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Title: Bird Communities in Commercially Thinned and Unthinned Douglas-fir Stands of Western Oregon

Signature redacted for privacy.

Abstract approved:

William C. McComb

I studied species' abundances and habitat relationships of breeding and winter birds in commercially thinned and unthinned Douglas-fir (Pseudotsuga menziesii) stands from May 1989 to June 1991. The study was conducted in 40- to 55-year-old stands in the Central Oregon Coast Ranges and the Tillamook State Forest. Total abundance and species diversity of breeding birds was greater in thinned stands. During the breeding season, Hammond's flycatchers (Empidonax hammondii), hairy woodpeckers (Picoides villosus), red-breasted nuthatches (Sitta canadensis), and dark-eyed juncos (Junco hyemalis) were more abundant in thinned than unthinned stands. Golden-crowned kinglets (Regulus satrapa), black-throated gray warblers (Dendroica nigrescens), and Pacific-slope flycatchers (Empidonax difficilis) were more abundant in unthinned stands.

During the winter, red-breasted nuthatches and winter wrens (Troglodytes troglodytes) were more abundant in thinned stands. Differences in abundances of bird species between thinned and unthinned stands seemed to be related to differences in stand structure caused by thinning and to differences in hardwood densities that were probably unrelated to thinning. Differences in abundances of bird species between the Central Coast Ranges and the Tillamook State Forest were related to differences in shrub cover, and densities of hardwoods, snags, and conifers (>56 cm dbh) between the 2 regions. I recommended a thinning regime that would encourage understory and hardwood development in combination with unthinned leave areas to provide snag recruitment and habitat for species associated with dense stands. This regime is intended to maximize bird diversity and abundance in 40- to 55- year-old Douglas-fir stands in western Oregon.

BIRD COMMUNITIES IN COMMERCIALLY THINNED AND UNTHINNED DOUGLAS-FIR STANDS OF WESTERN OREGON

by

Joan C. Hagar

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Typed by researcher for Joan C. Hagar

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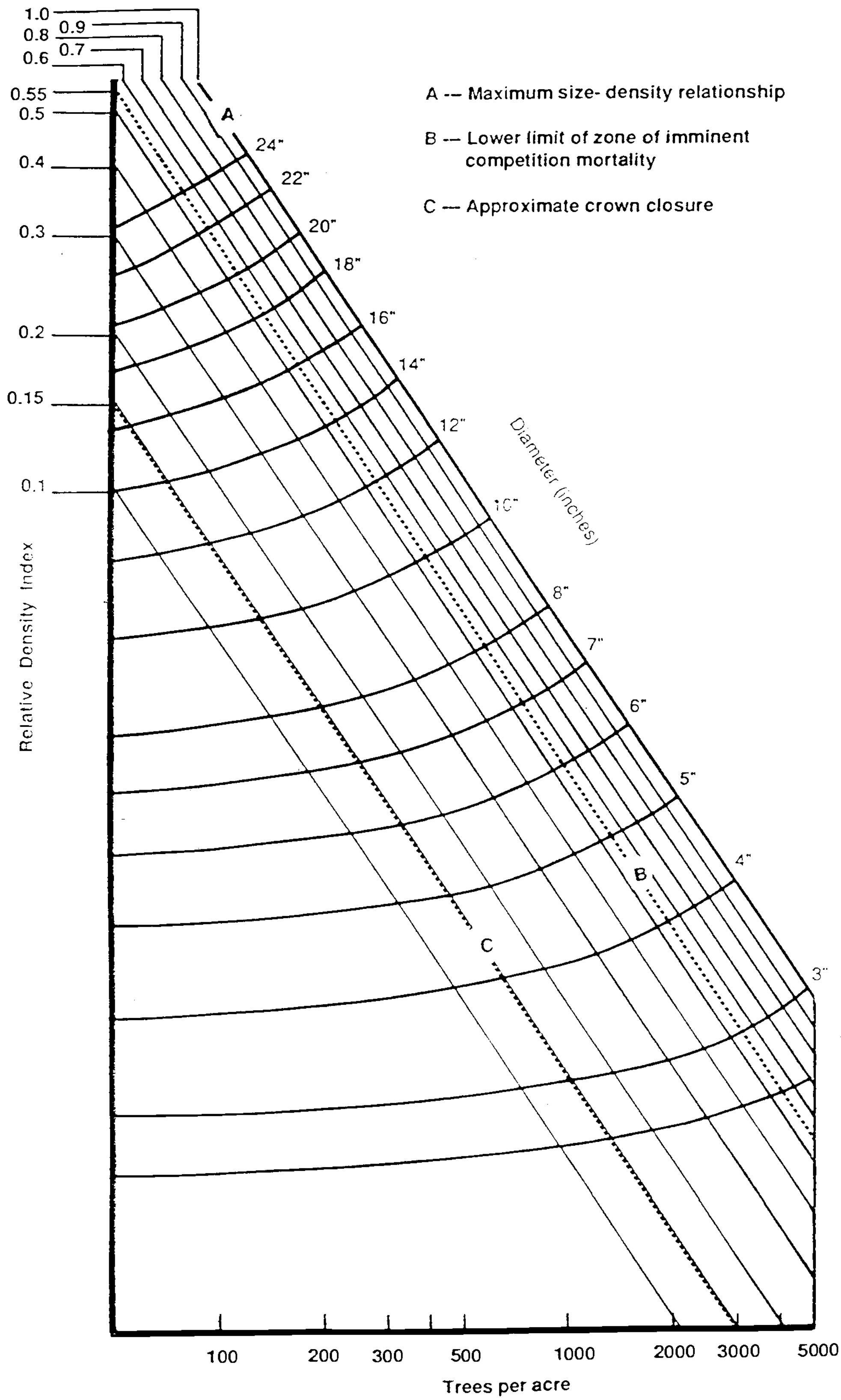
INTRODUCTION

Size and number of trees are 2 descriptors of stand structure commonly manipulated by silviculturists (Oliver and Larson 1990). Throughout the development of a forest stand, structure changes in predictable ways. As a stand develops, competition among trees causes mortality in suppressed and intermediate trees. This process, known as "self-thinning," changes stand structure as many small stems are replaced by fewer larger stems. A stand density diagram (Fig. 1) is a graphical representation of this size-density relationship. Silviculturists use stand density diagrams in planning the density management regime for a stand. Precommercial and commercial thinning are the tools used by silviculturists to manipulate stand structure by decreasing density.

Commercial thinning is the practice of removing merchantable trees from an even-aged stand of timber (Smith 1986). The traditionally recognized purposes of commercial thinning include stimulating the growth of potential crop trees by releasing them from competition, and providing an interim source of income for the landowner. Commercial thinning increases the efficiency of wood production by distributing volume growth on fewer, large stems and by

Figure 1. A stand density management diagram showing the relationship of stand density to average tree size for Douglas-fir. Adapted from Drew and Flewelling (1979).

Figure 1


1.0
0.9
0.8
0.7
0.6
0.55
0.5
0.4
0.3
0.2
0.15
0.1
Relative Density Index
A
24"
22"
20"
18"
16"
14"
12"
10"
8"
7"
6"
5"
4"
3"
Diameter (inches)
B
C
A -- Maximum size- density relationship
B -- Lower limit of zone of imminent competition mortality
C -- Approximate crown closure
100
200
300
500
1000
2000
3000
5000
Trees per acre

harvesting trees that would otherwise die from suppression (Smith 1986). Commercial thinning is a management practice that is likely to be used increasingly in western Oregon as the need for efficient management of timber increases (W. Emmingham, pers. comm.)

Commercial thinning may influence wildlife habitat because, like many silvicultural activities, it can alter stand structure and composition. The definition of stand structure from a bird habitat perspective includes more than the size and density of trees. Measures of the complexity of vegetation structure such as percent cover, depth, and volume of foliage, plant species diversity, and foliage height diversity (the distribution of foliage over vertical layers in a forest) have been positively related to bird species diversity (MacArthur and MacArthur 1961, Balda 1975, Noble et al. 1980, Bull and Skovlin 1982). Structurally complex forest stands provide more potential niches for bird species, and are therefore capable of supporting a more diverse bird community (Willson 1974, Dickson and Segelquist 1979). In western coniferous forests, changes in forest structure that increase habitat complexity, whether naturally occurring (e.g., succession) or management-induced (e.g., selective harvesting) usually result in increased bird species diversity (Meslow 1978, Morrison and Meslow 1983, Balda 1985, Verner and Larson 1989). Ecologists have suggested that thinning may increase bird species diversity by enhancing vertical diversity (Thomas et al. 1975, Langelier and Garton 1986). Diem and Zeveloff (1980) recommended thinning in ponderosa pine (Pinus ponderosa) stands to increase crown dimensions to benefit insectivorous birds that forage in crown foliage. Verner (1980) recommended thinning Sierran mixed-confer stands to encourage more rapid growth to large tree size. A few studies have provided support for such recommendations. Artman (1990) compared bird populations in thinned and unthinned western hemlock (Tsuga heterophylla) stands in western Washington and found that thinned stands had higher species diversity than similar stands that had not been thinned. Mannan and Meslow (1984) found that the degree of canopy openness in thinned 85-year-old mixed ponderosa pine and Douglas-fir (Psuedotsuga menziesii) forests in northeast Oregon was positively associated with the densities of 6 avian species.

Commercial thinning may not always increase vertical diversity in a stand (Hunter 1990:230). The structure resulting from a commercial thin depends not only on the number of trees removed but also on the dominance class of trees removed. Commercial thinning done in the Oregon Coast Ranges is typically accomplished by removing suppressed, intermediate, and codominant trees whose crowns comprise the middle to lower layers of the canopy (Mark Vomocil, pers. comm.; pers. observation). This method, called "thinning from below" can decrease the depth of the canopy layer, effectively removing a vegetative layer or layers from the stand. Thus, while commercial thinning may result in the development of understory layers in a stand, it may also reduce dimensions of the overstory layers (Hunter 1990).

Bird community response to forest management practices varies among species and the degree of habitat alteration (Noble et al. 1980, Freedman et al. 1981, Medin 1985). For instance, severe cuts that remove >80% of stand basal area will tend to favor early successional bird species, particularly those that forage and nest close to the ground, while species associated with closed canopies will decline or be absent (Hagar 1960, Blake 1982). Moderate cuts that reduce basal area by 30-50% also may favor early successional bird species, while maintaining or favoring some species associated with canopy foliage, such as some foliage- and aerial- feeders (Scott et al. 1982, Medin and Booth 1985). Species that forage on the trunks and limbs of trees tend to be negatively impacted by harvests that remove large trees (Franzreb and Ohmart 1978, Szaro and Balda 1979, Medin 1985). The effects of commercial thinning on individual bird species are expected to depend on the intensity of the thinning and the resulting stand structure.

The history of stand development prior to thinning and time elapsed since thinning also may influence stand structure and thus bird habitat. The density of the stand prior to thinning influences the crown dimensions of the residual trees. Trees in closely spaced stands will have a lower live crown ratio (proportion of length of stem with living branches) than those in more open stands because lower branches that are not adequately illuminated will die (Smith 1986:70). After thinning the crowns expand and the live crown ratio may increase until the canopy closes again. The time it takes for the canopy to reclose after thinning varies with tree height, growth rates, and thinning intensity (Oliver and Larson 1990:221). Stand density prior to thinning also may influence the amount and species of understory vegetation present in the stand at the time of thinning, but to my knowledge this relationship has not been studied in Pacific Northwest Douglas-fir forests. Understory vegetation is likely to be influenced as the levels of light penetrating the canopy vary with time since thinning. Crouch (1986) found an increase in herbaceous growth and reduced shrub production in the years immediately following commercial thinning of Ponderosa pine (Pinus ponderosa) in Colorado. Shrub production did not begin to increase until 3-5 years after thinning. Birds associated with herbaceous understory vegetation might be expected to be more abundant shortly after thinning, but they may be replaced with canopy-associated species over time.

Not all patterns in the diversity and abundance of forest birds can be related to vegetation complexity within a forest stand. The size of a forest stand in combination with its edge-to-interior ratio also have been associated with the presence and abundance of forest bird species (Ambuel and Temple 1983, Temple 1986). Both the density and the species richness of forest interior birds tend to be lower in smaller than in larger stands (Askins et al. 1987). In addition, a high edge-to-interior ratio may expose forest interior bird species to greater risks of nest predation, brood parasitism, and competition, resulting in a reduction in or elimination of their population(s) from a forest island (Temple 1986).

In order to maintain habitat for avian species in managed forests, it is essential to know which habitat features are important to avian communities and their component species and how these features are altered by management activities. Knowing the impact different types and intensities of commercial thinning has on birds and bird habitat may enable managers to achieve desired avian habitat while optimizing timber yields. The stand density diagram has been applied to wildlife management to illustrate the relationship of lodgepole pine (<u>Pinus contorta</u>) density on ungulate hiding and thermal cover (Smith and Long 1987). It also may be possible to use a stand density diagram to express bird habitat, enabling forest managers to assess a stand from both wildlife habitat and sivicultural perspectives simultaneously. If the stand density diagram is to function as a common language, and commercial thinning as a common tool, for foresters and wildlife managers, the relationship of stand density to the structural characteristics that are components of bird habitat must be understood. The purpose of my study was to compare avian abundance and community composition, and habitat features associated with bird abundance between commercially thinned and unthinned stands of Douglas-fir in western Oregon.

STUDY AREA

Study sites were located in the central Oregon Coast Ranges between 44° 37′ and 44° 22′ latitude in Benton and Lincoln Counties and in the northern Oregon Coast Range between 45° 45′ and 45° 35′ latitude in Tillamook and Washington Counties. Both the Central Coast region and the Tillamook sites were in the *Tsuga heteophylla* forest zone of the Oregon Coast Ranges (Franklin and Dyrness 1988). Stands were 40-55 years of age, and dominated by Douglas-fir overstories. 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*).

Sites in the Central Coast Range were on land managed by Starker Forests, Inc., Siuslaw National Forest, and Willamina Lumber Company. Elevation of sites in the central region was between 280 m and 468 m. Study sites in the northern Coast Range were located in the Tillamook State Forest, managed by the Oregon Department of Forestry (ODF). Elevation of these sites ranged from 340 m to 625 m.

The Tillamook State Forest is largely a product of several conflagrations which occurred between 1933 and 1945 and burned approximately 143,670 hectares of forest land (Oregon Department of Forestry 1983). Since the fires occurred, the forest has been naturally regenerated or planted uniformly under the singular management of the ODF. Clearcut harvesting and commercial thinning began in 1983 (Oregon Department of Forestry 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 Central Oregon Coast range, which is a mosaic of different age classes of forest created by cutting and multiple ownerships.

METHODS

Study site selection

I chose 4 commercially thinned and 4 unthinned stands in each of the 2 regions (16 total stands). Stands were selected as pairs, using criteria of age (40-55 years), size (minimum of 30 ha), elevation, aspect, vegetation association, and availability of a thinned and unthinned matching pair within 5 kilometers of each other. Because thinned stands in the Tillamook State Forest were surrounded by a matrix of even-aged unthinned forest, I placed study plots randomly in the unthinned matrix $\geq$100 m from a thinning boundary. Ages, densities, year thinned, and sizes of stands are summarized in Table 1.

Habitat sampling

I measured vegetation structure and composition at 4 bird count plots plus 4 random plots in each stand. Sixty-six habitat variables were either directly measured or derived for each plot (Table 2). Slope, aspect, and distances to edges and stream were measured at the plot center. Basal areas of conifers, hardwoods, and snags also were recorded from the plot center, using a 20 basal area factor (BAF) prism. Snags were tallied by size and decay class within 30 m (0.28-ha circular plot) of plot center. Decay classes of snags follow those defined by Cline et al. (1980). Percent cover (p.c.)

Table 1. Tree densities, stand sizes and ages, and time of thinning for 4 pairs of stands in the Central Coast Ranges and 4 pairs of stands in the Tillamook State Forest.

Region name / Stand name	Age (years)	Unthinned trees/ha	Unthinned relative density	Unthinned size (ha)	Thinned trees/ha	Thinned relative density	Thinned size (ha)	year thinned
Central Coast Range								
Burnt Woods	55	583	0.35	65	391	0.28	80	1979
Mary's Peak	55	663	0.45	90	343	0.25	75	1983
Mountain Fir	50	724	0.28	72	598	0.25	55	1975
Pigeon	50	469	0.28	97	386	0.19	100	1977
Tillamook State Forest								
Drift Creek	40	349	0.27	445	213	0.17	31	1984
Hump Creek	55	322	0.39	510	271	0.27	42	1983
Roger's Camp	40	437	0.30	440	346	0.22	34	1984
Timber Tiger	50	415	0.37	510	335	0.26	53	1985

Table 2. Habitat characteristics measured in plots centered on bird count points in 8 thinned and 8 unthinned Douglas-fir stands in the Central Oregon Coast Ranges and the Tillamook State Forest, Oregon, 1990.

Variable	Description
conifer basal area	conifer basal area (20 BAF), m^2/ha
hardwood basal area	hardwood basal area (20 BAF), m^2/ha
snag basal area	snag basal area (20 BAF), m^2/ha
10-cm conifers	conifer stems/ha, <10-cm dbh[a]
10-20-cm conifers	conifer stems/ha, 10-20-cm dbh
20-30-cm conifers	conifer stems/ha, 20-30-cm dbh
30-43-cm conifers	conifer stems/ha, 30-43-cm dbh
43-56-cm conifers	conifer stems/ha, 43-56-cm dbh
large conifers	conifer stems/ha, >56-cm dbh
conifer stems	conifer stems/ha, all dbh classes combined
10-cm hardwoods	hardwood stems/ha, <10-cm dbh
10-20-cm hardwoods	hardwood stems/ha, 10-20-cm dbh
20-30-cm hardwoods	hardwood stems/ha, 20-30-cm dbh
30-43-cm hardwoods	hardwood stems/ha, 30-43-cm dbh
large hardwoods	hardwood stems/ha, 30-56-cm dbh
hardwood stems	hardwood stems/ha, all dbh classes combined
all stems	conifer and hardwood stems/ha, all dbh
classes	combined
small snags dc 1	snags/ha, 10-30-cm dbh; decay class 1[b]
small snags dc 2-3	snags/ha, 10-30-cm dbh; decay class 2-3
small snags dc 4-5	snags/ha, 10-30-cm dbh; decay class 4-5
all small snags	snags/ha, 10-30-cm dbh; all decay classes combined
medium snags dc 1	snags/ha, 30-51-cm dbh; decay class 1
medium snags dc 2-3	snags/ha, 30-51-cm dbh; decay class 2-3
medium snags dc 4-5	snags/ha, 30-51-cm dbh; decay class 4-5
all medium snags	snags/ha, 30-51-cm dbh; all decay classes combined
large snags dc 1	snags/ha, >51-cm dbh; decay class 1
large snags dc 2-3	snags/ha, >51-cm dbh; decay class 2-3
large snags dc 4-5	snags/ha, >51-cm dbh; decay class 4-5

Table 2, continued

Variable	Description
all large snags	snags/ha, >51-cm dbh; all decay classes combined
pc slash	percent cover of downed woody debris >3-cm diameter
pc herbaceous plants	percent cover of forbs, grasses and other herbaceous plants
pc fern	percent cover of ferns
pc low shrubs	percent cover of low shrubs: 0-1.3 m
pc tall shrubs	percent cover of tall shrubs: 1.4-4.0 m
pc pole	percent cover of pole trees: 4.0-20.0 m
pc sawtimber	percent cover of sawtimber: >20.0 m
fern ht	average height (m) of fern
low shrub ht	average height (m) of low shrub layer
tall shrub ht	average height (m) of tall shrub layer
pole ht	average height (m) of pole layer
sawtimber ht	average height (m) of sawtimber layer
pc vine maple	percent cover of vine maple (Acer circinatum)
pc Oregon-grape	percent cover of dwarf Oregon grape (Berberis nervosa)
pc salal	percent cover of salal (Gaultheria shallon)
pc hazel	percent cover of hazel (Corylus cornuta)
pc huckleberry	percent cover of red huckleberry (Vaccinium parvifolium)
pc deciduous shrubs	percent cover of deciduous shrubs
pc evergreen shrubs	percent cover of evergreen shrubs
vine maple ht	average height (m) of vine maple
salal ht	average height (m) of salal
deciduous shrub ht	average height (m) of deciduous shrubs
evergreen shrub ht	average height (m) of evergreen shrubs
pc Douglas-fir	percent cover of Douglas-fir (Pseudotsuga menziesii)
pc conifers	percent cover of conifers (all species)
pc bigleaf maple	percent cover of bigleaf maple (Acer macrophyllum)
pc red alder	percent cover of red alder (Alnus rubra)

Table 2, continued

Variable	Description
pc hardwoods	percent cover of hardwoods (all species)
Douglas-fir ht	average height (m) of Douglas-fir
conifer ht	average height (m) of conifers (all species)
hardwood ht	average height (m) of hardwoods (all species)
elevation	elevation (m)
slope	average % slope within 20 m of plot center
aspect	average orientation of slope face in degrees within 20 m of plot center
distance to stand edge	distance (m) to nearest stand edge
distance to patch edge	distance in (m) to nearest patch ($\leq$0.8 ha) of different condition or plant community
distance to stream	distance (m) to nearest permanent stream

[a] dbh= diameter at breast height

[b] decay of snags ranked on a scale of 1 to 5, where 1 was recently dead and 5 was old and rotten, after Cline et al. (1980).

and vegetation height (ht.) were recorded in 4 satellite plots located at random distances 10-40 m from the main plot center. Herbaceous and fern cover were visually estimated in 0.01-ha circular plots centered on each satellite plot; shrub and tree cover were visually estimated, and live trees were tallied by diameter-class in 0.03-ha circular plots centered on each satellite plot. Percent cover and height were estimated 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), (see McGarigal and McComb 1992), as well as for each dominant shrub and tree species individually.

Bird Sampling

I 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 modified variable circular plots (Reynolds et al. 1980). Four randomly scattered points in each stand served as plot centers (total = 64 plots). Plot centers were >100 m apart and >100 m from a stand edge (not including roads.) All birds seen or heard by an observer standing at plot center were recorded by species and the estimated distance (m) to the bird was recorded. Birds observed flying over the plot were noted but not included in analyses.

I conducted breeding season counts from 1/2 hour before sunrise to 4 hours after sunrise on days without heavy rain or strong winds. Winter counts were conducted from sunrise to early afternoon in all but the most severe weather. I felt that because days with good weather can be rare in the Coast Ranges in the winter, it was necessary to conduct counts regardless of precipitation. This protocol ensured that enough counts were completed and that the data reflected bird-habitat relationships for a typical Coast Range winter.

Each plot was visited 4 times during breeding season counts. During the winter only 1 plot/stand/day was visited to reduce the chances of double-counting non-territorrial birds as they travelled throughout the stand. In the winter each plot was visited twice, therefore each stand was visited 8 times.

Data Analysis

Univariate procedures

I averaged habitat data from the 4 sample plots plus 4 random plots within each stand (n=128 habitat sampling points) and compared these averages between conditions (thinned and unthinned) within regions (Central Coast and Tillamook S.F.) and between regions using a split-plot ANOVA procedure (Petersen 1985:134-145). Region was the whole plot and condition was the subplot. The stand-nested-within region error term was used to test the effect of region. The overall error term was used to test for the condition effect and the condition-by-region interaction. The split-plot ANOVA procedure generated 16 residuals that I 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 using an appropriate transformation (Sabin and Stafford 1990). When an interaction between region and condition was indicated I used a Least-squares Means comparison procedure (SAS Institute, Inc. 1985:148-149) to determine which means differed ($\underline{P} \leq 0.10$) between conditions within each region. I used a distribution-free test (Friedman's test, Devore and Peck 1986) to compare habitat means between treatments for those 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 effects of region and condition-by-region interaction could not be assessed. I set all significance levels at $\underline{P} \leq 0.10$.

Breeding bird data from 1989 and 1990 were pooled and those species having ≥28 observations ≤60 m from a plot center were selected for analysis. The number of observations for each species was used as an index to abundance for all analyses. Abundance was summed over the 4 plots in each stand ($\underline{n}$=16 stands) and compared between conditions within regions and between regions using the split-plot ANOVA or Friedman's procedures described above. Species diversity, richness, and equitability also were compared between conditions within regions and between regions using these procedures, except that all observations made ≤100 m from plot center were used in analyses. This ensured that rare, wide-ranging species would be included in bird community level analyses. Shannon's function was used to calculate diversity (Shannon and Weaver 1949).

Multivariate procedures

Multiple regression and discriminant function analysis (DFA) were used to explore the relationships between the abundance or presence of each bird species having ≥28 observations and habitat features at both plot and stand scales. Because I did not describe habitat during the winter, only breeding bird-habitat relationships were analyzed.

For plot-level analysis, observations of species that occurred at ≥58 of the 64 plots were totalled for all count periods and used as the dependent variable in stepwise multiple regression, with habitat variables as the predictor variables. DFA was used to separate used plots from unused plots based on habitat features for those bird species that were observed at <58 but >15 plots. For stand-level analysis, stepwise multiple regression was used to describe bird-habitat relationships for those bird species observed in ≥12 of the 16 stands. DFA was not used for bird species observed in ≤12 stands because the small sample size would have limited the number of predictor variables to 2 (Williams and Titus 1988), making a multivariate analysis pointless. Therefore, a _t_-test was used to compare individual habitat variables between stands where a species was observed and stands where it was not observed. The level of significance at which <1 of apparent differences in habitat variables (_n_=72) between used and unused stands was caused by chance alone, was 0.01.

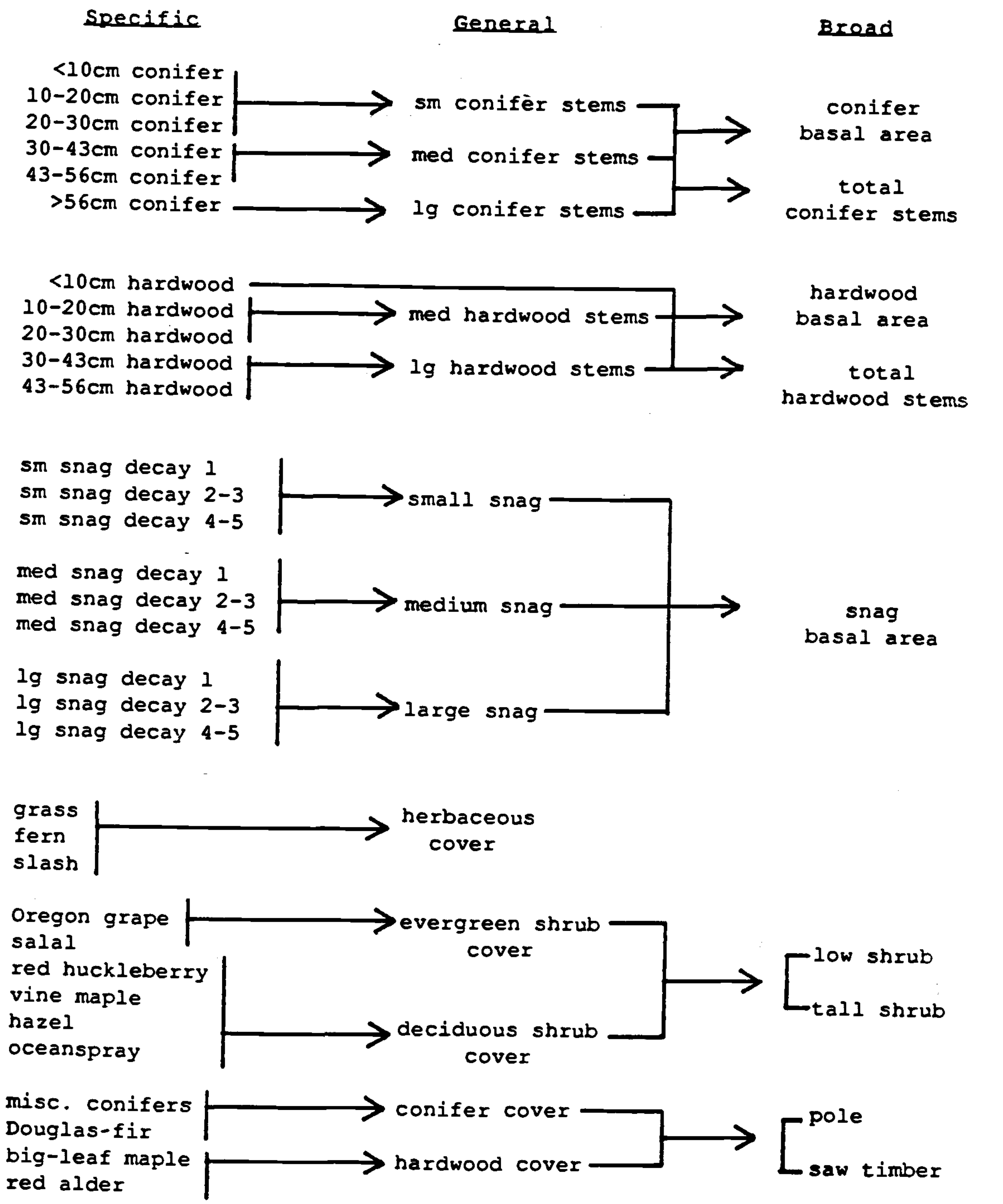
For all multivariate analyses, habitat variables were divided into 3 levels of resolution: specific, general, and broad (Figure 2). Within each level of resolution, habitat variables were further divided into groups comprised of (1) variables describing densities of tree stems, (2) variables describing layers of vegetation, (3) variables describing the species composition of the vegetation, and (4) variables describing physical aspects of the site.

When multiple regression was the appropriate method of analysis, a separate regression was run for each group of habitat variables. The variables selected from each group were used in another regression analysis to produce a model for each level of resolution. Habitat variables from each level of resolution were pooled in a final regression analysis to produce an overall model. No more than 6 predictor variables were retained in each stand-level model in order to ensure a sufficient number of degrees of freedom (Devore and Peck 1967:537).

When DFA was the appropriate method of analysis, a

Figure 2. Levels of resolution of habitat variables measured or derived for 8 commercially thinned and 8 unthinned Douglas-fir stands in western Oregon, 1990.

Figure 2


Specific
General
Broad
<10cm conifer
10-20cm conifer
20-30cm conifer
30-43cm conifer
43-56cm conifer
>56cm conifer
sm conifer stems
med conifer stems
lg conifer stems
conifer basal area
total conifer stems
<10cm hardwood
10-20cm hardwood
20-30cm hardwood
30-43cm hardwood
43-56cm hardwood
med hardwood stems
lg hardwood stems
hardwood basal area
total hardwood stems
sm snag decay 1
sm snag decay 2-3
sm snag decay 4-5
med snag decay 1
med snag decay 2-3
med snag decay 4-5
lg snag decay 1
lg snag decay 2-3
lg snag decay 4-5
small snag
medium snag
large snag
snag basal area
grass
fern
slash
herbaceous cover
Oregon grape
salal
red huckleberry
vine maple
hazel
oceanspray
evergreen shrub cover
deciduous shrub cover
low shrub
tall shrub
misc. conifers
Douglas-fir
big-leaf maple
red alder
conifer cover
hardwood cover
pole
saw timber

stepwise selection procedure (SAS Institute, Inc. 1985:406-414) was used first to reduce habitat variables to a useful subset. The canonical structure for the final group of habitat variables for each level of resolution was derived using a discriminant analysis procedure (SAS Institute, Inc. 1985:381-404). The maximum number of habitat variables allowed in a final DFA model was determined using the rule:

$$\underline{P} \leq \underline{n}/3$$

where $\underline{P}$ = number of discriminating variables and $\underline{n}$ = number of samples in the smallest of the 2 groups (used plots and unused plots) (Williams and Titus 1988). Classification was used to assess the effectiveness of the canonical function in discriminating between used and unused plots (McGarigal and Stafford, in prep.). Cohen's Kappa statistic (Titus et al. 1984) was calculated from the chance-corrected classification rate to provide a measure of model performance. A Kappa of 0 indicates no improvement in classification of group membership over chance whereas a Kappa close to 100 indicates good model performance.

Principal Components Analysis (PCA) was used to reduce the complex habitat variable data to a few dominant gradients of variation among the 16 stands. The Proc Factor procedure of SAS (SAS Institute, Inc. 1985:309-345) was used to ordinate stands along 3 gradients defined by linear combinations (Factors) of 12 habitat variables selected from the original data set. The variables chosen for the PCA were those that seemed useful in describing bird habitat (based on regression analyses) in addition to describing stand structure. A Pearson correlation analysis was used to investigate relationships between bird abundance and PCA scores for each stand. PCA scores were used to generate a plot of the 16 stands along the first 2 Factors. Based on this plot, the stands were separated into 4 groups. An ANOVA was then used to test for differences in bird abundance among the 4 PCA groups. Bird species that differed in abundance between regions were not included in this analysis because 1 group was comprised solely of stands from the Central Coast Range. A Least-squares Means comparison procedure (SAS Institute, Inc. 1985:148-149) was used to compare average bird abundance among the 4 groups. This part of the analysis was not determined *a priori* but rather evolved from the PCA results, therefore *P*-values were ignored and the results were considered purely exploratory.

RESULTS

Habitat Characteristics

Vegetation structure differed between thinned and unthinned stands, particularly in stem densities, herbaceous cover, and canopy cover (Table 3). Unthinned stands had greater conifer basal area and higher stem densities for 4 of 6 size classes of conifers (Fig. 3), as well as higher total densities of all live stems. Unthinned stands also had more 10- to 30-cm dbh snags in decay class 1 than thinned stands ($\underline{P}$=0.06). Stem densities of the smallest size class of hardwoods (<10 cm dbh) were higher in unthinned stands compared to thinned stands in the Tillamook S.F., but did not differ between conditions in the Central Coast region.

Thinned stands were characterized by having more herbaceous and fern cover than unthinned stands. Average grass cover was almost 3 times greater in thinned stands than in unthinned stands (Table 3). Both the percent cover and the average height of ferns was greater in thinned stands as compared to unthinned stands.

Notably, shrub cover did not differ between thinned and unthinned stands in either region (Table 3). In the Tillamook S.F. tall shrub cover was greatest in unthinned stands, but did not differ between thinned and unthinned stands in the Central Coast region (Fig. 4b). Although shrub cover itself did not differ consistently between stand conditions, the tall

Table 3. Habitat characteristics in 8 commercially thinned and 8 unthinned Douglas-fir stands in the Tillamook State Forest and the Central Oregon Coast Ranges, 1990. See Table 2 for descriptions of habitat variables and scientific names.

Habitat variable	Thinned x	Thinned SE	Unthinned x	Unthinned SE	P	P(i)[b]
Basal Area (m^2/ha)						
conifers	39.2	1.5	54.4	2.1	0.01[a]	0.37
hardwoods	1.9	0.6	2.0	0.9	0.89[a]	0.05
snags	4.9	0.8	6.1	1.1	0.64[a]	0.57
Stems/ha						
<10 cm conifers	26.0	6.7	32.3	8.7	0.46[a]	0.79
10-20 cm conifers	69.3	6.7	109.0	29.2	0.01[a]	0.09
20-30 cm conifers[d]	89.0	14.3	133.3	21.7	0.00[a]	0.04
30-43 cm conifers[d]	120.0	7.7	156.7	16.0	0.03[a]	0.05
43-56 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
all conifers	355.7	38.0	497.0	48.7	0.00[a]	0.09
<10 cm hardwoods	24.3	8.0	51.7	15.7	0.03[a]	0.03
10-20 cm hardwoods	14.3	4.7	19.7	7.3	0.56[c]	
20-30 cm hardwoods	11.0	3.7	7.3	2.3	0.38[a]	0.29
30-43 cm hardwooods	5.3	2.3	3.0	0.7	0.25[a]	0.09
all hardwoods	55.3	12.0	82.3	17.0	0.14[a]	0.05
all live stems	414.0	46.7	579.7	48.3	0.00[a]	0.61
Snags/ha						
small dc 1	26.0	2.3	41.7	3.5	0.06[a]	0.67
small dc 2-3[d]	12.3	1.4	12.6	1.6	0.97[a]	0.41
small dc 4-5	4.0	0.8	3.1	0.6	0.43[a]	0.06
medium dc 1	0.5	0.2	1.2	0.4	0.15[c]	
medium dc 2-3	0.4	0.2	1.2	0.3	0.03[a]	0.05
medium dc 4-5[d]	1.9	0.6	2.0	0.4	0.50[a]	0.17
large dc 1	0.0		0.3	0.3	0.34[c]	
large dc 2-3	0.06	0.06	0.11	0.07	0.51[c]	
large dc 4-5	4.0	0.8	3.0	0.6	0.59[a]	0.72
small snags	42.3	3.5	57.4	4.7	0.16[a]	0.37

Table 3, continued

Habitat variable	Thinned x	Thinned SE	Unthinned x	Unthinned SE	P	P(i)[b]
medium snags	2.9	0.7	4.4	0.6	0.07[a]	0.88
large snags	4.0	0.8	3.4	0.7	0.74[a]	0.61
Vegetation layers (% cover)						
slash	32.3	3.7	35.8	5.6	0.47[a]	0.03
herbaceous	23.3	3.8	11.8	2.8	0.03[a]	0.55
grass[d]	5.5	1.5	1.9	0.3	0.02[a]	0.57
fern	29.8	3.4	18.4	2.8	0.02[a]	0.54
low shrub	48.7	5.6	39.6	7.1	0.32[a]	0.18
tall shrub[4]	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
saw	52.8	2.7	63.2	2.2	0.01[c]	
cv saw	36.1	3.1	33.4	2.1	0.37	0.09
Layer heights (m)						
fern	0.48	0.02	0.39	0.02	0.02[a]	0.28
low shrub	0.55	0.05	0.57	0.05	0.57[a]	0.86
tall shrub	2.49	0.06	3.02	0.10	0.00[a]	0.46
pole	16.19	0.19	15.48	0.36	0.04[a]	0.01
saw	26.56	0.72	25.91	0.52	0.50[a]	0.90
Shrubs (% cover)						
vine maple	15.15	6.31	17.28	5.77	0.47[a]	0.12
Oregon grape	11.91	2.90	12.28	4.69	0.92[a]	0.15
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
ocean-spray	3.20	1.28	1.85	0.65	0.27[a]	0.10
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]	0.00
evergreen shrub	46.10	4.56	41.05	7.86	0.57[a]	0.16
Shrub height (m)						
vine maple	2.32	0.06	2.77	0.11	0.00[a]	0.07
salal	0.41	0.02	0.50	0.07	0.18[a]	0.91
hazel	1.96	0.23	2.56	0.15	0.08[a]	0.25

Table 3, continued

Habitat variable	Thinned x	Thinned SE	Unthinned x	Unthinned SE	P	P(i)[b]
deciduous shrub	1.76	0.13	2.43	0.10	0.00[a]	0.15
evergreen shrub	0.76	0.08	1.05	0.11	0.12[a]	0.84
Trees (% cover)						
Douglas-fir	57.24	2.17	66.41	2.88	0.02[a]	0.85
all conifers	59.17	2.16	74.28	3.40	0.02[a]	0.48
bigleaf maple	4.53	2.23	4.15	2.03	0.78[a]	0.20
red alder	1.86	0.64	1.45	0.53	0.50[a]	0.35
all hardwoods	9.41	3.00	11.52	2.53	0.41[a]	0.19
Tree heights (m)						
Douglas-fir	24.62	0.69	23.49	0.83	0.29[a]	0.47
all conifers	24.04	0.73	22.38	0.56	0.11[a]	0.32
bigleaf maple	17.03	0.80	17.71	1.41	0.98[a]	0.58
red alder	15.64	1.37	15.76	1.33	0.80[a]	0.56
all hardwoods	13.33	0.79	11.25	1.35	0.12[a]	0.46
Physical and distance variables						
elevation (m)	434.9	13.2	411.2	14.7	0.24[a]	0.08
slope (%)	21.7	1.9	27.3	1.8	0.23[c]	
distance to:						
paedge (m)	78.0	5.3	93.0	6.1	0.19[a]	0.60
stedge (m)	167.4	12.3	254.1	19.5	0.01[c]	
stream (m)	151.6	16.1	203.7	17.7	0.04[a]	0.70

[a] Significance level associated with rejection of the null hypothesis that there is no difference between means, split plot ANOVA.

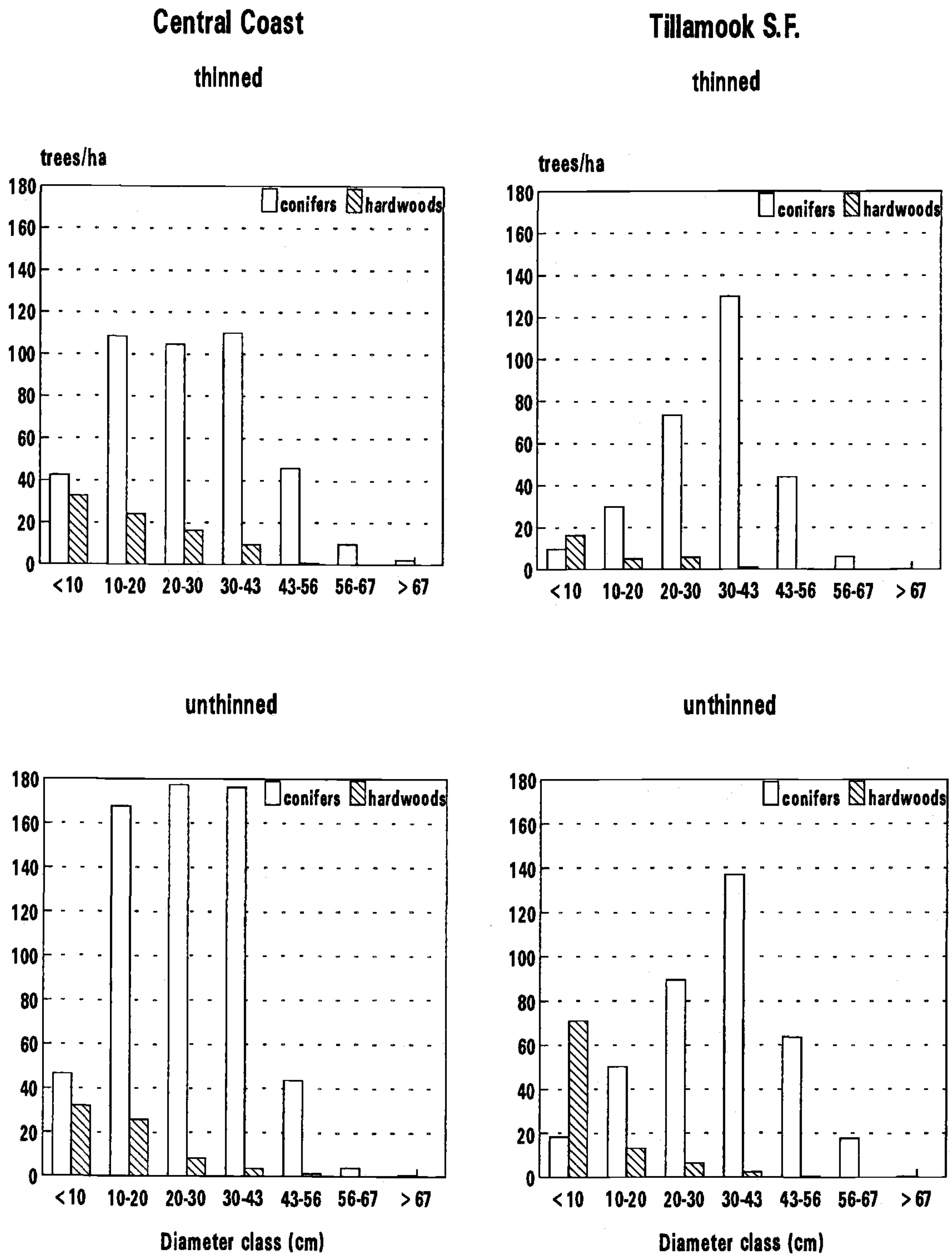
[b] Significance level associated with rejection of the null hypothesis that there is no interaction of Condition and Region, split plot ANOVA.

[c] Significance level associated with rejection of the null hypothesis that there is no difference between means, Friedman's test.

[d] Variable was log transformed (log10(VAR+1)) for analysis; means reported are untransformed means.

Figure 3. Diameter distributions of conifers and hardwoods for 4 thinned and 4 unthinned Douglas-fir stands in the Central Oregon Coast Ranges, and 4 thinned and 4 unthinned Douglas-fir stands in the Tillamook State Forest, 1990.

Figure 3


Central Coast
thinned
trees/ha
conifers
hardwoods
180
160
140
120
100
80
60
40
20
0
<10
10-20
20-30
30-43
43-56
56-67
>67
Tillamook S.F.
thinned
trees/ha
unthinned
unthinned
Diameter class (cm)
Diameter class (cm)

shrub layer averaged 0.5 m taller in unthinned stands compared to thinned stands in both regions.

Canopy cover, predominantly Douglas-fir, was greater in unthinned than in thinned stands (Table 3). This was true for both the pole and the sawtimber layers. In addition, the average height of the pole layer was lower in unthinned stands in the Tillamook S.F. (Fig. 4K), reflecting a greater depth of this layer in unthinned stands in this region.

Distance from plot centers to the edge of the stand averaged 1.5 times less in thinned stands than in unthinned stands (Table 3). This was probably because thinned stands were generally smaller and closer to roads.

Five variables reflecting stem densities of conifers and hardwoods, 3 shrub variables, and 9 other habitat variables differed between the Central Coast region and the Tillamook S.F. (Table 4). The Central Coast region had higher overall tree densities (mostly attributable to conifers 10-30 cm dbh) than the Tillamook S.F. (Fig. 3). The Central Coast region also had higher average hardwood cover, comprised primarily of bigleaf maple (Acer macrophyllum). Two shrub species, red huckleberry (Vaccinium parvifolium) and dwarf Oregon-grape, had greater cover in the Tillamook S.F. than in the Central Coast. The average distance to a patch edge was less in the Central Coast region than in the Tillamook S.F.

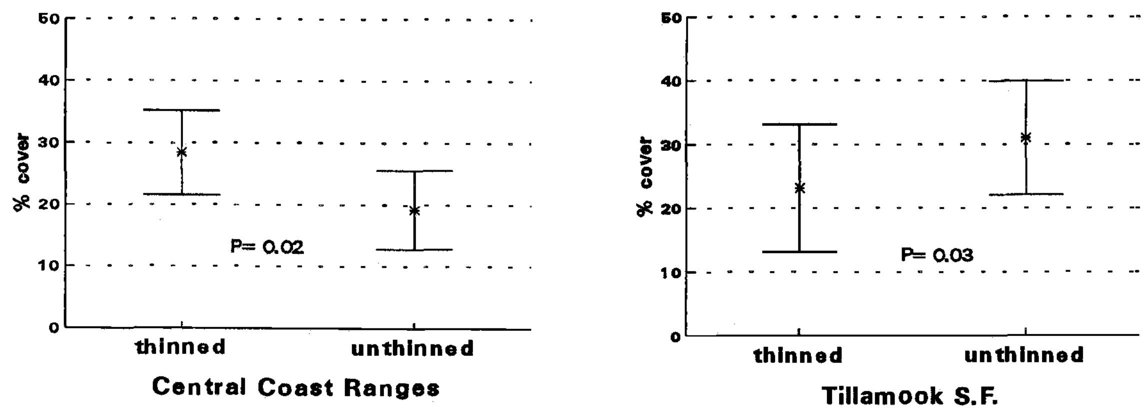
Table 4. Habitat characteristics in 8 Douglas-fir stands in the Central Coast Ranges and 8 stands in the Tillamook State Forest, Oregon. P = the significance level associated with rejection of the null hypothesis that there is no difference between means, split plot ANOVA.

Habitat variable	Central Coast		Tillamook		
	$\bar{x}$	SE	$\bar{x}$	SE	P
Cover (%)					
Oregon-grape	6.0	1.8	18.2	4.0	0.06
hardwood	14.6	2.8	6.3	1.8	0.09
low shrub	35.2	6.4	53.0	4.9	0.03
slash	40.4	4.2	27.6	3.4	0.05
red huckleberry	2.2	0.5	4.8	0.5	0.01
cv sawtimber	38.8	2.4	30.6	1.9	0.03
Stems/ha					
Conifers					
<10 cm dbh	44.7	7.0	14.0	3.0	0.01
10-20 cm dbh	138.0	26.7	40.0	6.7	0.04
20-30 cm dbh	141.0	18.7	81.3	14.7	0.05
<10-30 cm dbh	182.7	27.0	54.0	9.7	0.01
all conifers	520.3	46.0	335.3	24.7	0.01
Hardwoods					
30-43 cm dbh	6.5	1.9	1.7	0.7	0.05
Conifers and hardwoods					
<10-30 cm dbh	348.7	45.0	180.3	24.0	0.02
all size classes	597.3	50.0	396.3	33.0	0.01
Height (m)					
red alder	17.7	0.6	13.4	1.4	0.04
Distance (m)					
to patch edge	71.6	4.3	99.4	6.5	0.01

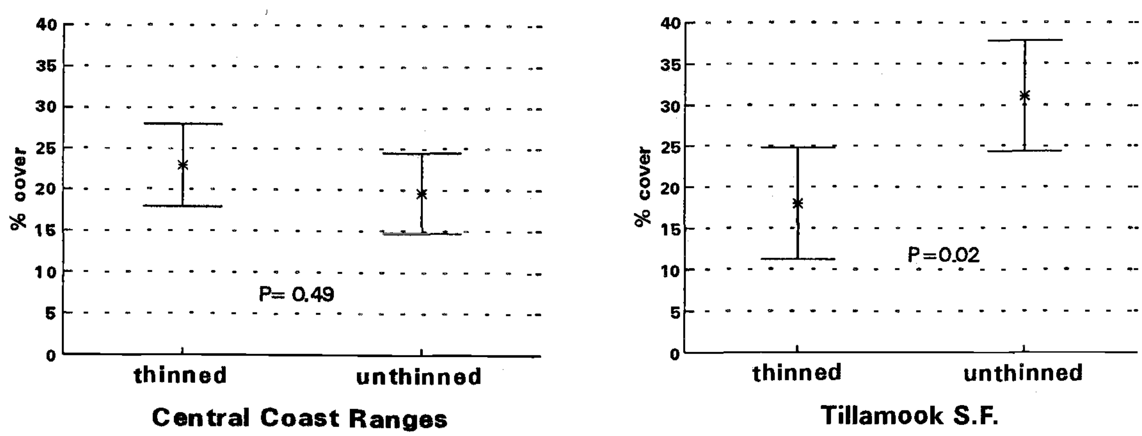
Figure 4. Means of habitat variables having an interaction between condition (thinned and unthinned) and region (Central Coast and Tillamook State Forest). *P*=level of significance associated with Least-squares Means multiple means comparison procedure.

Figure 4A - C

4A. Deciduous shrub cover



4B. Tall shrub cover



4C. Coefficient of variation of sawtimber cover

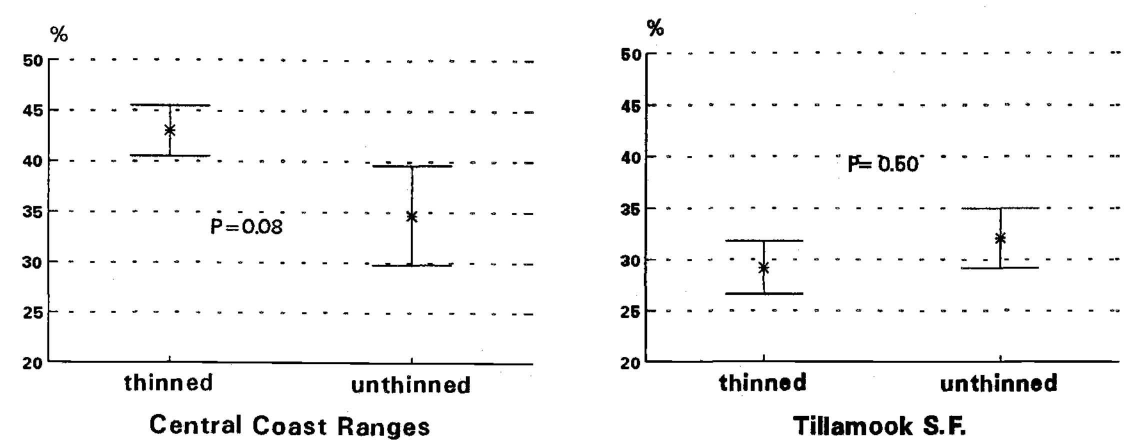
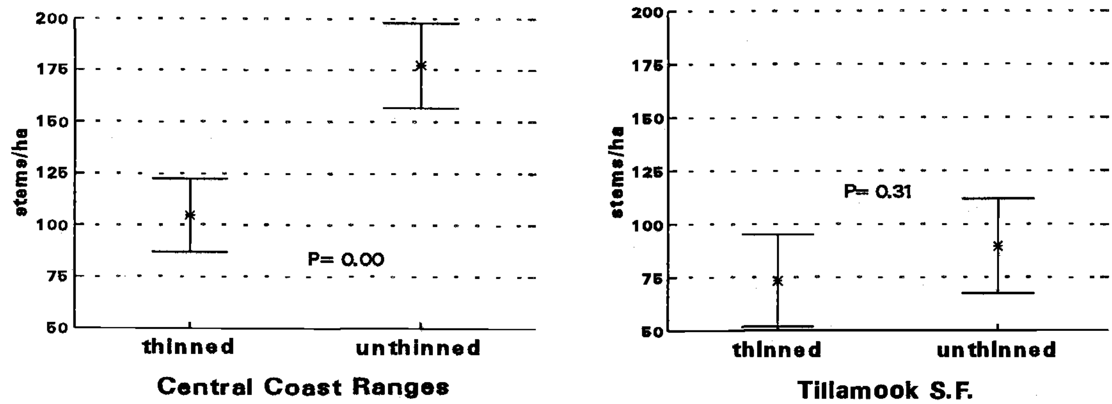
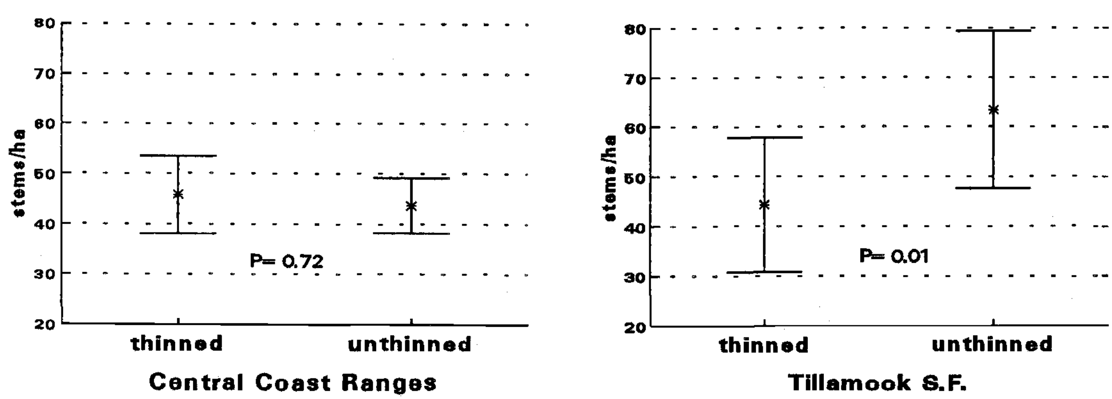


Figure 4D - F

4D. Density of 20-30 cm dbh conifers



4E. Density of 43-56 cm dbh conifers



4F. Density of > 56 cm dbh conifers

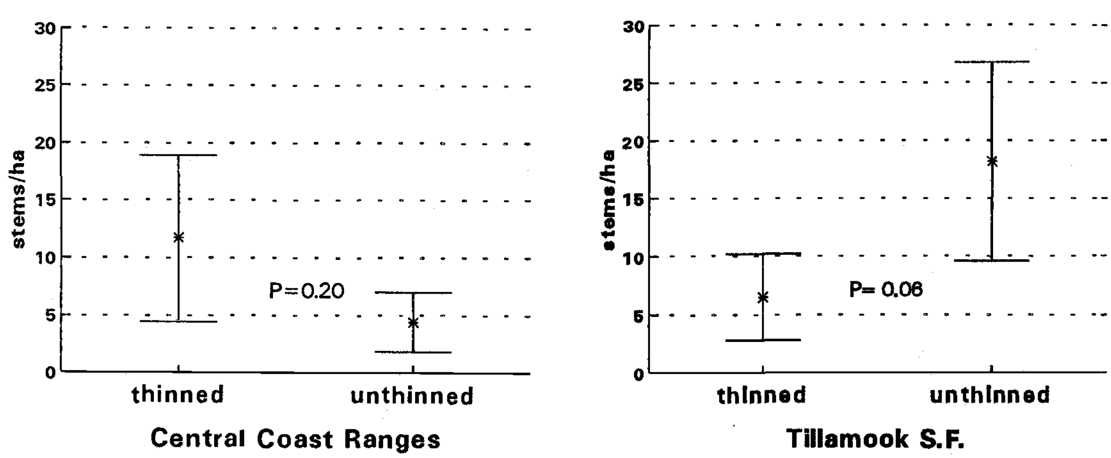
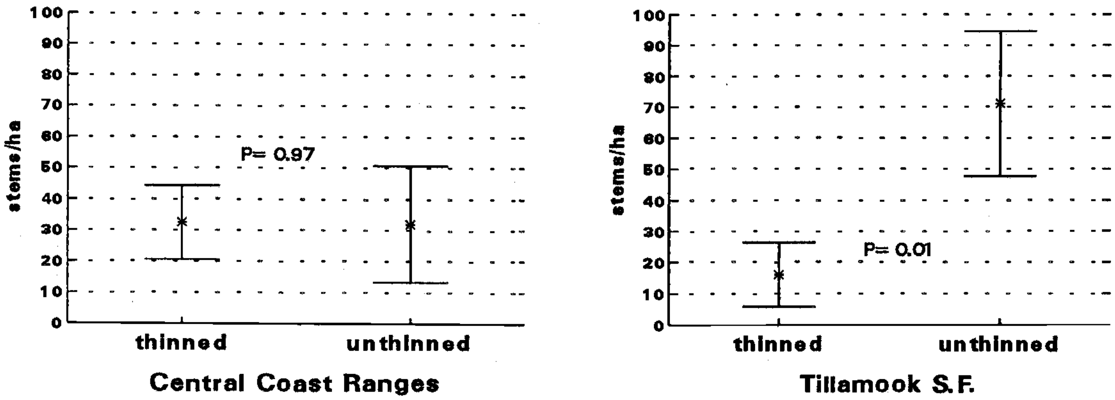
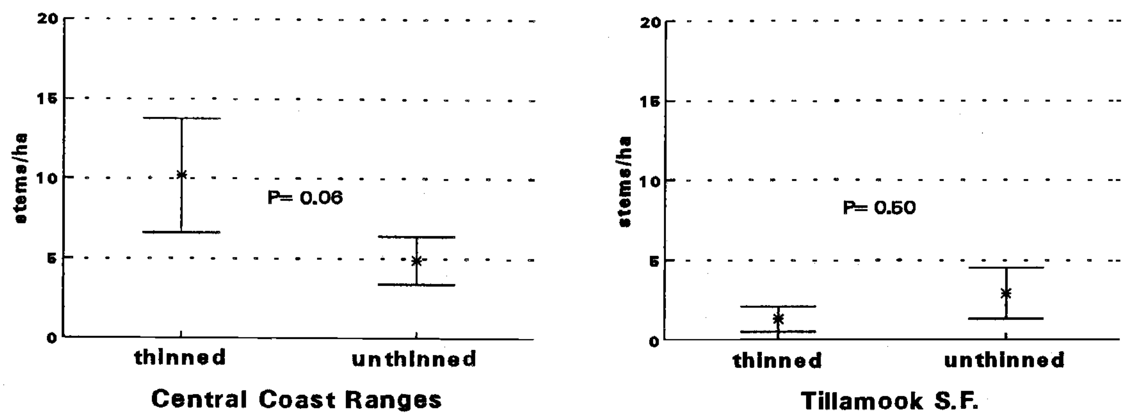


Figure 4G - I

4G. Density of < 1 0 cm dbh hardwoods



4H. Density of > 30 cm dbh hardwoods



4I. Density of hardwoods

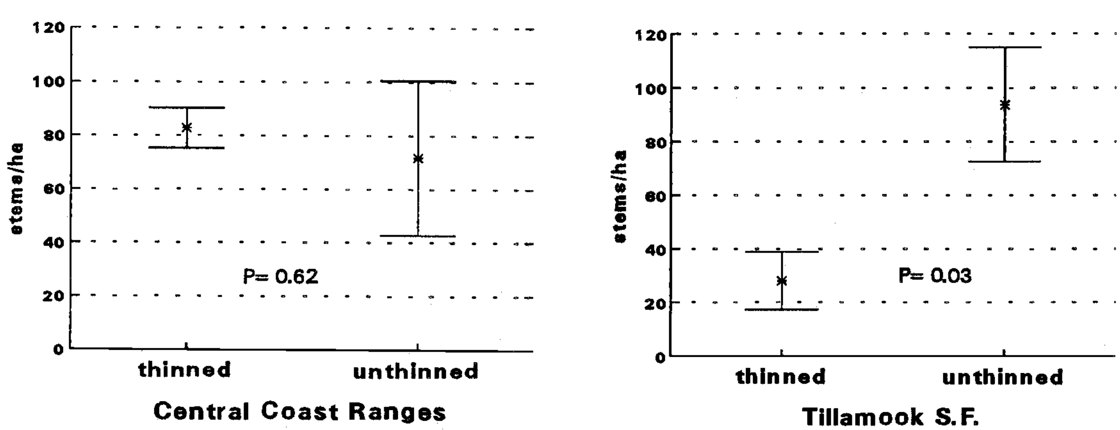
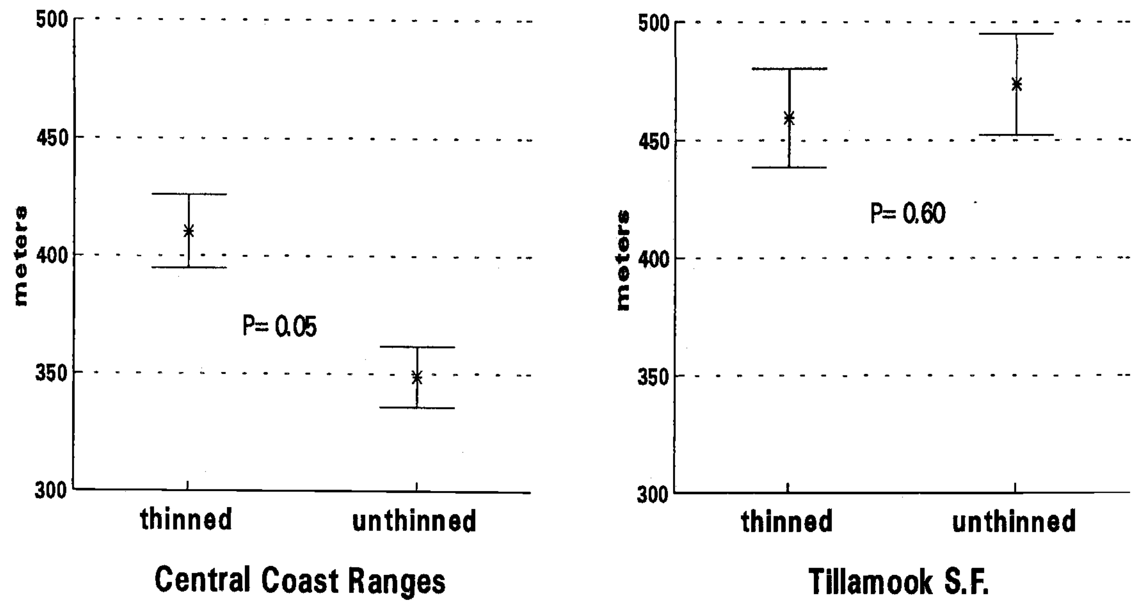


Figure 4J - K

4J. Elevation



4K. Height of pole cover

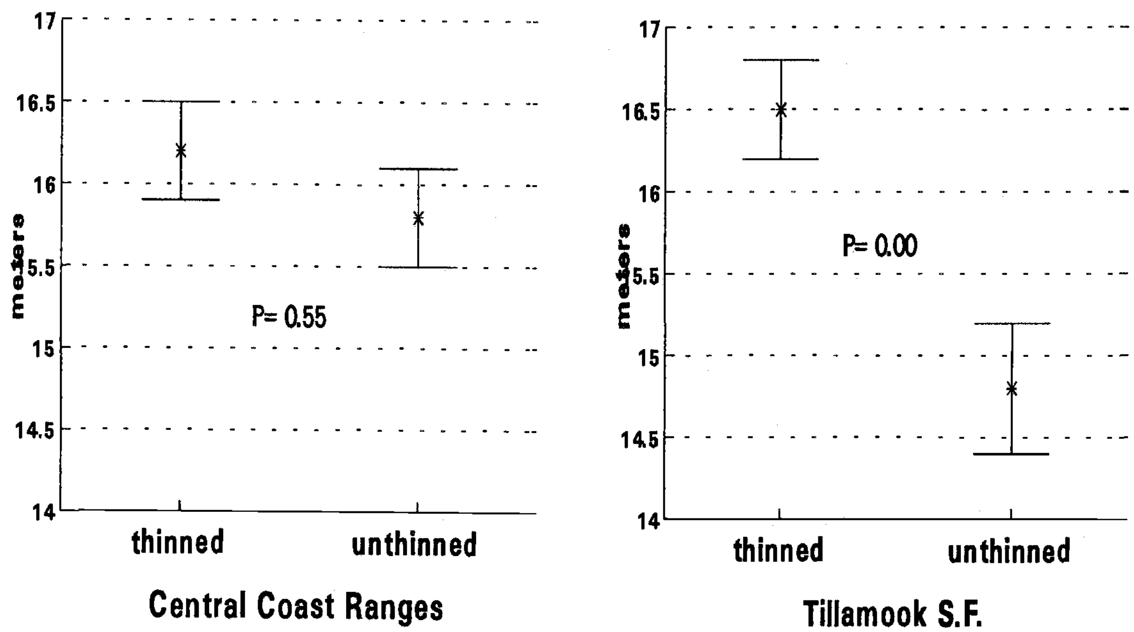
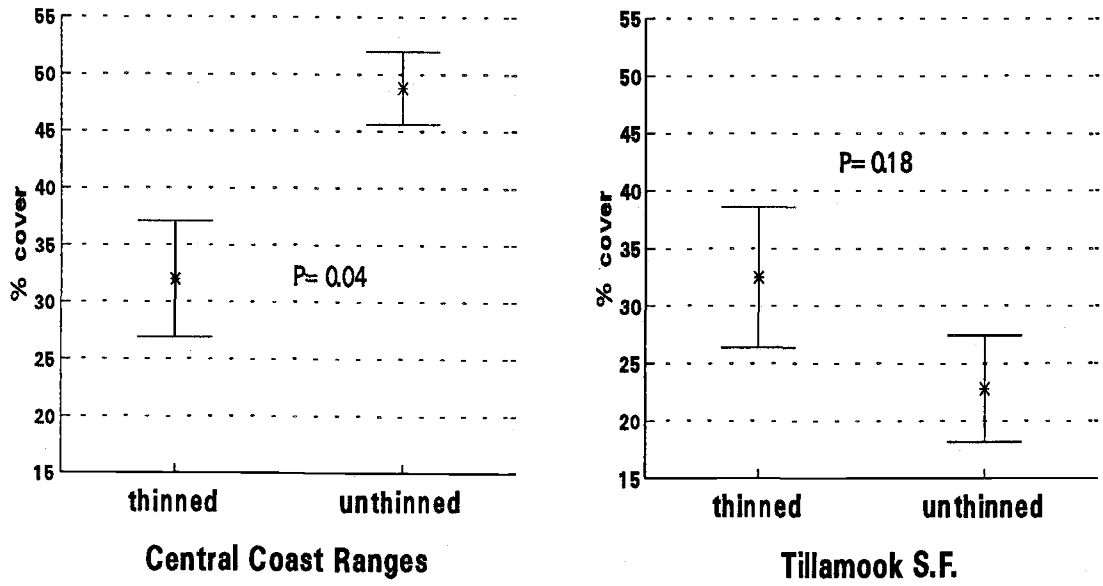
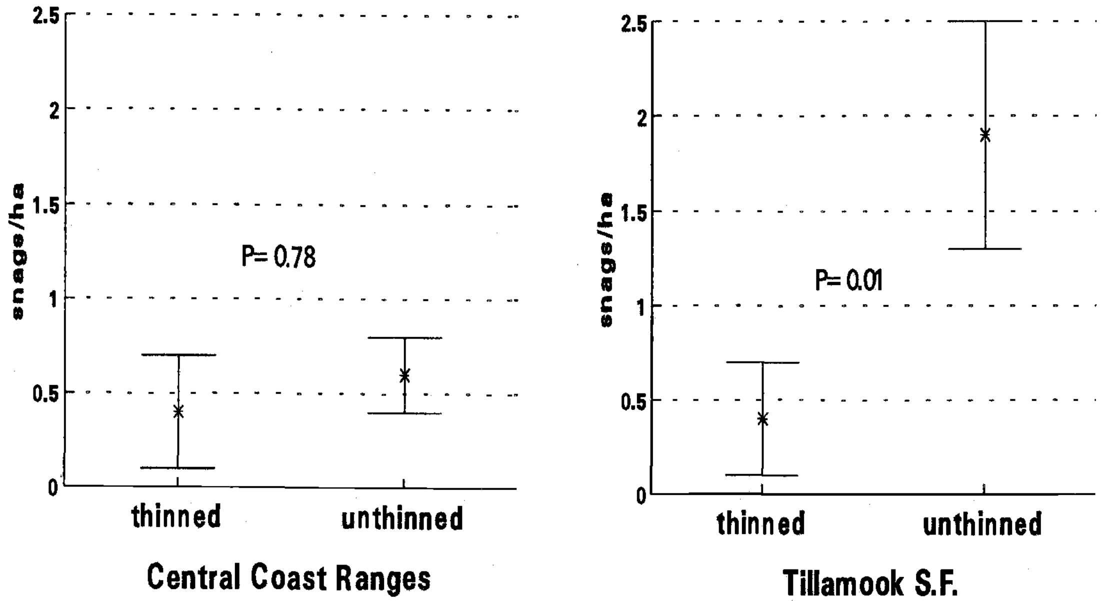


Figure 4L - M

4L. Slash cover



4M. Density of 30-51 cm dbh, dc 2-3 snags



I detected an interaction between region and condition for 13 habitat variables (Fig. 4A-M). Hardwood stem density and density of conifers >56 cm dbh was greater in Tillamook unthinned than thinned stands, but did not differ between stand conditions in the Central Coast. Cover of deciduous and tall shrubs were greater in unthinned stands than in thinned stands in the Tillamook S.F., whereas in the Central Coast region deciduous shrub cover was greater in thinned stands and tall shrub cover did not differ between conditions. Greater tall and deciduous shrub cover and hardwood stem density in the Tillamook unthinned stands was probably caused by the large component of vine maple in the understory of those stands. Slash cover was greater in unthinned stands in the Central Coast as compared to thinned stands in that region, but in the Tillamook S.F. slash cover did not differ between stand conditions.

Breeding Birds

During the 1989 and 1990 spring bird counts, I recorded 3,792 birds representing 43 species. The 4 most frequently recorded species collectively accounted for over 50% of my observations: hermit warblers (19%), winter wrens (13%), Pacific-slope flycatchers (11%), and Wilson's warblers (10%). I observed an average of 3.7 birds/ha in thinned stands and 3.2 birds/ha in unthinned stands during the 2 breeding seasons. I consistently observed 2 species only in thinned stands: Hammond's flycatcher ($\underline{n}$=93) and hairy woodpecker ($\underline{n}$=28). Seven other species also were observed incidentally ($\leq$5 times each) only in thinned stands and 6 species were observed incidentally only in unthinned stands (Appendix 1).

Bird species diversity was higher in thinned stands than in unthinned stands (Table 5). Species richness, diversity and abundance were higher in the Central Coast region than in the Tillamook S.F. (Table 6).

Of the 17 species having $\geq$28 observations, 4 were more abundant in thinned stands than in unthinned stands consistently between regions: dark-eyed junco, hairy woodpecker, Hammond's flycatcher, and red-breasted nuthatch (Table 5). Brown creepers and warbling vireos both were more abundant in the thinned stands in the Central region but they did not differ in abundance between thinned and unthinned stands in the Tillamook S.F. (Fig. 5B and 5D). Winter wrens were more abundant in thinned stands in the Central region, but were more abundant in unthinned stands in the Tillamook S.F. (Fig. 5E).

Three species were more abundant in unthinned stands than in thinned stands (Table 5). Golden-crowned kinglets and Pacific-slope flycatchers were more abundant in unthinned stands in both regions. Black-throated gray warblers were more abundant in unthinned than in thinned stands in the Central Coast region but did not differ between conditions in the Tillamook S.F. (Fig. 5A.)

Table 5. Abundance indices (observations / stand) of birds in 8 thinned and 8 unthinned Douglas-fir stands summed over 4 breeding season counts each in 1989 and 1990, Central Coast Ranges and Tillamook State Forest, Oregon. Only species with ≥28 total observations within a fixed radius plot (60 m radius) are included.

	Thinned		Unthinned			
Species	$\bar{x}$	SE	$\bar{x}$	SE	*P*	*P*(i)[b]
Black-throated gray warbler	7.0	1.7	12.6	2.8	0.03[a]	0.09
Brown creeper	7.2	1.7	4.9	1.5	0.02[a]	0.01
Chestnut-backed chickadee	14.0	1.8	12.1	2.0	0.37[c]	---
Dark-eyed junco	14.9	3.6	8.5	2.6	0.02[a]	0.35
Golden-crowned kinglet	16.0	1.5	23.9	1.3	0.00[a]	0.02
Gray jay	2.0	1.0	3.1	1.2	0.46[a]	0.09
Hairy woodpecker	3.5	0.9	0.0	0.0	0.00[c]	---
Hammond's flycatcher	11.6	4.2	0.0	0.0	0.00[c]	---
Hermit warbler	46.6	7.6	45.1	6.4	0.86[a]	0.84
Hutton's vireo	1.5	0.9	2.5	0.90	0.29[a]	0.42
Pacific-slope flycatcher	24.0	4.5	30.2	3.6	0.07[a]	0.50
Red-breasted nuthatch	3.6	1.0	0.9	0.5	0.07[a]	0.56
Swainson's thrush	9.2	2.3	8.1	1.6	0.61[a]	0.11
Warbling vireo	10.6	3.3	8.1	1.6	0.01[a]	0.03

Table 5, continued

	Thinned		Unthinned			
Species	$\bar{x}$	SE	$\bar{x}$	SE	P	P(i)[b]
Western tanager	3.2	1.0	1.6	0.6	0.26[a]	0.26
Wilson's warbler	27.6	5.7	20.9	4.5	0.37[a]	0.54
Winter wren	32.5	6.3	29.1	3.3	0.10[a]	0.00
Richness	24.5	1.2	22.6	0.9	0.18[a]	0.50
Abundance (birds/ha)	3.7	0.3	3.2	0.2	0.07[a]	0.04
Diversity	1.131	0.018	1.078	0.008	0.02[a]	0.45
Equitability	0.817	0.012	0.798	0.007	0.33[a]	0.88

[a] Significance level associated with rejection of the null hypothesis that there is no difference between means, split plot ANOVA.

[b] Significance level associated with rejection of the null hypothesis that there is no interaction of Condition and Region, split plot ANOVA.

[c] Significance level associated with rejection of the null hypothesis that there is no difference between means, Friedman's test.

Table 6. Abundance indices (observations/stand) for bird species that differed in abundance (P<0.10) between the Central Coast Range (n=8 stands) and the Tillamook State Forest (n=8 stands), Oregon. Observations were summed over 4 counts each, May-June, 1989 and 1990; thinned and unthinned stands combined.

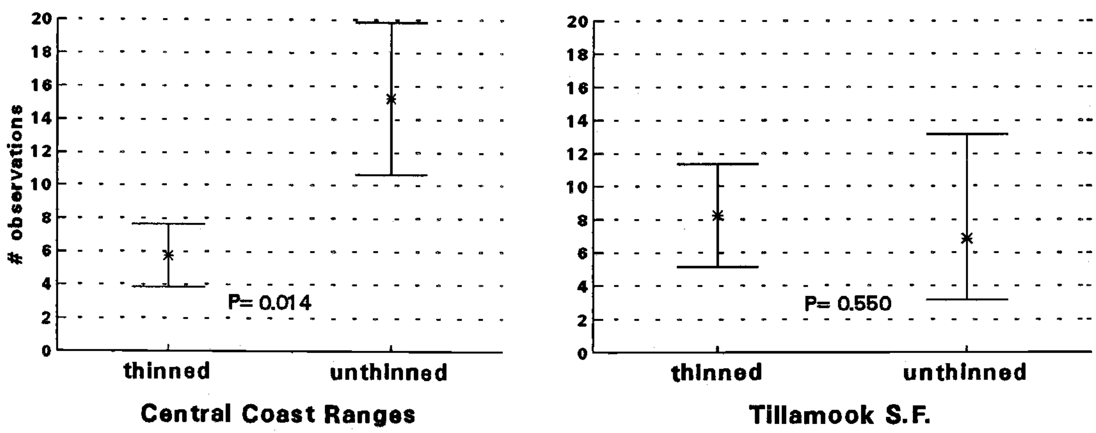
	Central		Tillamook		
Species	$\bar{x}$	SE	$\bar{x}$	SE	P[a]
Dark-eyed junco	5.4	1.4	18.0	3.1	0.02
Hermit warbler	58.9	4.3	32.9	5.7	0.01
Hutton's vireo	3.6	0.9	0.4	0.2	0.01
Warbling vireo	10.9	3.1	2.9	1.2	0.01
Wilson's warbler	17.6	4.4	30.9	5.0	0.09
Richness	25.6	1.0	21.5	0.5	0.00
Abundance (birds/ha)	3.7	0.3	3.1	0.2	0.09
Diversity	1.130	0.014	1.079	0.014	0.01

[a] Significance level associated with rejection of the null hypothesis that there is no difference between means, split plot ANOVA.

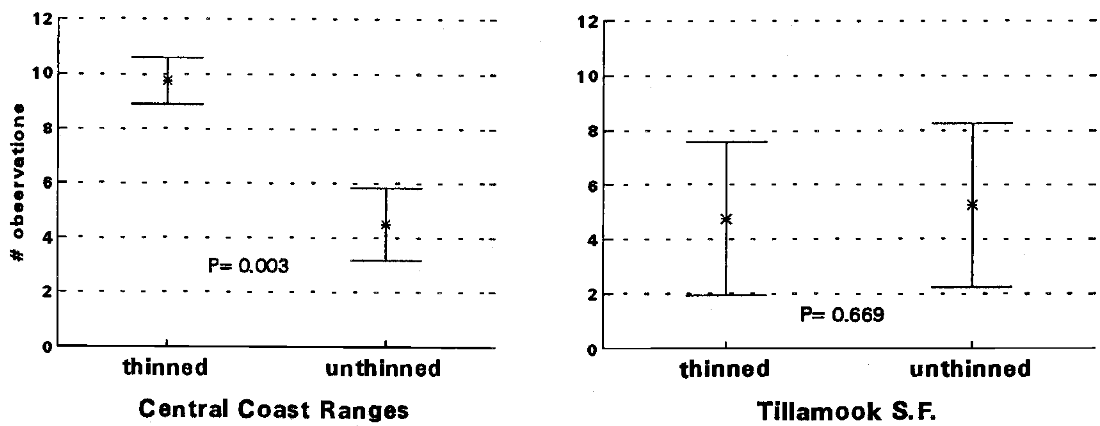
Figure 5. Average number of observations/ stand of bird species having an interaction between condition (thinned and unthinned) and region (Central Coast and Tillamook State Forest). *P*= level of significance associated with Least-squares Means multiple means comparison procedure.

Figure 5A - C

5A. Black-throated gray warbler



5B. Brown creeper



5C. Golden-crowned kinglet

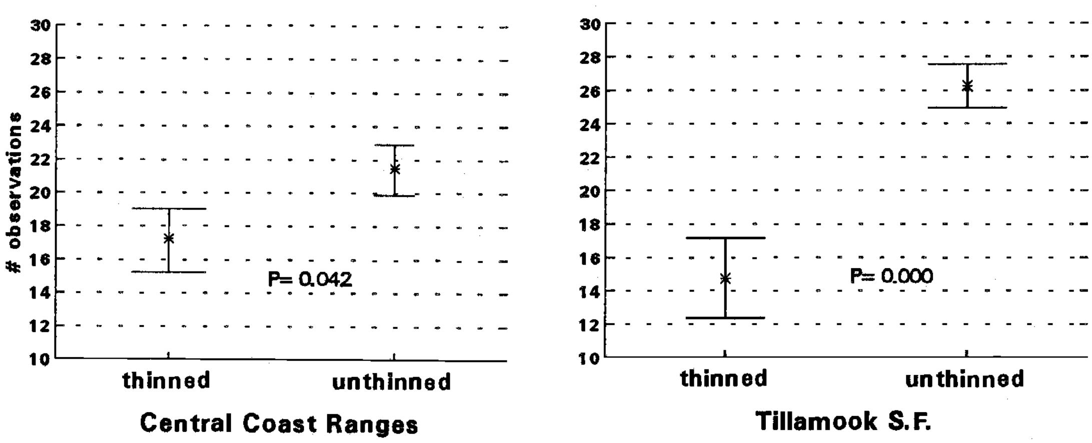
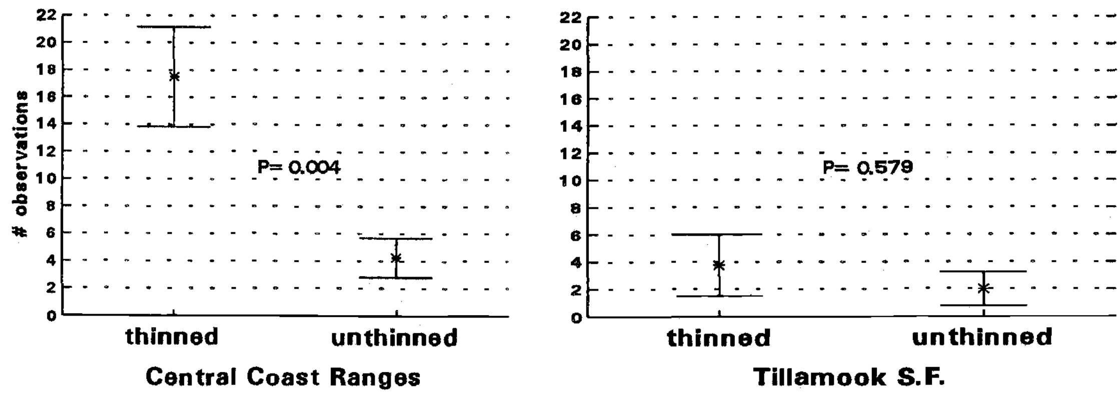
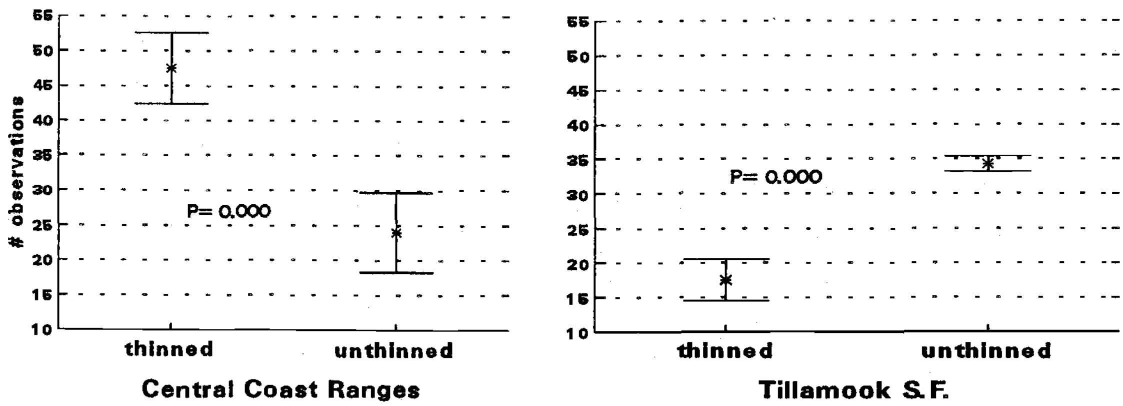


Figure 5D - F

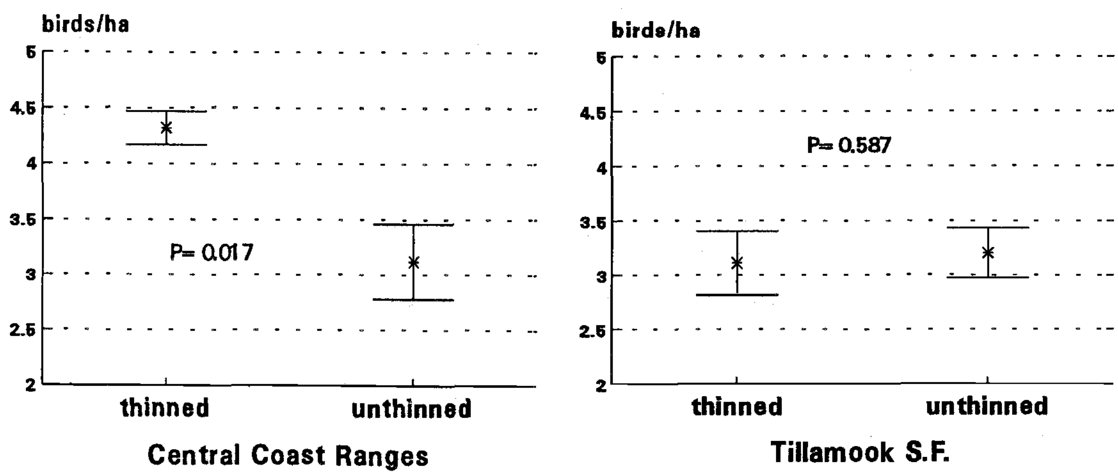
5D. Warbling vireo



5E. Winter wren



5F. Abundance



Eight species did not differ in abundance between conditions (Table 5). However, the power of the tests for these species, ranging from 0.10 for gray jays to 0.73 for hermit warblers, may not have been high enough to detect real differences.

Winter Birds

During the 1989-1990 winter count, I observed 1,553 birds representing 21 species in thinned and unthinned stands. Golden-crowned kinglets were the most common species, accounting for >30% of all observations. Chestnut-backed chickadees and winter wrens were the second and third most common species, respectively. Red crossbills and pine siskins also were commonly observed, but these were mostly flying over the plot and thus were not included in analyses. Only 5 species were observed frequently enough to permit analysis (Table 7). I did not describe winter habitat, therefore winter bird count results were limited to a comparison of species abundance and bird community parameters between conditions and regions.

Abundance, diversity, and equitability of winter birds did not differ between thinned and unthinned stands, although bird species richness was greater in thinned stands (Table 7).

Red-breasted nuthatches and winter wrens were more abundant in thinned than unthinned stands during the winter (Table 7). These results are consistent with breeding season

Table 7. Abundance indices (observations/stand) of winter birds in 8 commercially thinned and 8 unthinned Douglas-fir stands averaged over 8 counts from 12 November, 1989 to 5 April, 1990, Central Coast Ranges and Tillamook State Forest, Oregon.

	Thinned		Unthinned			
Species	$\bar{x}$	SE	$\bar{x}$	SE	P	P(i)[b]
Brown creeper	2.4	0.8	2.4	0.5	1.00[a]	0.47
Chestnut-backed chickadee	12.0	3.3	9.5	1.7	0.77[c]	---
Golden-crowned kinglet	32.6	8.6	29.4	7.1	0.74[a]	0.38
Red-breasted nuthatch	5.0	1.5	2.1	0.8	0.03[a]	0.43
Winter wren	8.5	1.0	4.7	0.4	0.01[c]	---
Richness	8.4	1.0	7.2	0.6	0.08[a]	0.61
Abundance (birds/ha)	1.1	0.1	0.9	0.05	0.18[a]	0.54
Diversity	0.638	0.074	0.583	0.061	0.45[a]	0.61
Equitability	0.693	0.058	0.676	0.053	0.82[a]	0.40

[a] Significance level associated with rejection of the null hypothesis that there is no difference between means, split plot ANOVA.

[b] Significance level associated with rejection of the null hypothesis that there is no interaction of Condition and Region, split plot ANOVA.

[c] Significance level associated with rejection of the null hypothesis that there is no difference between means, Friedman's test.

results for red-breasted nuthatches in both regions (Table 5), and for winter wrens in the Central Coast region (Fig. 5E). Chestnut-backed chickadees did not differ in abundance between stand conditions in either the winter or breeding season. Winter abundance patterns for brown creepers and golden-crowned kinglets were inconsistent with breeding season patterns: both of these species were equally abundant in thinned and unthinned stands during the winter.

Univariate results

Four bird species were observed in <12 stands; the habitat variables that differed between "used" and "unused" stands for each species are reported in Tables 8-11. Hairy woodpeckers (Table 8) and red-breasted nuthatches (Table 9) both used stands that had lower percent pole and Douglas-fir cover and lower average tall shrub height than unused stands. Stands used by Hammond's flycatchers (Table 10) also had lower percent pole cover and lower tall and deciduous shrub heights than unused stands. Stands used by hairy woodpeckers and Hammond's flycatchers had lower conifer basal area than unused stands because these 2 species were observed only in thinned stands. Stands used by Hutton's vireos were characterized by higher densities of 10-30-cm dbh conifers and had a greater hardwood component than unused stands (Table 11).

Table 8. Habitat variable means that differed ($\underline{P} \leq 0.05$, $\underline{t}$-test) between stands where **hairy woodpeckers** were observed ($\underline{n}$=9) and those where they were not observed ($\underline{n}$=7), western Oregon, May-June, 1989 and 1990.

Habitat Variable	Used $\bar{x}$	Used SE	Unused $\bar{x}$	Unused SE	$\underline{P}$
pc pole (%)	31.5	1.7	42.7	3.9	0.04
pc Douglas-fir (%)	58.3	2.2	66.3	3.3	0.05
conifer basal area (m^2/ha)	41.2	2.9	53.8	2.7	0.05
tall shrub ht (m)	2.6	0.1	3.0	0.1	0.01
deciduous shrub ht (m)	1.8	0.1	2.4	0.1	0.00

Table 9. Habitat variable means that differed ($\underline{P} \leq 0.05$, $\underline{t}$-test) between stands where **red-breasted nuthatches** were observed ($\underline{n}$=10) and those where they were not observed ($\underline{n}$=6), western Oregon, May-June, 1989 and 1990.

Habitat Variable	Used $\bar{x}$	Used SE	Unused $\bar{x}$	Unused SE	$\underline{P}$
pc pole (%)	32.9	2.3	42.2	4.3	0.05
pc Douglas-fir (%)	58.8	2.7	66.9	2.4	0.06
tall shrub ht (m)	2.6	0.3	3.0	0.3	0.03
hardwoods/ha	46.0	9.6	107.0	13.2	0.00

Table 10. Habitat variable means that differed ($\underline{P} \leq 0.05$, $\underline{t}$-test) between stands where **Hammond's flycatchers** were observed ($\underline{n}$=6) and those where they were not observed ($\underline{n}$=10), western Oregon, May-June, 1989 and 1990.

Habitat Variable	Used		Unused		
	x	SE	x	SE	P
pc pole (%)	30.0	1.8	40.2	3.1	0.04
conifer basal area (m^2/ha)	40.5	10.3	50.5	14.4	0.05
fern ht. (cm)	49.5	2.2	39.6	2.1	0.01
deciduous shrub ht. (m)	1.9	0.1	2.2	0.2	0.05
tall shrub ht. (m)	2.5	0.1	2.9	0.1	0.03
30-52 cm dbh snags/ha	2.3	0.5	4.4	0.4	0.01

Table 11. Habitat variable means that differed ($\underline{P} \leq 0.05$, $\underline{t}$-test) between stands where **Hutton's vireos** were observed ($\underline{n}$=10) and those where they were not observed ($\underline{n}$=6), western Oregon, May-June, 1989 and 1990.

Habitat Variable	Used		Unused		
	x	SE	x	SE	P
≥30 cm dbh hardwoods/ha	6.7	1.8	1.7	1.0	0.02
10-30 cm dbh hardwoods/ha	2.4	0.7	1.1	0.3	0.06
10-30 cm dbh conifers/ha	279.0	43.6	147.3	24.3	0.06
pc hardwood (%)	13.4	2.4	5.6	2.0	0.05
pc grass (%)	2.4	0.5	5.9	2.0	0.02

Multivariate results

I could not classify plots into "used" and "unused" groups for any species because the Cohen's <u>Kappa</u> statistic was <0.75 for all species, and <0.50 for 7 of 9 species. Classification rates $\leq$0.80 can be achieved by random chance alone (Rexstad et al. 1988) and models with such low rates cannot be considered useful.

Stand level stepwise regressions resulted in models that had higher R^2 than plot level regression models (Table 12). The majority of stepwise regression models at both stand and plot levels having the highest R^2 included habitat variables from >1 level of resolution. R^2's for stand-level models ranged from 0.68 for chestnut-backed chickadees to 0.93 for Pacific-slope flycatchers (Table 13, Table 14). Plot-level model R^2's ranged from 0.30 for chestnut-backed chickadees to 0.49 for Pacific-slope flycatchers.

Principal components analysis

Three components explained 78% of the variation among stands. The final communality estimates for the 12 variables comprising the components (Table 15) indicated that these components accounted for most of the variation in each variable (McGarigal and Stafford 1992:2-46). Factor 1 was positively associated with stem density of live trees and small snags, sawtimber cover, and hardwood cover, and negatively correlated with evergreen shrub cover. Factor 2

Table 12. Comparison of stand- and plot- level model R^2's for stepwise regressions of habitat variables and 5 bird species' abundances in 8 commercially thinned and 8 unthinned Douglas-fir stands in western Oregon, May-June, 1989 and 1990.

Species	Plot R^2	Stand R^2
Chestnut-backed chickadee	0.30	0.68
Golden-crowned kinglet	0.32	0.75
Hermit warbler	0.45	0.75
Pacific-slope flycatcher	0.49	0.93
Winter wren	0.38	0.81

Table 13. R^2's by level of habitat resolution for stand level bird - habitat regression models, western Oregon. **Bold-face** numbers are the highest R^2's. See Figure 1 for list of habitat variables included under each level of resolution.

	Level of Resolution			
Species	Specific	General	Broad	Combined
Black-throated gray warbler	0.7981	0.3680	0.5485	**0.8322**
Brown creeper	0.7507	**0.8437**	0.8049	0.7700
Chestnut-backed chickadee	0.3672	0.6070	0.4974	**0.6816**
Dark-eyed junco	0.6772	0.7908	0.8890	**0.9200**
Golden-crowned kinglet	0.1470	0.1957	0.7467	**0.7467**
Hermit warbler	**0.7502**	0.4452	0.5387	**0.7502**
Swainson's thrush	0.7357	0.6168	0.6363	**0.8075**
Warbling vireo	**0.9082**	0.8038	0.5886	0.8465
Pacific-slope flycatcher	0.8483	0.8554	0.8895	**0.9276**
Wilson's warbler	0.7839	0.6511	0.7210	**0.9128**
Winter wren	0.7039	**0.8100**	0.5033	**0.8100**
Richness	0.8245	0.3755	0.6193	**0.8901**
Abundance	0.7611	**0.8254**	0.6393	0.7650

Table 14. Stand level regression model parameters for bird species and vegetation characteristics of 8 commercially thinned and 8 unthinned Douglas-fir stands, western Oregon.

Bird Species	Habitat Variable	Coefficient	P	R^2
Black-throated gray warbler	constant	34.529	0.00	
	elevation	-0.010	0.01	
	pc grass	-16.599	0.00	
	pc hazel	+0.484	0.06	
	<10 cm dbh conifers/ha	-4.615	0.01	0.83
Brown creeper	constant	3.476	0.13	
	pc deciduous shrubs	+0.315	0.00	
	10-30 cm hardwoods/ha	+3.473	0.00	
	deciduous shrub ht.	-7.567	0.00	
	evergreen shrub ht.	+8.471	0.00	0.90
Chestnut-backed chickadee	constant	20.358	0.00	
	<10 cm dbh conifers/ha	+2.593	0.12	
	hardwood stems/ha	-2.052	0.15	
	>51 cm dbh snags/ha	+2.775	0.02	
	dist. to patch edge	-0.096	0.06	0.68
Dark-eyed junco	constant	32.647	0.00	
	low shrub ht.	-40.816	0.00	
	pc red huckleberry	+1.848	0.00	
	<10 cm dbh conifers/ha	-5.224	0.00	0.92
Golden-crowned kinglet	constant	-12.931	0.07	
	pc pole	+0.336	0.00	
	dist. to patch edge	+0.109	0.01	
	pc sawtimber	+0.194	0.06	0.75
Hermit warbler	constant	21.188	0.00	
	30- 43 cm dbh hardwoods/ha	+74.515	0.00	
	>51 cm dbh, dc 2-3 snags/ha	+138.292	0.00	
	pc hazel	+1.143	0.04	0.75
Swainson's thrush	constant	-29.414	0.02	
	pc salal	+0.274	0.00	
	sawtimber ht.	+0.984	0.04	
	cv sawtimber	+0.174	0.10	0.81
Pacific-slope flycatcher	constant	11.167	0.38	
	pc sawtimber	+0.554	0.00	
	>56 cm dbh conifers/ha	+13.552	0.00	
	hardwood basal area	+0.341	0.00	
	30- 52 cm dbh snags/ha	-6.701	0.01	
	cv sawtimber	-0.473	0.01	0.93

Table 14, continued

Bird Species	Habitat Variable	Coefficient	PR>T	R^2
Warbling vireo	constant	14.404	0.00	
	30- 43 cm dbh hardwoods/ha	+47.782	0.00	
	30- 43 cm dbh conifers/ha	-2.551	0.00	
	>51 cm dbh, dc 2-3 snags/ha	+69.622	0.00	
	4- 12 cm dbh, dc 1 snags/ha	-0.470	0.01	0.91
Wilson's warbler	constant	32.924	0.01	
	slash	-0.637	0.00	
	pc low shrubs	+0.281	0.01	
	low shrub ht.	+26.924	0.02	
	pc pole	-0.398	0.01	0.91
Winter wren	constant	2.575	0.61	
	>30 cm dbh hardwoods/ha	+68.661	0.00	
	>56 cm dbh conifers/ha	+16.887	0.00	
	pc evergreen shrubs	+0.164	0.09	0.81
Species richness	constant	22.808	0.00	
	30- 43 cm dbh hardwoods/ha	+21.478	0.00	
	dist. to patch edge	-0.045	0.03	
	43- 56 cm dbh conifers/ha	+1.712	0.01	
	>51 cm dbh, dc 2-3 snags/ha	+31.410	0.01	
	10- 20 cm dbh hardwoods/ha	-2.645	0.03	0.89
Abundance	constant	-163.507	0.02	
	conifer ht.	+13.191	0.00	
	30- 43 cm dbh hardwoods/ha	+154.135	0.00	
	pc salal	+1.585	0.00	
	cv sawtimber	+1.473	0.04	0.92

was positively correlated with tall, deciduous shrub cover and conifer height. Factor 3 was positively correlated with pole and evergreen shrub cover, and negatively correlated with fern cover.

Stands did not separate into distinct groups along the first 2 principal components axes, so I divided them into 4 groups by drawing lines through the origins of each axis (Fig. 6). The majority of thinned stands fell into Groups III and IV, on the low end of Factor 1 and the majority of unthinned stands were in Groups I and II, towards the high end of Factor 1, reflecting the difference in stem density (Fig. 7) and sawtimber cover between the 2 conditions. Thinned and unthinned stands were not separated well along the Factor 2 axis, which represented primarily a gradient in tall shrub cover and conifer height.

Results of ANOVA of bird species abundance among the 4 PCA groups indicated that 5 species were influenced by the habitat gradients described by the principal component factors (Table 16). Brown creepers were more abundant in stands in Groups II and IV than stands in Groups I and III, probably indicating the influence of conifer height in of Factor 2, with which they were associated (Table 17). Black-throated gray warblers were more abundant in stands in Group I than in Group III, indicating that Factor 1 had the strongest influence on them (Table 17). Golden-crowned kinglets in Groups I and III were more abundant than in Group IV,

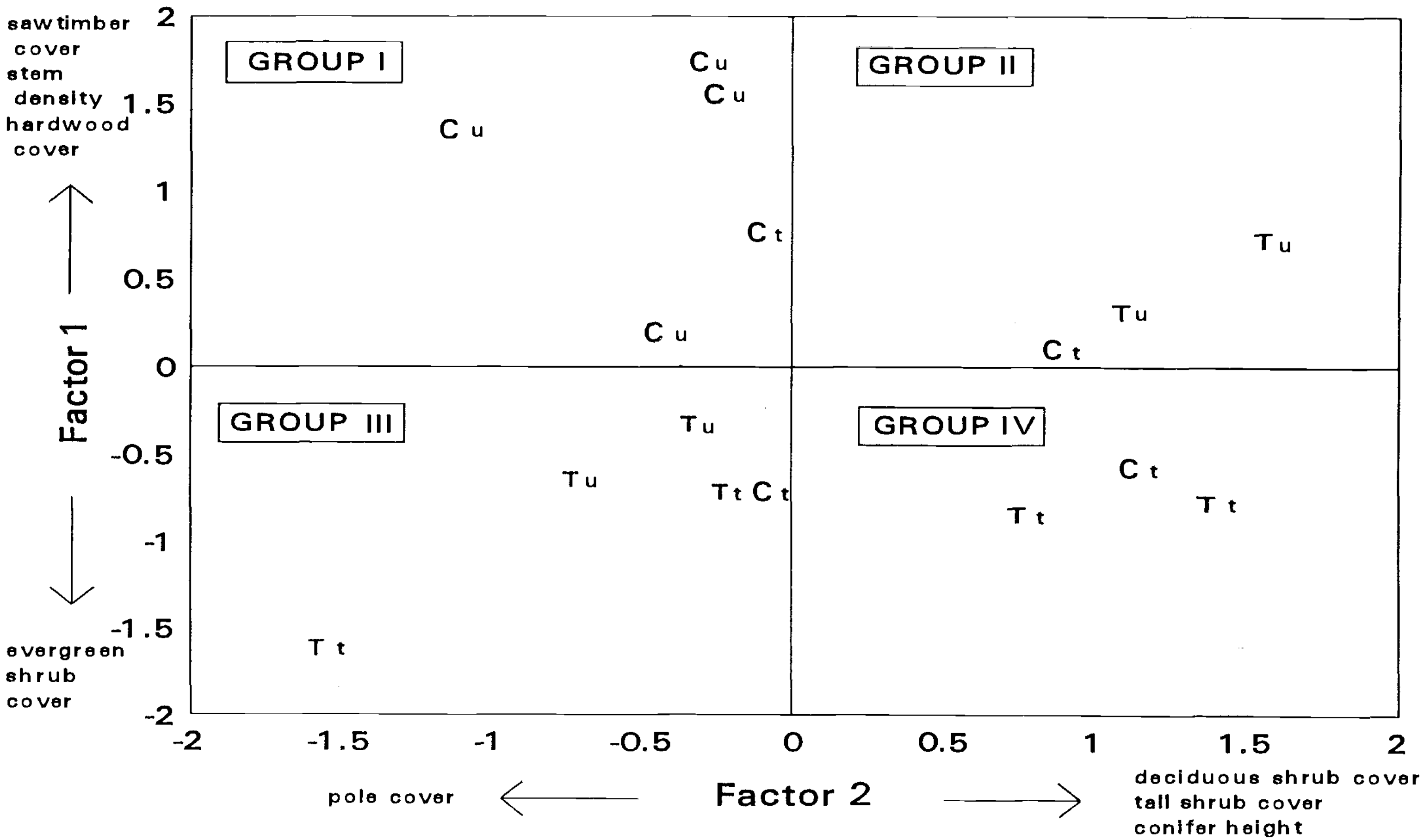
Table 15. Principal component loadings and final communality estimates for 12 habitat variables measured or derived from 8 commercially thinned and 8 unthinned Douglas-fir stands in western Oregon, 1990.

Habitat Variable	Factor 1	Factor 2	Factor 3	Final Communality Estimate
pc sawtimber	0.850	0.210	0.202	0.807
pc pole	0.066	-0.473	0.719	0.745
pc tall shrubs[a]	0.110	0.805	0.497	0.908
pc low shrubs	-0.599	0.518	0.501	0.878
pc fern	-0.564	0.159	-0.613	0.720
pc evergreen shrubs	-0.602	0.236	0.600	0.779
pc deciduous shrubs	0.021	0.906	0.149	0.843
pc conifer	0.732	-0.092	0.376	0.686
10- 30 cm dbh snags/ha	0.721	0.423	-0.136	0.717
pc hardwood	0.726	0.161	-0.331	0.662
total stems/ha	0.876	-0.122	0.152	0.804
conifer ht.	0.056	0.686	-0.551	0.777

[a] variable was Log10 + 1 transformed.

Figure 6. Ordination of Central Coast (C) and Tillamook State Forest (T) thinned (t) and unthinned (u) Douglas-fir stands along the first 2 principal components axes.

Figure 6



C= Central Coast stands t= thinned stands

T= Tillamook S.F. stands u= unthinned stands

Figure 7. Diameter distributions of conifers and hardwoods in each Principal Components Group described in Figure 6.

Figure 7

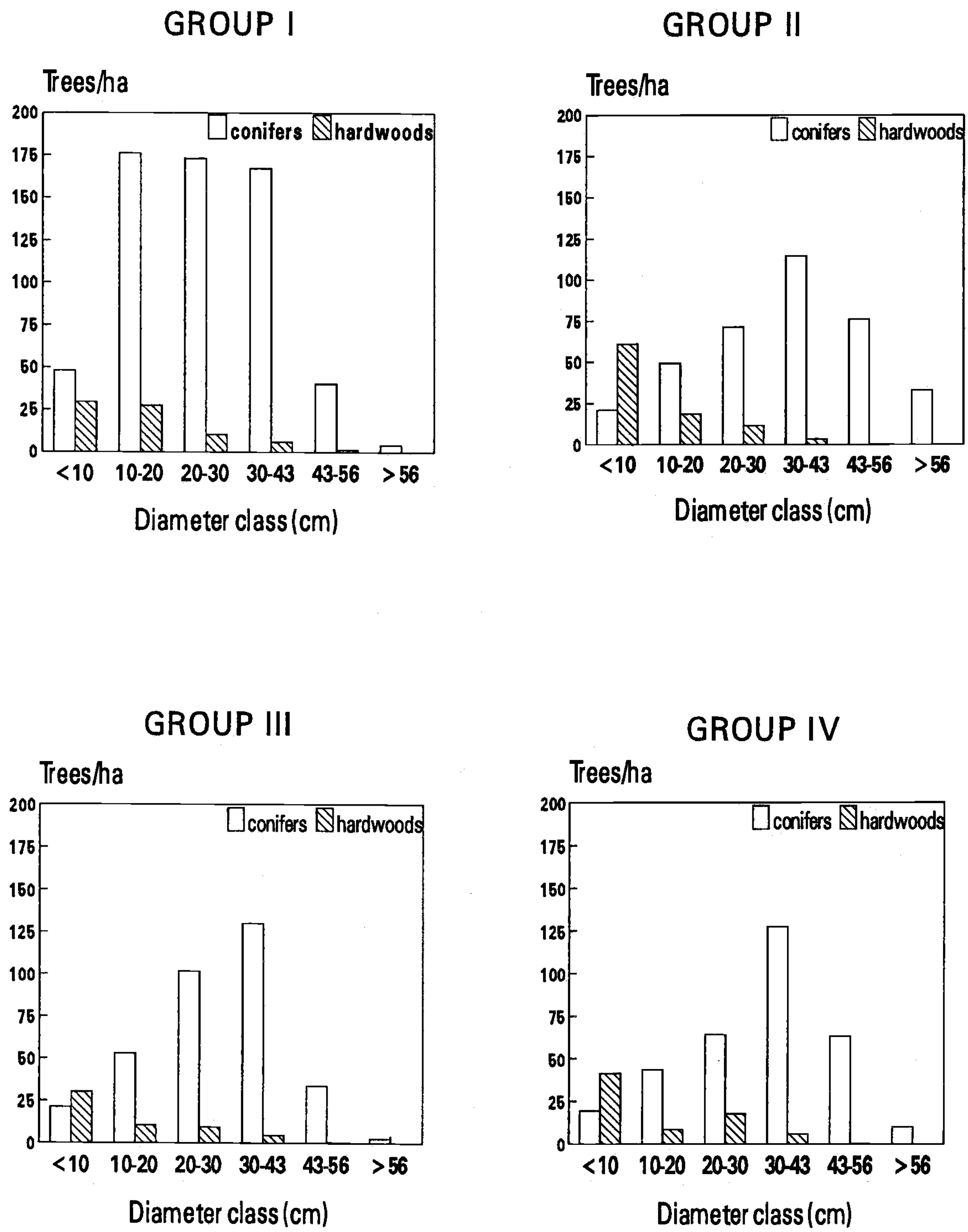

GROUP I
Trees/ha
200
175
150
125
100
75
50
25
0
conifers
hardwoods
<10
10-20
20-30
30-43
43-56
>56
Diameter class (cm)
GROUP II
Trees/ha
200
175
150
125
100
75
50
25
0
conifers
hardwoods
<10
10-20
20-30
30-43
43-56
>56
Diameter class (cm)
GROUP III
Trees/ha
200
175
150
125
100
75
50
25
0
conifers
hardwoods
<10
10-20
20-30
30-43
43-56
>56
Diameter class (cm)
GROUP IV
Trees/ha
200
175
150
125
100
75
50
25
0
conifers
hardwoods
<10
10-20
20-30
30-43
43-56
>56
Diameter class (cm)

Table 16. Bird abundance (mean number of observations and standard errors) among Principal Components Groups (derived from Fig. 6) in 8 commercially thinned and 8 unthinned Douglas-fir stands in western Oregon, 1989 and 1990. Means with same letters did not differ (Least-squares Means test). _P_-values are invalid for statistical inference because analysis was _a-posteriori_.

	Group 1		Group II		Group III		Group IV		
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	_P_
Black-throated gray warbler	A 14.0	3.8	AB 13.0	2.1	B 4.0	1.1	AB 9.3	4.1	0.10
Brown creeper	AB 5.2	1.2	A 10.0	1.7	B 2.6	2.4	A 9.3	0.9	0.05
Chestnut-backed chickadee	13.6	2.7	12.0	2.6	10.8	1.5	17.0	4.2	0.47
Golden-crowned kinglet	A 21.6	1.2	AB 20.7	3.3	A 21.8	2.8	B 13.3	2.7	0.14
Gray jay	1.4	0.5	3.7	2.3	4.4	1.6	0.3	0.3	0.19
Hairy woodpecker	1.2	1.2	0.3	0.3	2.8	1.5	2.3	0.7	0.56
Hammond's flycatcher	B 0.6	0.6	AB 6.0	6.0	B 3.4	3.4	A 18.3	8.5	0.08

Table 16, continued

	Group I		Group II		Group III		Group IV		
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	_P_
Pacific-slope flycatcher	A 31.0	3.9	A 39.0	3.5	B 16.8	3.0	AB 26.0	8.5	0.03
Red-breasted nuthatch	0.8	0.6	2.0	1.0	3.6	1.9	2.7	0.7	0.44
Swainson's thrush	6.6	2.1	11.7	3.8	6.4	1.4	13.0	4.0	0.23
Western tanager	1.6	0.7	2.7	1.2	2.6	1.4	3.3	2.4	0.84
Winter wren	30.6	7.9	39.3	5.4	28.8	7.3	26.0	3.6	0.70
Richness	25.4	1.4	22.7	0.3	22.2	1.6	23.7	1.7	0.40

reflecting the kinglets' selection of stands with high sawtimber and pole cover. Regression results also indicated that golden-crowned kinglet abundance was positively correlated with pole and sawtimber cover (Table 17 and Appendix 2). Hammond's flycatchers had a higher average abundance in stands in Group IV (a group consisting of only thinned stands) than in stands in Groups I and II, reflecting a selection for stands with lower stem densities and a more open lower canopy. Pacific-slope flycatchers were more abundant in Groups I and II than in Group III, indicating that they were influenced by the greater stem densities of conifers and hardwoods represented by Factor 1. Both Factor 1 and Factor 2 were positively correlated with Pacific-slope flycatcher abundance (Table 17).

Diversity, equitability, and 7 bird species were correlated with $\geq$1 of the 3 principal component factors (Table 17). In addition to the correlations mentioned above, hairy woodpeckers and red-breasted nuthatches were negatively correlated with Factors 1 and 3, indicating an avoidance of dense stands with well-developed canopy layers. Dark-eyed junco and Wilson warbler abundance also had a negative correlation with Factor 1, probably because they did not use the densest stands that had the lowest percent cover of shrubs. Wilson's warblers and Swainson's thrushes were both positively correlated with Factor II, which represented a gradient in tall shrub cover. Hutton's vireos showed a

Table 17. Pearson correlation coefficients for bird species abundance and the first 3 principal components for 16 Douglas-fir stands, western Oregon. Numbers in **bold** type are significant correlations at $P \leq 0.05$.

	Factor 1		Factor 2		Factor 3	
Bird Species	r	P	r	P	r	P
Black-throated gray warbler	+0.430	0.10	+0.204	0.45	+0.040	0.88
Brown creeper	+0.146	0.59	**+0.671**	0.00	-0.416	0.11
Chestnut-backed chickadee	+0.043	0.87	+0.112	0.68	+0.110	0.68
Dark-eyed junco	**-0.705**	0.00	-0.282	0.29	-0.145	0.59
Golden-crowned kinglet	+0.347	0.19	-0.319	0.23	+0.382	0.21
Gray jay	-0.133	0.62	-0.247	0.36	+0.066	0.81
Hairy woodpecker	-0.463	0.07	-0.198	0.46	**-0.525**	0.04
Hammond's flycatcher	-0.324	0.22	+0.478	0.06	-0.214	0.43
Hermit warbler	+0.437	0.09	+0.156	0.56	-0.133	0.62
Hutton's vireo	+0.471	0.07	-0.004	0.99	+0.150	0.58
Pacific-slope flycatcher	**+0.564**	0.02	**+0.547**	0.03	-0.134	0.62
Red-breasted nuthatch	**-0.560**	0.02	-0.250	0.35	-0.490	0.05
Swainson's thrush	-0.148	0.58	**+0.552**	0.03	+0.350	0.18
Warbling vireo	-0.069	0.80	-0.098	0.72	-0.382	0.14
Western tanager	-0.202	0.45	+0.155	0.57	-0.424	0.10
Wilson's warbler	**-0.510**	0.04	**+0.678**	0.00	+0.194	0.47
Winter Wren	+0.129	0.63	+0.263	0.32	-0.155	0.57
Abundance	-0.043	0.87	**+0.591**	0.02	-0.251	0.35
Richness	+0.280	0.29	+0.103	0.70	-0.245	0.36
Diversity	-0.175	0.52	+0.073	0.79	**-0.534**	0.03
Equitability	**-0.518**	0.04	-0.054	0.84	-0.346	0.19

positive correlation with Factor 1, which also was positively correlated with hardwood cover. Diversity showed a negative relationship to percent pole and evergreen shrub cover through its negative correlation with Factor 3. Species that were not ubiquitous (dark-eyed junco, hairy woodpecker, red-breasted nuthatch, and Wilson's warbler) were negatively correlated to Factor 1, whereas ubiquitous species (Pacific-slope flycatchers and black-throated gray warblers) were positively correlated to this factor. This probably explains why equitability was negatively correlated with Factor 1.

DISCUSSION

Habitat Characteristics

The vegetative structure of commercially thinned Douglas-fir stands differed from that of unthinned stands. Thinned stands had lower densities of most size-classes of conifers, including trees 10-56 cm dbh. Basal area was greater in unthinned stands, and volume loss caused by mortality also seemed to be greater based on the number of 10- to 30-cm dbh snags. Given that the stands within a region were chosen to be as similar as possible in all aspects except thinning treatment, these differences in tree density and basal area were expected (Smith 1986).

Thinning reduced canopy cover in both the pole and sawtimber layers. In addition, the depth of the pole layer was less in thinned stands, creating more open space beneath the canopy. This structure was probably a result of the thinning-from-below strategy, which removes suppressed and co-dominant trees (Smith 1986, Hunter 1990:230).

Herbaceous understory plants, including grasses and ferns, were more prolific in thinned stands than in unthinned stands, but shrub cover was not greater in thinned stands. Herbaceous plants respond more quickly than woody plants to light gaps created by thinning (Mitchell 1983, Crouch 1986). In contrast, shrub production can be reduced in the years immediately after thinning (Mannan 1977, Crouch 1986). If the canopy has been closed for a long time prior to a light thinning, resulting in severe suppression of the understory shrubs, they may not regain vigor before the canopy closes again. The Starker Forests perform light thinnings to minimize competition between the conifer crop and shrubs (Mark Vomicil, pers. comm.) The more recent and slightly more intensive thinning done in the Tillamook S.F. seems to have had the effect of trampling the shrubs, in particular the tall deciduous shrubs such as vine maple and hazel (pers. obs.). Tall shrub and deciduous shrub cover was actually greater in unthinned stands in the Tillamook S.F. as compared to thinned stands in that region.

Bird Communities

Bird species diversity, a function of both numbers of species and the distribution of individuals among species (evenness), was greater in thinned stands than in unthinned stands. Species that were uncommon, such as Hammond's flycatchers, most of the cavity-nesters, and warbling vireos, were more abundant in or unique to thinned stands, contributing to the higher diversity. Most of these species (except the warbling vireo) seemed to be responding to the more open structure of thinned stands compared to unthinned stands (see species discussion). Other investigators also have related bird species richness and diversity to canopy openness (Szaro and Balda 1979, Artman 1990).

Differences in species richness and diversity of birds during the breeding season were greater between regions than between conditions (Table 5, Table 6). Multiple regression procedures did not produce a biologically meaningful model linking bird species diversity to habitat features, but a regression model was produced for bird species richness, a component of diversity. The number of bird species present in a stand was positively correlated with ≥30-cm dbh hardwoods, ≥56-cm dbh conifers, and >52-cm dbh snags, and negatively correlated with the distance to a patch edge. Although the size-classes of hardwoods and conifers chosen by the model would not be considered "large" by the standards of a typical old-growth conifer stand in western Oregon (Franklin and Spies 1991), they represented the largest trees found consistently on my study plots. The greater density of large hardwoods, accompanied by greater deciduous foliage cover, and the shorter average distance to a patch edge in the Central Coast region may have been at least partially responsible for the greater bird species richness and diversity observed there. Variables describing live deciduous trees also were positively related to bird species richness and bird abundance in unmanaged forests in western Oregon and Washington (Huff and Raley 1991). Several species of long-distance migrants are strongly associated with deciduous vegetation, including warbling vireos, Wilson's warblers, and black-throated gray warblers (Brown 1985). Even small patches of deciduous trees can have a positive influence on densities of certain bird species in conifer-dominated plant communities (Morrison and Meslow 1983). The density of >52-cm dbh snags did not differ between the Central Coast region and the Tillamook S.F., but this variable was associated with species richness. Snags provide critical habitat for a group of birds that nest in cavities and forage on dead wood (Mannan 1977, Nelson 1988). In unmanaged forests, the presence and abundance of cavity-nesting birds has been strongly linked to the presence of snags, particularly >50-cm dbh snags (Carey et al. 1991, Huff and Raley 1991).

The average distance to a patch edge was less in the Central Coast region than in the Tillamook S.F. The correlation between bird species richness and distance to a patch edge is consistent with the phenomenon of "edge-effect" which has been discussed and documented by many authors (Leopold 1933, Thomas et al. 1979, Strelke and Dickson 1980). Many of the patch edges in this study were either road edges, where a narrow forest road (≤10-m) cut through a stand, or riparian zones. In both cases, 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 (Wiens 1974, Anderson and Ohmart 1980, Urban and Smith 1989).

Species-habitat relationships

Flycatchers

Both species of _Empidonax_ flycatchers showed differences in abundance between thinned and unthinned stands; Hammond's flycatchers were observed only in thinned stands and Pacific-slope flycatchers were slightly more abundant in unthinned stands. Hammond's flycatchers forage for aerial insects by sallying into open spaces beneath overstory canopy and between trees (Mannan 1984). They are specific in habitat and nest-site selection, using conifer and mixed conifer-hardwood stands that have large (x=104 cm dbh), tall (x=50 m) trees with well-developed crowns, but overall an open canopy with few understory trees (x= 110-353 stems/ha) (Mannan 1984, Sekai and Noon 1991). Hammond's flycatchers were not found in Douglas-fir/tanoak (_Lithocarpus densiflora_) stands <90 years old in Northern California (Sekai and Noon 1991), and they have been associated with old-growth stands in western Washington because old-growth forests tend to have the open canopies used by Hammond's flycatchers (Manuwal 1991). This habitat specificity may explain why Hammond's flycatchers were found only in thinned stands in my study. Thinned stands may have provided more suitable habitat for Hammond's flycatchers because the canopies were more open as reflected by the lower percent cover in the pole and sawtimber layers, and because more open space was available for foraging under the canopy. It seems possible that the structural changes induced by commercial thinning made it possible for Hammond's flycatchers to occupy otherwise unsuitable young Douglas-fir stands. In addition, aerial insects were more abundant in thinned than unthinned stands (Appendix 3), so thinned stands may have provided more prey for Hammond's flycatchers.

In contrast to Hammond's flycatchers, Pacific-slope flycatchers are more general in their habitat selection (Sekai and Noon 1991) and were ubiquitous in my study, although slightly more abundant in unthinned stands. Sekai 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, unthinned stands in my study had a deeper pole layer, more small conifers and hardwoods, and greater sawtimber and pole cover than thinned stands. Regression models indicated that sawtimber cover explained 43% of the variation in Pacific-slope flycatcher abundance among stands.

Hardwood variables were positively associated with Pacific-slope flycatcher abundance at both the plot and stand scales. They were more abundant on plots with red alder (Alnus rubra), and in stands that had higher hardwood basal area. Pacific-slope flycatchers have been associated with riparian habitat in coniferous forests, possibly because of the occurrence of deciduous trees in riparian zones (Kessler and Kogut 1985, Carey 1988).

In western Oregon, Pacific-slope flycatchers were more abundant in old-growth forests than in young (30- to 80-year-old) unmanaged stands (Carey et al. 1991), and selected sites with >100 cm-dbh trees (Gilbert and Allwine 1991). In my study, Pacific-slope flycatchers were more abundant in stands with higher densities of >56 cm dbh conifers.

Foliage-gleaners

Three species that forage and nest in forest canopies and shrub layers differed in abundance between thinned and unthinned stands. Black-throated gray warblers and golden-crowned kinglets were more abundant in unthinned stands, while warbling vireos were more abundant in thinned stands.

Black-throated gray warblers were observed in all stands, but were most abundant in unthinned stands. They are associated with shrub stages and shrub-forest edges, and dense sapling pole stages of northwest forests (Brown 1985). Gilbert and Allwine (1991) found black-throated gray warblers primarily in young stands having broadleaved trees in the Oregon Cascades. Unthinned stands in my study had higher stem densities of live trees, and in the Tillamook S.F., had higher densities of hardwood stems, which may have made them more suitable habitat for black-throated gray warblers than thinned stands.

Like black-throated gray warblers, golden-crowned kinglets also are found in dense forests, but they are strongly associated with conifers (Manuwal 1983, McGarigal and

McComb 1992). Golden-crowned kinglets are common permanent residents of northwest coniferous forests and are associated with dense conifer foliage across most seral stages (Mannan and Meslow 1984, Carey et al. 1991). During the breeding season golden-crowned kinglets were more abundant in unthinned stands in the Tillamook S.F., but their abundance did not differ between stand conditions in the Central Coast region. Sawtimber and pole cover was positively associated with kinglet abundance at both the plot and stand levels. Sawtimber and pole cover was greater in unthinned stands in both regions, so it is not clear why kinglets only differed between conditions in the Tillamook S.F. and not in the Central Coast region.

Other studies also have described a decline in golden-crowned kinglet abundance after harvests or tree removals resulting in a reduction of canopy cover (summarized by Medin 1985, Tobalske et al. 1991). However, golden-crowned kinglets seem to maintain at least a presence in conifer stands that have some canopy remaining after tree removal.

Golden-crowned kinglet abundance did not differ between stand conditions during the winter. Marcot (1985) found that golden-crowned kinglets in northwestern California Douglas-fir stands had lowest measures of niche breadth during the breeding season and highest measures during the winter. In other words, they seemed to be more selective of habitat during the breeding season and became more general in habitat use during the winter. This type of seasonal shift in habitat use may explain why golden-crowned kinglets were more abundant in unthinned stands during the breeding season, but not during the winter.

Warbling vireos were more abundant in thinned stands in the Central Coast region than in unthinned stands in that region but did not differ between stand conditions in the Tillamook S.F. Warbling vireos feed and nest in hardwoods (Harrison 1978:258, Brown 1985), and their abundance was probably more influenced by tree species composition (the distribution of hardwoods) than by stand structure (Mannan 1977). Regression models indicated that warbling vireos were most abundant in stands that had the highest densities of hardwoods >30 cm dbh. Although thinned stands in the Central Coast region had greater densities of hardwoods >30 cm dbh than unthinned stands, the difference is more likely caused by chance rather than by thinning. I did not detect a relationship between warbling vireo abundance and stand density using PCA. Mannan (1977) also found a high density of warbling vireos in a 55-year-old thinned Douglas-fir stand in western Oregon, but he too attributed this to the proximity of adjacent red alder stands, not to stand structure.

Hutton's vireos, western tanagers, and hermit warblers did not differ in abundance between stand conditions. Hutton's vireos and hermit warblers differed in abundance between regions: both were more abundant in the Central Coast region than in the Tillamook S.F.. Both of these species have been associated with young forests in the Pacific Northwest (Manuwal 1991); Hutton's vireos have been positively associated with hardwoods and hermit warblers have been positively associated with conifers (Ralph et al. 1991). Hutton's vireos may have been more abundant in the Central Coast region because hardwood cover and density of 30- to 40-cm dbh hardwoods were greater than in the Tillamook S.F.. Hermit warblers feed in the upper canopy of coniferous forests (Manuwal 1991) and may have been more abundant in the Central Coast region because the density of conifers was greater in stands that I sampled in that region .

Other possible reasons for differences in abundances of individual species between regions include the influence of latitude (Emlen et al. 1986), and possible regional differences in landscape patterns.

Ground and shrub foragers/nesters

Wilson's warblers and Swainson's thrushes are both species that forage and nest in the shrub layer (Harrison 1979:273, 242). Neither of these species differed in abundance between thinned and unthinned stands, probably because shrub cover did not differ consistently between stand conditions. Wilson's warblers were slightly more abundant in the Tillamook S.F., probably because low shrub cover, with which they were positively correlated, was greater in that region.

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). This species typically increases in abundance after harvests that reduce canopy cover (summarized by Medin 1985). Similarly, dark-eyed juncos were more abundant in commercially thinned stands than in unthinned stands in my study. They showed a strong negative correlation with a principal components axis reflecting increasing tree and snag density and decreasing evergreen shrub cover. Stand level regression models indicated that junco abundance increased as average height of low shrubs and density of small conifer stems decreased, and red huckleberry cover increased. Artman (1990) also found a higher density of dark-eyed juncos in commercially thinned western hemlock stands than in similar unthinned stands. Junco abundance in her study was negatively correlated with tree density and positively correlated with grass and seedling cover, which was greater in thinned stands.

Dark-eyed juncos were more abundant in the Tillamook S.F. than in the Central Coast region. This could be caused by the overall lower tree density in the Tillamook stands compared to the Central Coast stands, but other confounding factors also could be involved, such as differences in latitude and regional landscape patterns.

Winter wrens were more abundant in thinned stands than unthinned stands in the Central Coast region. Conversely they were more abundant in unthinned than thinned stands in the Tillamook S.F.. Factors other than stand density and canopy cover probably influenced winter wren abundance. Regression models at both the plot and stand level indicated a positive association between winter wren abundance and >30 cm dbh hardwoods. Conifers >56 cm dbh and evergreen shrub cover also were selected in the stand level model. The density patterns of >56 cm dbh conifer and >30 cm dbh hardwood stems were similar to the abundance pattern of winter wrens: greater in Tillamook unthinned than thinned stands and greater in Central Coast thinned than unthinned stands. Winter wrens were more abundant in older than younger stands, and were associated with large trees (>30 cm dbh) by other investigators (Barrows 1986, Artman 1990, Gilbert and Allwine 1991). They also have been associated with shrub cover >1.3 m (McGarigal and McComb 1992).

Winter wrens were more abundant in thinned stands than unthinned stands across both regions in the winter. It is not clear why winter wrens were more abundant in Tillamook unthinned stands during the breeding season, but shifted to greater abundance in thinned stands during the winter. Winter wrens have been reported to shift habitat use seasonally. Marcot (1985) observed that winter wrens had the highest abundance in the medium sawtimber (modal stem dbh = 29- to 53-cm) stage of northern California unmanaged Douglas-fir forests during the breeding season, but throughout the rest of the year their density was highest in shrub-sapling stages. Barrows (1986) reported that winter wrens in northern California seemed to be randomly distributed among habitats in the winter but were found almost exclusively in old-growth habitat in the spring and summer.

Winter wrens are associated with the forest floor throughout the year. Although winter wrens have been associated with slash (Armstrong 1955), I did not detect a relationship between slash cover and winter wren abundance. It seems likely that winter wrens responded to characteristics of the forest floor that may not have been measured adequately in my study.

Cavity-nesters

Only 28 observations of hairy woodpeckers were made in the 2 years of breeding bird counts, and only 7 observations were made during the winter count. Carey et al. (1991) and Nelson (1989) reported that hairy woodpeckers are rare in young (30- to 90-year-old) unmanaged stands in the Oregon Coast Range, but that they increased in abundance with stand age. Hairy woodpeckers forage on the bark of live and dead trees, using dominant Douglas-fir (Carey et al. 1991), although they also have been described as habitat generalists (Raphael and White 1984). They use hard snags ≥50-cm dbh for nesting (Nelson 1989). In spite of this association with large trees and snags, hairy woodpeckers were more abundant in thinned stands where densities of >56-cm dbh conifers and 30- to 52-cm dbh snags were lower compared to unthinned stands. Hairy woodpeckers have home ranges of 9-15 ha (Brown 1985), so they could have been using thinned stands primarily for foraging, while using adjacent stands for nesting. However, I opportunistically found 3 hairy woodpecker nests during the 2 years of bird counts, all of them in thinned stands.

Hairy woodpecker abundance can remain stable or increase after tree removal (summarized by Medin 1985.) Increased foraging substrate provided by slash and residual trees (Hagar 1960, Putnam 1983) and increased openness of stands (Putnam 1983) have been suggested as possible reasons why hairy woodpeckers may show a positive numerical response to tree removal. In my study, stands used by hairy woodpeckers had lower conifer basal area and less pole and Douglas-fir cover than unused stands (Table 8), indicating a selection for open stands. It is not clear why more open stands might provide more suitable habitat for hairy woodpeckers.

Brown creepers forage on the main stems of live trees, select >50 cm dbh snags for nesting, and are more abundant in old-growth than in young unmanaged Douglas-fir forests in western Oregon (Carey et al. 1991). In my study, few trees attained the diameters selected by brown creepers, but the strong positive correlation between brown creeper abundance and PCA Factor 2 (Table 17) may have reflected a selection by creepers for the greater foraging surface area provided by taller trees with less foliage in the pole layer. A summary by Medin (1985) indicates that brown creepers have been negatively impacted by most kinds of tree removal because of the resulting reduction in bark surface. However, Artman (1991) found a higher abundance of brown creepers in commercially thinned western hemlock stands than in similar unthinned stands. In my study, brown creepers were more abundant in thinned stands in the Central Coast region but did not differ in abundance between stand conditions in the Tillamook S.F. I cannot explain this result.

Red-breasted nuthatches were not common on my study sites, but were slightly more abundant in thinned stands than unthinned stands during both the breeding and winter seasons. Red-breasted nuthatches have been associated with old-growth forests in Oregon because they select >50 cm trees for foraging and nesting (Nelson 1989, Carey et al. 1991). Nelson (1989) characterized them as inhabitants of dense forests in the Oregon Coast Ranges because she found that nuthatch densities increased with canopy cover and snag densities. However, red-breasted nuthatches were common in 85-year-old thinned stands in northeastern Oregon (Mannan 1982), and they were more abundant in commercially thinned than unthinned western hemlock forests in western Washington (Artman 1990). Stands used during the breeding season by red-breasted nuthatches in my study had less pole and Douglas-fir cover

(Table 9), and nuthatch abundance was negatively correlated with a principal components gradient representing stem density, indicating a preference for more open stands. Red-breasted nuthatches may use different foraging patterns in younger, managed stands than in old-growth stands (Mannan 1982.)

Red-breasted nuthatches also were more abundant in thinned than unthinned stands during the winter. Mannan (1977) reported that red-breasted nuthatches were common in a 55-year-old thinned stand during the winter, but absent from a 72-year-old unthinned stand. He hypothesized that the numerous stumps and greater slash component in the thinned stand may have attracted nuthatches and other bark-foragers. Lundquist and Manuwal (1990) observed that red-breasted nuthatches shifted their foraging behavior in winter to use the lower portion of tree boles, away from branches. Thinned stands in my study may have provided better winter habitat for red-breasted nuthatches because the reduced foliage in the pole layer probably resulted in more bole area away from branches for foraging.

Chestnut-backed chickadee abundance did not differ between stand conditions during either the breeding or winter seasons. Nelson (1989) and Carey et al. (1991) found chestnut-backed chickadee abundance to be positively correlated with density of large snags (>50 cm dbh), and large conifers (>100 cm dbh). Densities of >52 cm dbh snags did not differ between thinned and unthinned stands in my study. Conifers >100 cm dbh did not occur in my stands, but densities of the largest conifers (56- to 67-cm dbh) did not differ between stand conditions. Given these results, chestnut-backed chickadee abundance would not have been expected to differ between stand conditions. Marcot (1985) reported that chestnut-backed chickadee habitat niche breadth was similar among seasons in northern California Douglas-fir forests. This is consistent with my finding of no difference in chickadee abundance patterns between seasons.

Scope and Limitations of the Study

The scope of my study was restricted to 40- to 55-year-old Douglas-fir- dominated stands in the 2 regions studied. Additional research would be needed to determine if the same patterns hold for 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.

Time since thinning is probably an important factor influencing habitat structure and therefore bird community composition. I was unable to assess the influence of time since thinning on the results of my study because it was confounded with region effects: Tillamook stands generally were thinned more recently than Central Coast stands.

Within each region, thinned and unthinned stands were adequately replicated, but plot-level analyses were pseudoreplicated. Results of plot-level multivariate analyses should be interpreted with caution because plots within a stand were not independent (Hurlbert 1984). Plot-level results should be considered purely exploratory and are useful only for suggesting hypotheses to be tested. This also is true for the PCA results because they were derived from a-posteriori analysis.

Another limitation of my study was that I was 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. Such species are nonetheless important members of the forest wildlife community.

Conclusions

Commercially thinned stands had greater diversity and abundance of breeding birds, and greater species richness of wintering birds than unthinned stands. The relative openness of the canopy and lower tree densities of thinned stands seem to have provided better habitat for Hammond's flycatchers, hairy woodpeckers, red-breasted nuthatches, and dark-eyed juncos during the breeding season. Commercially thinned stands seem to have provided better wintering habitat for red-breasted nuthatches and winter wrens.

Three bird species were more abundant in unthinned stands during the breeding season: golden-crowned kinglets, Pacific-slope flycatchers, and black-throated gray warblers. Although these species are common in western Oregon forests during the breeding season (Carey et al. 1991), their populations are experiencing an overall decline as mature forests are harvested for timber (Raphael et al. 1991). The Breeding Bird Survey trend data for Oregon indicates that golden-crowned kinglet populations have experienced a decline of almost 6%/year since 1968, and black-throated gray warbler populations have declined 8.2%/year since 1982 (Sam Droege, U.S. Fish and Wildlife Service, pers. comm.). In the interest of conserving biodiversity, land managers would be wise to provide for the habitat needs of even the common forest species now.

Some habitat characteristics that seemed to be unrelated to commercial thinning in my study were important to bird species richness and abundances. Hardwoods (black-throated gray warbler, Hutton's vireo, Pacific-slope flycatcher, warbling vireo), large (>52 cm dbh) snags (chestnut-backed chickadee, hermit warbler, warbling vireo), and large (>56 cm dbh) conifers (Pacific-slope flycatchers, winter wrens) were associated with the abundance of 7 bird species. Differences in species richness and abundances between regions (Table 6), and some differences between conditions (Table 5), seemed to be mostly related to differences in hardwood densities (Hutton's vireo, warbling vireo, black-throated gray warbler), occurrence of >56 cm dbh conifers and >30 cm dbh hardwoods (winter wren), and shrub cover (Wilson's warbler). These habitat features did not seem to be influenced by thinning in my study, although thinning could be used to manipulate them (Hunter 1990:227-230).

Management Implications

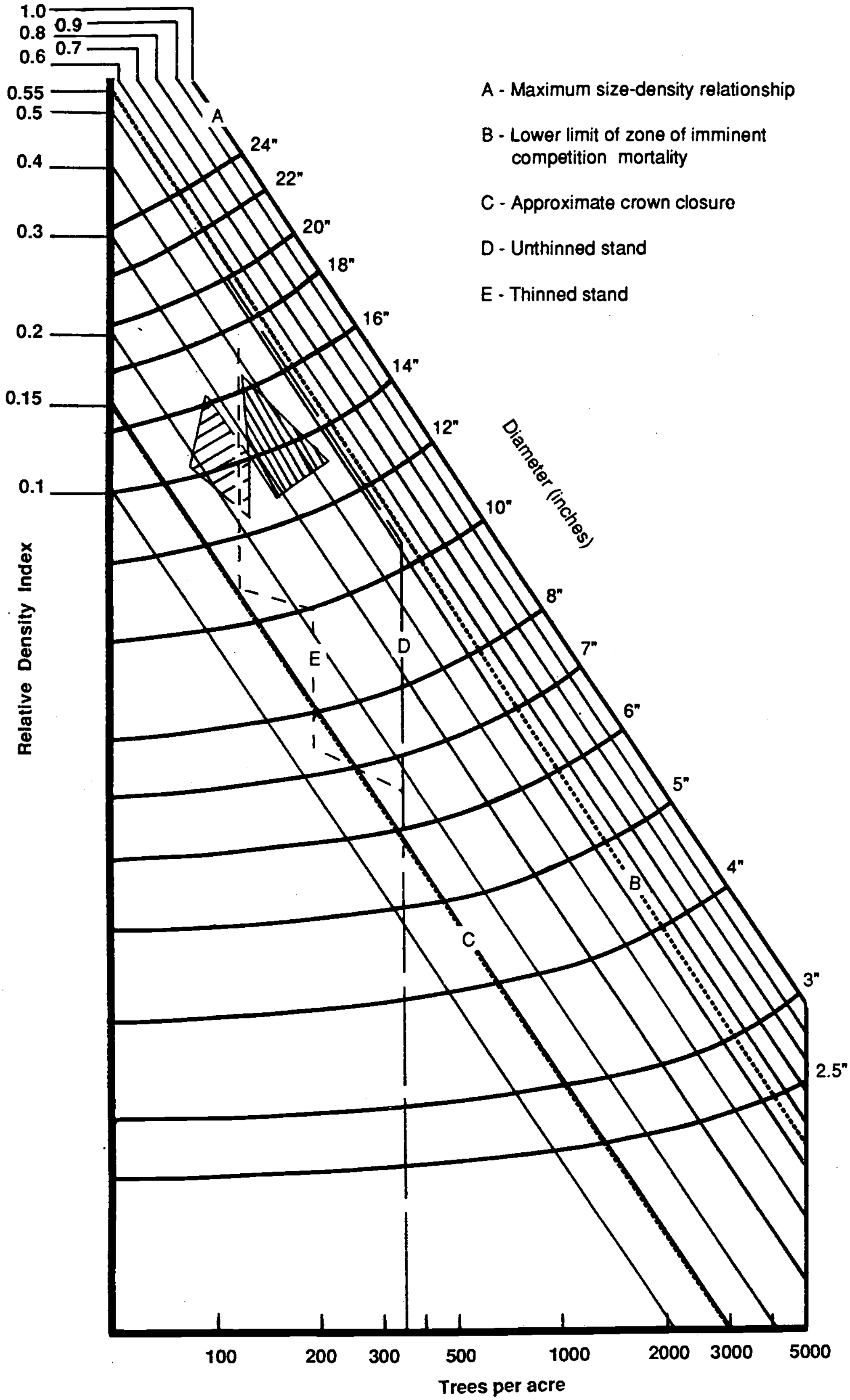
Commercial thinning may be a valuable tool for land owners managing multiple resources. In addition to enhancing timber production, thinning has the potential to enhance bird habitat in overstocked second-growth Douglas-fir stands. Hammond's flycatchers, red-breasted nuthatches, dark-eyed juncos, and winter wrens are species that were associated with commercially thinned stands in my study. These species deserve the attention of land managers because they are declining (19.5%, 0.2%, 1.7%, and 6.6%/year, respectively) in abundance in Oregon according to Breeding Bird Survey trend data (Sam D. Droege, U.S. Fish and Wildlife Service, pers. comm.). It is important that habitat components such as snags and hardwoods also are maintained in young managed stands. Some bird species associated with these features, such as chestnut-backed chickadees (snags), and warbling vireos and black-throated gray warblers (hardwoods) also seem to be experiencing population declines (2.0%, 1.0%, and 8.2%/year, respectively) in Oregon (Breeding Bird Survey trend data, Sam D. Droege, U.S. Fish and Wildlife Service, pers. comm.).

The following hypothesis outlines a thinning strategy for land managers who are interested in enhancing avian diversity and abundance. The goal of the strategy is to create habitat heterogeneity both within and between stands, and to provide the structural features which my study suggested are important components of avian habitat. Because the patterns suggested by my study are only associative, the following hypothesis needs to be tested with manipulative experimentation.

Based on the results of my study, I hypothesize that a thinning regime in the Central Coast Range or Tillamook S.F. suggested by line E in Figure 8 would produce a stand that would support a more diverse, species-rich bird community by the time it attained and average dbh of 35 cm (14 in.) than an unthinned stand (line D), if consideration was given to retaining hardwoods and snags. Thinning regime E would maintain a relatively open canopy throughout the development of the stand because it would not allow the stand to grow far beyond the canopy-closure line. In contrast to a stand produced by trajectory D, shrubs may be maintained in the understory of the thinned stand, and the growth of hardwoods retained in the stand would be enhanced. The enhancement of shrubs and hardwoods would favor species such as Wilson's warblers, Swainson's thrushes, Hutton's vireos, and warbling vireos. Maintaining the relatively open canopy and lower stem density of regime E also would favor Hammond's flycatchers, hairy woodpeckers, red-breasted nuthatches, and dark-eyed

Figure 8. Density management diagram for Douglas-fir showing the growth trajectory of an unthinned stand (line D) and a hypothetical thinning regime (line E) that might result in a stand with suitable habitat for Hammond's flycatchers, hairy woodpeckers, red-breasted nuthatches, and dark-eyed juncos. The stand E would be kept close to the crown closure line (C) by thinning once precommercially and again commercially in order to maintain shrubs and herbaceous ground cover throughout stand development. Shrubs would provide habitat for Wilson's warblers and Swainson's thrushes. The outlined areas marked 'T' and 'U' represent the range of densities and sizes of conifers (hardwoods not included) occurring in the thinned and unthinned stands respectively in my study.

Figure 8


A - Maximum size-density relationship
B - Lower limit of zone of imminent competition mortality
C - Approximate crown closure
D - Unthinned stand
E - Thinned stand
Relative Density Index
1.0
0.9
0.8
0.7
0.6
0.55
0.5
0.4
0.3
0.2
0.15
0.1
Diameter (inches)
24"
22"
20"
18"
16"
14"
12"
10"
8"
7"
6"
5"
4"
3"
2.5"
A
B
C
D
E
100
200
300
500
1000
2000
3000
5000
Trees per acre

juncos. On the other hand, golden-crowned kinglets and Pacific-slope flycatchers would probably be more abundant under the no-thinning regime, although they would probably be present in all stands. Black-throated gray warblers might be more abundant in the unthinned stand only if hardwoods were present. If some dense patches of trees were left unthinned within the stand represented by line E, then bird species diversity and richness might be further enhanced on the stand-level because habitat for species preferring denser vegetation would be maintained, albeit on a small scale. Alternatively, unthinned strips or patches (approximately 8 ha per 40 ha of thinning) could be left adjacent to thinned stands, so that the habitat needs of all forest birds are met on a basin-level.

The stand suggested by thinning regime E (Fig. 8) would likely experience little competition mortality, so snags may be scarce. Snags could be maintained in the stand by creating them artificially, by leaving unthinned areas where competition mortality may occur, or by a combination of these strategies. Competition mortality in unthinned leave areas might provide small (<30 cm dbh) snags, whereas trees >30 cm dbh could be killed to provide larger snags. Thinning could accelerate tree growth, making it possible to create larger snags than might occur in an unthinned stand of the same age (Neitro et al. 1985).

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APPENDICES

APPENDIX 1

List of common and scientific names of bird species observed in 8 commercially thinned and 8 unthinned Douglas-fir stands during 2 breeding counts and 1 winter count in the Central Coast Ranges and the Tillamook State Forest, Oregon, 1989-1990.

Turkey vulture[b]
Cathartes aura

Sharp-shinned hawk
Accipiter striatus

Red-tailed hawk[a]
Buteo jamaicensis

Northern pygmy owl
Glaucidium gnoma

Blue grouse
Dendragapus obscurus

Ruffed grouse
Bonasa umbellus

Band-tailed pigeon
Columba fasciata

Rufous hummingbird[a]
Selasphorus rufus

Pileated woodpecker
Dryocopus pileatus

Hairy woodpecker
Picoides villosus

Northern flicker[a]
Colaptes auratus

Red-breasted sapsucker
Sphyrapicus thyroideus

Olive-sided flycatcher
Contopus borealis

Pacific-slope flycatcher
Empidonax difficilis

Gray jay
Perisoreus canadensis

Steller's jay
Cyanocitta stelleri

Common raven
Corvus corax

Chestnut-backed chickadee
Parus rufescens

Bushtit[b]
Psaltriparus minimus

Red-breasted nuthatch
Sitta canadensis

Brown creeper
Certhia americana

Winter wren
Troglodytes troglodytes

Golden-crowned kinglet
Regulus satrapa

Townsend's solitaire
Myadestes townsendii

Swainson's thrush
Catharus ustulatus

Hermit thrush
Catharus guttatus

Appendix 1, continued

Western wood-peewee
Contopus sordidulus

Hammond's flycatcher
Empidonax hammondii

Wrentit[b]
Chamaea fasciata

Hutton's vireo
Vireo huttoni

Warbling vireo
Vireo gilvus

Orange-crowned warbler
Vermivora celata

Nashville warbler[a]
Vermivora ruficapilla

Yellow-rumped warbler
Dendroica coronata

Black-throated gray warbler
Dendroica nigrescens

Hermit warbler
Dendroica occidentalis

MacGillivray's warbler
Oporornis tolmiei

Wilson's warbler
Wilsonia pusilla

Western tanager
Piranga ludoviciana

American robin
Turdus migratorius

Varied thrush
Ixoreus naevius

Black-headed grosbeak
Pheucticus melanocephalus

Rufous-sided towhee[a]
Pipilo erythrophthalmus

Song sparrow[a]
Melospiza melodia

Dark-eyed junco
Junco hyemalis

Brown-headed cowbird
Molothrus ater

Purple finch
Carpodacus purpureus

Red crossbill[b]
Loxia curvirostra

Pine siskin[b]
Carduelis pinus

American goldfinch[b]
Carduelis tristis

Evening grosbeak
Coccothraustes vespertina

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[a] Species observed incidentally ($\leq$5 times) only in thinned stands.

[b] Species observed incidentally ($\leq$5 times) only in unthinned stands.

APPENDIX 2

Mean birds/area index (number of observations/40 ha) in 4 commercially thinned and 4 unthinned Douglas-fir stands in the Central Coast Ranges and 4 commercially thinned and 4 unthinned stands in the Tillamook State Forest, Oregon, May-June 1989 and 1990. Density indices were calculated by determing an effective radius of detection for each species, then dividing the number of observations made within this distance limit by the area sampled (area sampled/plot times the number of visits/plot), and then expanding to 40 ha.

	Central Coast Ranges				Tillamook S.F.			
	Thinned		Unthinned		Thinned		Unthinned	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Black-throated gray warbler	4.66	1.09	11.66	3.18	6.06	2.28	7.77	2.51
Brown creeper	10.78	0.94	4.98	1.46	5.25	3.11	5.81	3.33
Chestnut-backed chickadee	21.10	4.18	19.90	5.69	17.91	3.21	14.33	2.52
Golden-crowned kinglet	25.88	2.86	31.45	2.63	21.50	3.53	41.40	2.34
Gray jay	2.49	0.98	1.55	0.40	0.78	0.47	3.26	1.25
Hairy woodpecker	2.80	0.74	0.0	0.0	2.18	1.18	0.0	0.0

Appendix 2, continued

Species	Central Coast Ranges				Tillamook S.F.			
	Thinned		Unthinned		Thinned		Unthinned	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Hammond's flycatcher	36.25	14.74	0.0	0.0	8.12	5.90	0.0	0.0
Hermit warbler	66.92	6.13	63.33	8.17	36.23	11.74	36.50	6.92
Hutton's vireo	2.18	0.97	4.35	1.16	0.47	0.30	0.93	0.40
Pacific-slope flycatcher	23.54	4.97	25.77	4.02	21.91	6.30	28.61	6.22
Red-breasted nuthatch	2.95	0.93	1.09	0.47	4.51	1.42	1.09	0.89
Swainson's thrush	10.96	3.27	7.30	2.73	6.70	2.13	9.33	2.42
Western tanager	4.51	1.20	0.78	0.47	1.55	0.97	1.71	0.64
Wilson's warbler	21.31	4.84	10.55	4.95	29.42	9.62	29.02	3.54
Winter wren	44.44	4.60	21.10	5.38	16.44	2.49	31.05	1.16

APPENDIX 3

Plot level regression model parameters for bird species and vegetation characteristics of 8 commercially thinned and 8 unthinned Douglas-fir stands, western Oregon.

Bird Species	Habitat Variable	Coefficient	P	R^2
Chestnut-backed chickadee	constant	-2.699	0.198	
	30- 51-cm dbh, dc 4-5 snags	+0.541	0.002	
	pc red alder	+0.165	0.016	
	pc pole	-0.042	0.009	
	pc conifer	+0.064	0.003	
	fern ht.	+4.968	0.023	0.30
Golden-crowned kinglet	constant	-3.471	0.182	
	pc sawtimber	+0.074	0.000	
	pc pole	+0.054	0.005	
	conifer ht.	+0.161	0.065	
	low shrub ht.	-2.959	0.017	0.31
Hermit warbler	constant	-3.928	0.320	
	vine maple ht.	-0.889	0.034	
	conifer ht.	+0.560	0.000	
	20-30 cm dbh conifers/ha	+0.751	0.001	
	20-30 cm dbh hardwoods/ha	+2.756	0.004	
	dist. to patch edge	-0.022	0.041	0.45
Pacific-slope flycatcher	constant	2.951	0.005	
	pc red alder	+0.377	0.000	
	10-30 cm dbh, dc 1 snags/ha	+0.216	0.000	
	pc fern	+0.106	0.001	
	pc grass[a]	-3.695	0.019	
	10-30 cm dbh, dc 2-3 snags/ha	+0.251	0.039	
	10-30 cm dbh, dc 4-5 snags/ha	-0.446	0.042	0.50
Winter Wren	constant	3.138	0.000	
	>30 cm dbh hardwoods/ha	+8.346	0.000	
	pc hazel[a]	+3.508	0.001	
	pc huckleberry	+0.326	0.006	0.38

[a] variable was Log10+1 transformed.

APPENDIX 4

Arthropod abundance in commercially thinned and unthinned Douglas-fir stands in the Central Coast Range, Oregon.

Introduction

Commercially thinned Douglas-fir stands in my study seemed to have provided better habitat for Hammond's flycatchers than unthinned stands. The openness of the canopy may have allowed this species to forage in gaps between trees and beneath the canopy (Sekai and Noon 1991). However, the availability of food for forest birds also is a function of prey abundance (Holmes and Schultz 1988). I tested the hypothesis that arthropods were more abundant in thinned than unthinned stands by sampling arthropod abundance beneath the canopy in a subset of my study stands in the Central Coast Range.

Methods

Insect traps were placed at 1 randomly selected bird census plot in each of 3 thinned and 3 unthinned stands in the Central Coast Range. Traps consisted of 3 40 x 40-cm pieces of hardware cloth strung vertically from a branch beneath the lower canopy. Distance between each section of trap was approximately 20 cm. The hardware cloth was coated with Tanglefoot™, a sticky substance that caused insects to adhere to the wire mesh. Traps were left hanging for 2 5-day sessions in late June 1990. After each 5-day period, trapped insects were tallied by size class (<0.10 cm, 0.11- 0.50-cm, 0.51- 1.00-cm, and 1.01- 2.00-cm) and taxanomic order. Size classes represented arthropod body length.

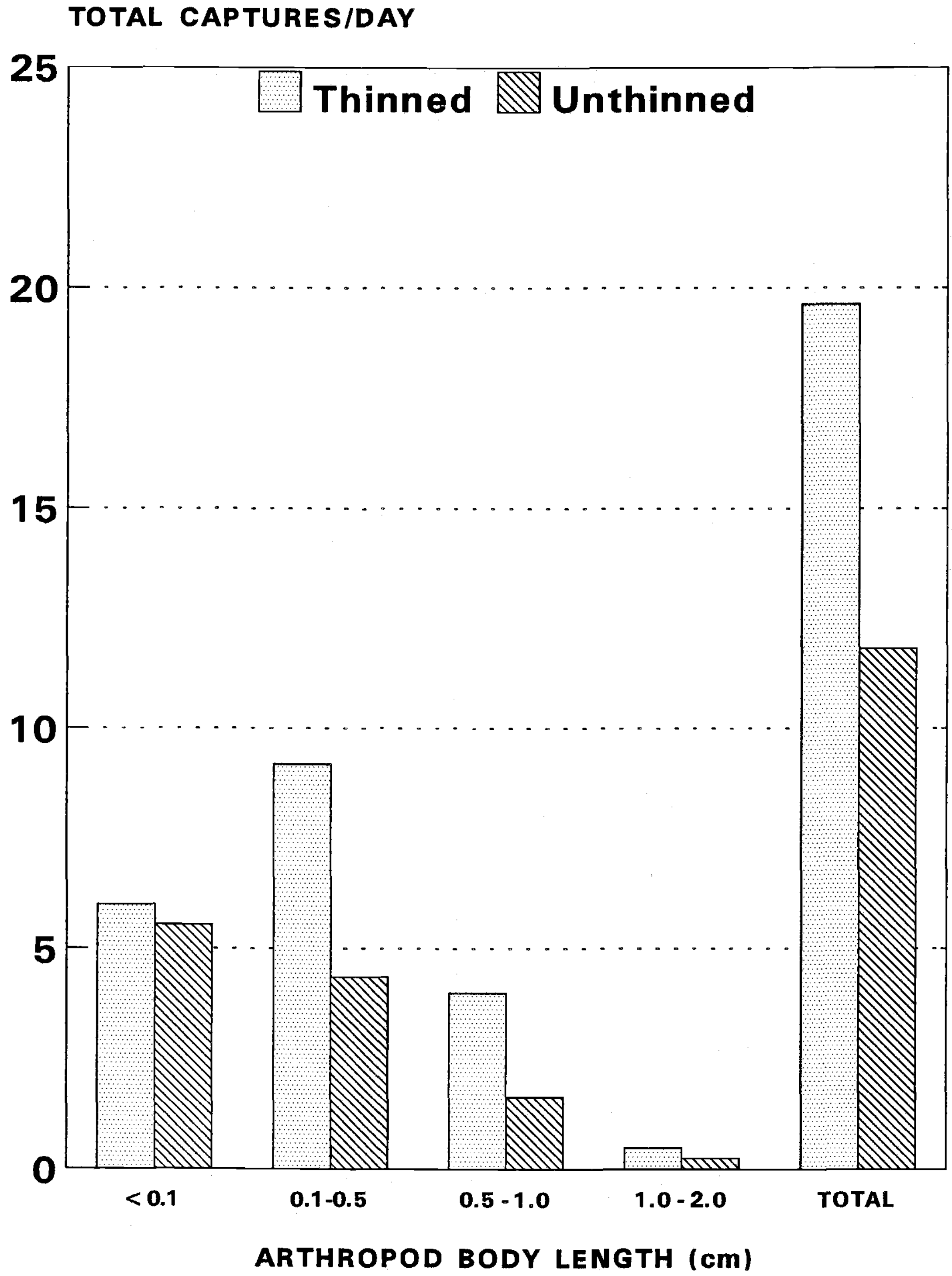
Tallies for each size class of arthropod were averaged across the 2 sample periods for each of the 6 stands (3 thinned and 3 unthinned.) The Wilcoxon rank-sum procedure was used to test the null hypothesis that the mean number of insect captures for each size class did not differ between thinned and unthinned stands.

Results

Dipterans were the most frequently captured order, accounting for 68% of the captures in thinned stands and 72% in unthinned stands. Coleoptera was the second most abundant order, representing 23% of the captures in thinned and 20% in unthinned stands. Other orders captured included Hymenoptera, Homoptera, Hemiptera, and Lepidoptera. Arthropods <0.1-cm and >1.0-cm in length did not differ in abundance between stand conditions. Arthropods between 0.1 and 1.0-cm were more abundant in thinned than unthinned stands (0.1- to 0.5-cm, $P=0.08$; 0.5- to 1.0-cm, $P=0.05$). Capture rates of all sizes and orders of arthropods combined were higher in thinned than unthinned stands ($P=0.05$) (Fig. 9).

Figure 9. Total captures/day of arthropods in 3 commercially thinned and 3 unthinned Douglas-fir stands in the Central Coast Range, Oregon, June 1990.

Figure 9


TOTAL CAPTURES/DAY
25
20
15
10
5
0
Thinned
Unthinned
< 0.1
0.1-0.5
0.5 - 1.0
1.0 - 2.0
TOTAL
ARTHROPOD BODY LENGTH (cm)

Discussion

By reducing competition and increasing insolation, thinning can result in more rapid growth of residual trees (Smith 1986) and understory vegetation (Mitchell 1983). This shift in nutrient availability after thinning may favor herbivorous insects that select fast-growing plants (Coley et al. 1985). Percent cover of forbs, which was greater in thinned than unthinned stands in my study, and vegetation height also have been positively correlated with arthropod abundance (Blenden et al. 1986). Thinning also may increase abundance of stump- and slash-colonizing insects (Witcosky et al. 1986). A combination of these effects may explain why I captured more insects in thinned than unthinned stands.

Although I do not know which insect orders comprise the major portion of Hammond's flycatcher diets, Otvos and Stark (1985) found that Coleoptera composed the largest portion of the diet of olive-sided flycatchers, and Hymenoptera was the most common food for ash-throated flycatchers in northern California. I assumed that all arthropods trapped were potential prey for Hammond's flycatchers because the sampling design was biased toward air-borne insects.