AN ABSTRACT OF THE THESIS OF

Jonathan P. Brooks for the degree of Master of Science in Forest Science presented on February 4, 1997. Title: Bird-Habitat Relationships at Multiple Spatial Resolutions in the Oregon Coast Range.

Abstract approved: ______________________________

William C. McComb

I analyzed the relationship between avian abundance and landscape structure at five spatial resolutions for 30 subbasins in the central Oregon Coast Range using remotely sensed data and a geographic information system (GIS). I developed maps of forest successional stages from Landsat Thematic Mapper (TM) data at a spatial resolution of 25 meters, or 0.06 hectares (ha). I applied a pixel aggregation technique to produce images at minimum mapping units (MMU) of 0.25, 1, 4, and 16 ha. Using a spatial pattern analysis program, I quantified the landscape structure of each subbasin at the five MMU's. I used bird abundance data from a previous study to model the relationships between the landscape structure at each MMU and abundance of each of five bird species: brown creeper (Certhia americana), gray jay (Perisoreus canadensis), Hammond's flycatcher (Empidonax hammondii), red-breasted nuthatch (Sitta canadensis), and song sparrow (Melospiza melodia). At all MMU's, the patch composition (the proportional abundance of each subbasin in a particular patch type) explained much of the variation in abundance for all species. For brown creeper, gray jay, Hammond's flycatcher, and red-breasted nuthatch, the percentage of mixed and conifer large sawtimber in the subbasin explained 42-78% of the variation in abundance. Mean patch size of mixed and conifer large sawtimber was a significant predictor of brown creeper abundance at fine MMU's and for the red-breasted nuthatch at the coarsest MMU. The percentage of the subbasin in mixed small sawtimber was a significant predictor of Hammond's flycatcher abundance at the three coarsest MMU's. Percentage of the landscape in hardwood small/large sawtimber explained much of the variation in abundance for song sparrows. Landsat TM data can be useful in determining relationships between bird abundance and habitat. For the range of species and MMU's I analyzed, patch composition seemed to be more important for determining bird-habitat relationships than attributes of patch structure such as size and shape.

Master of Science thesis of Jonathan P. Brooks presented on February 4, 1997

APPROVED:

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Head of Department of Forest Science

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Jonathan P. Brooks, Author

BIRD-HABITAT RELATIONSHIPS AT MULTIPLE SPATIAL RESOLUTIONS IN THE OREGON COAST RANGE

by

Jonathan P. Brooks

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INTRODUCTION

Habitat structure plays an important role in regulating forest vertebrate populations across landscapes (Morrison et al. 1992:44; Harris 1984:19). Habitat was defined by Hutto (1985) as a "spatially contiguous vegetation type that appears more or less homogeneous throughout and is physiognomically distinct from other such types." McGarigal and Marks (1995) defined landscape as an area of land that contains an interacting mosaic of patches or landscape elements. Forman and Godron (1986) defined a patch as an area that differs in appearance from its surroundings, while Morrison et al. (1992:42) referred to a habitat patch as an area that has homogeneous environmental conditions to some extent.

The structure of a habitat includes both composition and pattern across a landscape. Composition refers to the presence and amount of a particular habitat type. Pattern describes the location of habitat patches in relation to other patches (i.e., how patches are distributed within a landscape) and the spatial characteristics (e.g., size, shape) of the patches themselves. The abundance of many vertebrate species is sensitive to the amount and distribution of suitable habitat (Rosenberg and Raphael 1986). McGarigal and McComb (1995) found a strong association between the abundances of 2 bird species and the amount of conifer large sawtimber in subbasins of the Oregon Coast Range. Anthony et al. (1996) found that abundances of four bird species in the Oregon

Cascades were higher in mature and old-growth forest riparian areas than in young riparian forests during the breeding season. Ambuel and Temple (1983) detected a high correlation between bird species diversity and amount of contiguous forested area in Wisconsin. Various studies have demonstrated the effect of habitat pattern on vertebrate populations. Hawrot and Niemi (1996) examined the effects of edge type and patch shape on avian populations and determined that a combination of both was successful in explaining most of the variation in abundance for 4 species. Coker and Capen (1995) found that brown-headed cowbirds (Molothrus ater) were more likely to be found in disturbance patches that were in close proximity to other such patches.

Ecological processes commonly operate at various spatial and temporal scales (Virkkala 1991). Traditional studies of ecological processes have concentrated on temporal changes and single study sites or small geographic areas. It has become apparent that such studies do not capture processes that may be occurring at the landscape level. In an ecological context, it may be more meaningful to consider scale from the perspective of the organism that is being studied. Individual species respond to environmental conditions at different scales within a landscape. For example, a small ground-dwelling insect may perceive habitat at 1 square meter. A large vertebrate such as an owl, however, may perceive habitat on the order of several hundred or thousand square meters (McGarigal and Marks 1995).

One approach to investigating the relationship between vertebrate abundance and habitat structure at various spatial scales is to develop models of wildlife-habitat relationships using a geographic information system (GIS). Confusion often arises with terminology used to describe levels of observation in studies. This confusion stems partly from different definitions of words from various disciplines. In the field of landscape ecology, Forman and Godron (1986:191) defined scale as the level of spatial (and temporal) resolution that is perceived or considered in a landscape. A cartographic definition of scale is the ratio of length of an object on a map to that object's true length on the ground (Clarke 1990:49). A fine scale in a landscape ecological context refers to a small area, whereas the same area on a map is large scale (i.e., the ratio of map length to true length is large). Conversely, a coarse or broad scale in landscape ecology is denoted as small scale on a map.

Resolution is a term that is frequently used interchangeably with scale, although it is often incorrect to do so. Resolution was defined by Forman and Godron (1986:193) as the degree to which small objects are distinguishable. Turner (1990) defined resolution, also called grain size, as the area depicted by each data unit. Landscape patterns smaller than the grain size cannot be detected (Schulz and Joyce 1992). The grain size for a landscape is different than the grain size for an organism. The former is dependent upon the manner in which humans perceive their surroundings while the latter is dependent upon how the organism perceives its habitat (Forman and Godron 1986:217). The extent, or the overall size of the study area, also must be considered for landscape studies. The grain and the extent of landscape studies have a strong influence on the ecological patterns and processes that can be detected (Schulz and Joyce 1992).

Ecological studies using a GIS are constrained by the limitations of the existing technology and by the available data. For example, vegetation classifications that are mapped from satellite imagery are limited by the spatial resolution, or pixel size, of the satellite sensors (Benson and MacKenzie 1995). It may be desirable to use vegetation maps of coarser resolutions because it can reduce the complexity of a landscape and the cost for data acquisition and storage. One technique for developing maps of vegetation at various resolutions is to aggregate satellite data to coarser resolutions. A common method is to increase the grain size and aggregate pixels based on a majority rule (Figure 1). This technique involves specifying a particular grain size. A moving window is passed over the image and pixels are aggregated into a single data unit based on the class of the majority of pixels (Turner et al. 1989). Another method is to aggregate pixels based on a minimum mapping unit, or MMU. Scott et al. (1993) defined MMU as the smallest area depicted on a map. The MMU aggregation technique may be more desirable than increasing grain size because important properties of landscapes are frequently lost using a majority rule grain size aggregation technique (Benson and MacKenzie 1995).

For the purposes of my research, I chose to aggregate pixels using MMU's rather than increasing grain size, or changing the resolution. Use of MMU's allows the possibility that some structural features, such as edges that have been shown to be important for some wildlife species (Temple 1986), will be maintained at coarser levels of observation. Another consideration is that the amount of core area will be exaggerated using an aggregation technique based on grain size.

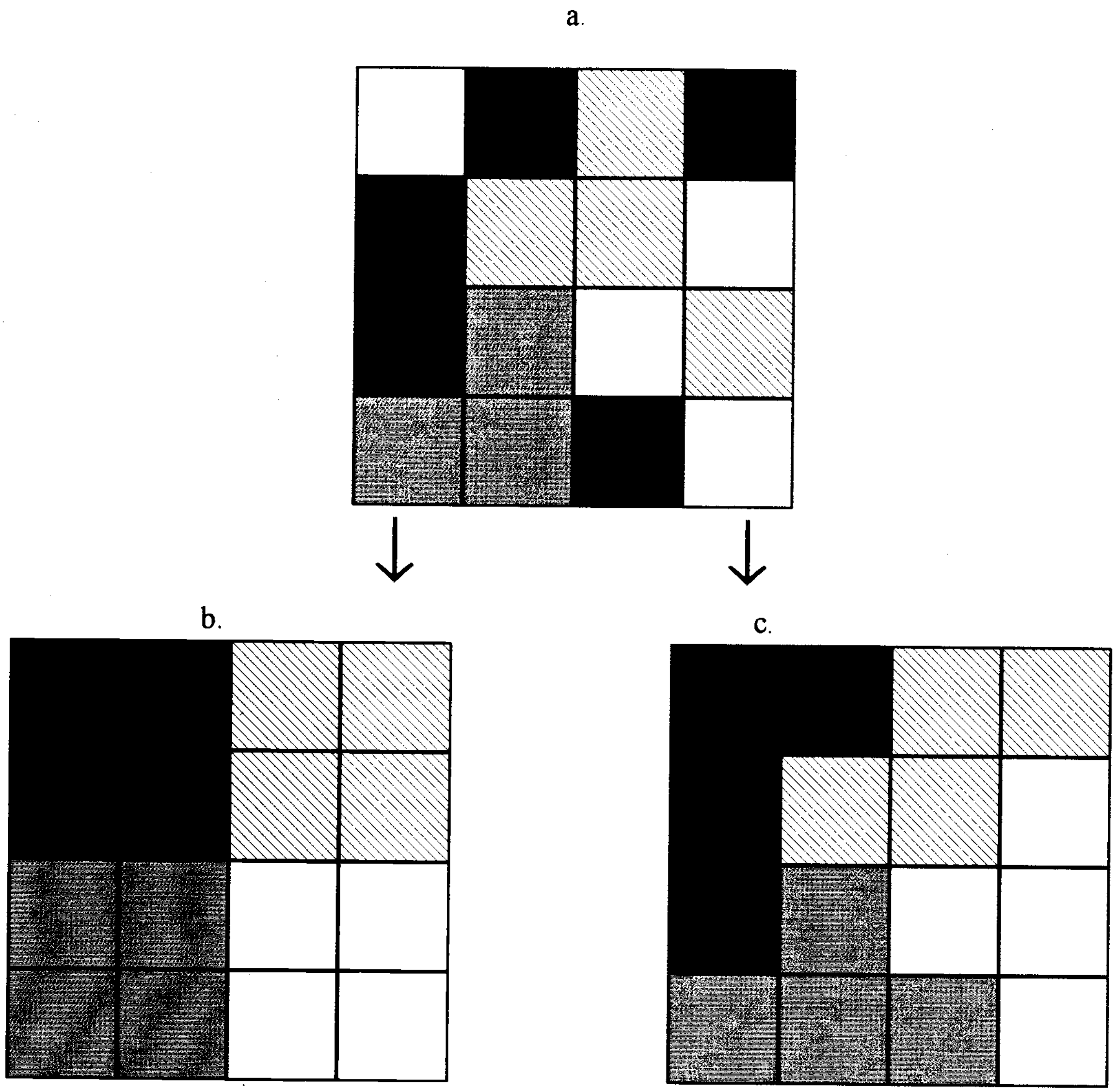

Figure 1. Effects of using two pixel aggregation techniques on a hypothetical landscape (a). Landscape (b) was derived by using an increasing grain size with a majority rule. Landscape (c) was derived by using a minimum mapping unit.

OBJECTIVES

I estimated the relationship between landscape structure (composition and pattern) and the abundance of several species of breeding birds in the central Oregon Coast Range at various MMU's. My general approach was similar to that used by McGarigal and McComb (1995). I used the bird abundance data that they collected, but I employed different vegetation maps to investigate relationships. Specifically, I used raster-based satellite imagery rather than vector-based maps developed from aerial photographs. My objectives were:

1) to estimate the degree of association between landscape metrics derived from aerial photographs and metrics derived from satellite imagery;

2) to determine which landscape metrics are most associated with the abundance of 5 bird species and use those metrics to develop predictive models of bird abundance;

3) to assess changes in the relationships between bird abundance and landscape structure across multiple minimum mapping units.

STUDY AREA

The study area was selected by McGarigal (1993). Three basins were chosen that are located in the central Oregon Coast Range (Figure 2). The Drift Creek basin lies within Lincoln County (latitude 44° 24’ to 44° 34’; longitude 123° 44’ to 123° 58’). The Lobster Creek basin is located mainly in Benton and Lincoln Counties (latitude 44° 11’ to 44° 22’; longitude 123° 31’ to 123° 52’). The Nestucca River basin is located chiefly in Tillamook County (latitude 45° 08’ to 45° 22’; longitude 123° 27’ to 123° 58’). Elevations range from sea level to 968 m. Land ownership is primarily federal (managed by the U.S. Forest Service and the Bureau of Land Management) with some private industrial forest land. The study area is almost completely forested and contains a mixture of young (0-40 years), even-aged stands and late-seral (120-140 years) forest stands with infrequent mid-aged (40-100 years) and older (>140 years) stands (McGarigal 1993).

The study area was classified as temperate coniferous forest by Ohmann (1996) and lies in the western hemlock (Tsuga heterophylla) forest zone as described by Franklin and Dyrness (1988:70). The overstory is predominantly Douglas-fir (Pseudotsuga menziesii), western hemlock, and red alder (Alnus rubra). Other tree species include bigleaf maple (Acer macrophyllum) and western redcedar (Thuja plicata). The understory vegetation consists of salmonberry (Rubus spectabilis), vine maple (Acer circinatum), Oregon-grapes (Berberis spp.), salal (Gaultheria shallon), huckleberries (Vaccinium spp.), and western swordfern (Polystichum munitum) (McGarigal 1993).

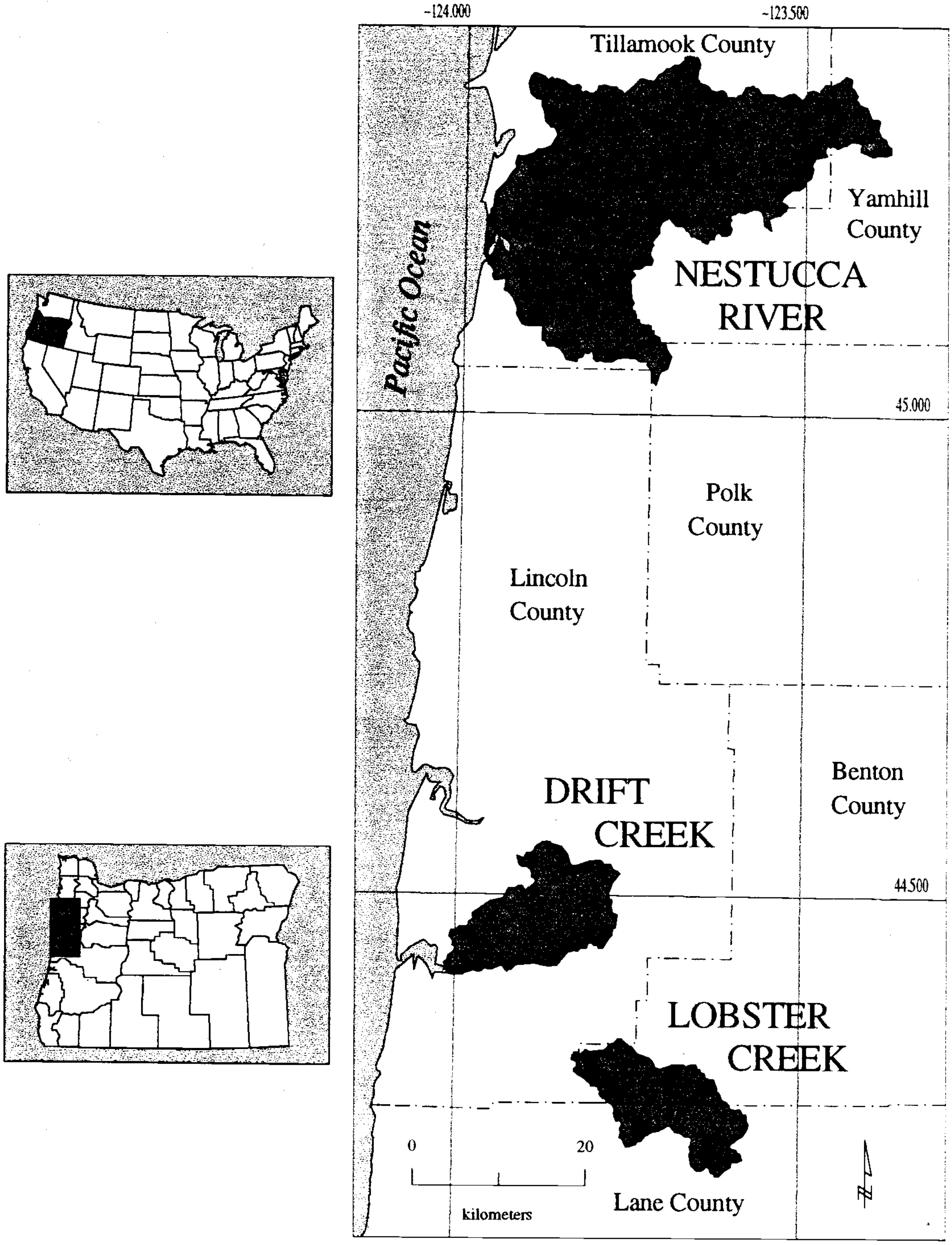

Figure 2. Location of Drift Creek, Lobster Creek, and Nestucca River basin study areas in the central Oregon Coast Range.

The climate is wet, mild maritime. Winters are wet and mild with an average January temperature of 2.4° C, while summers are cool and dry with an average July temperature of 16.6° C. Average annual precipitation ranges from 150 to 300 cm and occurs principally as winter rain (Franklin and Dyrness 1988:71).

METHODS

Study Site Selection

The study sites were selected by McGarigal (1993). Ten subbasins within each of the 3 basins (Drift Creek, Lobster Creek, and Nestucca River) were chosen based on the percentage of each subbasin in late-seral forest condition and the spatial configuration of late-seral forest. The 30 subbasins contained 0, 20, 40, 60, 80, or 100% late-seral forest area. Spatial configuration was designated either high or low complexity for the 20 - 80% late-seral forest subbasins, while those that contained either 0% or 100% late-seral forest were designated low complexity. Subbasins ranged in size from 248 to 296 ha.

Bird Surveys

I used breeding bird abundance data from McGarigal and McComb (1995). For each subbasin, the first transect and sample point were randomly located and subsequent sample points were established uniformly in a grid pattern. Transects were spaced 400 m apart and sample points were placed every 200 m along each transect, yielding 32-38 sample points per subbasin.

Diurnal breeding birds were sampled using a variable circular plot method (Reynolds et al. 1980) between May 1 and July 12. Drift Creek, Lobster Creek, and Nestucca River basins were sampled in 1990, 1991, and 1992, respectively. Each subbasin was sampled 4 times at regular intervals.

Vegetation Mapping

An area corresponding to each of the three basins was extracted from a 1988 Landsat Thematic Mapper (TM) satellite image (scenes 4628 and 4629; Oregon State University, Department of Forest Science, Corvallis, OR., unpubl.) at a 25- x 25-meter resolution. The TM data were classified by vegetation reflectance values (Sabins 1987:87) into forest successional classes based on vegetation cover, tree size (diameter at breast height - DBH), and/or species composition (Table 1). The classes and names are modified from Brown (1985:22) with the exception of shadow/burned clearcut, which was derived from the Landsat TM classification.

Overall classification accuracy for the images was 83%. This classification accuracy was based only on composition classes and was conducted using an independent model testing sample (stratified random sample) from plot data interpreted from aerial photographs. Specific classification accuracies were as follows: water 100%, hardwoods 89%, mixed 63%, conifer 95%, open 71%, and semi-closed 60% (Tom Maiersperger, pers. comm.). The dbh classes also were developed from plot data interpreted from aerial photographs, but classification accuracies were not available.

There were some differences between the vegetation classes that I used and those of McGarigal and McComb (1995). I had a total of 12 vegetation classes as opposed to 27 for McGarigal and McComb (1995). I used a cutoff of 80% cover dominance for hardwood, mixed, and conifer composition while McGarigal and McComb (1995) used 70%. For example, if a forested patch had 75% conifer composition, it was classified by McGarigal and McComb (1995) as conifer. By my classification, the same patch would not be conifer. There was a 2 cm difference in the sapling/pole tree diameter class. I

Table 1. Vegetation classification of 1988 Landsat Thematic Mapper (TM) data for 30 subbasins in the Oregon Coast Range.

Class Name	Definition	Classification Accuracy
71 - 100% Total Tree Canopy Cover (closed canopy)		
Hardwood sapling/pole	80 - 100% hardwood composition, 0 - 28 cm dbh	89% (combined hardwood class)
Hardwood small/large sawtimber	80 - 100% hardwood composition, > 28 cm dbh	
Mixed conifer/hardwood sapling/pole	< 80% hardwood and conifer composition, 0 - 28 cm dbh	63% (combined mixed class)
Mixed conifer/hardwood small sawtimber	< 80% hardwood and conifer composition, 28 - 53 cm dbh	
Mixed conifer/hardwood large sawtimber	< 80% hardwood and conifer composition, > 53 cm dbh	
Conifer sapling/pole	80 - 100% conifer composition, 0 - 28 cm dbh	95% (combined conifer class)
Conifer small sawtimber	80 - 100% conifer composition, 28 - 53 cm dbh	
Conifer large sawtimber	80 - 100% conifer composition, > 53 cm dbh	
0 - 70% Total Tree Canopy Cover		
Shadow/burned clearcut		
Water		100%
Open canopy	0 - 40% total tree cover	71%
Semi-closed canopy	41 - 70% total tree cover	60%

used a dbh of $\leq$28 cm for the pole class while McGarigal and McComb (1995) used $\leq$30 cm. The greatest differences between the 2 vegetation classifications were in the non-forested classes. My classification for open patch type included trees and used a tree crown cover between 0 and 40% whereas McGarigal and McComb (1995) used a grass-forb and a shrub class based on <20% tree crown cover.

In order to generate Landsat TM images at various MMU's, I used the MERGE program, a rule-based merging algorithm (VIMAP, Version 3.01. University of Montana, Missoula, MT., unpubl.). This program aggregates pixels to a user-defined minimum mapping unit based on similarities in the spectral properties of each of the pixel classes (see Appendix 1). I aggregated image pixels using each of the 3 basins as the landscape extent, rather than each of the 30 subbasins, in order to control for changes in patch composition along the subbasin boundaries. I did not separate public lands from private lands. I allowed all classes to merge with all other classes with the exception of water. I started with a 1-pixel (25 x 25m) mmu and aggregated the pixel classes in successive square 25-meter increments. Thus, I obtained vegetation maps at the following MMU's: 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225, and 256. From the resulting images, I selected those at 1, 4, 16, 64, and 256 MMU for data analysis. These correspond to an effective area of 0.06, 0.25, 1.00, 4.00, and 16.00 ha, respectively.

I used the ARC/INFO Geographic Information System (GIS) (ESRI 1996. Version 7.04. Environmental Systems Research Institute, Redlands, CA.) to integrate each of the five images with maps of the subbasins. Specifically, I overlaid vector coverages of each of the 30 subbasins onto the five images and clipped out the corresponding areas.

The Landsat TM images were taken in 1988, while bird abundance data were collected in 1990, 1991, and 1992. Some differences existed between my vegetation classes and those that were actually present at the time that the bird abundance data were collected. Some areas had been altered dramatically by management activities. These areas were identified from aerial photographs and located on the images, and the forest successional classes were changed to the vegetation class at the time of the actual bird censuses. Areas in 2 subbasins, one representing about 6% and the other about 4% of the total subbasin, were reclassified in this manner. Although other natural successional changes took place in the years between image production and bird data collection, I did not account for these changes because they were subtle and not uniform across each of the subbasins.

Data Analysis

I selected 5 species and used an index of abundance as the dependent variable in regression analyses. The index was the number of individuals of each species observed per sample point per day for each subbasin (McGarigal and McComb 1995). I selected these species because they represent a suite of habitat associations and territory sizes. Three species were associated with large sawtimber patches; the brown creeper (Certhia americana), gray jay (Perisoreus canadensis), and Hammond's flycatcher (Empidonax hammondii) (McGarigal 1993). The brown creeper is a bark forager that primarily utilizes tree boles (Harrap and Quinn 1995:187). The gray jay is an omnivore that gleans food from the ground and from foliage (Ehrlich et al. 1988:410). The Hammond's flycatcher sallies into open spaces below the forest canopy in pursuit of flying insects (Mannan 1984). It is listed as a large sawtimber-old growth associate by Brown (1985:105); however, studies by Carey et al. (1991) characterized the Hammond's flycatcher as a young (40 to 72 years old) forest associate. The red-breasted nuthatch (Sitta canadensis), a bark forager that utilizes branches more than boles, was found to be associated with patches of conifer large sawtimber (McGarigal and McComb 1995). The song sparrow (Melospiza melodia) is associated with shrubby areas and open sapling/pole patches (Brown 1985:136).

Residual plots of the indices of bird abundance were evaluated for normality and constant variance and revealed the need for transformation. The dependent variables were log-transformed ($\log_{10}(y + 1)$) (Sabin and Stafford 1990).

Prior to quantifying the landscape structure of the subbasins, I combined the mixed conifer/hardwood large sawtimber and the conifer large sawtimber vegetation classes to produce a single mixed and conifer large sawtimber class. I was unable to extract a > 53-cm hardwood class from the images. Some studies have suggested, however, that few bird species are associated with the large hardwood component of Coast Range forests (Carey et al. 1991). Subsequent use of the term 'large sawtimber' refers to the combined mixed and conifer large sawtimber class unless otherwise noted.

I quantified the landscape structure of every subbasin at each of the five MMU's using FRAGSTATS (McGarigal and Marks 1995). FRAGSTATS calculates indices of structure for each patch, for each patch type (class), and for the entire landscape. I used class indices to serve as the independent variables in regression analyses. I calculated 33 area and pattern metrics that can be grouped into broad categories (Table 2). I calculated several area metrics using FRAGSTATS. These quantify landscape composition but not pattern. Several core area metrics also were calculated using a 100-m buffer strip around each patch. This distance was chosen because other avian studies have shown that the effects associated with edge habitat, such as nest parasitism and predation, lessen considerably past 100 m (Temple 1986).

I used FRAGSTATS to calculate several metrics of patch density, size, and variability that represent the configuration of the landscape. I calculated several edge metrics using FRAGSTATS. I developed an edge-contrast weighting scheme similar to that used by McGarigal (1993). Weights ranged from 0 (no edge contrast) to 1 (maximum edge contrast). Each change in seral stage was given a weight of 0.2, while each change in plant community was given a weight of 0.05. Also, a change between a vegetation class with 0-80% tree canopy cover and a class with 81-100% tree canopy cover was given a weight of 0.05.

Many of the metrics provided by FRAGSTATS are redundant and may be highly correlated with each other (McGarigal and Marks 1995). In order to reduce the number of independent variables, I used Pearson's product moment correlation analysis (SAS Inst. Inc. 1990a:209). For pairs of variables that were highly correlated ($r \geq 0.80$), I eliminated one of the variables based partly on its interpretability as an ecological

Table 2. Landscape metrics derived for 30 subbasins in the Oregon Coast Range using FRAGSTATS.

Acronym	Index name (units)	Description
Area Metrics		
CA	Class area (ha)	Amount of landscape in a particular patch type.
TA	Total landscape area (ha)	Total landscape area.
%LAND	Percentage of landscape (%)	Percentage of landscape in a particular patch type.
LPI	Largest patch index	Percentage of landscape in largest patch of a particular patch type.
Patch Density, Size, And Variability Metrics		
NP	Number of patches (#)	Number of patches
PD	Patch density (#/100 ha)	Density of patches.
MPS	Mean patch size (ha)	Average size of patch.
PSSD	Patch size standard deviation (ha)	Measure of absolute variation in patch size.
PSCV	Patch size coefficient of variation (%)	Measure of relative variation in patch size.
Edge Metrics		
TE	Total edge (m)	Total edge length of a particular patch type.
ED	Edge density (m/ha)	Density of edge of a particular patch type.
CWED	Contrast-weighted edge density (m/ha)	Density of edge between adjacent patches, weighted by differences in seral stage, plant community, and vegetation cover, of a particular patch type.
TECI	Total edge contrast index (%)	Total edge contrast as a percentage of maximum contrast.
MECI	Mean edge contrast index (%)	Mean patch edge contrast as a percentage of maximum contrast.
AWMECI	Area-weighted mean edge contrast index (%)	Similar to mean patch edge contrast, but patch edge weighted by patch area.

Table 2, continued

Acronym	Index name (units)	Description
Shape Metrics		
LSI	Landscape shape index	Landscape shape complexity.
MSI	Mean shape index	Average patch shape for a particular patch type.
AWMSI	Area-weighted mean shape index	Similar to average patch shape, but patch shape index weighted by patch area.
DLFD	Double log fractal dimension	Patch shape complexity
MPFD	Mean patch fractal dimension	Mean patch shape complexity
AWMPFD	Area-weighted mean patch fractal dimension	Similar to mean patch shape complexity, but patch shape weighted by patch area
Core Area Metrics		
C%LAND	Core area percentage of landscape (%)	Core area percentage of landscape in a particular patch type.
TCA	Total core area (ha)	Core area amount of landscape in a particular patch type.
NCA	Number of core areas (#)	Number of core areas
CAD	Core area density (#/100 ha)	Density of core areas
MCA1	Mean core area per patch (ha)	Mean core area per patch.
CASD1	Patch core area standard deviation (ha)	Measure of absolute variation in core area per patch.
CACV1	Patch core area coefficient of variation (%)	Measure of relative variation in core area per patch.
MCA2	Mean area per disjunct core (ha)	Mean area per disjunct core.
CASD2	Disjunct core area standard deviation (ha)	Measure of absolute variation in size of disjunct core areas.
CACV2	Disjunct core area coefficient of variation (%)	Measure of relative variation in size of disjunct core areas.
TCAI	Total core area index (%)	Percentage of landscape in core area of a particular patch type.
MCAI	Mean core area index (%)	Average percentage of a patch that is core area.

indicator and partly on subjective criteria. In general, I tended to retain metrics that described the landscape in relative, rather than absolute, terms because relative variables accounted for differences in subbasin size. I also correlated my habitat variables at each MMU with those of McGarigal's (1993) and, when possible, I retained those variables that were highly correlated (Table 3). I wished to retain at least one variable from each group of metrics and to restrict the number of independent variables to approximately one-half of the sample size (Devore and Peck 1986:537).

Table 3. Pearson's product moment correlations of landscape metrics of vegetation maps derived from Landsat Thematic Mapper (TM) data with metrics of vegetation maps derived from interpretation of aerial photographs for 30 subbasins in the Oregon Coast Range. Metrics shown were derived from the large sawtimber vegetation class. Bold indicates significance level (p) ≤ 0.05.

	Minimum Mapping Unit (ha)									
	0.06		0.25		1.00		4.00		16.00	
Variable	r	P	r	P	r	P	r	P	r	P
%LAND	**+0.79**	**<0.01**	**+0.78**	**<0.01**	**+0.78**	**<0.01**	**+0.75**	**<0.01**	**+0.70**	**<0.01**
MPS	**+0.40**	**0.03**	**+0.50**	**<0.01**	**+0.53**	**<0.01**	+0.31	0.10	+0.30	0.11
CWED	+0.14	0.45	+0.03	0.88	+0.15	0.42	+0.34	0.07	+0.28	0.13
AWMECI	**+0.65**	**<0.01**	**+0.53**	**<0.01**	**+0.52**	**<0.01**	**+0.36**	**0.05**	+0.23	0.22
AWMSI	-0.18	0.33	-0.20	0.28	-0.23	0.22	-0.13	0.50	-0.02	0.92
C%LAND	+0.21	0.27	**+0.44**	**0.02**	**+0.57**	**<0.01**	**+0.56**	**<0.01**	**+0.54**	**<0.01**
TCAI	+0.12	0.52	+0.33	0.08	**+0.47**	**0.01**	**+0.53**	**<0.01**	**+0.53**	**<0.01**

After variable elimination, I retained a total of 15 habitat variables for the regression analysis. Six variables expressed aspects of landscape structure for the focal patch type: mean patch size, contrast-weighted edge density, area-weighted mean edge contrast index, area-weighted mean shape index, core area percentage of landscape, and total core area index. I defined focal patch type as the type with which McGarigal and McComb (1995) found each species to be most closely associated. The remaining 9 variables were the proportional abundance of landscape in each of the patch types except for water and shadow/burned clearcut. I omitted water because it was uncommon in the study area. I also omitted shadow/burned clearcut because I was unable to distinguish one from the other. Water and shadow/burned clearcut accounted for 1.2% and 5.5%, respectively, of the total vegetation classes across the 3 basins.

Stepwise multiple regression analysis was used to examine relationships between bird abundance and landscape (habitat) variables. Variables were required to have a significance level ≤ 0.05 for entering into and staying in the regression models (SAS 1990b:1367).

I used the large sawtimber vegetation class as the focal patch type for brown creeper, gray jay, Hammond's flycatcher, and red-breasted nuthatch. The open vegetation class was used as the focal patch type for the song sparrow. To examine abundance and habitat relationships, I used only subbasins in which the focal patch type was present. The large sawtimber vegetation class was present in all subbasins ($\underline{n} = 30$). For the song sparrow, I was limited by the number of subbasins that contained the open canopy class. The maximum number of subbasins containing open vegetation was 19, and this number decreased consistently with coarser MMU. Therefore, I used a slightly different technique. I was limited by degrees of freedom to only the 3 finer MMU's (n=19 at 0.06 ha, n=17 at 0.25 ha, and n=14 at 1 ha). I performed 2 separate regressions. First I included only the proportional abundance for each patch type in a multiple linear regression and determined which patch type(s) showed a strong ($p \leq 0.05$) positive or negative association with song sparrow abundance. Then I included only these patch types and the habitat structural variables in a separate regression.

RESULTS

Effects of Minimum Mapping Unit on Patch Type

The composition of habitat patches in the 3 basins varied depending on MMU. As MMU increased (i.e., became coarser), patches that were smaller and more fragmented disappeared while larger, homogeneous patches tended to increase in size. Although there were slight differences in each of the 3 basins, some general tendencies were consistent among basins. As MMU became coarser, the area in hardwood small/large sawtimber class increased while area of conifer large sawtimber showed a moderate gain (Figure 3). The amount of area in the mixed small sawtimber, mixed large sawtimber, hardwood sapling/pole, and open classes decreased. All other classes showed little or no variation in composition across MMU's.

Correlation Analysis

In general, the landscape variables that I used in my regression analyses were highly correlated with McGarigal and McComb's (1995). This was evident particularly at my 1-ha MMU which was close to the minimum patch size of 0.8 ha that McGarigal and McComb (1995) used for vegetation mapping. At 1 MMU, 5 of the 7 variables showed a significant correlation. The proportional abundance of large sawtimber as I defined it was highly correlated with large sawtimber as defined by McGarigal and McComb (1995) at all MMU's (Table 3). Edge indices were correlated at finer MMU's but not at the coarser MMU's. Core area metrics tended to be better correlated at the coarser MMU's. Shape metrics were not correlated at any MMU. This is not surprising

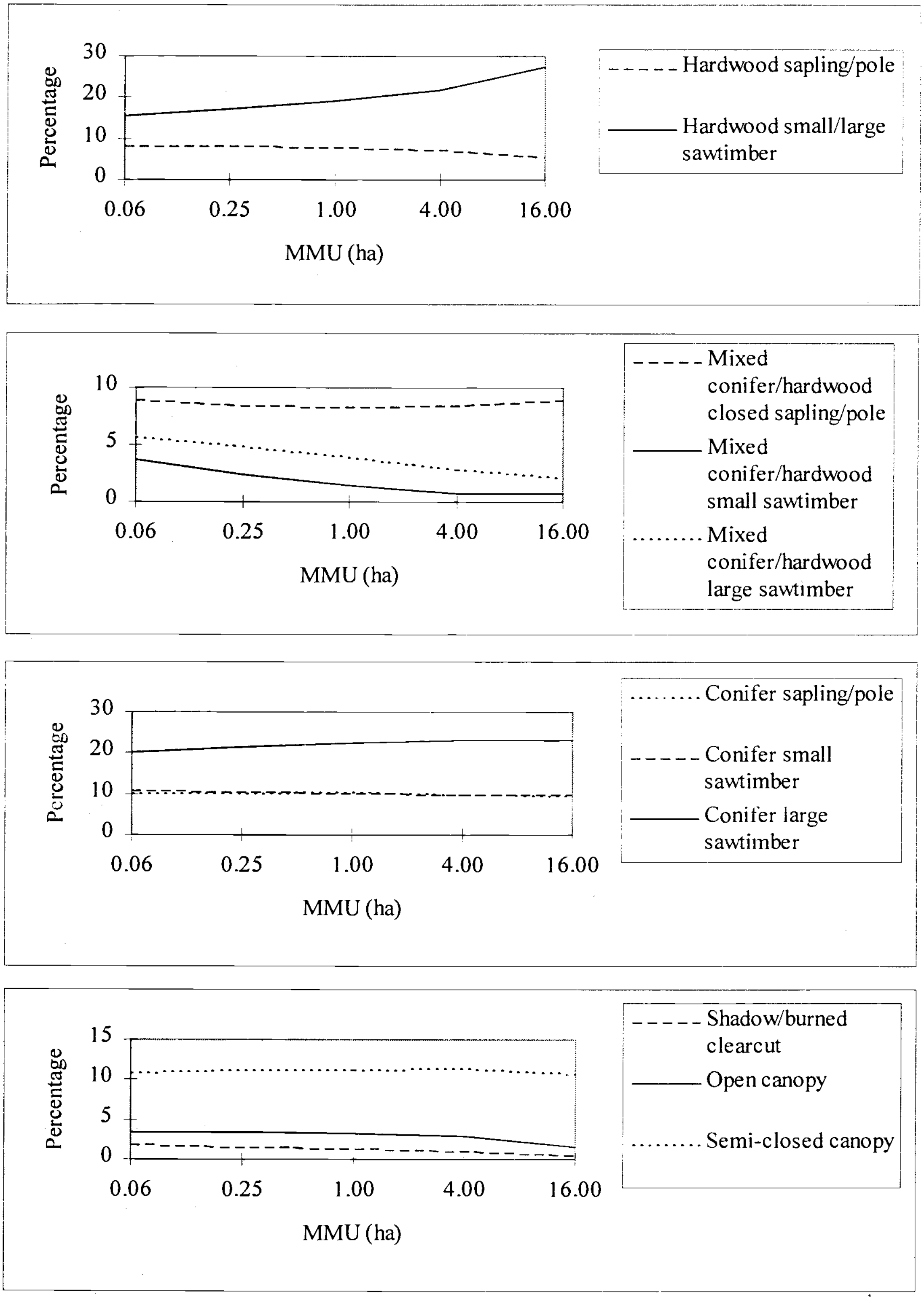

Figure 3. Percentage of vegetation classes at 5 minimum mapping units (mmu). Percentages were averaged among Drift Creek, Lobster Creek, and Nestucca River basins in the Oregon Coast Range.

because of the differences in the manner in which vegetation data were represented (raster vs. vector).

Regression Analysis

For the four bird species associated with large sawtimber, the proportional abundance of a subbasin in large sawtimber explained much of the variation in abundance at all MMU's (42-78%) with the exception of gray jay at the 0.06-ha MMU (Table 4). The percent of subbasin in large sawtimber explained 73-78% of the variation in brown creeper abundance at all MMU's. Mean patch size of large sawtimber explained an additional 4-5 % of the variance in abundance at the 3 finer MMU's (0.06, 0.25 and 1 ha) and was negatively associated with brown creeper abundance. Mean patch sizes (ha) at each MMU were as follows: 3.2 at 0.06 ha, 6.2 at 0.25 ha, 11.1 at 1 ha, 21.2 at 4 ha, and 25.2 at 16 ha. The percentage of landscape in large sawtimber core area (>100 m from edge) was positively associated with brown creeper abundance at a 0.25-ha MMU. Core area size ranged from 0 to 10.6 ha with a mean of 2.2 ha at the 0.25-ha MMU.

For the gray jay, the amount of variation in abundance explained by percentage of subbasin in large sawtimber ranged from 42-47% at 4 of 5 MMU's. There was no association between gray jay abundance and proportional abundance of the subbasin in large sawtimber at the finest (0.06 ha) MMU using my parameters. The only other habitat variable associated with gray jay abundance was contrast-weighted edge density at the 0.06-ha MMU.

Percentage of the subbasin in large sawtimber explained 53-59% of the variation in Hammond's flycatcher abundance at all MMU's. Percentage of each subbasin in mixed conifer and hardwood small sawtimber was associated with Hammond's flycatcher abundance at the 3 coarsest MMU's (1, 4, and 16 ha). In addition, percentage of each subbasin in the open canopy class explained 6% of the variation in abundance at the 1-ha MMU.

Over half of the variation in red-breasted nuthatch abundance was explained at all MMU's (50-58%) by percentage of subbasin in large sawtimber. Abundance of this species showed a negative association with mean patch size of large sawtimber only at the coarsest (16-ha) MMU.

For the song sparrow, percentage of landscape in the hardwood small/large sawtimber class explained 49-51% of the variation in abundance at the 3 MMU's I analyzed. Contrast-weighted edge density explained an additional 13% of variation in abundance at the 0.06-ha MMU and an additional 16% at 0.25 ha. Song sparrow abundance was negatively associated with percentage of landscape in open canopy core area at the 0.25-ha MMU. It should be noted that, although the proportional abundance of landscape in open canopy was not included in model, it narrowly missed entry into the model at 0.06-ha MMU (p=0.053). At the 0.25-ha MMU, 15% of the variation in song sparrow abundance was explained by the percentage of landscape in open canopy in the first regression model of patch areas, but it showed no association with abundance in the second regression model of patch areas and patch structural variables.

Table 4. Results of multiple linear regression analysis for brown creeper, gray jay, Hammond's flycatcher, and red-breasted nuthatch based on mixed and conifer large sawtimber as the focal patch type, and song sparrow based on open canopy as the focal patch type for 30 subbasins in the Oregon Coast Range.

Bird Species	Resolution (ha)	Variable	Coefficient	*P*-value	Partial R^2	Model $R^{2\,a}$	Adjusted R^2
Brown creeper	0.06	constant	-0.002	0.928			
		%LAND	0.009	<0.001	0.73	0.73	
		MPS	-0.009	0.015	0.05	0.79	0.77
	0.25	constant	0.020	0.429			
		%LAND	0.009	<0.001	0.74	0.74	
		MPS	-0.014	0.020	0.05	0.79	
		C%LAND	0.021	0.028	0.04	0.82	0.80
	1	constant	0.034	0.167			
		%LAND	0.008	<0.001	0.74	0.74	
		MPS	-0.005	0.033	0.04	0.78	0.76
	4	constant	0.060	0.016			
		%LAND	0.006	<0.001	0.74	0.74	0.73
	16	constant	0.070	0.002			
		%LAND	0.006	<0.001	0.78	0.78	0.77

Table 4, continued

Bird Species	Resolution (ha)	Variable	Coefficient	*P*-value	Partial R^2	Model $R^{2\,a}$	Adjusted R^2
Gray jay	0.06	constant	-0.035	0.168			
		CWED	0.004	<0.001	0.49	0.49	0.47
	0.25	constant	0.017	0.301			
		%LAND	0.002	<0.001	0.45	0.45	0.43
	1	constant	0.021	0.179			
		%LAND	0.002	<0.001	0.47	0.47	0.45
	4	constant	0.029	0.062			
		%LAND	0.002	<0.001	0.43	0.43	0.41
	16	constant	0.034	0.023			
		%LAND	0.002	<0.001	0.42	0.42	0.40

Table 4, continued

Bird Species	Resolution (ha)	Variable	Coefficient	*P*-value	Partial R^2	Model R$^{2\,a}$	Adjusted R^2
Hammond's flycatcher	0.06	constant	0.015	0.659			
		%LAND	0.006	<0.001	0.53	0.53	0.52
	0.25	constant	0.022	0.510			
		%LAND	0.006	<0.001	0.54	0.54	0.53
	1	constant	-0.006	0.833			
		%LAND	0.005	<0.001	0.55	0.55	
		%LAND MIXED SMALL SAWTIMBER	0.033	0.006	0.08	0.63	
		%LAND OPEN CANOPY	0.012	0.029	0.06	0.70	0.66
	4	constant	0.046	0.068			
		%LAND	0.004	<0.001	0.59	0.59	
		%LAND MIXED SMALL SAWTIMBER	0.028	0.006	0.10	0.69	0.67
	16	constant	0.054	0.026			
		%LAND	0.004	<0.001	0.58	0.58	
		%LAND MIXED SMALL SAWTIMBER	0.020	0.003	0.12	0.70	0.67

Table 4, continued

Bird Species	Resolution (ha)	Variable	Coefficient	*P*-value	Partial R^2	Model $R^{2\,a}$	Adjusted R^2
Red-breasted nuthatch	0.06	constant	0.005	0.774			
		%LAND	0.003	<0.001	0.51	0.51	0.49
	0.25	constant	0.009	0.607			
		%LAND	0.003	<0.001	0.51	0.51	0.49
	1	constant	0.015	0.393			
		%LAND	0.003	<0.001	0.53	0.53	0.51
	4	constant	0.023	0.163			
		%LAND	0.002	<0.001	0.50	0.50	0.48
	16	constant	0.020	0.144			
		%LAND	0.003	<0.001	0.58	0.58	
		MPS	-0.001	0.040	0.06	0.64	0.61

Table 4, continued

Bird Species	Resolution (ha)	Variable	Coefficient	*P*-value	Partial R^2	Model R^2 [a]	Adjusted R^2
Song sparrow	0.06	constant	0.174	0.003			
		%LAND HARDWOOD SMALL/LARGE SAWTIMBER	0.012	0.002	0.51	0.51	
		CWED	0.062	0.029	0.13	0.64	0.60
	0.25	constant	0.163	0.001			
		%LAND HARDWOOD SMALL/LARGE SAWTIMBER	0.009	0.007	0.51	0.51	
		CWED	0.081	0.001	0.16	0.67	
		C%LAND	-0.237	0.007	0.15	0.82	0.77
	1	constant	0.290	<0.001			
		%LAND HARDWOOD SMALL/LARGE SAWTIMBER	0.009	0.005	0.49	0.49	0.44

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[a] NOTE: Sums may differ slightly from partial r^2 values due to rounding errors.

DISCUSSION

Vegetation Mapping

The pixel aggregation technique that I used to produce images at different MMU's causes smaller, highly fragmented habitat patches to dissolve at coarser MMU's. Private lands in these subbasins are mainly industrial forest land on which large tracts of young (0-40 years), even-aged Douglas-fir plantations predominate. On the private lands, a matrix of late-seral Douglas-fir and red alder forest is mixed with young, even-aged Douglas-fir plantations 8 to 25 ha in size (McGarigal 1993).

The mixed conifer/hardwood small and large sawtimber patches declined the most as MMU increased, indicating that these habitats are the smallest and most highly fragmented in basins used for this study (Figure 3). The greatest increase was seen in the hardwood small/large sawtimber class. The area of habitat patches in conifer did not differ significantly among MMU's.

Similar results were reported by Turner (1990), who found that as resolution became coarser, less dominant cover types always decreased and less dominant cover types that were dispersed disappeared more rapidly than those that were clumped.

Bird-Habitat Relationships

Brown Creeper

The percentage of each subbasin in the combined mixed and conifer large sawtimber class consistently explained much of the variation in abundance (73-78 %) for brown creepers at every MMU. This is in agreement with other studies that have found a positive correlation between brown creeper abundance and large (>100 cm dbh) trees in the Oregon Coast Range (Carey et al. 1991) and in the southern Washington Cascades (Mariani and Manuwal 1990). The association of brown creeper abundance with the mixed component of forest patches also is consistent with the results of Adams and Morrison (1993), who observed highest abundance of brown creepers in forest stands with diverse tree species composition in the Sierra Nevada.

Brown creeper abundance was negatively associated with mean patch size at the 3 finer MMU's. Mean patch size is one measure of the degree of forest fragmentation. A smaller mean patch size indicates a higher degree of fragmentation. This association is consistent with the results of McGarigal and McComb (1995) who found that brown creepers occupied landscapes in which large sawtimber patches were more heterogeneous or fragmented.

Davis (1978) observed brown creeper territory sizes ranging from 2.3 to 6.4 ha. The mean percentage of a subbasin in large sawtimber core area at 0.25-ha MMU is 1.3 ha, which is very close to the lower estimate of brown creeper territory size. Brown creeper abundance showed a positive association with this core area variable and suggests that large sawtimber core area patches may provide suitable habitat if they are at least the same size as the territory.

Gray Jay

Percentage of large sawtimber did not explain any variation in gray jay abundance at the finest (0.06-ha) MMU. In fact, there was a non-significant (p=0.29) negative association between gray jay abundance and percentage of large sawtimber. Contrast-weighted edge density explained 49% of the variation in abundance at the 0.06-ha MMU. At the remaining 4 MMU's, gray jay abundance was associated only with the proportional abundance of large sawtimber, explaining 42-47% of the variation in abundance. The gray jay is a large sawtimber associate, and it is expected that the percentage of subbasin in mixed and conifer large sawtimber would explain a substantial amount of the variation in abundance. The relatively low explanatory power of the regression models in comparison to other large sawtimber associates may be due to processes that are operating above the coarsest MMU I used in my study and may be related to the gray jay's estimated territory size of 41 ha (Shank 1986).

Hammond's Flycatcher

In addition to the percentage of large sawtimber in a subbasin, the percentage of mixed conifer/hardwood small sawtimber in each subbasin explained an additional 6-12% of the variation in bird abundance at the 3 coarser MMU's. This trend is first evident at the 1-ha MMU, which corresponds approximately to the Hammond's flycatcher's estimated territory size of 0.6-1.5 ha (Manuwal 1970). It is also at 1 ha that species abundance shows a positive association with percentage of open canopy (0-40% tree cover). This is consistent with other studies that indicate the preference of the Hammond's flycatcher for habitats with a combination of tall (13-20 m), dense, mixed conifers and hardwoods and dense deciduous vegetation with canopy openings (Manuwal 1970).

Red-breasted Nuthatch

The red-breasted nuthatch is normally associated with conifer large sawtimber (McGarigal 1993). The relatively weak relationships between nuthatch abundance and percentage of landscape in large sawtimber may be due to the inclusion of mixed conifer/hardwood large sawtimber. The r^2 value for the red-breasted nuthatch increased significantly at the 16-ha MMU. At this MMU, the percentage of mixed large sawtimber among the 3 basins was at its lowest level (< 1%) before the mixed large sawtimber class was combined with the conifer large sawtimber class (Figure 3). Since the percentage of conifer large sawtimber remained constant among the 5 MMU's, the ratio of conifer to mixed was highest in the combined mixed and conifer large sawtimber class at the 16-ha MMU. This may account for the increase in the amount of variation in red-breasted nuthatch abundance explained by percentage of the large sawtimber class in a subbasin at the 16-ha MMU.

Red-breasted nuthatch abundance was negatively associated with mean patch size of large sawtimber at the 16 ha MMU. Mean patch size ranged from 0-198 ha with a mean of 25 ha. Larger mean patch size at coarse MMU's indicates a more homogeneous landscape. These results are consistent with Hawrot and Niemi (1996), who suggest that red-breasted nuthatch abundance is positively associated with subtle edges and a more fragmented landscape. I was unable to find data on the territory size of the red-breasted nuthatch. Brown (1985:115), however, estimated breeding bird densities at 1-3 breeding birds/ha, providing an estimated territory size of 0.3-1 ha.

Song Sparrow

It was unexpected that the percentage of subbasin in hardwood small/large sawtimber, rather than open canopy patch type (Brown 1985:135), explained about half (49-51%) of the variation in song sparrow abundance at the 3 MMU's I used. This result may be a function of the edges associated with the hardwood small/large sawtimber patch type rather than patch composition. Song sparrow abundance was positively associated with contrast weighted edge density at the 0.06- and 0.25-ha MMU's. There was a strong negative association between bird abundance and the percent of core area in open canopy at the 0.25-ha MMU. These results may represent the song sparrow's preference for edges (Brown 1985:137). The 0.25-ha MMU corresponds quite well with the estimated 0.28-ha territory size of the song sparrow (Brown 1985:135) and may indicate that the species perceives landscape patches at the size of its territory.

Scope and Limitations

My study was limited by the resolution of the data. Bird abundance may be affected by processes that are acting above or below the limits of resolution. For example, Wiens and Rotenberry (1981) found that some species of shrubsteppe birds were associated with certain habitat variables at a continental scale. Yet, the same species were associated with completely different habitat variables at a regional scale. Landscape patterns smaller than the grain size cannot be detected (Schulz and Joyce 1992), although it seems an unlikely scenario because the territory sizes of the species I studied were larger than the finest minimum mapping unit I used. My research did not take into account within-patch structural features such as snag abundance or downed logs. These data were not available from the Landsat TM imagery that I used. These features are particularly important for the red-breasted nuthatch and the brown creeper and certainly would be expected to affect their abundance.

Interactions of habitat variables and temporal variations in bird abundance can affect the wildlife-habitat relationship models. I did not account for interactions between or among habitat variables that may be suggested by other statistical techniques such as principal components analysis. For example, McGarigal (1993) found that a gradient of patch shape and edge contrast helped explain 33% of the variance in gray jay abundance. In my study, I only looked at spatial aspects and did not account for temporal aspects such as seasonality and changes in bird abundance from year to year.

Conclusions and Management Implications

Data on landscape composition and structure obtained from Landsat TM satellite imagery can be useful for determining relationships between bird abundance and habitat, at least for the bird species and range of minimum mapping units I investigated. Patch composition seems to be more important in determining the abundance of bird species associated with large sawtimber than patch structural attributes such as edge contrast and patch shape. Abundances of the four bird species associated with large sawtimber that I analyzed responded positively to the percentage of mixed and conifer large sawtimber in each subbasin at all MMU's, although the strength of the relationships varied among species and MMU's. The levels of association may be changing based on the MMU because of the manner in which the bird species perceive habitat patches. Abundance of the song sparrow, an open canopy associate, showed no association with the percentage of subbasin in open canopy; rather, it responded to the amount of each subbasin in hardwood small/large sawtimber. This may be due more to the edge habitat associated with these patches rather than to the composition of the hardwood small/large sawtimber patches themselves. The relationship between song sparrow abundance and patch composition would probably be strengthened by the inclusion of a true grass/forb or shrub vegetation class (Brown 1985:26). The Landsat TM data available did not allow me to delineate these classes.

Landsat TM data can complement field data collection used to describe some aspects of wildlife habitat structure and composition. It allows more efficient and cost-effective description of vegetation data over larger areas than traditional field methods. If investigators are to use the data for making land management decisions, however, it is imperative that they select the correct minimum mapping unit or grain size and areal extent for the species in question.

One potential method for determining the appropriate minimum mapping unit and extent at which to investigate bird-habitat relationships is to use territory size of the individual species under consideration. For bird species with small territory sizes, a MMU equal to or smaller than their territory size is important for capturing habitat features that are associated with its abundance. For example, the Hammond's flycatcher has an average territory size of approximately 1 ha (Manuwal 1970). At this MMU in my study, there is a considerable increase in the amount of variation in Hammond's flycatcher abundance explained by the habitat variables. Other species with large territory sizes, such as the gray jay, may require a coarser MMU to determine habitat features that are associated with bird abundance. I was not able to investigate this in my study, however, because the gray jay's territory size is larger than the coarsest MMU I used. The extent of the study area should exceed the bird's territory size if associations between abundance and habitat variables are to be detected.

Recommendations for future research include expanding the scope of the study and model validation. Because my study was based on empirical data, I can only infer that the relationships I observed are valid for the 250-300-ha extent of my subbasins and for the 5 MMU's I used. The scope of inference could be expanded by assessing changes in bird-habitat relationships at coarser MMU's. For example, it would be interesting to investigate relationships of habitat and gray jay abundance at MMU's above the gray jay's estimated 41-ha territory size. Model validation would involve testing bird-habitat relationship models at other locations (Morrison et al. 1992:331). Model validation also would include an additional assessment of the accuracy of the structural characteristics of the Landsat TM data.

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APPENDICES

Appendix 1. Similarity matrix of vegetation classes for pixel aggregation of Landsat TM satellite data in Drift Creek, Lobster Creek, and Nestucca River basins in the Oregon Coast Range. Higher number indicates more similarity.

	Hardwood sapling/pole	Hardwood small/large sawtimber	Mixed closed sapling/pole	Mixed small sawtimber	Mixed large sawtimber	Conifer sapling/pole	Conifer small sawtimber	Conifer large sawtimber	Shadow/ burned clearcut	Open canopy	Semi-closed canopy
Hardwood small/large sawtimber	9.21										
Mixed closed sapling/pole	8.94	27.74									
Mixed small sawtimber	4.87	7.86	9.67								
Mixed large sawtimber	4.26	6.87	7.78	26.73							
Conifer sapling/pole	7.27	9.25	13.61	11.11	7.88						
Conifer small sawtimber	3.80	5.41	6.21	16.67	19.61	7.27					
Conifer large sawtimber	2.88	3.88	4.15	7.02	8.80	4.39	10.98				
Shadow/ burned clearcut	2.19	2.86	2.87	3.55	4.08	2.72	3.99	5.50			
Open canopy	2.10	2.64	2.51	2.51	2.69	2.19	2.47	2.61	3.91		
Semi-closed canopy	3.78	5.92	5.23	4.56	4.85	3.90	4.01	3.65	3.80	4.72	

Appendix 2. Landsat Thematic Mapper images of a sample subbasin in the Oregon Coast Range at 5 minimum mapping units (MMU).