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Short-term response of songbirds to experimental thinning of young Douglas-fir forests in the Oregon Cascades

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Abstract

Commercial thinning has the potential to increase structural diversity in managed conifer stands and redirect development of young stands towards structure characteristic of late-seral habitats. Thinning to increase diversity, however, is likely to require different strategies than thinning to maximize timber production. To prescribe thinning regimes that will promote diversity, managers need more information on response of wildlife to a range of thinning intensities and patterns. We studied the response of forest songbirds to three different intensities and patterns of thinning in 40-year-old stands dominated by Douglas-fir (*Pseudotsuga menziesii*) in the Oregon Cascades. We estimated densities of songbirds for 2 years before and 4 years after experimental thinning with standard point count methodology. We compared changes in density before and after thinning between each thinning treatment and the control with repeated measures analysis of variance. Thinning increased species richness and the density of 10 species. Furthermore, the frequency of detection of four additional species increased in thinned stands. Thinning decreased the density of five species, but no species was excluded by thinning. Our results were largely consistent with those from other studies of bird response to thinning from different regions of the Pacific Northwest. We conclude that commercial thinning rapidly promotes diversity of breeding songbirds in young, conifer-dominated stands. However, we suggest using a variety of thinning intensities and patterns, ranging from no thinning to very widely spaced residual trees, in order to maximize avian diversity at the landscape scale and structural diversity both within and among stands.

Keywords: Bird communities; Bird species diversity; Commercial thinning; Forest management; Oregon Cascades

1. Introduction

Young plantations that have developed after clearcutting currently dominate millions of acres of forested landscapes in Western Oregon and Washington (DeBell et al., 1997). Such extensive cover of dense pole stands probably would be unlikely under a natural disturbance regime (Morrison and Swanson, 1990). Forests that develop following natural disturbances typically retain diverse plant species composition, large trees, and large amounts of woody debris and are spatially heterogeneous (Franklin et al., 1981; Spies et al., 1988; Spies and Franklin, 1989). In contrast, young, managed forests often are structurally simple and do not provide the range and diversity of structural features for wildlife that natural forests do (Hansen et al., 1991; Carey, 1998). Furthermore,

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young stands that have regenerated following clearcutting may never develop the structural features characteristic of present old growth (Tappeiner et al., 1997a; Poage, 2000).

Over the last decade, the forest management paradigm on public lands has changed from timber production to ecosystem function. As a result, strategies to restore a natural range of variability in forest structure and to maintain biodiversity are needed (Forest Ecosystem Management Assessment Team, 1993). Management goals for young stands on public lands include the incorporation of structural characteristics typical of natural young forests and more rapid development of late-successional habitat (Forest Ecosystem Management Assessment Team, 1993). Implicit in both these goals is the promotion of biological diversity at stand and landscape scales.

The potential of commercial thinning to increase structural diversity in managed conifer stands and redirect the developmental trajectory of young stands towards greater structural diversity has gained recognition over the past decade (Spies et al., 1991; DeBell et al., 1997; Tappeiner et al., 1997b; Carey et al., 1999). Thinning to promote structural diversity in vegetation may be accomplished with lower densities than are typical of strictly commercial operations and with irregular spacing of residual trees (Carey, 1995; Tappeiner et al., 1997b). Commercial thinning can increase structural diversity by affecting all layers of vegetation, from overstory trees to ground cover. If a goal of management is to represent natural young stands more closely in the short term and to redirect stand development to increase structural diversity (i.e., achieve old-growth structure sooner) in the long term, alternative intensities and patterns of thinning need to be examined.

Thinning in young conifer plantations may improve habitat for some species of native songbirds (Hagar et al., 1996). Responses of the bird community to thinning seem to be generally positive (increased species richness, increased abundance of some species, no species excluded from thinned stands). However, many studies that have examined birds in thinned stands treat only a limited range of thinning intensity (Hagar et al., 1996). Traditional thinning practices aimed at maintaining the dominance of conifers may not increase structural diversity for wildlife (Thysell and Carey, 2000; Wilson and Carey, 2000).

Investigators are beginning to study the response of songbirds to various intensities of thinning (this study; Hayes et al., 2003), but managers need more information across broad geographic regions to determine guidelines for residual tree densities and patterns for thinning prescriptions to enhance avian diversity. In the Pacific Northwest, most studies of bird response to thinning have been conducted in the Coast Ranges (Hagar et al., 1996; Haveri and Carey, 2000; Hayes et al., 2003); little is known about how forest songbirds in other regions respond to thinning.

The Young Stand Thinning and Diversity Study (YSTDS) was initiated by the Willamette National Forest in the late-1980s to experimentally evaluate economic, ecological, and social aspects of alternative thinning treatments in young stands (Hunter, 1993, 2001). A long-term goal of the study is to determine how thinning strategy influences the development of late-successional habitat in 35- to 50-year-old plantations. This paper compares the immediate (1–4 years post-harvest) effects of thinning on songbird abundance and species composition in three intensities and patterns of thinning to those in unharvested controls.

2. Methods

2.1. Design and site selection

Study sites were on the Willamette National Forest on the west slope of the central Oregon Cascade Range. There were four replicates of three silvicultural treatments—light thin (LT), light thin with gaps (LG), and heavy thin (HT)—and uncut controls. Each of the four stands comprising a block was assigned a different treatment. Harvesting occurred between January 1995 and September 1997. Following harvest, slash was piled and burned in all thinned units.

All sites were within the western hemlock (*Tsuga heterophylla*) zone (Franklin and Dyrness, 1988) and were dominated by Douglas-fir (*Pseudotsuga menziesii*). Western hemlock and western redcedar (*Thuja plicata*) were also common. Hardwoods such as bigleaf maple (*Acer macrophyllum*) and giant chinquapin (*Chrysolepis chrysophylla*) comprised a minor component of the overstory. Dominant understory species included sword fern (*Polystichum munitum*), salal (*Gaultheria shallon*), vine maple (*Acer circina-

tum), Oregon grape (*Mahonia nervosa*), and Pacific rhododendron (*Rhododendron macrophyllum*). Elevation of study sites ranged from 440 to 900 m; elevation of stands within a block generally differed by less than 240 m. Stand sizes ranged from 19 to 30 ha for thinned stands, and up to 53 ha for control stands.

Stands had been clear-cut 35–45 years before thinning entries. Stand density before thinning averaged approximately 620 trees per ha (tph) (range: 453–899 tph) >13 cm diameter at breast height (dbh). Trees averaged 28 cm dbh and 25 m in height (Bohac et al., 1997). Treatments were designed to represent both a range of natural disturbance intensities typical of western Oregon forests and prescriptions being considered by forest managers. The LT treatment represented minimum disturbance by maintaining a relatively closed canopy and was expected to develop less understory but a higher yield of conifers than other treatments. Average relative density of residual trees in LTs was 45 (approximately 330 tph). The LG treatment represented severe disturbance on a small scale and was expected to produce diverse, old-growth-like structure relatively rapidly as a result of differential tree size and growth among matrix, gap, and edge conditions. Average relative density of residual trees in LGs was 39 (approximately 290 tph). The HT treatment was intended to produce large trees and snags, and provide understory structure over a 100-year rotation. Average relative density of residual trees in HTs was 30 (approximately 250 tph). The uncut control represented untreated plantations to be compared with thinned treatments. Average relative density of trees in controls during the post-thinning sampling period was 90 (approximately 830 tph).

2.2. Bird surveys

Using standard point count methodology (Ralph et al., 1995), we sampled birds at three to five stations in each stand. Point count stations were separated by $\geq$150 m, and were $\geq$75 m from stand edges, road buffers, or riparian buffers. The pre-harvest bird counts were repeated five times each year between early May and late-June in 1992 and 1993 by a single observer. The pre-harvest observer waited 2 min at each station before recording birds during an 8-min count period. Three different observers conducted surveys in each post-harvest year (1997–1999, 2001). Each point count station was sampled in three visits between late-May and late-June in 1997 and 1998, and during four visits from 23 May to 15 July in 1999 and 2001. Observers recorded the species and distance to each bird detected during a 10-min count period at each station for all post-harvest surveys. All surveys were conducted between 0.5 h before and 4 h after sunrise. Surveys were not conducted during periods of heavy rain or strong wind (Robbins, 1981).

2.3. Data analysis

Response variables were the community-level descriptor species richness and estimates of breeding density (birds/40 ha) for 23 bird species. Species richness was calculated as the number of species/stand per year. We also assessed treatment effects for cavity nesters as a group and for neotropical migrants as a group. Species included in the cavity-nesting group were chestnut-backed chickadee, red-breasted nuthatch, brown creeper, red-breasted sapsucker, hairy woodpecker, northern flicker, and pileated woodpecker. Species included in the neotropical migrant group were common nighthawk, rufous hummingbird, black-throated gray warbler, western wood-pewee, olive-sided flycatcher, Pacific-slope flycatcher, Hammond's flycatcher, Swainson's thrush, hermit thrush, warbling vireo, hermit warbler, MacGillivray's warbler, Wilson's warbler, western tanager, and black-headed grosbeak. Scientific names for bird species are given in Appendix A.

2.3.1. Density estimates

We defined three phases of the study: pre-harvest (1992–1993), post-harvest phase 1 (1997–1998), and post-harvest phase 2 (1999, 2001); breeding densities were calculated for species that were present in 30% of the stand by phase combinations ($n = 48$). We calculated bird density for each stand in a single year as the number of birds detected divided by the effective area surveyed, where the numerator and the denominator were summed across repeated visits to each station within each stand within a year. To estimate the effective area surveyed for each species at every point count, we used a detectability model that adjusted the effective area surveyed for every bird observation to average detectability conditions (Beavers and Ramsey, 1998). We assumed that three factors influenced detectability: the observer, the number of minutes past sunrise, and tree density. Seven models were developed to predict effective area at average detectability conditions for each species: three univariate (single factor) models, three two-factor models, and the model incorporating all three factors. We used Akaike's information criterion (AIC) to select the best model for each species (Burnham and Anderson, 1998).

2.3.2. *Repeated measures analysis of variance*

To account for the correlation between data collected in the same stands over time, we used repeated measures ANOVA for a completely randomized block design to test for effects of thinning treatments on species richness and bird density. We averaged bird density across the 2 years within each phase for each stand ($n = 16$ stands/phase). Densities were log-transformed to meet model assumptions of normal distribution and constant variance. The distribution of residuals was checked after the models were fit to verify that assumptions were met. We used SAS statistical software for all analyses (SAS Institute, 1990). We used $\alpha = 0.10$ to evaluate the significance of treatment effects.

For bird species that occurred in >30% of stands during the pre- and at least one post-harvest phase, we tested the null hypothesis that the difference in density between each post-harvest phase and the pre-harvest phase was the same for all treatments. A statistically significant interaction of phase and treatment indicated that changes in density over time differed among treatments. For each species with a significant interaction of phase and treatment ($P \leq 0.01$, ANOVA), we used least-square means to calculate the mean difference in log-transformed density between each post-harvest phase and the pre-harvest phase for each treatment. The back-transformation of the log of the difference in density between post- and pre-harvest phases is an estimate of the ratio of post- to pre-harvest density. Therefore, ratios with a lower confidence limit >1 indicated an increase in density over time, and those with an upper confidence limit <1, a decrease. We used the 90% confidence intervals around these ratios to compare density changes among treatments. Two treatments were considered to differ to an ecologically significant degree if the confidence interval for density change of one did not overlap the mean of the other (Steidl et al., 1997; Di Stefano, 2004). We also used this method of comparing 90% confidence limits around density ratios for species with too few observations (occurred in <50% of the stands across all phases) to meet statistical assumptions for ANOVA. The ratio of post- to pre-harvest density was a better response variable than density alone for assessing treatment effect for uncommon species because it tended be less dominated by 0s.

3. Results

3.1. *Response of species assemblage and groups*

Bird species richness was positively affected by thinning. Although bird species richness decreased from the pre-harvest phase to the first post-harvest phase, the decrease in the thinned stands was not as great as in the controls (Fig. 1) This positive effect of treatment was not statistically significant during the first post-harvest phase ($P = 0.26$), but the change in richness from pre-harvest to the second post-harvest phase was different in thinned stands than in controls by a statistically significant margin ($P = 0.009$;

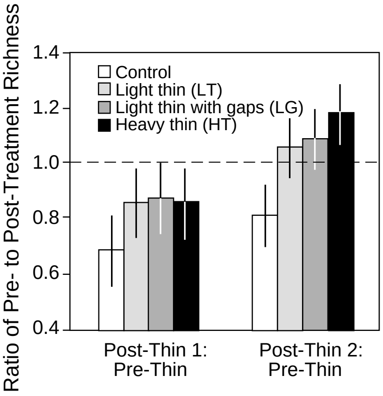

Fig. 1. Average ratio of bird species richness (number of species/stand) after to before application of three thinning treatments in Douglas-fir stands, Willamette National Forest. All treatments were unthinned during the pre-treatment phase (1992–1993); Controls remained unthinned during first post-treatment (1997–1998) and second post-treatment (1999, 2001) phases of the thinning experiment. Confidence limits (90%) that include 1 indicate no significant change in species richness from pre- to post-harvest phases within a treatment; estimates >1 indicate an increase in richness post-harvest; estimates <1 indicate decreases.

Fig. 1). Controls decreased in richness during this phase by an average of 3.9 species per stand, whereas thinned stands increased in richness by 1.4 species per stand in LTs to as much as 3.6 species per stand in HTs.

Both the cavity nesting and the neotropical migrant groups increased in density during the first post-harvest phase and decreased during the second post-harvest phase (Fig. 2). For cavity-nesters as a group, these changes were the same for all treatments, including control, indicating an absence of thinning effects (Fig. 2A). Density of neotropical migrants as a group decreased less in the HTs than in controls by a statistically significant margin during the second post-harvest phase (Fig. 2B), indicating a positive effect of this treatment ($P = 0.02$, least-square means test).

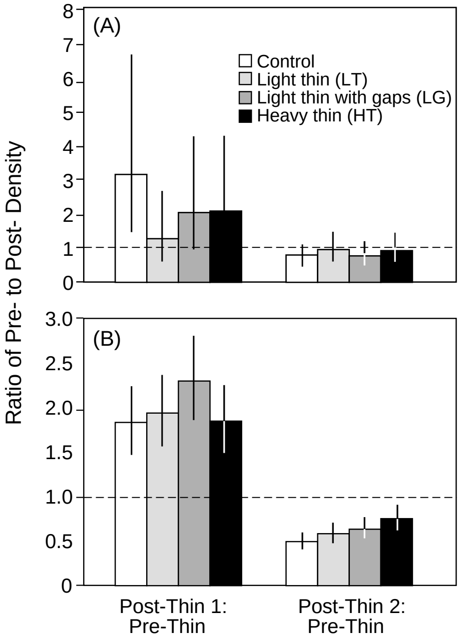

Fig. 2. Median ratio of bird density (birds/40 ha) after (Post1: 1997–1998; Post 2: 1999, 2001) to before (Pre: 1992–1993) application of 3 thinning treatments in Douglas-fir stands, Willamette National Forest for (A) cavity-nesting and (B) neotropical migrant groups. Bird groups are defined in text. Confidence limits (90%) that include 1 indicate no significant change in density from pre- to post-harvest phases within a treatment; estimates >1 indicate an increase in density post-harvest; estimates <1 indicate decreases.

No exotic species were recorded during any phase of the study. However, the brown-headed cowbird (*Molothrus ater*), a species native to North America that has expanded its range from the Great Plains to occupy most of the continent (Ehrlich et al., 1988), was observed during the first post-harvest phase in one thinned stand within a few miles of pasture.

3.2. Species with positive response to thinning

Ten species showed evidence of a positive response to thinning (Fig. 3). Density of these species either did not change or decreased in controls (90% confidence limits overlap values ≤ 1), while increasing to an ecologically significant degree in one or more thinning treatments during one or both post-harvest phases. The density of six of these species tended to increase with increasing thinning intensity. Increases that were greater in HTs than in LTs and LGs at an ecologically significant level were consistent for both post-harvest phases for gray jays (Fig. 3A), red-breasted sapsuckers (Fig. 3B), and MacGillivray's warblers (Fig. 3C). Increases in density of hairy woodpeckers were greatest in HTs, intermediate in LGs, and least in LTs during the first post-harvest phase, but by the second post-harvest phase, hairy woodpecker density had increased equally over controls in all thinning treatments (Fig. 3D). Increases in density of Townsend's solitaires in HTs were greater than those in LTs and LGs at an ecologically significant level only for the second post-harvest phase (Fig. 3E). Density increases were greater in HTs and LGs than in LTs for dark-eyed juncos for both post-harvest phases (Fig. 3F), and for rufous hummingbirds during only the first post-harvest phase (Fig. 3G).

Densities of two species that responded positively to thinning were highest in the gap thins. Increases in density of American robins were greater in LGs than LTs at an ecologically significant level during both post-harvest phases (Fig. 3H). An increase in western tanager density in LGs was significantly greater than that in LTs during the second post-harvest phase (Fig. 3I).

Finally, Hammond's flycatcher density increased dramatically after harvest, although a potential negative relationship to thinning intensity was indicated (Fig. 3J). An increase in density of Hammond's flycatchers was greater in the LTs and LGs relative to

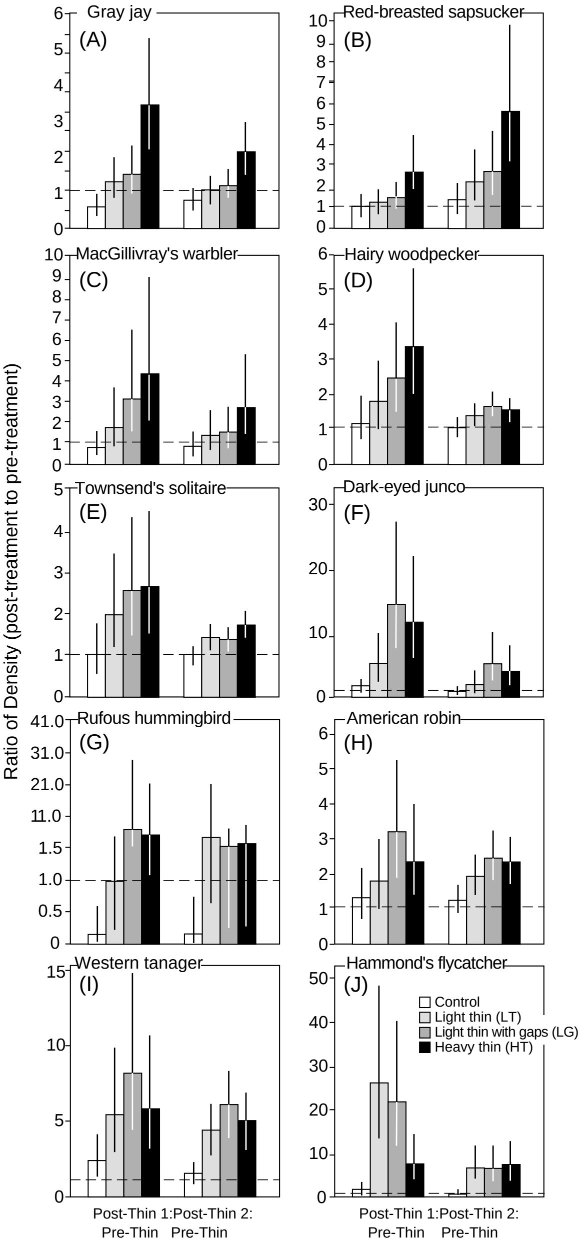

Fig. 3. Median ratio of bird density (birds/40 ha) after (Post1: 1997–1998; Post 2: 1999, 2001) to before (Pre: 1992–1993) application of 3 thinning treatments in Douglas-fir stands, Willamette National Forest for bird species that responded positively to thinning. Confidence limits (90%) that include 1 indicate no significant change in density from pre- to post-harvest phases within a treatment; estimates >1 indicate an increase in density post-harvest; estimates <1 indicate decreases.

HTs by an ecologically significant margin during the first post-harvest phase. However, during the second post-harvest phase, density of Hammond's flycatchers in all thinned treatments increased equally over that in controls.

The frequency of detection of four additional species increased in thinned stands during the post-harvest phase (Table 1). Although these species were observed too infrequently to permit statistical analyses, we believe that their occurrence only in thinned stands during the post-harvest phase, compared to their rarity during the pre-harvest phase of the study, suggests a response to thinning treatments. Nesting of one of these species, the common nighthawk, was confirmed in a LG stand during the second post-harvest phase.

3.3. Species with negative response to thinning

No species that regularly occurred before harvest was absent from thinned stands during the post-harvest phases, but the density of five species decreased in one or more of the thinning treatments relative to controls (Fig. 4A–E). Densities of all five of these species increased in controls from pre- to the first post-harvest phase, while simultaneously decreasing, or increasing significantly less, in the thinned treatments. By the second post-harvest phase, median densities of all species except golden-crowned kinglets (Fig. 4A) had decreased from pre-harvest levels even in control stands, although decreases in thinned stands were greater by an ecologically significant level. In general, density decreases were less in LTs than in LGs and HTs, although this difference was ecologically significant only for winter wrens for both post-harvest phases (Fig. 4B), and for varied thrushes for the first post-harvest phase (Fig. 4C).

4. Discussion

The thinning intensities and patterns that we examined produced songbird assemblages that were more species-rich than those in control stands. Increases in the density of 10 species, the appearance of four species that were rare or absent before thinning, and the fact that no species was extirpated as a result of thinning explained the increase in species richness.

Table 1
Total number of observations and frequency of occurrence of uncommon bird species before and after thinning harvests

Species	Total observations (% frequency of occurrence)[a]		
	Pre-harvest, all stands ($N = 32$)	Post-harvest	
		Controls ($N = 16$)	Thinned ($N = 48$)
Common nighthawk (*Chordeiles minor*)	6 (2)	0 (0)	17 (14)
Western wood-pewee (*Contopus sordidulus*)	3 (1)	0 (0)	21 (10)
Olive-sided flycatcher (*Contopus cooperi*)	0 (0)	0 (0)	10 (12)
Spotted towhee (*Pipilo maculates*)	3 (1)	0 (0)	19 (9)

Species shown were observed only in thinned stands during post-treatment sampling. N is the total number of stand × year combinations possible for each treatment and phase combination.

[a] % of stand × year units in which ≥1 bird was observed within 100 m of observer.

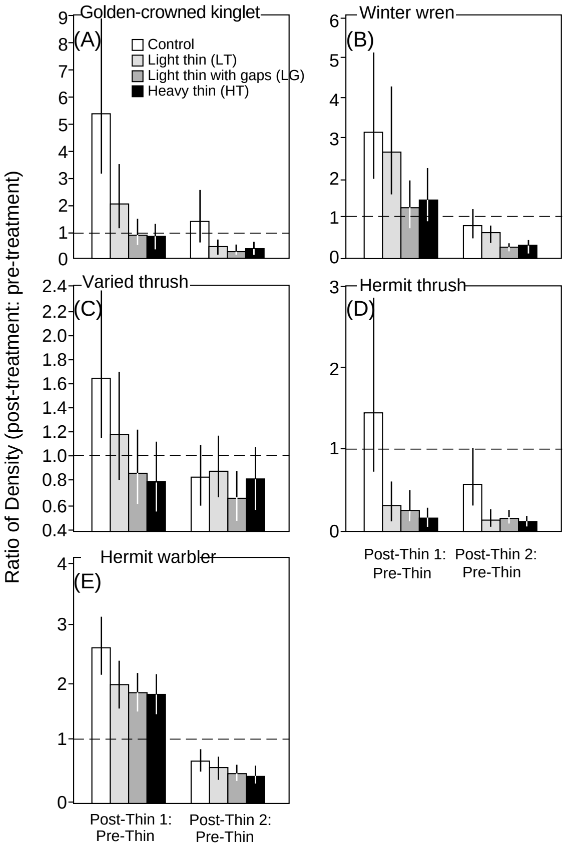

Fig. 4. Median ratio of bird density (birds/40 ha) after (Post1: 1997–1998; Post 2: 1999, 2001) to before (Pre: 1992–1993) application of 3 thinning treatments in Douglas-fir stands, Willamette National Forest for bird species that responded negatively to thinning. Confidence limits (90%) that include 1 indicate no significant change in density from pre- to post-harvest phases within a treatment; estimates >1 indicate an increase in density post-harvest; estimates <1 indicate decreases.

Interestingly, the species that responded positively to thinning represented a broad range of seral-stage associations, from early (MacGillivray's warbler), to mid- (western tanager, Hammond's flycatcher), and even late-seral associates (red-breasted sapsucker; Gilbert and Allwine, 1991). Species that responded positively also represented a variety of foraging guilds, including the ground-foraging dark-eyed junco, foliage-gleaning western tanager, bark-foraging red-breasted sapsucker, and several species of aerial insectivores (e.g., olive-sided flycatcher). Differences in species richness between thinned treatments and controls overshadowed differences among thinning intensities in the first few years following harvest. Over a longer time, however, differential development of stand structure is likely to result in divergent diversity patterns among treatments (Garman et al., 2002).

Six of the species that responded positively to thinning were likely responding to changes in canopy structure that enhanced foraging opportunities. Hammond's flycatcher, olive-sided flycatcher, western wood-pewee, and common nighthawk feed exclusively on aerial arthropods gleaned in flight. Townsend's solitaires and western tanagers also flycatch (Dowlan, 2003; Hudon, 1999).

The dramatic positive response of Hammond's flycatcher to thinning in young stands (ca. 35–45 years old) has been documented in other studies (Hagar et al., 1996; Hayes et al., 2003). Suitable habitat for Hammond's flycatcher includes open space for foraging beneath the canopy (Mannan, 1984; Sedgwick, 1994), which became available only after thinning of the stands in our study. The slight evidence we found that the positive response of Hammond's flycatchers may decrease with thinning intensity is not consistent with Hayes et al. (2003), who did not find an effect of thinning intensity on this species in the Coast Range. If this effect was real, it was also only temporary, since density of Hammond's flycatcher had increased equally in all treatments over controls by the second post-harvest phase. Furthermore, the positive effects of thinning for Hammond's flycatchers are expected to persist over the long term because this species has been associated with late-seral structural conditions (McGarigal and McComb, 1995). Thinning is expected to accelerate the development of large overstory trees with well-developed canopies (Garman et al., 2002) that Hammond's flycatchers use as nest sites (Mannan, 1984; Sakai and Noon, 1991).

The positive response of Townsend's solitaires and western tanagers also has been documented previously (Hagar et al., 1996; Hayes et al., 2003). Townsend's solitaires breed in forest openings, open coniferous forests, and edges of recent clear-cuts (Dowlan, 2003). Similarly, western tanagers favor open forests with breaks in the canopy that are characteristic of intermediate densities of overstory trees (Jewett et al., 1953; Hansen et al., 1995). Western tanager abundance generally increases or remains unchanged in response to selective harvesting (Hudon, 1999). Given their association with open forest conditions, it is not surprising that thinning enhanced habitat for solitaires and western tanagers. The benefits of thinning for these species are expected to last only as long as the openness lasts.

Increases in the abundance or occurrence of common nighthawks, olive-sided flycatchers and western wood-pewees following thinning have not been reported for other studies examining bird response to silviculture in young conifer stands, although recent studies support these trends for the latter two species (Hayes et al., 2003; J. Weikel, personal communication). Common nighthawks have experienced significant population declines in western Oregon in recent decades (Altman, 2003a) and the olive-sided flycatcher is on the Oregon State Sensitive Species List (Oregon Natural Heritage Program, 1998). Therefore, both species merit special concern from land managers. Thinning may have created suitable nesting habitat for common nighthawks by exposing patches of bare rock and ground that they use for nesting (Altman, 2003a). This benefit is not likely to last long, as ground vegetation develops in response to thinning. Olive-sided flycatchers typically inhabit edges between old- and young-growth forests or open or semi-open forest stands with a low percentage of canopy cover (Altman and Sallabanks, 2000). They forage for aerial insects from a high, prominent perch such as a tree or snag that emerges above the surrounding forest (Altman, 2003b). Thinning in young stands, particularly if residual trees are irregularly spaced, may create the uneven canopy structure that facilitates foraging. However, we observed common nighthawks and olive-sided flycatchers too infrequently to evaluate whether their abundance varied significantly among the different intensities and patterns of thinning.

Western wood-pewees typically inhabit deciduous woodlands or mixed deciduous/conifer forest and are rare in dense conifer forests of western Oregon (Morrison and Meslow, 1983). They also forage on aerial insects in openings in the forest canopy. The gaps in the canopy created by thinning may have been critical in allowing western wood-pewees to colonize some of our young conifer stands. Olive-sided flycatchers and western wood-pewees are likely to persist in thinned stands only for as long as the gappy, uneven canopy structure persists. As the canopy in lightly thinned stands closes in the absence of further disturbance, they will no longer provide suitable habitat for these aerially foraging species. Suitable habitat is likely to last longer in HT stands and may be maintained indefinitely in LG stands, as long as canopy height in gaps is different from that of the stand matrix. Continued monitoring of bird abundance will be necessary to determine the timing and structural conditions that constitute the threshold of habitat occupancy for these species.

Increases in the densities of dark-eyed juncos and MacGillivray's warblers following thinning probably were related to reduced canopy cover (Chambers, 1996; Hagar et al., 1996; Hayes et al., 2003). Dark-eyed juncos are partially granivorous (Ellison, 1934; Adams, 1947) and may also have been responding to increased cover of herbaceous seed-producing plants in thinned stands (Bohac et al., 1997). MacGillivray's warblers forage on insects in low shrubs and herbs, close to the forest floor (Morrison, 1981; Morrison and

Meslow, 1983). Although shrub cover did not increase significantly in thinned stands (Bohac et al., 1997), reducing canopy cover to the levels retained in the HT and LG treatments appeared to increase the suitability of habitat for MacGillivray's warblers. Because both these species are associated with open habitats, their abundance should decrease in thinned stands over time, as canopies close again. Canopies of LT stands are expected to close most rapidly, so abundance of dark-eyed juncos and MacGillivray's warblers is likely to decrease in this treatment type first.

The reasons for increases in density of hairy woodpeckers and frequency of red-breasted sapsuckers following thinning are not known, but may have been related to the attraction of these species to trees wounded during thinning. The abundance of hairy woodpeckers and other cavity-nesting, bark-foraging species has been positively associated with thinning (Hagar et al., 1996: hairy woodpecker, red-breasted nuthatch, brown creeper; Hayes et al., 2003: hairy woodpecker) or low-density stands (Weikel and Hayes, 1999: red-breasted nuthatch).

Although five species decreased in abundance in response to one or more of the thinning treatments, all species that regularly occurred before harvest also were present afterward. All the species that decreased in density after thinning except the hermit thrush were common on all our study sites and are among the most common breeding birds in the region (Gilbert and Allwine, 1991; Huff and Raley, 1991). For example, in spite of a decrease in density, hermit warblers and winter wrens remained among the most frequently detected species across all treatments. Some of the species that responded negatively to thinning in the short term (e.g., hermit warbler and golden-crowned kinglet) are likely to respond positively in the long term, when canopies close, because they are associated with dense conifer canopies (Hagar et al., 1996; Ingold and Galati, 1997), and/or with late-seral habitats (varied thrush, golden-crowned kinglets, and winter wrens; Gilbert and Allwine, 1991; Forest Ecosystem Management Assessment Team, 1993). Thinned stands are expected to achieve old-growth structure sooner than unthinned stands (Bailey et al., 1998; Bailey and Tappeiner, 1998).

One goal of managers of young conifer plantations may be to develop forest structure that more closely resembles naturally regenerated forests than the simplified structure that typically follows clear-cut harvesting (Hansen et al., 1991). Managed forests that resemble natural forests in structure and composition would be expected to support similar songbird assemblages. Although bird assemblages in our unthinned stands were similar to assemblages described in naturally regenerated stands of similar ages in the Cascade Range (Gilbert and Allwine, 1991), there were some important qualitative differences. Four species (hermit warblers, winter wrens, Pacific-slope flycatchers, and chestnut-backed chickadees) that ranked among the six most frequently detected species in our controls were similarly ranked by Gilbert and Allwine (1991). Unlike Gilbert and Allwine (1991), however, we did not find red-breasted nuthatches or their *Empidonax* category (Hammond's and gray flycatchers combined) to be among even the 10 most frequently detected species in our untreated stands.

Differences in abundances of these species may reflect structural differences between young stands that develop without management following a natural disturbance and stands, such as those we studied, that are regenerated from clear-cuts (Hansen et al., 1991). For example, red-breasted nuthatches use large snags for nesting (Nelson, 1989) and may have been more abundant in natural young stands (Gilbert and Allwine, 1991) than in the stands we sampled because natural stands tend to have a relatively high density of large snags (Spies and Franklin, 1991), whereas snag density in our stands was low (3 snags/ha >30 cm dbh; JCH, unpublished data). Large, live "legacy" trees often persist in naturally regenerated young stands but are scarce in stands harvested with traditional clear-cut methods, such as the stands we sampled.

Important structural differences between the young stands we sampled and naturally regenerated young stands likely influenced the songbird assemblage. Therefore, bird assemblages in young plantations are probably not representative of those in naturally regenerated young stands. In light of the work of Gilbert and Allwine (1991), our results suggest that thinning of plantations may not immediately produce bird assemblages characteristic of natural young stands. Nonetheless, we conclude that thinning is an important tool for increasing bird species richness in young, managed conifer stands. A long-term strategy to manage for young stands that mimic the structure of natural young stands may include thinning for diversity combined with retention of legacy structures, such as large live trees and snags, at rotation (Carey et al., 1996; Wilson and Carey, 2000).

Most effects of thinning on songbirds that we observed were positive or neutral, but the negative effects should not be overlooked. First, our observations of brown-headed cowbirds in one thinned stand that was <2 km from pastureland suggest that openings in the forest resulting from thinning and associated skid trails may facilitate invasion of forested areas by this species. Although they forage in agricultural fields and pastures, cowbirds parasitize the nests of forest birds, often selecting host nests close to a forest edge (Gates and Gysel, 1978). Therefore, bird species that are susceptible to parasitization by cowbirds (e.g., thrushes and warblers that build open cup nests) may incur decreased reproductive rates in thinned stands bordering pasture and farmland.

A second negative effect was the decrease in density of hermit thrushes in thinned stands. In many parts of its breeding range, the hermit thrush is associated with dense, young coniferous forests with open understories and has declined in abundance in response to logging (Jones and Donovan, 1996). This species warrants special concern because, unlike other species for which we observed an immediate decline in abundance, it is not likely to increase again as treated stands develop over time. Thinning may degrade habitat quality for this species, in the short term by decreasing canopy cover and in the long term by increasing understory cover.

Finally, some species, such as Pacific-slope flycatcher, Swainson's thrush, and black-throated gray warbler, decreased in density across all stands from pre- to post-harvest phases (Appendix A). We could not attribute this to a negative stand-level effect of thinning because these species decreased in control as well as thinned stands, but other studies have reported negative responses to thinning by Pacific-slope flycatchers and black-throated gray warblers (Hayes et al., 2003; Hagar et al., 1996). Density decreases of these species in control stands may have been attributable to reduced suitability of adjacent thinned stands, negative edge effects, or both (Hunter, 1990). Thus, the decrease in density across all treatments exhibited by these species may have resulted if minimum habitat area requirements were not met by the unthinned stands (Wiens, 1989). However, empirical evidence for sensitivity to area or habitat fragmentation has not been demonstrated for any of these species (McGarigal and McComb, 1995).

5. Conclusions

We suggest using a variety of thinning intensities and patterns, ranging from no thinning to very widely spaced residual trees. This approach would maximize structural diversity both within and among stands and is likely to maximize avian diversity at the landscape scale. Decisions on whether and how much to thin may be based on goals related to economics, wildlife habitat, forest health, or any number of factors, but should consider the landscape context of the units to be treated.

Species richness increased in all thinning treatments relative to unthinned stands. This suggests that commercial thinning is effective in rapidly promoting diversity of breeding songbirds in young Douglas-fir-dominated stands. However, we do not recommend applying thinning indiscriminately across a landscape for at least three reasons: consistent short-term negative response of several species to thinning (Fig. 4; Hayes et al., 2003); facilitation of invasion of forested habitats by brown-headed cowbirds, with accompanying decreases in productivity of forest birds; and the long-term flexibility for future management and research that leaving some stands unthinned would preserve.

We cannot recommend any single thinning treatment as "the best" for managing songbird habitat. Differences between thinning treatments and the control overshadowed differences among thinning treatments. With the exception of the Hammond's flycatcher, species that responded positively to thinning generally increased most in the HT and/or LG treatments and least in LTs. Similarly, those that responded negatively to thinning decreased least in the LT and most in the HT and/or LG (Fig. 4). We strongly recommend continued monitoring of both habitat structure and avian assemblages. This will provide the opportunity to determine which treatments achieve species habitat goals (e.g., providing optimum habitat for old-growth associates) most rapidly, for the longest time, or both.

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Appendix A

Density estimates (birds/40 ha; with 90% CI) of birds before (pre-treatment) and after (post-treatment) thinning for three thinning treatments and controls ($n = 4$ stands/treatment), Willamette National Forest, 1992–2001. Overall phase means are given for species for which no treatment effect was detected. Species are listed in taxonomic order within response group

Common name (scientific name)	Treatment[a]	Pre-treatment (1992–1993)	Post-treatment period 1 (1997–1998)	Post-treatment period 2 (1999, 2001)
Positive response to thinning				
Rufous hummingbird (*Selasphorus rufus*)	Control	8.1 (2.8, 23.8)	0.0 (0.0, 4.2)	0.0 (0.0, 4.2)
	LT	2.4 (0.0, 7.0)	2.3 (0.0, 9.8)	8.7 (2.0, 37.1)
	LG	4.6 (1.6, 13.4)	28.5 (6.7, 120.8)	6.0 (1.4, 25.4)
	HT	4.9 (1.7, 14.4)	22.7 (5.3, 96.2)	7.1 (1.7, 30.1)
Red-breasted sapsucker (*Sphyrapicus ruber*)	Control	0.0 (0.0, 0.0)	0.0 (0.0, 1.6)	1.1 (0.0, 1.9)
	LT	0.0 (0.0, 0.0)	0.0 (0.0, 1.6)	2.1 (1.2, 3.7)
	LG	0.0 (0.0, 0.0)	1.3 (0.0, 2.1)	2.6 (1.5, 4.6)
	HT	0.0 (0.0, 0.0)	2.7 (1.7, 4.4)	5.6 (3.2, 9.9)
Hairy woodpecker (*Picoides villosus*)	Control	1.0 (1.0, 1.1)	1.1 (0.0, 2.0)	0.0 (0.0, 1.2)
	LT	0.0 (0.0, 1.0)	1.7 (1.0, 3.0)	1.3 (1.1, 1.6)
	LG	0.0 (0.0, 1.0)	2.4 (1.4, 4.2)	1.6 (1.3, 2.0)
	HT	0.0 (0.0, 1.0)	3.4 (2.08, 5.8)	1.5 (1.2, 1.9)
Hammond's flycatcher (*Empidonax hammondii*)	Control	1.3 (0.0, 2.1)	2.4 (1.2, 4.6)	2.1 (1.3, 3.2)
	LT	2.0 (1.3, 3.1)	52.3 (27.0, 101.3)	13.9 (8.9, 21.6)
	LG	1.1 (0.0, 1.7)	24.1 (12.4, 46.6)	7.4 (4.8, 11.6)
	HT	1.1 (0.0, 1.7)	8.7 (4.5, 16.8)	8.3 (5.3, 12.9)
Gray jay (*Perisoreus canadensis*)	Control	1.9 (1.3, 2.7)	0.0 (0.0, 1.7)	1.4 (0.0, 2.0)
	LT	1.5 (1.0, 2.0)	1.8 (1.0, 3.1)	1.4 (0.0, 2.0)
	LG	1.4 (0.0, 2.0)	2.0 (1.2, 3.5)	1.6 (1.1, 2.2)
	HT	0.0 (0.0, 1.4)	3.4 (2.0, 5.9)	2.1 (1.5, 2.9)
Townsend's solitaire (*Myadestes townsendi*)	Control	0.0 (0.0, 0.0)	0.0 (0.0, 1.7)	0.0 (0.0, 1.2)
	LT	0.0 (0.0, 0.0)	2.0 (1.2, 3.4)	1.4 (1.2, 1.7)
	LG	0.0 (0.0, 0.0)	2.5 (1.5, 4.3)	1.4 (1.1, 1.6)
	HT	0.0 (0.0, 0.0)	2.6 (1.6, 4.5)	1.7 (1.4, 2.0)

Appendix A. (*Continued*)

Common name (scientific name)	Treatment[a]	Pre-treatment (1992–1993)	Post-treatment period 1 (1997–1998)	Post-treatment period 2 (1999, 2001)
American robin (*Turdus migratorius*)	Control	0.0 (0.0, 1.1)	1.3 (0.0, 2.1)	1.2 (0.0, 1.6)
	LT	1.1 (1.0, 1.2)	2.0 (1.2, 3.3)	2.1 (1.6, 2.7)
	LG	0.0 (0.0, 1.1)	3.1 (1.9, 5.2)	2.4 (1.8, 3.2)
	HT	0.0 (0.0, 1.1)	2.4 (1.4, 3.9)	2.3 (1.8, 3.0)
MacGillivray's warbler (*Oporornis tolmiei*)	Control	1.6 (1.2, 2.1)	0.0 (0.0, 2.0)	0.0 (0.0, 1.8)
	LT	1.1 (0.0, 1.5)	1.8 (0.0, 3.7)	1.4 (0.0, 2.5)
	LG	1.9 (1.4, 2.6)	5.9 (2.9, 12.1)	2.5 (1.4, 4.5)
	HT	1.8 (1.3, 2.4)	7.5 (3.7, 15.4)	4.6 (2.6, 8.3)
Western tanager (*Piranga ludoviciana*)	Control	1.4 (0.0, 2.0)	3.1 (1.8, 5.3)	1.5 (1.0, 2.2)
	LT	2.0 (1.4, 2.9)	10.8 (6.3, 18.7)	7.4 (5.1, 10.7)
	LG	1.2 (0.0, 1.7)	9.4 (5.5, 16.2)	6.0 (4.1, 8.7)
	HT	1.6 (1.1, 2.4)	9.4 (5.4, 16.2)	6.9 (4.7, 10.0)
Dark-eyed junco (*Junco hyemalis*)	Control	8.7 (4.8, 15.9)	15.8 (10.3, 24.4)	7.5 (6.2, 9.0)
	LT	8.7 (4.8, 15.9)	45.4 (29.4, 70.0)	18.4 (15.3, 22.2)
	LG	4.2 (2.3, 7.7)	61.9 (40.1, 95.4)	22.2 (18.5, 26.8)
	HT	6.8 (3.7, 12.3)	79.5 (51.5, 122.5)	27.9(23.2, 33.7)
Negative response to thinning				
Winter wren (*Troglodytes troglodytes*)	Control	24.9 (18.8, 32.9)	79.0 (55.1, 113.2)	19.0 (13.0, 27.8)
	LT	25.7 (19.5, 34.0)	66.9 (46.7, 96.0)	12.8 (8.7, 18.6)
	LG	30.1 (22.8, 39.8)	35.8 (24.9, 51.3)	5.6 (3.9, 8.2)
	HT	22.6 (17.1, 29.9)	31.9 (22.2, 45.7)	5.2 (3.6, 7.6)
Golden-crowned kinglet (*Regulus satrapa*)	Control	22.1 (16.1, 30.4)	115.8 (70.3, 190.6)	29.7 (18.1, 48.7)
	LT	23.9 (17.4, 32.9)	47.4 (28.8, 78.1)	8.2 (5.0, 13.4)
	LG	27.6 (20.1, 38.0)	23.7 (14.4, 39.0)	7.0 (4.3, 11.5)
	HT	24.3 (17.7, 33.4)	19.0 (11.5, 31.3)	7.8 (4.8, 12.8)
Hermit thrush (*Catharus guttatus*)	Control	9.9 (7.1, 13.8)	14.2 (7.0, 28.9)	5.6 (3.9, 8.0)
	LT	8.3 (6.0, 11.6)	2.4 (1.2, 4.9)	1.1 (0.0, 1.6)
	LG	7.5 (5.4, 10.5)	1.9 (0.0, 3.8)	1.1 (0.0, 1.6)
	HT	12.4 (8.9, 17.3)	1.6 (0.0, 3.3)	1.1 (0.0, 1.6)
Varied thrush (*Ixoreus naevius*)	Control	1.8 (1.3, 2.4)	3.0 (2.3, 3.8)	1.5 (1.2, 2.0)
	LT	1.2 (0.0, 1.7)	1.4 (1.1, 1.8)	1.1 (0.0, 1.4)
	LG	1.8 (1.3, 2.4)	1.5 (1.2, 2.0)	1.2 (0.0, 1.5)
	HT	1.5 (1.1, 2.0)	11.2 (0.0, 1.5)	1.2 (0.0, 1.6)
Hermit warbler (Dendroica occidentalis)	Control	42.0 (33.4, 52.9)	109.4 (91.4, 131.0)	26.2 (21.7, 31.6)
	LT	47.0 (37.4, 59.2)	91.2 (76.1, 109.2)	23.0 (19.1, 27.8)
	LG	49.0 (38.9, 61.6)	88.5 (73.9, 106.0)	20.1 (16.7, 24.3)
	HT	48.6 (38.6, 61.1)	85.9 (71.8, 102.9)	18.9 (15.7, 22.8)

Appendix A. (*Continued*)

Common name (scientific name)	Treatment[a]	Pre-treatment (1992–1993)	Post-treatment period 1 (1997–1998)	Post-treatment period 2 (1999, 2001)
No response detected				
Pacific-slope flycatcher (*E. difficilis*)	All	11.9 (9.2, 15.4)	6.3 (3.8, 10.3)	3.8 (3.0, 4.7)
Steller's jay (*Cyanocitta stelleri*)	All	1.9 (1.5, 2.4)	3.3 (2.5, 4.4)	1.8 (1.4, 2.4)
Chestnut-backed chickadee (*Poecile rufescens*)	All	15.9 (13.3, 18.8)	35.6 (23.3, 54.4)	8.8 (7.3, 10.6)
Red-breasted nuthatch (*Sitta canadensis*)	All	2.1 (1.6, 2.8)	1.2 (1.0, 1.3)	3.6 (3.0, 4.4)
Brown creeper (*Certhia americana*)	All	1.8 (1.3, 2.5)	2.5 (1.4, 4.4)	1.8 (1.4, 2.3)
Swainson's thrush (*Catharus ustulatus*)	All	19.7 (17.2, 22.7)	9.3 (6.7, 12.9)	7.7 (5.9, 10.0)
Hutton's vireo (*Vireo huttoni*)	All	2.9 (2.4, 3.3)	1.9 (1.5, 2.5)	2.0 (1.6, 2.5)
Warbling vireo (*V. gilvus*)	All	1.8 (1.3, 2.4)	1.6 (1.1, 2.4)	1.5 (1.2, 2.0)
Black-throated gray warbler (*D. nigrescens*)	All	3.7 (2.3, 6.0)	1.7 (1.1, 2.6)	1.0 (0.0, 1.1)
Wilson's warbler (*Wilsonia pusilla*)	All	1.5 (1.1, 2.1)	1.1 (0.0, 1.3)	1.4 (1.1, 1.7)
Black-headed grosbeak (*Pheucticus melanocephalus*)	All	2.6 (1.9, 3.5)	3.0 (2.2, 4.0)	1.8 (1.4, 2.3)
Purple finch (*Carpodacus purpureus*)	All	1.3 (1.1, 1.5)	1.4 (1.0, 1.8)	1.2 (1.0, 1.4)

[a] Light thin, LT; light thin with gaps, LG; heavy thin, HT.

References

Adams, L., 1947. Food habits of three common Oregon birds in relation to reforestation. J. Wildl. Manage. 11 (3), 281–282.

Altman, B., Sallabanks, R., 2000. Olive-sided flycatcher (*Contopus cooperi*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, No. 502. The Birds of North America, Inc., Philadelphia, PA, 28 pp.

Altman, B., 2003a. Common nighthawk. In: Marshall, D., Hunter, M., Contreras, A. (Eds.), The Birds of Oregon: A General Reference. Oregon State University Press, Corvallis, OR, pp. 330–333.

Altman, B., 2003b. Olive-sided flycatcher. In: Marshall, D., Hunter, M., Contreras, A. (Eds.), The Birds of Oregon: A General Reference. Oregon State University Press, Corvallis, OR, pp. 374–376.

Bailey, J.D., Tappeiner, J.C., 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. For. Ecol. Manage. 108, 99–113.

Bailey, J.D., Mayrsohn, C., Doescher, P.S., St. Pierre, E., Tappeiner, J.C., 1998. Understory vegetation in old and young Douglas-fir forests of western Oregon. For. Ecol. Manage. 112, 289–302.

Beavers, S.C., Ramsey, F.L., 1998. Detectability analysis in transect surveys. J. Wildl. Manage. 62, 948–957.

Bohac, S.A., Lattig, M.D., Tucker, G.F., 1997. Initial vegetative response to alternative thinning treatments in second growth Douglas-fir stands of the Central Oregon Cascades. The Evergreen State College.

Burnham, K.P., Anderson, D.R., 1998. Model Selection and Inference: A Practical Information-theoretic Approach. Springer-Verlag, New York.

Carey, A.B., 1995. Sciurids in Pacific Northwest managed and old-growth forests. Ecol. Appl. 5, 648–661.

Carey, A.B., 1998. Ecological foundations of biodiversity: lessons from natural and managed forests of the Pacific Northwest. In: Trofymow, J.A., MacKinnon, A. (Eds.), Proceedings of a Workshop on Structure, Process and Diversity in Successional Forests of British Columbia, February 17–19, 1998, Victoria, BC. Northwest Sci. 72 (Special Issue 2), 127–133.

Carey, A.B., Thysell, D.R., Villa, L., Wilson, T., Wilson, S., Trappe, J.M., Colgan, W., Ingham, E.R., Holmes, M., 1996. Foundations of biodiversity in managed Douglas-fir forests. In: Peterson, D.L., Climas, C.V. (Eds.), The Role of Restoration in Ecosystem Management. Society for Ecological Restoration, Madison, WI, pp. 68–82.

Carey, A.B., Thysell, D.R., Brodie, A., 1999. The forest ecosystem study: background, rationale, implementation, baseline conditions, and silvicultural assessment. PNW-LGR-457. USDA, Forest Service, Pacific Northwest Research Station, Portland, OR.

Chambers, C.L., 1996. Response of terrestrial vertebrates to three silvicultural treatments in the central Oregon Coast Range. Ph.D. Dissertation. Oregon State University, Corvallis.

DeBell, D.S., Curtis, R.O., Harrington, C.A., Tappeiner, J.C., 1997. Shaping stand development through silvicultural practices. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forest for the 21st Century: The Science of Ecosystem Management. Island Press, Washington, DC, pp. 141–149.

Di Stefano, J., 2004. A confidence interval approach to data analysis. For. Ecol. Manage. 187 (2/3), 173–183.

Dowlan, S. 2003. Townsend's solitaire. In: Marshall, D., Hunter, M., Contreras, A. (Eds.), The Birds of Oregon: A General Reference. Oregon State University Press, Corvallis, OR, pp. 478–480.

Ellison, L., 1934. Notes on food habits of juncos. Condor 36, 176–177.

Ehrlich, P.R., Dobkin, D.S., Wheye, D., 1988. The Birder's Handbook. Simon and Schuster, New York.

Forest Ecosystem Management Assessment Team (FEMAT), 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report 1996-793-071. Forest Ecosystem Management Assessment Team, United States Government Printing Office, Washington, DC.

Franklin, J.F., Dyrness, C.T. (Eds.), 1988. The Natural Vegetation of Oregon and Washington. Oregon State University Press, Corvallis, OR.

Franklin, J.F., Cromack, K., Denison, W., McKee, A., Maser, C., Sedell, J., Swanson, F.J., Juday, G., 1981. Ecological characteristics of old-growth Douglas-fir forests. PNW-GTR-118. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Garman, S.L., Cissel, J.H., Mayo, J.H., 2002. Accelerating development of late-successional conditions in young managed Douglas-fir stands: a simulation study. PNW- GTR-557. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Gates, J.E., Gysel, L.W., 1978. Avian nest dispersion and fledging success in field-forest ecotones. Ecology 59 (5), 871–883.

Gilbert, F.F., Allwine, R., 1991. Spring bird communities in the Oregon Cascade Range. In: Ruggiero, L.F., Aubry, K.B., Carey, A.B., Huff, M.F. (Eds.), Wildlife and Vegetation of Unmanaged Douglas-fir Forests. Proceedings of a Symposium on Old Growth Douglas-fir Forests: Wildlife Communities and Habitat Relationships, March 29–31, 1989, Portland, OR. PNW-GTR-285. USDA Forest Service, Pacific Northwest Research and Experiment Station, Portland, OR, pp. 145–158.

Hagar, J.C., McComb, W.C., Emmingham, W.H., 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildl. Soc. Bull. 24, 353–366.

Hansen, A.J., Spies, T.A., Swanson, F.J., Ohmann, F.J., 1991. Conserving biological diversity in managed forests. Bioscience 41, 382–392.

Hansen, A.J., McComb, W.C., Vega, R., Raphael, M.G., Hunter, M., 1995. Bird habitat relationships in natural and managed forests in the west Cascades of Oregon. Ecol. Appl. 5, 555–569.

Haveri, B.A., Carey, A.B., 2000. Forest management strategy, spatial heterogeneity, and winter birds in Washington. Wildl. Soc. Bull. 28, 643–652.

Hayes, J.P., Weikel, J.M., Huso, M., 2003. Effects of commercial thinning on breeding birds in the northern Coast Range of Oregon. Ecol. Appl. 13, 1222–1232.

Hudon, J., 1999. Western Tanager (*Piranga ludoviciana*). In: Poole, A., Gill, F. (Eds.), Birds of North America, No. 432. The Academy of Natural Science, Philadelphia, PA.

Huff, M.H., Raley, C.M., 1991. Regional patterns of diurnal breeding bird communities in Oregon and Washington. In: Ruggiero, L.F., Aubry, K.B., Carey, A.B., Huff, M.F. (Eds.), Wildlife and Vegetation of Unmanaged Douglas-fir Forests. Proceedings of a Symposium on Old Growth Douglas-fir Forests: Wildlife Communities and Habitat Relationships, March 29–31, 1989, Portland, OR. PNW-GTR-285. USDA Forest Service, Pacific Northwest Research and Experiment Station, Portland, OR, pp. 177–205.

Hunter, M.L., 1990. Wildlife, Forests, and Forestry. Prentice-Hall, Englewood Cliffs, NJ.

Hunter, M., 1993. Young managed stands. cascade center for ecosystem management communique. USDA Forest Service, Willamette National Forest, Blue River Ranger District, Blue River, OR. http://www.fsl.orst.edu/ccem/pdf/comque.pdf, accessed 4/3/03.

Hunter, M., 2001. Management in young forests. Cascade Center for Ecosystem Management Communique 3. USDA Forest Service, Willamette National Forest, Blue River Ranger District, Blue River, OR. http://www.fsl.orst.edu/ccem/pdf/Comque3.pdf.

Ingold, J.L., Galati, R., 1997. Golden-crowned kinglet (*Regulus satrapa*). In: Poole, A, Gill, F. (Eds.), Birds of North America, No. 301. The Natural Academy of Science, Philadelphia, PA.

Jewett, S.G., Taylor, W.P., Shaw, W.T., Aldrich, J.W., 1953. Birds of Washington State. University of Washington Press, Seattle, WA.

Jones, P.W., Donovan, T.M., 1996. Hermit thrush (*Catharus guttatus*). In: Poole, A., Gill, F. (Eds.), Birds of North America, No. 261. The Natural Academy of Science, Philadelphia, PA.

Mannan, R.W., 1984. Habitat use by Hammond's flycatcher in old-growth forests, northeastern Oregon. Murrelet 65, 84–86.

McGarigal, K., McComb, W.C., 1995. Relationships between landscape structure and breeding birds in the Oregon Coast Range. Ecol. Monogr. 65, 235–260.

Morrison, M.L., 1981. The structure of western warbler assemblages: analysis of foraging behavior and habitat selection in Oregon. Auk 98, 578–588.

Morrison, M.L., Meslow, E.C., 1983. Bird community structure on early-growth clearcuts in western Oregon. Am. Midl. Nat. 110, 129–137.

Morrison, P.H., Swanson, F.J., 1990. Fire history and pattern in a Cascade Range landscape. PNW-GTR-254. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Nelson, S.K. 1989. Habitat use and densities of cavity-nesting birds in the Oregon Coast Ranges. M.S. Thesis. Oregon State University, Corvallis.

Oregon Natural Heritage Program, 1998. Rare, Threatened, and Endangered Plants and Animals of Oregon. Oregon Natural Heritage Program, Portland, OR.

Poage, N.J., 2000. Structure and development of old-growth Douglas-fir in central western Oregon. Ph.D. Dissertation. Oregon State University, Corvallis.

Ralph, C.J., Droege, S., Sauer, J.R., 1995. Managing and monitoring birds using point counts: standards and applications. In: Ralph, C.J, Sauer, J.R., Droege, S. (Eds.), Monitoring Bird Populations by Point Counts. PSW-GTR-149. USDA Forest Service, Pacific Southwest Research Station, Albany, CA, pp. 161–175.

Robbins, C.S., 1981. Bird activity levels related to weather. In: Ralph, C.J., Scott, J.M. (Eds.), Estimating Numbers of Terrestrial Birds. Studies in Avian Biol. 6, 301–310.

Sakai, H.F., Noon, B.R., 1991. Nest-site characteristics of Hammond's and Pacific-Slope Flycatchers in northwestern California. Condor 93, 563–574.

SAS Institute, 1990. SAS/STAT User's Guide, Version 6, vol. 2, 3rd ed. SAS Institute, Inc., Cary, NC.

Sedgwick, J.A. 1994. Hammond's flycatcher (*Empidonax hammondii*). In: Poole, A., Gill, F. (Eds.), Birds of North America, No. 109. The Natural Academy of Science, Philadelphia, PA.

Spies, T.A., Franklin, J.F., 1989. Gap characteristics and vegetation response in coniferous forests of the Pacific Northwest. Ecology 70, 543–545.

Spies, T.A., Franklin, J.F., 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. In: Ruggiero, L.F., Aubry, K.B., Carey, A.B., Huff, M.F. (Eds.), Wildlife and Vegetation of Unmanaged Douglas-fir Forests. Proceedings of a Symposium on Old Growth Douglas-fir Forests: Wildlife Communities and Habitat Relationships, March 29–31, 1989, Portland, OR. PNW-GTR-285. USDA Forest Service, Pacific Northwest Research and Experiment Station, Portland, OR, pp. 91–109.

Spies, T.A., Franklin, J.F., Thomas, T.B., 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology 69, 1689–1702.

Spies, T.A., Tappeiner, J., Pojar, J., Coates, D., 1991. Trends in ecosystem management at the stand level. Trans. N. Am. Wildl. Nat. Resour. Conf. 56, 628–639.

Steidl, R., Hayes, J.P., Schauber, E., 1997. Statistical power analysis in wildlife research. J. Wildl. Manage. 61, 270–279.

Tappeiner, J.C., Huffman, D.W., Marshall, D., Spies, T.A., Bailey, J.D., 1997a. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. Can. J. For. Res. 27, 638–648.

Tappeiner, J.C., Lavender, D., Walstad, J., Curtis, R.O., DeBell, J.S., 1997b. Silvicultural systems and regeneration methods: current practices and new alternatives. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry for the 21st Century. Island Press, Washington, DC, pp. 151–164.

Thysell, D.R., Carey, A.B., 2000. Effects of forest management on understory and overstory vegetation: a retrospective study. PNW-GTR-488. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Weikel, J.M., Hayes, J.P., 1999. Foraging ecology of cavity-nesting birds in young forests of the northern Coast Range of Oregon. Condor 101, 58–66.

Wiens, J.A. 1989. The Ecology of Bird Communities: vol. 2. Processes and Variations. Cambridge University Press, Cambridge, UK.

Wilson, S.M., Carey, A.B., 2000. Legacy retention versus thinning: influence on small mammals. Northwest Sci. 74, 131–145.