizes is a result of relatively small thinned stands being imbedded in a vast unthinned matrix in the TSF. Unthinned stands averaged 495 trees/ha (range 322–724) and had an average relative density index (ratio of actual stand density to the maximum stand density attainable in a stand with the same mean tree volume; Drew and Flewelling 1979) of 0.34 (range 0.27–0.49). Thinned stands averaged 360 trees/ha (range 213–598), their relative densities averaged 0.24 (range 0.17–0.27), and they were treated 5–15 years prior to sampling. As is typical in managed Douglas-fir stands in the Coast Range, commercial thinning on our study areas was accomplished by removing suppressed trees from the lower and intermediate crown classes ("thinning from below;" Smith 1962:64–69). Sites in the CCR were managed by Starker Forests, Inc., Siuslaw National Forest, and Willamina Lumber Company; elevation was 280–468 m. Study sites in the TSF were managed by the Oregon Department of Forestry; elevation was 340–625 m.

Bird sampling

The senior author counted birds from early May through late June in 1989 and 1990 and during the winter from 12 November 1989 through 5 April 1990, using variable circular plots (Reynolds et al. 1980). Four randomly located points in each stand served as plot centers (total = 64 plots). Plot centers were ≥130 m apart (range 130–590 m, $\bar{x}$ = 234) and >100 m from a stand edge (not including forest access roads). An observer standing at plot center for 10 minutes recorded species of birds seen or heard and estimated distance (m) to birds. Repeat observations of individual birds during a single count day were noted and excluded from analyses. Birds observed flying over the plot were not included in analyses.

We conducted counts at each plot 4 times/breeding season, from 0.5 hour before sunrise to 4 hours after sunrise on days when rain or wind did not reduce bird activity. We conducted winter counts from sunrise to early afternoon, visiting thinned and unthinned pairs of stands on the same day. Because we wanted to sample bird use of stands for foraging and cover during wet winter weather, we conducted surveys in all but the most severe weather. During winter, we visited each stand 8 times, 1 plot/stand/day to reduce the chances of double-counting non-territorial birds as they foraged throughout the stand.

Habitat sampling

We measured vegetation structure and composition at 4 bird-count plots plus 4 additional stratified-random plots in each stand that did not overlap themselves or bird count plots. Sixty-six habitat variables were either directly measured or derived for each plot. At the plot center we recorded slope, aspect, and distances to stand and patch edges and streams. Stands and patches were delineated on the basis of condition or plant community differences (Brown 1985:19–31); stands were defined as ≥3 ha, patches were ≥1 ha but <3 ha in size. We used a 20-basal area factor prism to record basal areas of conifers, hardwoods, and snags from the plot center. We tallied snags by diameter (dbh; 10–30 cm, 31–53 cm, and >53 cm) and decay class (Cline et al. 1980) within 30 m of plot center. We recorded % cover and vegetation height for all woody plants in 4 satellite plots at random distances 10–40 m from each plot center. Herbaceous and fern cover were visually estimated from 0.01-ha circular plots at the center of each satellite plot; percent shrub and tree cover were visually estimated, and live-tree stems were tallied by diameter-class (<10 cm, 10–20 cm, 21–30 cm, 31–43 cm, 44–56 cm, 57–68 cm, 69–81cm, and >81 cm) in 0.03-ha circular plots centered on each satellite plot. We estimated % cover and height for 4 vertical layers of vegetation: low shrub (0–1.3 m), tall shrub (>1.3–4.0 m), pole (>4–20 m), and sawtimber (>20 m; McGarigal and McComb 1992), as well as for each dominant shrub and tree species individually.

Data analysis

Breeding bird species observed ≥2 times in ≥6 thinned/unthinned pairs of stands were selected for analysis. Data from bird species observed less frequently than this did not provide sufficient information to reliably detect differences between thinned and unthinned stands while conforming to assumptions of the statistical models. To identify differences that may have been influenced by differential detectability between thinned and unthinned stands, we compared mean detection distances between thinned and unthinned stands for each species meeting the above criteria. For those species for which mean detection distance did not differ between thinned and unthinned stands, we pooled data from both stand types to determine effective detection distance. If mean detection distance differed between thinned and unthinned stands for a species, we calculated the effective detection distance for each stand type separately and used the lowest distance of the 2 for analyses. We determined an effective detection distance by examining histograms of 10-m-interval distance bands to locate the distance at which detections decreased by ≥50% from 1 band to the next. When no such decrease was evident, we used the first distance band which included ≥75% of the observations for a given species to indicate the effective detection distance (modified from Reynolds et al. 1980). The number of observations/stand/year (n = 16 stands) within the effective detection distance for each species served as an index of abundance for the species-level analyses.

We tested for a year-by-condition (thinned vs. unthinned) interaction for each species using a split-split-plot analysis of variance (ANOVA; Petersen 1985:235–238) with region as the whole plot, condition as the subplot, and year as the sub-subplot. Only black-throated gray warblers (*Dendroica nigrescens*) showed a year-by-condition interaction (F = 13.5; 1, 11 df; P = 0.003). Data from the 1989 and 1990 breeding seasons were averaged for other species, and observations were compared between thinned and unthinned stands within regions using a split-plot ANOVA (Petersen 1985:134–145). Region was the whole plot, and condition was the subplot. The overall error term was used to test for the condition effect and the condition-by-region interaction. The split-plot ANOVA generated 16 residuals which we evaluated for normal distribution and homogeneity of variance (Sabin and Stafford 1990). When residuals seemed to deviate from a normal distribution or indicated non-constant variance, variables were transformed (log10 [variable + 1]; Sabin and Stafford 1990). When an interaction between region and thinning was detected we used a least-squares means comparison procedure (SAS Inst., Inc. 1985:148–149) to determine which means differed ($P \leq 0.10$) between conditions within each region. We used a distribution-free test (Friedman's test; Devore and Peck 1986:609) to compare means between treatments for variables that did not improve in normality following transformation. The Friedman's test allowed comparisons of dependent variables among treatments within blocks; thus, when it was necessary to use this test, the condition-by-region interaction could not be assessed. We also compared species richness between thinned and unthinned stands within regions using these procedures; however, we used all observations (not including repeat observations of the same bird/stand/day) made ≤100 m from plot center in analyses to include species with the largest effective detection distance (100 m). Species that were incidental on our study sites and wide-ranging species were included in these community-level analyses.

We used stepwise multiple regression to relate habitat features and observations/stand/year of breeding bird species observed in ≥12 of the 16 stands. Because we did not describe habitat during the winter, we analyzed only breeding bird-habitat relationships. We eliminated highly correlated ($P <$ 0.01) vegetation variables prior to regression analysis. No more than 5 predictor variables were retained for each analysis to ensure a sufficient number of degrees of freedom (Devore and Peck 1986:537). For species that occurred in <12 stands, we compared habitat features between used and unused stands using t tests (SAS Inst., Inc. 1985: 217-221), but because of multiple comparisons, experimentwise error rates for these comparisons exceed indicated P-values.

We compared each habitat variable selected in stepwise regression for each species between thinned and unthinned stands within regions using the split-plot ANOVA or Friedman's procedures described above. We set all significance levels at $P \leq$ 0.05, but considered $P \leq 0.10$ as marginally significant. We calculated power using PASS software (J. Hintze, NCSS/Power analysis and sample size, version 1, NCSS, Kaysville, Ut., 1991).

Results and discussion

Community patterns

Breeding season. We observed a total of 3,792 birds representing 43 species during the breeding season. Bird species richness did not seem to be affected by thinning (Table 1). Rather, species richness was positively related to density of hardwoods 31- to 43-cm dbh, conifers ≥56-cm dbh, and snags >53-cm dbh, and negatively related to the distance to a patch edge (Table 2).

Although density of hardwoods 31- to 43-cm dbh did not differ between thinned and unthinned stands (Table 3), it was an important predictor of bird-species richness. Several bird species associated with deciduous vegetation, including warbling vireos (*Vireo gilvus*), Pacific-slope flycatchers (*Empidonax difficilis*), Wilson's warblers (*Wilsonia pusilla*), black-headed grosbeaks (*Pheucticus melanocephalus*), and black-throated gray warblers (Brown 1985), contributed to species richness on the study sites containing deciduous trees. Huff and Raley (1991) also found that variables describing live deciduous trees were positively related to bird-species richness and bird abundance in unmanaged forests in western Oregon and Washington. Even small patches of deciduous trees in conifer-dominated plant communities can have a positive influence on densities of certain bird species (Morrison and Meslow 1983).

The density of snags >53-cm dbh and conifers >56-cm dbh (maximum = 80-cm dbh) did not differ between thinned and unthinned stands (Table 3). These size classes of snags and conifers were the largest trees found consistently in the stands we sampled, although they are much smaller than trees found in old-growth conifer stands in western Oregon (Franklin and Spies 1991). Snags provide habitat for birds that nest in cavities and forage on dead wood (Mannan et al. 1980, Nelson 1989). In unmanaged forests, the presence and abundance of cavity-nesting birds has been linked to the presence of snags, particularly snags >50-cm dbh (Carey et al. 1991, Huff and Raley 1991).

The average distance to a patch edge did not differ between thinned and unthinned stands (Table 3). More than 70% of the patch edges in our stands were created where either gravel roads <10 m wide or headwater streams passed through a stand. Roads and streams were considered patches, rather than stand edges, when they dissected an otherwise uniform stand, creating a narrow, linear discontinuity. Road and stream patches were characterized by multiple layers of deciduous shrubs and trees that created horizontal heterogeneity in the stand. Such habitat heterogeneity has been linked to bird-species richness and diversity (Carey 1988).

Winter. We observed a total of 1,553 birds representing 21 species in thinned and unthinned stands in winter. Abundance of winter birds did not differ between thinned and unthinned stands, but bird species richness was marginally greater in thinned stands (Table 1).

Species patterns

Species consistently associated with thinned stands. Six bird species were consistently more abundant in thinned than unthinned stands across years and regions: hairy woodpecker (*Picoides villosus*), red-breasted nuthatch (*Sitta canadensis*), Hammond's flycatcher (*Empidonax hammondii*), war-

Table 1. Mean abundance (observations/stand/year) and standard error for bird species with ≥2 observations in ≥6 of 8 pairs of thinned and unthinned Douglas-fir stands (4 sample points/stand) in 1989–1990, Coast Ranges, Oregon. *P* is the probability associated with the test of the null hypothesis that means are not different; *P*(I) is the probability associated with the test of the null hypothesis that stand condition does not interact with region, the central Oregon Coast Ranges (CCR) and Tillamook State Forest (TSF).

	Thinned		Unthinned				
Species	$\bar{x}$	SE	$\bar{x}$	SE	*P*	*P*(I)[b]	Power[e]
Breeding birds							
Hairy woodpecker	2.2	0.5	0.4	0.2	0.04[c]	0.80	0.53
Hammond's flycatcher	4.4	1.3	0.0	0.0	<0.01[d]	—	0.59
Pacific-slope flycatcher	14.0	1.7	16.7	1.5	0.10[c]	0.37	0.36
Gray jay	1.3	0.4	1.9	0.6	0.30[c]	0.05	0.19
Chestnut-backed chickadee	6.1	0.9	5.4	0.9	0.57[c]	0.77	0.14
Red-breasted nuthatch	3.0	0.6	0.9	0.3	0.04[c]	0.47	0.54
Brown creeper	3.6	0.6	2.4	0.6	0.02[c]	0.01	0.71
Winter wren	16.2	2.3	14.6	1.3	0.10[c]	<0.01	0.34
Golden-crowned kinglet	7.4	0.7	11.4	0.7	<0.01[c]	0.01	0.96
American robin[f]	1.6	0.5	0.7	0.2	0.13[c]	0.81	0.26
Swainson's thrush	5.9	0.9	5.7	0.9	0.85[c]	0.16	0.12
Hutton's vireo	1.1	0.3	2.1	0.6	0.11[c]	0.26	0.30
Warbling vireo	7.0	1.3	3.4	0.8	0.06[c]	0.27	0.47
Black-throated gray warbler	3.5	0.7	6.3	1.3	0.03[c]	0.09	0.60
Hermit warbler	23.3	2.8	22.6	2.2	0.86[c]	0.84	0.16
Wilson's warbler	15.6	2.3	12.2	2.1	0.13[d]	—	0.30
Western tanager	2.6	0.6	1.2	0.3	0.07[c]	0.02	0.44
Black-headed grosbeak[g]	1.2	0.5	2.1	0.8	0.16[a]	—	0.25
Dark-eyed junco	9.9	1.9	5.1	1.1	<0.01[c]	0.12	0.89
Evening grosbeak	4.7	1.0	2.0	0.9	0.05[c]	0.40	0.45
Richness	24.5	1.2	22.6	0.9	0.18[c]	0.50	0.64
Abundance (birds/ha)	3.7	0.3	3.2	0.2	0.07[c]	0.04	0.35
Winter birds							
Gray jay	1.7	0.6	1.6	0.7	0.90[c]	0.41	0.10
Chestnut-backed chickadee	12.0	3.3	9.5	1.7	0.77[d]	—	0.21
Red-breasted nuthatch	5.0	1.5	2.1	0.8	0.03[c]	0.43	0.84
Brown creeper	2.4	0.8	2.4	0.5	1.00[c]	0.47	0.10
Winter wren	8.5	1.0	4.7	0.4	0.01[d]	—	0.96
Golden-crowned kinglet	32.6	8.6	29.4	7.1	0.74[c]	0.38	0.12
Richness	8.4	1.0	7.2	0.6	0.08[c]	0.61	0.66
Abundance (birds/ha)	1.1	0.1	0.9	0.05	0.18[c]	0.54	0.42

[a] Test of the null hypothesis of no difference between means, ANOVA; 1, 3 df., based on stands in CCR only.
[b] Test of the null hypothesis of no interaction of thinning with region, ANOVA; 1, 6 df.
[c] Test of the null hypothesis of no difference between means, ANOVA; 1, 6 df.
[d] Test of the null hypothesis of no difference between means, Friedman's test; 14 df.
[e] Power of the test of the difference between thinned and unthinned means (PASS software, Hintze 1991).
[f] *Turdus migratorius*
[g] *Pheucticus melanocephalus*

bling vireo, dark-eyed junco (*Junco hyemalis*), and evening grosbeak (*Coccothraustes vespertinus*; Table 1). Ten other species also were observed incidentally (≤5 times each) only in thinned stands (Table 4).

Two bark-foraging species were more abundant in thinned than unthinned stands in our study (Table 1). Red-breasted nuthatches were more abundant in thinned than unthinned stands during breeding and winter seasons, but hairy woodpeckers showed this pattern only during the breeding season and were rarely observed on any of our study sites during winter. Both of these species have been associated with old-growth forests in Oregon because they select trees and snags >50-cm dbh for foraging and nesting (Nelson 1989; Carey et al. 1991). In spite of their association with large trees and snags, hairy woodpeckers and red-breasted nuthatches were more abundant in thinned stands, where densities of conifers >56-cm dbh and snags >53-cm dbh did not differ from those in unthinned stands (Table 3). Foraging substrate provided by slash and residual trees (Hagar 1960, Putnam 1983) and increased openness

Table 2. Regression models describing the relationships between index to bird abundance (number of observations/stand/year) and vegetation characteristics in 8 commercially thinned and 8 unthinned Douglas-fir stands, western Oregon, 1989–1990.

Species	Habitat variable	Coefficient	*P*	Cum. R^2
Hairy woodpecker	constant	18.875	<0.01	
	sawtimber cover (%)	−0.314	<0.01	0.46
	hardwood cover (%)	+0.194	0.02	0.65
Pacific-slope flycatcher	constant	−24.730	0.02	
	sawtimber cover (%)	+0.739	<0.01	0.43
	>56-cm dbh conifers/ha	+22.588	<0.01	0.70
	hardwood basal area	+13.009	<0.01	0.84
Gray jay	constant	37.682	<0.01	
	height of pole layer (m)	−2.262	<0.01	0.45
	red alder cover (%)	+0.801	0.02	0.65
Chestnut-backed chickadee	constant	20.358	<0.01	
	<10-cm dbh conifers/ha	+2.593	0.12	0.23
	total hardwood stems/ha	−2.052	0.15	0.42
Red-breasted nuthatch	constant	24.740	<0.01	
	sawtimber cover (%)	−0.279	<0.01	0.43
	pole cover (%)	−0.208	<0.01	0.62
	30- to 51-cm dbh snags/ha	+2.850	0.03	0.75
Brown creeper	constant	3.476	0.13	
	decid. shrub cover (%)	+0.315	<0.01	0.36
	10- to 31-cm hardwoods/ha	+3.473	<0.01	0.56
	deciduous shrub height (m)	−7.567	<0.01	0.67
	evergreen shrub height (m)	+8.471	<0.01	0.84
Winter wren	constant	2.575	0.61	
	>31-cm dbh hardwoods/ha	+68.661	<0.01	0.53
	>56-cm dbh conifers/ha	+16.887	<0.01	0.75
	evergreen shrub cover (%)	+0.164	0.09	0.81
Golden-crowned kinglet	constant	−12.931	0.07	
	pole cover (%)	+0.336	<0.01	0.42
	distance to patch edge (m)	+0.109	0.01	0.66
	sawtimber cover (%)	+0.194	0.06	0.75
American robin	constant	1.283	0.76	
	sawtimber cover (%)	−0.161	<0.01	0.35
	slash cover (%)	+0.115	<0.01	0.59
	herbaceous cover (%)	+3.713	0.02	0.68
	pole cover (%)	+0.077	0.07	0.77
Swainson's thrush	constant	−29.414	0.02	
	salal cover (%)	+0.274	<0.01	0.68
	sawtimber height (m)	+0.984	0.04	0.76
Hutton's vireo	constant	−1.768	0.22	
	20- to 30-cm dbh conifers/ha	+1.074	0.02	0.44
	10- to 20-cm dbh hardwoods/ha	+2.688	0.05	0.59
Warbling vireo	constant	14.404	<0.01	
	30- to 43-cm dbh hardwoods/ha	+47.782	<0.01	0.66
	30- to 43-cm dbh conifers/ha	−2.551	<0.01	0.72

(continued)

of stands (Putnam 1983) have been suggested as reasons why hairy woodpeckers may show a positive numerical response to tree removal. In our study, a negative association with sawtimber cover explained >40% of the variation in abundance of hairy woodpeckers and red-breasted nuthatches (Table 2), indicating a selection for open stands. During winter, thinned stands may have provided better habitat for red-breasted nuthatches because reduced foliage in the pole layer probably resulted in more bole area for foraging (Lundquist and Manuwal 1990).

Hammond's flycatchers were observed exclusively in thinned stands (Table 1). Hammond's flycatchers forage for aerial insects by sallying into open spaces beneath the overstory canopy and between trees (Mannan 1984). Hammond's flycatchers are thought to be associated with old-growth stands in western Washington because these forests

Table 2. (continued) Regression models describing the relationships between index to bird abundance (number of observations/stand/year) and vegetation characteristics in 8 commercially thinned and 8 unthinned Douglas-fir stands, western Oregon, 1989–1990.

Species	Habitat variable	Coefficient	*P*	Cum. R^2
Black-throated gray warbler	constant	34.529	<0.01	
	elevation (m)	−0.010	0.01	0.55
	grass cover (%)	−16.599	<0.01	0.64
	<10-cm dbh conifers/ha	−4.615	0.01	0.73
	hazel cover (%)	+0.484	0.06	0.83
Hermit warbler	constant	21.188	<0.01	
	31- to 43-cm dbh hardwoods/ha	+74.515	<0.01	0.48
	>53-cm dbh snags/ha	+138.29	<0.01	0.63
Wilson's warbler	constant	32.924	0.01	
	slash cover (%)	−0.637	<0.01	0.70
	low shrub cover (%)	+0.281	0.01	0.82
	low shrub height (m)	+26.924	0.02	0.86
Western tanager	constant	17.386	<0.01	
	>53-cm dbh snags/ha	+2.006	<0.01	0.26
	sawtimber cover (%)	−0.321	<0.01	0.47
	hardwood cover (%)	+0.290	<0.01	0.74
Dark-eyed junco	constant	32.647	<0.01	
	low shrub height (m)	−40.816	<0.01	0.50
	red huckleberry cover (%)	+1.848	<0.01	0.82
	<10-cm dbh conifers/ha	−5.224	<0.01	0.92
Evening grosbeak	constant	−7.125	0.19	
	CV sawtimber cover (%)	0.638	<0.01	0.52
	hazel cover (%)	0.589	0.01	0.68
	pole cover (%)	−0.285	0.01	0.81
Species richness	constant	22.808	<0.01	
	31- to 43-cm dbh hardwoods/ha	+21.478	<0.01	0.48
	distance to patch edge (m)	−0.045	0.03	0.67
	>56-cm dbh conifers/ha	+1.712	0.01	0.77
	>53-cm dbh, decay 2–3 snags/ha	+31.410	0.01	0.82
	10- to 20-cm dbh hardwoods/ha	−2.645	0.03	0.89
Abundance	constant	−163.507	0.02	
	conifer height (m)	+13.191	<0.01	0.45
	31- to 43-cm dbh hardwoods/ha	+154.135	<0.01	0.67
	salal cover (%)	+1.585	<0.01	0.89
	CV sawtimber cover (%)	+1.473	0.04	0.92

tend to have open canopies (Manuwal 1991). Percent cover in the pole and sawtimber layers was lower in thinned than in unthinned stands (Table 3). Thinned stands may have provided more suitable habitat for Hammond's flycatchers than unthinned stands because canopies in thinned stands provided more open space available for foraging under the canopy. The structural changes resulting from commercial thinning may have made it possible for Hammond's flycatchers to occupy otherwise unsuitable young Douglas-fir stands. A preliminary investigation of differences in abundance of aerial insects between stands indicated that thinned stands may have provided more prey for Hammond's flycatchers. This hypothesis needs to be tested more rigorously.

Warbling vireos, a species that feeds and nests in hardwoods (Brown 1985, Harrison 1987:258), also were more abundant in thinned than unthinned stands, but this was probably due to tree species composition (i.e., hardwood density) rather than stand structure. Not surprisingly, we found that abundance of warbling vireos was associated positively with densities of hardwoods 31- to 43-cm dbh, and negatively with densities of conifers 31- to 43-cm dbh (Table 2). Hardwoods 31- to 43-cm dbh did not differ in abundance between thinned and unthinned stands, but conifers of that size

Table 3. Average habitat characteristics for 8 commercially thinned and 8 unthinned Douglas-fir stands, Oregon Coast Ranges, 1990. Only variables that varied with bird abundance are shown. *P* is the probability associated with the test of the null hypothesis that means not different; *P*(I) is the probability associated with the test of the null hypothesis that stand condition does not interact with region, the Central Oregon Coast Ranges (CCR) and Tillamook State Forest (TSF).

	Thinned		Unthinned			
Habitat variable	$\bar{x}$	SE	$\bar{x}$	SE	*P*	*P*(I)[b]
Basal area of hardwoods (m²/ha)						
Stems/ha by dbh class	1.9	0.6	2.0	0.9	0.89[a]	0.05
<10 cm conifers	26.0	6.7	32.3	8.7	0.46[a]	0.79
31–43 cm conifers	120.0	7.7	156.7	16.0	0.03[a]	0.05
44–56 cm conifers	45.0	7.3	53.7	8.7	0.07[a]	0.04
>56 cm conifers	9.0	4.0	11.3	5.0	0.56[a]	0.04
10–20 cm hardwoods	14.3	4.7	19.7	7.3	0.56[c]	—
31–43 cm hardwoods	5.3	2.3	3.0	0.7	0.25[a]	0.09
Snags/ha by dbh and decay class						
10–30 cm, decay 2–3[d]	12.3	1.4	12.6	1.6	0.97[a]	0.41
31–53, decay 1	0.5	0.2	1.2	0.4	0.15[c]	—
>53 cm, decay 2–3	0.06	0.06	0.11	0.07	0.51[c]	—
Vegetation layers (% cover)						
slash	32.3	3.7	35.8	5.6	0.47[a]	0.03
grass[d]	5.5	1.5	1.9	0.3	0.02[a]	0.57
low shrub	48.7	5.6	39.6	7.1	0.32[a]	0.18
tall shrub	20.4	4.0	25.4	4.4	0.14[a]	0.03
pole	30.5	1.5	42.3	3.4	0.01[a]	0.17
sawtimber	52.8	2.7	63.2	2.2	0.01[c]	—
CV (%) sawtimber	36.1	3.1	33.4	2.1	0.37[a]	0.09
Trees (% cover)						
hardwood	9.4	3.0	11.5	2.5	0.41[a]	0.19
red alder	1.9	0.6	1.4	0.5	0.50[a]	0.35
Layer heights (m)						
tall shrub	2.49	0.06	3.02	0.10	<0.01[a]	0.46
pole	16.2	0.19	15.48	0.36	0.04[a]	0.01
sawtimber	26.56	0.72	25.91	0.52	0.50[a]	0.90
Shrubs (% cover)						
salal	24.33	4.67	21.18	5.24	0.66[a]	0.28
hazel	3.19	1.51	3.85	2.18	0.66[a]	0.88
red huckleberry	4.14	0.48	2.88	0.85	0.10[a]	0.30
deciduous shrub	25.73	5.68	25.13	5.53	0.77[a]	<0.01
evergreen shrub	46.10	4.56	41.05	7.86	0.57[a]	0.16
Deciduous shrub height (m)	1.76	0.13	2.43	0.10	<0.01[a]	0.15
Elevation (m)	434.9	13.2	411.2	14.7	0.24[a]	0.08
Distance to patch edge (m)	78.0	5.3	93.0	6.1	0.19[a]	0.60

[a] Test of the null hypothesis of no difference between means, split-plot ANOVA; 1, 11 df.
[b] Test of the null hypothesis of no interaction of thinning and region, split-plot ANOVA; 1, 6 df.
[c] Test of the null hypothesis of no difference between means, Friedman's test; 14 df.
[d] Variable was log transformed (log10[VAR+1]) for analysis; means reported are untransformed means.

were less abundant in thinned than unthinned stands (Table 3).

Dark-eyed juncos also were more abundant in thinned stands than in unthinned stands (Table 1). Dark-eyed juncos forage and nest on or close to the ground and are associated with forest openings and patches of early successional vegetation in northwest forests (Mannan and Meslow 1984, Kessler and Kogut 1985). Juncos often increase in abundance after harvests reduce canopy cover (summarized by Medin 1985). Numbers of junco observations increased as average height of low shrubs and density of small (<10-cm dbh) conifer stems decreased, and as red huckleberry (*Vaccinium parvifolium*) cover increased (Table 2). However, red huckleberry cover did not differ between thinned and unthinned stands (Table 3). Artman (1990) also found a higher density of dark-eyed juncos in commercially thinned western hemlock stands than in unthinned stands. Junco abundance in her study was negatively correlated with tree density

Table 4. Number of pairs of stands in which incidental (observed in <6 of 8 pairs of thinned and unthinned Douglas-fir stands) bird species and abundance (observations/stand/year, 4 sample points/stand) were recorded May–June, 1989 and 1990, Coast Ranges, Oregon.

Species	Number of stand pairs	Thinned $\bar{x}$	Thinned (SE)	Unthinned $\bar{x}$	Unthinned (SE)
Turkey vulture *(Cathartes aura)*	1	0	—	0.06	(0.06)
Sharp-shinned hawk *(Accipiter striatus)*	1	0.12	(0.12)	0.06	(0.06)
Red-tailed hawk *(Buteo jamaicensis)*	1	0.06	(0.06)	0	—
Band-tailed pigeon *(Columba fasciatus)*	2	0.37	(0.22)	0.06	(0.06)
Rufous hummingbird *(Selasphorus rufus)*	1	0.31	(0.15)	0	—
Northern flicker *(Colaptes auratus)*	1	0.37	(0.18)	0	—
Pileated woodpecker *(Dryocopus pileatus)*	3	0.19	(0.10)	0.37	(0.18)
Olive-sided flycatcher *(Contopus borealis)*	1	0.12	(0.08)	0	—
Western wood-pewee *(Contopus sordidulus)*	1	0	—	0.06	(0.06)
Common raven *(Corvus corax)*	1	0.31	(0.25)	0.06	(0.06)
Bushtit *(Psaltriparus minimus)*	1	0	—	0.06	(0.06)
Townsend's solitaire *(Myadestes townsendii)*	1	0.06	(0.06)	0	—
Hermit thrush *(Catharus guttatus)*	3	0.56	(0.33)	0.94	(0.36)
Varied thrush *(Ixoreus naevius)*	4	0.31	(0.25)	0.62	(0.24)
Wrentit *(Chamea fasciata)*	1	0	—	0.06	(0.06)
Orange-crowned warbler *(Vermivora celata)*	5	0.69	(0.28)	0.81	(0.23)
Nashville warbler *(Vermivora ruficapilla)*	1	0.12	(0.08)	0	—
Yellow-rumped warbler *(Dendroica coronata)*	1	0.06	(0.06)	0	—
Townsend's warbler *(Dendroica townsendi)*	1	0	—	0.06	(0.06)
MacGillivray's warbler *(Oporornis tolmei)*	4	0.94	(0.28)	0.44	(0.26)
Rufous-sided towhee *(Pipilo erythrophthalmus)*	1	0.19	(0.14)	0	—
Song sparrow *(Melospiza melodia)*	1	0.06	(0.06)	0	—
Brown-headed cowbird *(Molothrus ater)*	1	0.06	(0.06)	0	—
Purple finch *(Carpodacus purpureus)*	4	0.69	(0.24)	0.75	(0.39)
Red crossbill *(Loxia curvirostra)*	1	0	—	0.06	(0.06)
Pine siskin *(Carduelis pinus)*	1	0.06	(0.06)	0.12	(0.12)
American goldfinch *(Carduelis tristus)*	1	0	—	0.06	(0.06)

and positively correlated with grass and seedling cover, which was greater in thinned stands.

Pole cover was the only habitat characteristic associated with evening grosbeak abundance (Table 2) that differed between thinned and unthinned stands (Table 3). The buds of deciduous trees and shrubs are a favored food of evening grosbeaks (Ehrlich et al. 1988), and we found a positive association between grosbeak abundance and beaked hazel (*Corylus cornuta*) cover (Table 2). Evening grosbeaks may have been more abundant in thinned stands because the reduced pole and sawtimber cover (Table 3) may have made hazel shrubs more accessible for feeding. Evening grosbeak abundance varied positively with the coefficient of variation of sawtimber; this may indicate the use of canopy gaps, where buds of deciduous trees and shrubs would be more accessible than in a continuous conifer canopy.

Species consistently associated with unthinned stands. Pacific-slope flycatchers (*Empidonax difficilis*) were consistently, though marginally, more abundant in unthinned than thinned stands between regions during the breeding season (Table 1). The actual difference in abundance of this species between thinned and unthinned stands may have been greater than suggested in Table 1 because the mean detection distance was greater (F = 9.47; 1, 11 df; P = 0.02) in thinned ($\bar{x}$ = 50.2 m, SE = 2.71) than unthinned stands ($\bar{x}$ = 42.1 m, SE = 1.08). Sakai and Noon (1991) described Pacific-slope flycatcher nesting habitat as having a lower mid-canopy bole height, a greater number of small trees, and a more closed canopy than random sites. Similarly, in our study, Pacific-slope flycatchers were associated with dense stands and closed canopies. Sawtimber cover, hardwood basal area, and density of conifers >56-cm dbh explained 72% of variation in Pacific-slope flycatcher abundance among stands (Table 2). Pacific-slope flycatchers have been associated with riparian habitat in coniferous forests, possibly because of the occurrence of deciduous hardwoods in riparian zones (Carey 1988). Although Pacific-slope flycatchers in our study were associated with hardwood basal area, they were not associated with riparian areas. Seven additional species were observed incidentally, only in unthinned stands (Table 4).

Species inconsistently associated with thinned or unthinned stands. Gray jays (*Perisoreus canadensis*) were more abundant ($P < 0.01$) in unthinned ($\bar{x} = 2.6$, SE = 1.1, $n = 4$) than thinned ($\bar{x} = 0.6$, SE = 0.3, $n = 4$) stands in the TSF, but they were slightly more abundant ($P = 0.10$) in thinned ($\bar{x} = 2.0$, SE = 0.6, $n = 4$) than unthinned ($\bar{x} = 1.2$, SE = 0.5, $n = 4$) stands in the CCR. The regression model for gray jays indicated that their abundance varied positively with red alder (*Alnus rubra*) cover and negatively with height of the pole layer (Table 2). Red alder cover did not differ between thinned and unthinned stands (Table 3), but pole layer height was lower ($P < 0.01$) in TSF unthinned than thinned stands. Gray jays are reported to use mixed-conifer forests (Brown 1985) and usually nest low in the canopy (1.5–3.7 m above forest floor; Harrison 1987:216), so the pattern we found is not surprising. Gray jays did not differ in abundance between thinned and unthinned stands during winter (Table 1).

Brown creepers (*Certhia americana*) and western tanagers (*Piranga ludoviciana*) were more abundant ($P < 0.01$) in thinned ($\bar{x} = 4.9$, SE = 0.4, $n = 4$; $\bar{x} = 4.0$, SE = 0.7) than unthinned ($\bar{x} = 2.25$, SE = 0.7, $n = 4$; $\bar{x} = 0.6$, SE = 0.4) stands in the CCR, but they did not differ in abundance ($P > 0.10$) between thinned ($\bar{x} = 2.4$, SE = 1.4, $n = 4$; $\bar{x} = 1.25$, SE = 0.6) and unthinned stands ($\bar{x} = 2.6$, SE = 1.5, $n = 4$; $\bar{x} = 1.9$, SE = 0.5) in the TSF during the breeding season. Brown creeper abundance did not differ between thinned and unthinned stands in either region during winter (Table 1). Brown creepers forage on the boles of live trees, select snags >50-cm dbh for nesting, and are more abundant in old than in young unmanaged Douglas-fir forests in western Oregon (Carey et al. 1991). Few trees attained diameters >50 cm in our stands, which may explain why brown creepers were uncommon. Brown creeper abundance in our stands was associated positively with shrub and hardwood characteristics (Table 2). Of these, only deciduous shrub height differed between thinned and unthinned stands (Table 3). Artman (1990) found a higher abundance of brown creepers in commercially-thinned western hemlock stands than in similar unthinned stands.

Western tanager abundance varied positively with the density of snags >53-cm dbh and deciduous hardwood cover, and negatively with sawtimber cover. Of these variables, only sawtimber cover differed between thinned and unthinned stands (Table 3). Tanagers are not considered a snag-associated species, but Manuwal (1991) also found tanager abundance to be correlated positively with a vegetation variable primarily comprised of snags. Although western tanagers rarely nest in deciduous trees (Harrison 1987: 387), they are found in mixed-conifer-deciduous stands (Brown 1985).

Winter wrens (*Troglodytes troglodytes*) were more abundant ($P < 0.001$) in thinned ($\bar{x} = 23.75$, SE = 2.55, $n = 4$) than unthinned ($\bar{x} = 12.00$, SE = 2.85, $n = 4$) stands in the CCR, but were more abundant ($P < 0.001$) in unthinned ($\bar{x} = 17.12$, SE = 0.55, $n = 4$) than thinned stands ($\bar{x} = 8.75$, SE = 1.51, $n = 4$) in the TSF in the breeding season. During winter, winter wren abundance was consistently greater in thinned stands (Table 1). Winter wren abundance was associated positively with hardwoods >31-cm dbh, conifers >56-cm dbh, and evergreen shrub cover (Table 2). The density of hardwoods 31-cm dbh was greater ($P = 0.06$) in CCR thinned ($\bar{x} = 10.2$/ha, SE = 3.6) than unthinned ($\bar{x} = 4.9$/ha, SE = 1.5) stands; the density of conifers >56-cm dbh was greater ($P < 0.06$) in TSF unthinned ($\bar{x} = 18.2$/ha, SE = 8.6) than thinned stands ($\bar{x} = 6.5$/ha, SE = 3.7). Other authors have reported that winter wrens were more abundant in old than in young stands and were associated with trees >30-cm dbh (Barrows 1986, Artman 1990, Gilbert and Allwine 1991). Winter wrens also have been associated with shrub cover >1.3 m tall (McGarigal and McComb 1992). This observation is consistent with our finding that winter wrens were more abundant in unthinned stands in the TSF, where cover of tall shrubs was greater ($P = 0.02$; $\bar{x} = 31.1$, SE = 6.7) than in thinned stands in that region ($\bar{x} = 18.0$, SE = 6.8).

Golden-crowned kinglets (*Regulus satrapa*) were more abundant in unthinned than in thinned stands during the breeding season but did not differ in abundance between thinned and unthinned stands during the winter (Table 1). Kinglet abundance during the breeding season differed between stand types in both regions but the difference was greater in the TSF (Table 1). Golden-crowned kinglets are found in dense conifer forests during the breeding season (McGarigal and McComb 1992). Not surprisingly, sawtimber and pole cover was positively associated with kinglet abundance (Table 2) and was greater in unthinned than in thinned stands (Table 3). Other studies also have described a decline in golden-crowned kinglet abundance after harvests that reduced canopy cover (summarized by Medin 1985, Tobalske et al. 1991). Although golden-crowned kinglets were less abundant than in unthinned stands, they occurred in all of our thinned stands. Marcot (1985:92) found that in northwestern California Douglas-fir stands, niche breadths for golden-crowned kinglets were lowest during the breeding season and highest during the winter. This pattern may explain why we did not detect a difference in abundance between thinned and unthinned stands during winter. Golden-crowned kinglet abundance in our study increased with increasing distance from patch edge, indicating this species may be sensitive to forest fragmentation.

Black-throated gray warbler abundance did not differ between thinned and unthinned stands in 1989 ($P > 0.10$), but in 1990 they were more abundant ($P < 0.01$) in unthinned ($\bar{x}$ = 8.75, SE = 1.99) than in thinned stands ($\bar{x}$ = 2.75, SE = 0.67) in both regions. Hazel (*Corylus* spp.) cover and density of conifers <10-cm dbh were positively associated with black-throated gray warbler abundance (Table 2), whereas grass cover was negatively associated with their abundance. Dense shrubs and small conifers probably limit grass development. Grass cover was lower in unthinned than in thinned stands (Table 3). The abundance of black-throated gray warblers also was associated negatively with elevation.

Species not associated with thinned or unthinned stands. The abundance of 6 species did not differ between thinned and unthinned stands (Table 1). However, the power of the tests for these species, ranging from 0.12 for Swainson's thrushes (*Catharus ustulatus*) to 0.30 for Hutton's vireos (*Vireo huttoni*) and Wilson's warblers (Table 1), may not have been high enough to detect differences. Although thinning did not seem to affect abundance of these species, the abundance of 5 of these species varied with measured differences in specific vegetation variables (Table 2).

Chestnut-backed chickadee (*Parus rufescens*) abundance did not differ between thinned and unthinned stands in winter or breeding seasons (Table 1). Nelson (1989) and Carey et al. (1991) found chestnut-backed chickadee abundance to be positively correlated with density of snags >50-cm dbh and conifers >100-cm dbh. We found chestnut-backed chickadees positively associated with density of conifers <10-cm dbh and density of snags >53-cm dbh, and negatively associated with hardwood stem density and distance to patch edge (Table 2). None of these habitat characteristics differed between thinned and unthinned stands (Table 3).

Hermit warblers (*Dendroica occidentalis*) have been associated positively with conifers (Ralph et al. 1991), although we found their abundance associated with hardwoods 31- to 43-cm dbh (Table 2). Wilson's warblers and Swainson's thrushes are both species that forage and nest in the shrub layer (Harrison 1987:273, 242), and shrub cover did not differ between thinned and unthinned stands (Table 3). Wilson's warbler abundance was associated positively with shrub cover and height, and negatively associated with slash cover (Table 2). Swainson's thrush abundance was associated with salal cover and height of the overstory canopy (sawtimber; Table 2). Neither of these features differed between thinned and unthinned stands (Table 3).

Scope and limitations of the study

The scope of our study was restricted in several ways. First, our study was short-term and observational. Therefore, it cannot be assumed that the patterns of bird abundance we observed were strictly effects of the treatments we sampled. Numerous factors operating on scales of time and space beyond those encompassed by our study (2 yrs and stand-size, respectively) could have influenced bird abundance.

Second, we only sampled 40- to 55-year-old Douglas-fir-dominated stands in 2 regions. Additional research would be needed to determine if patterns were similar in other areas of the Oregon Coast Range, in other stand age classes, over a higher or lower range of stand densities, and in stands dominated by species other than Douglas-fir.

Third, time since thinning is probably an important factor influencing habitat structure and therefore bird-community composition. We were unable to assess this factor because time since thinning differed between regions: TSF stands, 4–8 years since thinning; CCR stands, 7–15 years since thinning.

Finally, we were able to assess habitat relationships for only those bird species amenable to being counted. Wide-ranging or inconspicuous species, such as raptors and grouse, were observed too infrequently to permit analysis (Table 4). Such species are important members of the forest-wildlife community.

Management recommendations

Commercial thinning may be a valuable tool for land owners managing multiple resources. In addition to enhancing timber production, thinning has the potential to enhance habitat for some native forest-associated bird species in overstocked second-growth Douglas-fir stands. Hammond's flycatchers and western tanagers, both neotropical migrant species, were associated with commercially thinned stands in our study. These species deserve the attention of land managers because, according to Breeding Bird Survey trend data, they declined in abundance (at average rates of 19.5%/year and 3.8%/year, respectively, from 1982 to 1991) in Oregon (Sam D. Droege, U.S. Fish and Wildl. Serv., Laurel, Md., pers. commun.). Populations of some bird species associated with snags (chestnut-backed chickadees) and hardwoods (warbling vireos and black-throated gray warblers) also seemed to be declining in Oregon (at rates of 2.0%/year, 1.0%/year, and 8.2%/year, respectively, from 1982 to 1991; Breeding Bird Survey trends, Sam D. Droege, U.S. Fish and Wildl. Serv., Laurel, Md., pers. commun.). Commercial thinning could be used to manipulate snag and hardwood resources to provide habitat for these species.

Land managers who thin from below in overstocked stands in the Oregon Coast Range may increase the abundance of several species associated with old, unmanaged forests (e.g., Hammond's flycatcher, red-breasted nuthatch). Managers interested in further enhancing structural features associated with the richness of bird species native to Coast Range Douglas-fir forests could develop prescriptions that increase size and abundance of hardwoods, conifers, and snags, while providing shrub cover (associated with the abundance of several species). If the following recommendations are followed, bird response should be monitored because our study results did not establish cause and effect relationships.

We suggest periodic thinning from below in Douglas-fir stands to maintain a relative density between 0.2 and 0.3 (i.e., allow only short periods of crown closure) and release hardwoods; this probably would enhance growth rates of hardwoods and large conifers. The relatively open canopy maintained under this type of thinning regime would allow development of shrub cover associated with the abundance of Wilson's warblers, Swainson's thrushes, and warbling vireos. A low relative stem density also may favor Hammond's flycatchers, hairy woodpeckers, and dark-eyed juncos.

Golden-crowned kinglets and Pacific-slope flycatchers probably would be more abundant in stands kept at relative densities >0.4 (near the self-thinning zone, relative density = 0.55). Black-throated gray warblers might be more abundant in heavily-stocked stands if hardwoods were present. If thinning intensity was variable through each stand (relative density 0.2–0.7 within the stand) then bird species richness might be further enhanced on the stand-level because habitat for species preferring dense vegetation might be maintained on a small scale. Unthinned strips or patches (approx 8 ha/40 ha of thinning, large enough to include the territories of the species that we sampled) could be left adjacent to or within thinned stands. Alternatively, some adjacent stands could be left unthinned, so that the habitat needs of all of the birds that we sampled might be met among stands.

In stands thinned as we suggest, little competition mortality would be expected, except where relative density was >0.55 (Drew and Flewelling 1979), so snags would probably be small and scarce. Snags could, however, be created artificially (Bull and Partridge 1986). Alternatively, when trees in the intermediate and suppressed crown classes approached the appropriate size, patches could be left unthinned to allow for mortality from competition (Drew and Flewelling 1979). Early and frequent thinning could accelerate tree growth, making it possible to create larger snags than would occur in an unthinned stand of the same age.

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