AN ABSTRACT OF THE THESIS OF

Lori A. Hennings for the degree of Master of Science in Wildlife Science with a minor in Forest Science presented on April 26, 2001. Title: Riparian Bird Communities in Portland, Oregon: Habitat, Urbanization, and Spatial Scale Patterns

Abstract Approved: _______________________
W. Daniel Edge

Urban ecosystems are characterized by human disturbance and changes in the amount, types, and spatial arrangement of wildlife habitat. The relative importance of habitat and human-associated variables to urban birds is unknown. In 1999, I surveyed spring bird and plant communities along 54 perennial streams in the Portland, Oregon metropolitan region. My objectives were to determine (1) what habitat and human-associated variables were related to avian community measures, (2) how far from riparian areas did relationships between avifauna and canopy cover and development extend, and (3) habitat characteristics associated with individual bird species. I used Principal Components Analysis to cluster and reduce the number of explanatory variables, and regressed bird community variables against the resulting principal components. Total and nonnative bird

abundance were negatively related to the first principal component, PC1 (high-scoring PC1 sites had wide, structurally complex native forests) ($r^2 = 0.38$, $P < 0.0001$ and $r^2 = 0.63$, $P < 0.0001$, respectively). Several weak ($r^2 = 0.17$-0.31, $P < 0.003$) curvilinear relationships emerged between overall and native species richness and diversity versus PC1. Neotropical migratory bird (NMB) species richness and diversity were negatively related to human development variables, and positively related to native shrubs (adjusted $r^2 = 0.21$ and 0.18, respectively; $P < 0.003$). I regressed bird community variables against canopy cover and street density for each of ten 50-m buffers around sites, then plotted the model fit (r^2) against buffer width. Native and nonnative abundance measures were negatively related to canopy cover. Total abundance was best predicted by canopy cover 300-350 m from the stream whereas nonnative abundance was predicted nearly equally by canopy cover in each buffer. The relationships between total species richness, native species richness, total diversity and native diversity were curvilinearly related to canopy cover, with canopy in the first 50 m appearing most important. Neotropical migratory bird species richness, diversity and abundance were negatively related to street density within 150 m of the stream. Brown-headed Cowbird (*Molothrus ater*) abundance was increasingly, negatively related to canopy cover as spatial scale increased. I used logistic regression to identify habitat and/or human-associated variables that predicted the occurrence of 32 species. The occurrence of four species (American Crow [*Corvus brachyrhynchos*], House Finch [*Carpodacus mexicanus*], Red-breasted Nuthatch

[*Sitta canadensis*], and Vaux's Swift [*Chaetura vauxi*]) was positively, and five species (Black-headed Grosbeak [*Pheucticus melanocephalus*], Common Yellowthroat [*Geothlypis trichas*], Rufous Hummingbird [*Selasphorus rufus*], Steller's Jay [*Cyanocitta setlleri*], and Swainson's Thrush [*Catharus ustulatus*]) negatively related to human-associated variables. My results suggest that increasing urban canopy cover is the most valuable land management action for many breeding bird species. Preserving large undeveloped habitats and controlling urban sprawl may help prevent regional declines of NMB species.

RIPARIAN BIRD COMMUNITIES IN PORTLAND, OREGON: HABITAT, URBANIZATION, AND SPATIAL SCALE PATTERNS

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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In loving memory of Virginia Barnes and Tracy Chitwood

RIPARIAN BIRD COMMUNITIES IN PORTLAND, OREGON: HABITAT, URBANIZATION, AND SPATIAL SCALE PATTERNS

INTRODUCTION

Human population growth, combined with an increasing proportion of U.S. citizens living in or near cities, is creating fundamental shifts in the amount, types, and spatial configuration of wildlife habitat (McDonnell and Pickett 1990; Parlange 1998). From 1970 to 1990, 7.7 million ha of U.S. rural lands became urban. In the Portland, Oregon urban region, population doubled between 1940 and 1970, and the amount of land occupied quadrupled (Loy et al. 1976). Oregon's population is projected to increase another 32% by 2025 (U.S. Census Bureau 2000; Oregon Progress Board 2000). The Portland urban area currently comprises approximately 3% of the state's total area and contains nearly 42% of the state's population (Portland State University 2000; Torgerson 2000).

Ecologists view urban areas as distinct ecosystems with characteristic structures, processes, and functions common to cities worldwide (Marzluff et al. 1998; Parlange 1998). However, we are still building the knowledge base necessary to manage urban ecosystems for both people and wildlife, and the rapid proliferation of urban habitats adds a sense of urgency to these efforts.

Urbanization permanently changes the land cover and habitat available to birds and other biota by creating dwellings, industrial areas, transportation systems, and other systems supporting human occupation of the land (Marzluff et al. 1998). In riparian habitats these changes manifest in terms of the quality and quantity of available habitat, alterations in patch dynamics, disturbance, and alterations in plant and wildlife community composition (Adams and Dove 1989; Baschak and Brown 1995; Martin and Finch 1995). Some changes, such as increased bird abundance and proliferation of non-native and generalist species, are common to cities worldwide (Marzluff et al. 1998). Other alterations, such as shifts in species composition, migratory guilds and scale-dependent responses to habitat changes, are largely unknown and may be region-specific. For example, Brown-headed Cowbird nest parasitism appears to increase in some urban areas, but not others (Hahn and Hatfield 1995; Nilon et al. 1995).

In urban ecosystems the relative importance of habitat and human-associated variables is unknown, and may depend on regional vegetation characteristics and urbanization patterns. For example, in southern California, Guthrie (1974) compared bird communities between suburbs and native sage-scrub habitat. Bird diversity was similar and abundance was higher in suburbs compared to native habitats, attributed to enhanced vegetation cover and diversity in suburban habitats. Rosenberg et al. (1987) documented similar findings in Tempe, Arizona. These study areas have naturally sparse nonurban vegetation. However, in Santa Clara, California vegetation is lusher, and the composition of the bird community shifted from predominantly native species in undisturbed habitats to invasive and exotic species in the most developed area, apparently related to habitat structure along the urban gradient (Blair 1996). Diversity and species richness peaked in moderately disturbed sites. Clergeau et al. (1998) detected a pattern of decreasing spring bird diversity from least to most urbanized areas in two major cities on different continents. Goldstein et al. (1986) found that woody vegetation volume alone accounted for 50% of the variation in breeding bird species richness in Amherst, Massachusetts.

Evidence linking urbanization to habitat structure and nonnative plant communities has important implications for native birds. Native birds tend to prefer native plants and structurally complex habitats (Rosenberg et al. 1987; Mills et al. 1991; Case 1996; Germaine et al. 1998), while nonnative birds prefer nonnative plants and simplified habitats (Mills et al. 1991; Munyenyembe et al. 1989; Case 1996; Pavlik and Pavlik 2000). Areas strongly impacted by humans harbor less native plant communities and more nonnative birds, factors that probably negatively influence the majority of native bird species. Thus, both habitat and human-associated variables are likely to be important, while their relative importance may change regionally.

In non-urban habitats, spatial scale influences variables important to birds (Freemark and Merriam 1986; McGarigal and McComb 1995; Saab 1999). Organisms probably use more than one spatial scale for habitat selection, perhaps based on a hierarchical scheme. Similar studies conducted under different scales may yield apparently conflicting results (Haney 1999). The spatial scale appropriate for any study depends on the questions asked, the organisms studied, and the time periods considered; in relatively unstudied systems such as urban habitats, determining appropriate spatial scales should precede or accompany ecological studies (Wiens 1989).

In 1999, I surveyed spring bird and plant communities in 54 sites along small perennial streams in the Portland, Oregon urban region. My first goal was to determine what habitat or development variables were associated with avian abundance and community measures (nonnative, total, and Neotropical migratory bird [NMB] abundance; native and NMB species richness; and native, total, and NMB Shannon diversity). My second goal was to explore the spatial extent, within 500 m of each site, of the relationships between bird community variables and forest canopy cover, proportion of vacant lands, and street density. My third goal was to assess species-habitat relationships, including habitat and development variables, for species occurring with sufficient frequency for analysis.

STUDY AREA

The Portland study area encompasses portions of three counties (Clackamas, Multnomah, and Washington) in the northern Willamette Valley in northwest Oregon, an area roughly 55 x 30 km (Appendix 1). Metro Regional Services (Metro) directs regional master planning processes such as growth management, habitat protection, and parks and greenspaces planning and acquisition. The study area includes Metro's 95,648-ha urban growth boundary (UGB) plus a buffer of 1.6 km. Portland's climate is mild, with wet winters and warm, dry summers. Precipitation averages 95 cm/year, falling primarily as rain from October through May (Portland Parks and Recreation 1995). The average temperature in January is 3.8°C and 19.8°C in July (Torgerson 2000).

The Willamette River flows into the Columbia River at the northern portion of the city. Rivers and their numerous tributaries comprise over 1,600 km of waterways within the Portland region's UGB. The Portland region originally contained approximately 2,092 km of streams, but an estimated 644 km (31%) have been lost or culverted through development (Metro Growth Management Services 1999). In undisturbed conditions, uplands were dominated by western hemlock (*Tsuga heterophyla*), while lowland valleys were dominated by Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and Oregon white oak (*Quercus garryana*) (Lev and Sharp 1991; Poracsky 1991). Riparian habitats in 2000 contain remnants of once-extensive stands of black cottonwood (*Populus trichocarpa*), Oregon ash (*Fraxinus latifolia*), red alder (*Alnus rubra*), and willow (*Salix* spp.). In 1989, Metro estimated 59,489 ha of natural areas remained in the Portland region; a decade later 6,475 ha (11%) had been lost or substantially altered. However, nearly 11% (10,092 ha) of total lands within the UGB were preserved as parks, greenspaces and open spaces (Metro Regional Services 2000).

METHODS

SITE SELECTION

I used ArcView and Metro's GIS themes including parks and open space, stream routes, tax lots, and 1998 and 1999 aerial photos to identify potential study sites on public land (for metadata see Metro Regional Services 2000). My *a priori* selection criteria were small, perennial streams (approximately 1-8 m channel width) on public land that were dominated by deciduous forest and whose lengths were sufficient to include four or five point count stations (550-700 m). I focused on small streams because they are numerous in the region and on deciduous habitat because it is the most common habitat type on small streams in the study area. I identified 54 sites within the study area (Appendix 1). Sites included all available sites that met my criteria, with three exceptions: one site was omitted for safety reasons, and two were omitted because steep slopes caused too much water noise to hear birds.

BIRD SAMPLING

At each site I established four or five point count stations (sample units) along the stream for bird surveys, each separated by 150 m. We surveyed birds three times per site during May and June 1999, once each during early, mid, and late spring. Each survey at a site was conducted by a different observer to reduce observer bias. We alternated starting ends and alternated order of survey (first or second surveyed that day) to reduce time-of-day bias. We recorded each bird seen or heard at a point count station within a 50-m radius; point counts lasted for 8 min after a 2-min waiting period. We began surveys at sunrise and ended by 0930 h, avoiding rainy or windy conditions. Number of detections per station was averaged by species over the three surveys, and all the stations at a site were averaged to yield site-level bird information. Thus, my index of bird abundance is the average number of bird detections per point count station. Similarly, species richness is the average number of species, and diversity is average Shannon diversity (see Magurran 1988:35 for diversity equation), per visit at a point count station.

VEGETATION SAMPLING

In late June and July 1999, I measured or visually estimated habitat variables relating to riparian forest structure, composition and human disturbance (Appendix 2). I established three 7-m radius plots near the stream for each point count station (5.9% of total point count area). One plot was located at the point count station, and the other two were located 15 m perpendicular to the stream, 25 m laterally from each side of the first plot (Figure 1). Within each plot I visually estimated percent total, native and nonnative cover in herbaceous, low shrub (< 1.5 m), high shrub (1.5-7.0 m), and canopy layers, and percent cover of downed wood, trails, and impervious surfaces (see Appendix 3 for descriptive statistics for variables). Data for the three vegetation plots were averaged for each point count station, then stations were averaged to yield site-level habitat information. I measured forest width perpendicular to the stream, distance to nearest forest edge, distance to nearest canopy gaps $\geq$7.0 m diameter, distance to nearest building (single family dwelling or larger, sheds excluded), and

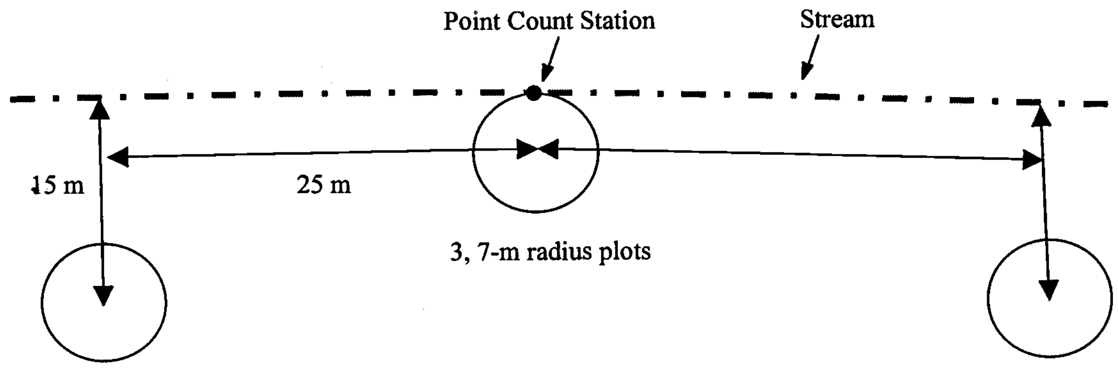

Figure 1. Schematic diagram of vegetation sampling plots conducted at each avian point count station in 54 riparian sites in the Portland, Oregon area during June and July, 1999.

distance to nearest paved road at each point count station using ArcView GIS Version 3.1 (Environmental Systems Research Institute Inc. 1998) and 1999 aerial photos. I averaged point count data by site for each of these variables.

GIS DATA COLLECTION

To assess the spatial influence of canopy cover and development around each site on bird communities, I drew a series of ten 50-m concentric buffers (500 m total on each side of the stream; Figure 2) using ArcView GIS, version 3.1. Metro's 1998 canopy cover GIS layer (24-m pixel resolution satellite imagery) generalizes each pixel into four canopy cover classes (0-25%, 26-50%, 51-75%, and 76-100%; Metro Regional Services 2000). Adjacent same-class pixels were aggregated to form polygons in a shapefile; polygons could then be "clipped" to precisely fit site buffers. I calculated average canopy cover class for each buffer.

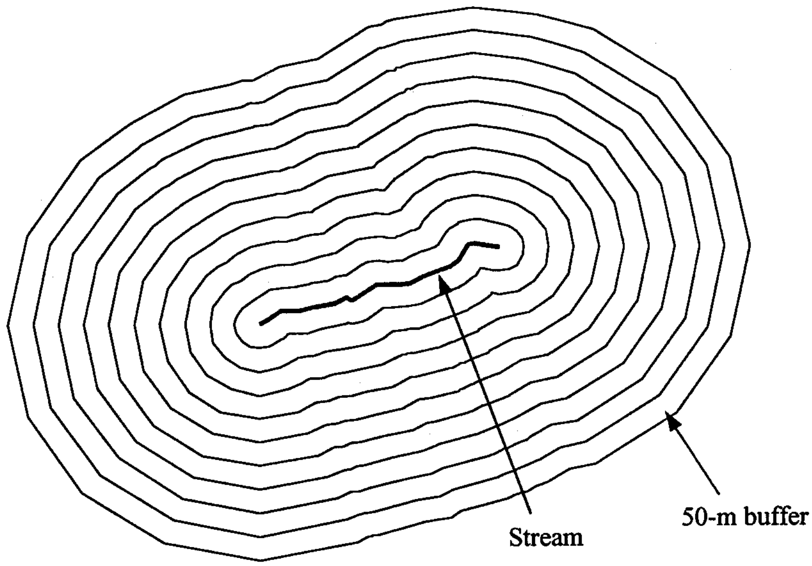

Figure 2. Illustration of a study site (stream reach) with ten 50-m buffers. Data were used to analyze spatial relationships between bird community variables and canopy cover, vacant lands, and street density around 54 riparian sites in the Portland, Oregon area, 1999.

Total impervious area provides a reliable estimate of urbanization in the Pacific Northwest (May et al. 1997; May and Horner 2000), but that data was not available in my study area. I used two methods to assess urbanization within each buffer. First, I calculated the density of paved streets (m/ha) within each buffer using Metro's 1999 streets theme; in Seattle, Washington, streets were a reliable surrogate variable for total impervious area (May et al. 1997). Second, I used Metro's 1999 undeveloped land theme to obtain the proportion of undeveloped land within each buffer, including undeveloped properties as well as parks and greenspaces.

STATISTICAL ANALYSIS

Principal Components Analysis

I performed Principal Components Analysis (PCA) using SAS v. 7.0 (SAS Institute, Inc. 1998) to reduce the number of explanatory variables. Prior to PCA, I omitted HERB, HERBALIEN, HIGHSHRUB, CANCOV, SLASH, and SLOPE because they were correlated ($r^2 > 0.50$) with other variables I retained (see Appendix 2 for variable descriptions and Appendix 4 for pairwise correlations). Principal component rotation was unnecessary. I retained all Principal Components (PC's) explaining greater than five percent of variation in the data and regressed bird abundance and community variables against these six (PC's) using backward elimination ($P \leq 0.10$ to enter model, $P \leq 0.05$ to remain in model). For significant models in the PCA analysis, I conducted simple linear regression of the dependent variable against the original independent variables with coefficient loadings of ≥ 0.20 for a PC.

Spatial Analysis

To assess the spatial influence of canopy cover and development, I regressed bird abundance and community variables against CANCOV, STREETS, and VACANT for each of ten cumulative buffers (Figure 2). For example, the first regression was against Buffer 1 data (first 50 m around the stream), the second was against Buffers

1 + 2 (first 100 m), the third against Buffers 1 + 2 + 3 (first 150 m), etc. This resulted in an r^2 statistic measuring the strength of each relationship (e.g., species richness versus CANCOV) for increasingly large buffers out to 500 m. To identify potential spatial patterns in bird response to canopy cover and development, I plotted the r^2 statistic for each bird-buffer relationship against distance from the stream to assess how these relationships varied over space.

Species-Habitat Relationships

My goal in assessing species-habitat relationships was to identify specific habitat components related to each bird species. I used data collected from onsite vegetation plots, GIS data for the first 50-m buffer (BUF1CC, VACANT, and STREETS), and aerial photography data (DISTEDGE, DISTROAD, DISTBLDG and FORESTWD) to identify bird species-habitat relationships. Variables for these analyses were averaged across each site; therefore some variables important at the microhabitat scale may not be measurable or significant at this resolution. For example, I was unable to assess plant species associated with individual bird species. Thus, my results represent general forest structure and development conditions rather than microhabitat characteristics.

I assessed habitat relationships for each bird species using logistic regression. I reduced the set of potentially important variables based on (a) visual examination of scatterplots to identify nonlinear relationships; (b) correlation analysis and subsequent removal of one of the correlated pair when $r^2 > 0.30$ to reduce multiple colinearity; and (c) biology of the species (i.e., include variables suspected to be biologically important to the species; for example, snags for woodpeckers). This typically resulted in a subset of 8-15 variables. With this variable subset, I used binary (presence or absence) logistic regression and backward elimination ($P \leq 0.10$ to enter model, $P \leq 0.05$ to remain in model) to build species-habitat models. All final models contained one to three explanatory variables, with no significant ($P < 0.05$) interactions among variables.

RESULTS

VEGETATION CHARACTERISTICS

There was considerable variability among sites for canopy and other habitat descriptors. Sites averaged 32% canopy cover, but ranged from 1% - 75% (Appendix 3). Average forest width was 155 m, but ranged from 3 m to 1,881 m. Big-leaf maple (*Acer macrophyllum*), red alder, and Oregon ash were the dominant forest canopy species, but Douglas-fir, Oregon white oak, native willow, and Western red cedar (*Thuja plicata*) were also important canopy species. When present, nonnative forest canopy composed only a small fraction of canopy cover in most sites.

Total shrub cover averaged 52%, ranging from < 1% to 92%. Low shrub and high shrub cover averaged 41% and 39%, respectively; nonnatives were more prominent in low shrubs (average 23%) than high shrubs (average 10%). Himalayan blackberry (*Rubus discolor*) dominated shrub layers at the highest number of sites, but Oregon ash, Pacific blackberry (*R. ursinis*), native willow, common snowberry (*Symphoricarpos albus*), Western red cedar, native and nonnative rose (*Rosa* spp.), English ivy (*Hedera helix*), red-osier dogwood (*Cornus sericea*), native and nonnative hawthorn (*Crataegus* spp.) and hazelnut (*Corylus cornuta*) also provided substantial shrub cover at many sites.

The herb layer was least native in composition, averaging nearly 36% nonnative cover. Total herb cover averaged 49%, and native herb cover 14%. Many sites, particularly those with narrow riparian forests, were dominated by nonnative lawns, grasses or reed canarygrass (*Phalaris arundinacea*), or by a variety of other nonnative herbs. However, native herb cover increased at wider sites, with sword fern (*Polystichum munitum*), lady fern (*Athyrium filix-femina*), Pacific waterleaf (*Hydrophyllum tenuipes*), fringecup (*Tellima grandiflora*), and native horsetail ferns (*Equisetum* spp.) as the dominant species.

BIRD COMMUNITIES

I recorded 8,901 detections of 90 bird species (Appendix 5) at 54 sites during May and June, 1999. Bird abundance averaged 11.8 birds (S.D. = 3.1, Appendix 3); the 10 most abundant species (European Starling [*Sturnus vulgaris*], Song Sparrow [*Melospiza melodia*], American Robin [*Turdus migratorius*], Black-capped Chickadee [*Poecile atricapilla*], Spotted Towhee [*Pipilo maculatus*], Brown-headed Cowbird [*Molothrus ater*], Red-winged Blackbird [*Agelaius phoeniceus*], Bewick's Wren [*Thryomanes bewickii*], House Finch [*Carpodacus mexicanus*] and House Sparrow [*Passer domesticus*]) comprised 67.1% of total bird detections. Two nonnative species, European Starling and House Sparrow, comprised 20.1% of total bird detections. The average species richness was 6.67 species (S.D. = 1.14), and diversity averaged 1.68 (S.D. = 0.19).

PRINCIPAL COMPONENTS ANALYSIS

My PCA model included 16 habitat variables (Appendix 6). The first six principal components explained 84.2% of the variation in the data. I interpret PC1 as a forest width, native vegetation and habitat structure gradient. Sites with high PC1 scores had more total native plants in herbaceous, low shrub, high shrub and canopy layers, and the forest canopy was deeper with more slash and large downed wood on the forest floor, than low-scoring sites. I interpret PC2 as a nonnative shrub gradient in which high-scoring sites contained more total low shrub cover, and higher proportions of nonnative low and high shrub cover than low-scoring sites. High PC2 scores generally indicated widespread Himalayan blackberry along streams, but also some nonnative hawthorn and rose. I interpret PC3 as a gradient of human development near sites. Sites with high PC3 scores had higher street density and higher proportions of developed lands within 50 m around the stream than low-scoring sites. I interpret PC4 as a gradient of human trails and impervious surfaces. Sites with high PC4 scores contained more human trails and impervious surfaces near the stream than low-scoring sites. I interpret PC5 as a bare ground gradient; high PC5-scoring sites also tended to have more human trails and fewer streets nearby than low-scoring sites, but these variables were less important relative to bare ground. I interpret PC6 as a native shrub and leaf litter gradient. Sites with high PC6 scores had sparse native shrub cover and more leaf litter than low-scoring sites.

Total bird abundance was negatively related to PC1 ($r^2 = 0.38$, $P < 0.0001$; Figure 3a); nonnative bird abundance had a similar relationship with PC1 ($r^2 = 0.63$, $P < 0.0001$; Figure 3b). Native bird abundance was unrelated to any of the PC's ($P > 0.05$). Species richness and native species richness were curvilinearly related to PC1 and peaked at mid-range PC1 scores (-0.5 to 1.0) (multiple linear regressions with a squared term, adjusted $r^2 = 0.17$, $P > 0.003$, and adjusted $r^2 = 0.18$, $P = 0.003$, respectively). Neotropical migratory bird species richness was negatively related to a combination of two variables, PC3 and PC6 (adjusted $r^2 = 0.21$, $P = 0.0008$). Native bird diversity (Figure 4) and overall bird diversity were curvilinearly related to PC1 and peaked at mid-range PC1 scores (-0.5 to 1.0) (multiple linear regressions with a squared term, adjusted $r^2 = 0.31$, $P < 0.0001$ and adjusted $r^2 = 0.24$, $P < 0.001$, respectively). Neotropical migratory bird diversity was negatively related to PC3 and PC6 similar to NMB species richness (adjusted $r^2 = 0.18$, $P = 0.003$).

I regressed bird community variables against high loading (> 0.20) variables of principal components. Bird abundance was negatively related to HERBNATIVE, and nonnative bird abundance was negatively related to HERBNATIVE, HSHRUBNAT and FORESTWD (regression statistics in Appendix 7). Species richness was unrelated to any habitat variable, but native species richness was curvilinearly related to FORESTWD. Shannon diversity was unrelated to any habitat variable, but native diversity was curvilinearly related to FORESTWD and LOWSHRUB. None of the NMB measures were strongly related to any of the habitat variables.

SPATIAL ANALYSIS

I plotted the average change (in absolute values) between adjacent buffers for three themes, canopy cover 1998 (BUFCC), undeveloped land (VACANT), and street density (STREETS) (Figure 5). Variation between adjacent buffers was highest within the first two or three buffers for each variable, after which changes between buffers was similar and less variable. I regressed bird community variables against GIS-measured explanatory variables (BUFCC, VACANT, and STREETS) separately for each

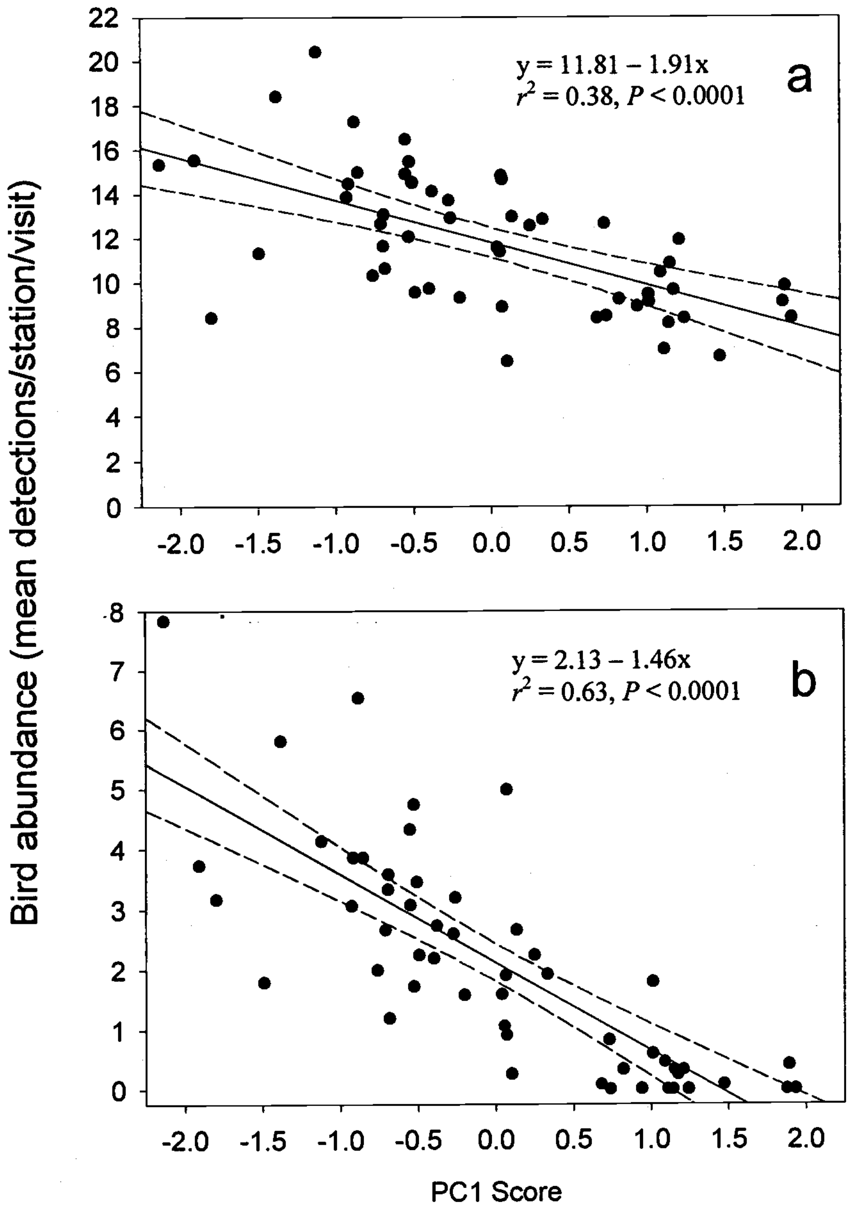

Figure 3. Total (a) and nonnative (b) bird abundance versus Principal Components Analysis PC1 scores for 54 riparian sites in the Portland, Oregon area, May and June 1999. Circles represent sites, solid line is regression line, and dashed line is 95% confidence interval for the regression line.

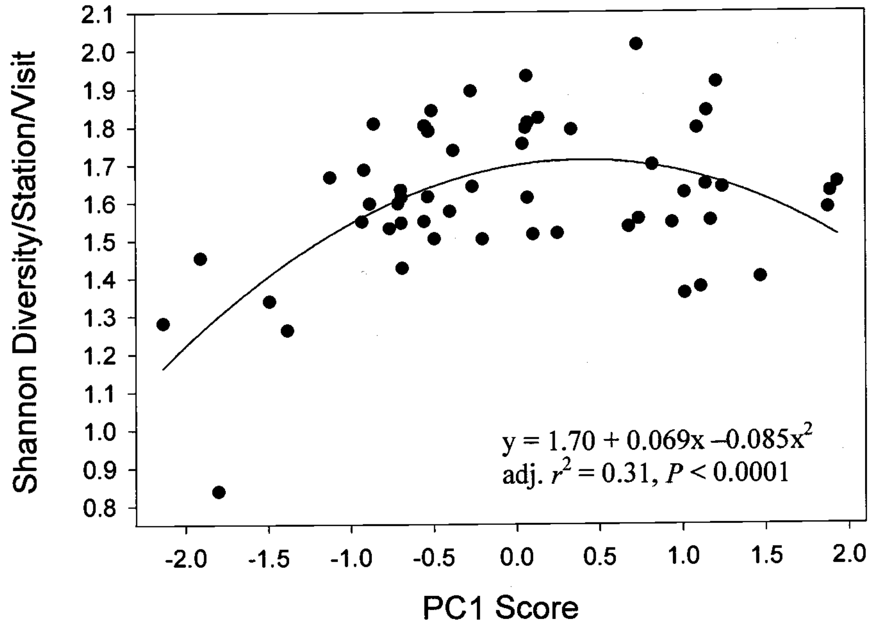

Figure 4. Native bird diversity versus Principal Components Analysis PC1 score for birds surveyed in 54 riparian sites in the Portland, Oregon area, May and June 1999. Circles represent sites; curve is regression line.

cumulative buffer set, then plotted the model fit statistic (r^2) against buffer width to determine if bird community variables were most related to a particular spatial scale. These plots suggest changes across scale in the strength of linear relationships, depending on the response variable (Figure 6).

Total bird abundance along the stream was negatively related ($P < 0.0001$) to BUFCC in all 10 buffers, but correlations were highest 300 m from the stream (Figure 6a). Total abundance was also negatively related to VACANT, but the strength of the relationship increased after 100 m (Figure 6a). Nonnative bird abundance was negatively related ($P = 0.0001$) to BUFCC in all buffers, but no spatial scale appeared to be most important ($r^2 \sim 0.50$ in all buffers; Figure 6b). Nonnative bird abundance was also negatively related ($P < 0.001$) to VACANT in all buffers, but the relationship was strongest within the first 100 m ($r^2 = 0.25$-0.28). In contrast, STREETS was not significantly related to nonnative bird abundance in the first 50 m, but the relationship strengthened through the next three buffers (Figure 6b). Neotropical migratory bird abundance was negatively related to STREETS in all buffers, but correlations were highest in the first three buffers (Figure 6e).

Native species richness was curvilinearly related to BUFCC (peaking in mid-range canopies) in the 0-50 m buffer (adjusted $r^2 = 0.23$, $P < 0.001$), less so in the 51-100 m buffer (adjusted $r^2 = 0.16$, $P < 0.05$), and became insignificant by 350 m (Figure 6c). Total species richness was negatively related to BUFCC in all 10 buffers, also peaking in mid-range canopies (approximately 25%-50%); the first buffer appeared most important in this relationship (Figure 6d).

Native and total bird diversity were related to BUFCC similar to species richness, but native diversity provided a better model fit (adjusted $r^2 = 0.33$, $P < 0.0001$) in which the first three or four buffers appeared most important (Figure 6c). Neotropical migratory bird species richness was negatively related to STREETS ($P < 0.05$) in all buffers, but the relationship was strongest between 100-150 m (Figure 6e).

I modeled Brown-headed Cowbird abundance as a function of canopy cover in each buffer because several studies suggest negative relationships with landscape-scale forest canopy cover, and because of cowbird potential to influence the reproductive success of host species (Coker and Capen 1995; Hahn and Hatfield 1995). No relationship was apparent within the first 100 m, but the predictive value of canopy cover steadily increased out to 500 m ($r^2 = 0.15$, $P < 0.0004$; Figure 6f). The relationship between cowbird abundance and canopy cover was negative in all buffers.

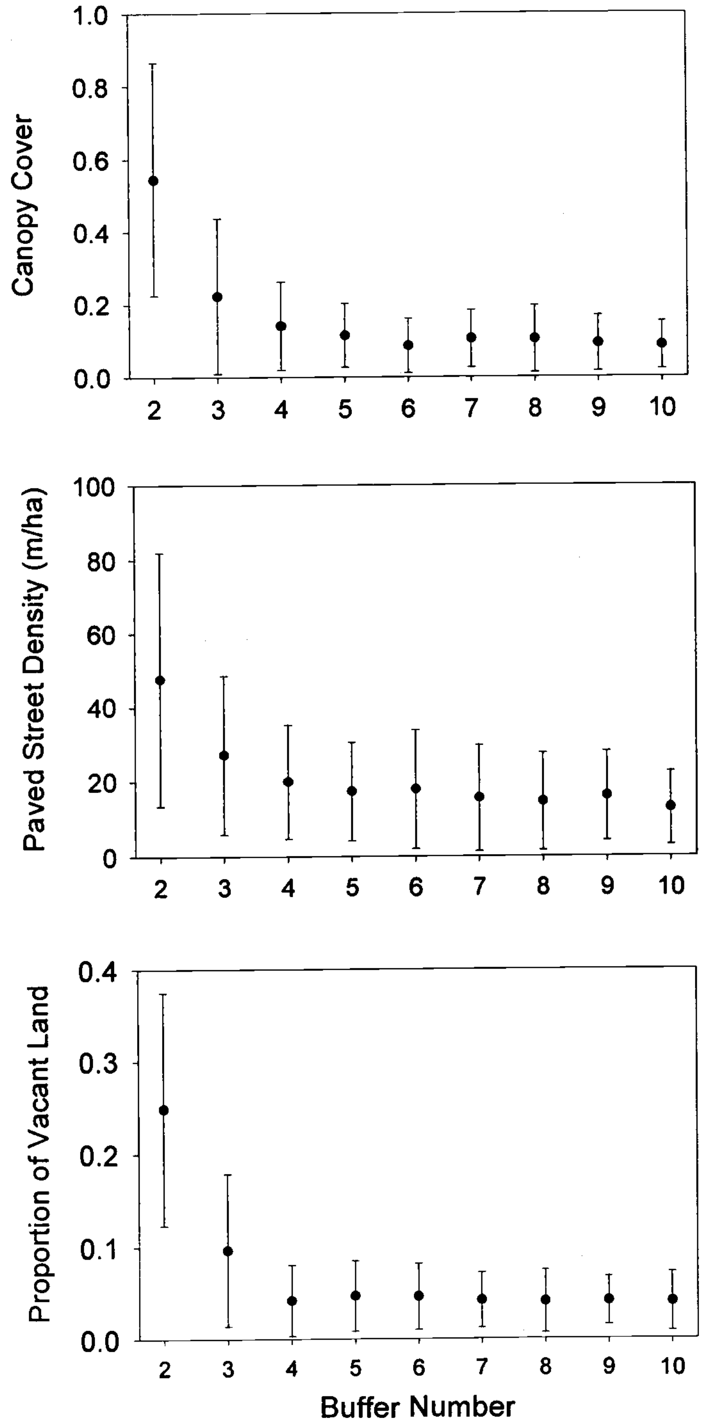

Figure 5. Mean (± S.D.) change in canopy cover, street density and proportion of vacant land between adjacent 50-m buffers surrounding 54 riparian sites in the Portland, Oregon area, 1999. Buffer 2 represents the mean difference between Buffer 1 and Buffer 2 (absolute value); Buffer 3 represents the difference between Buffer 2 and Buffer 3, etc.

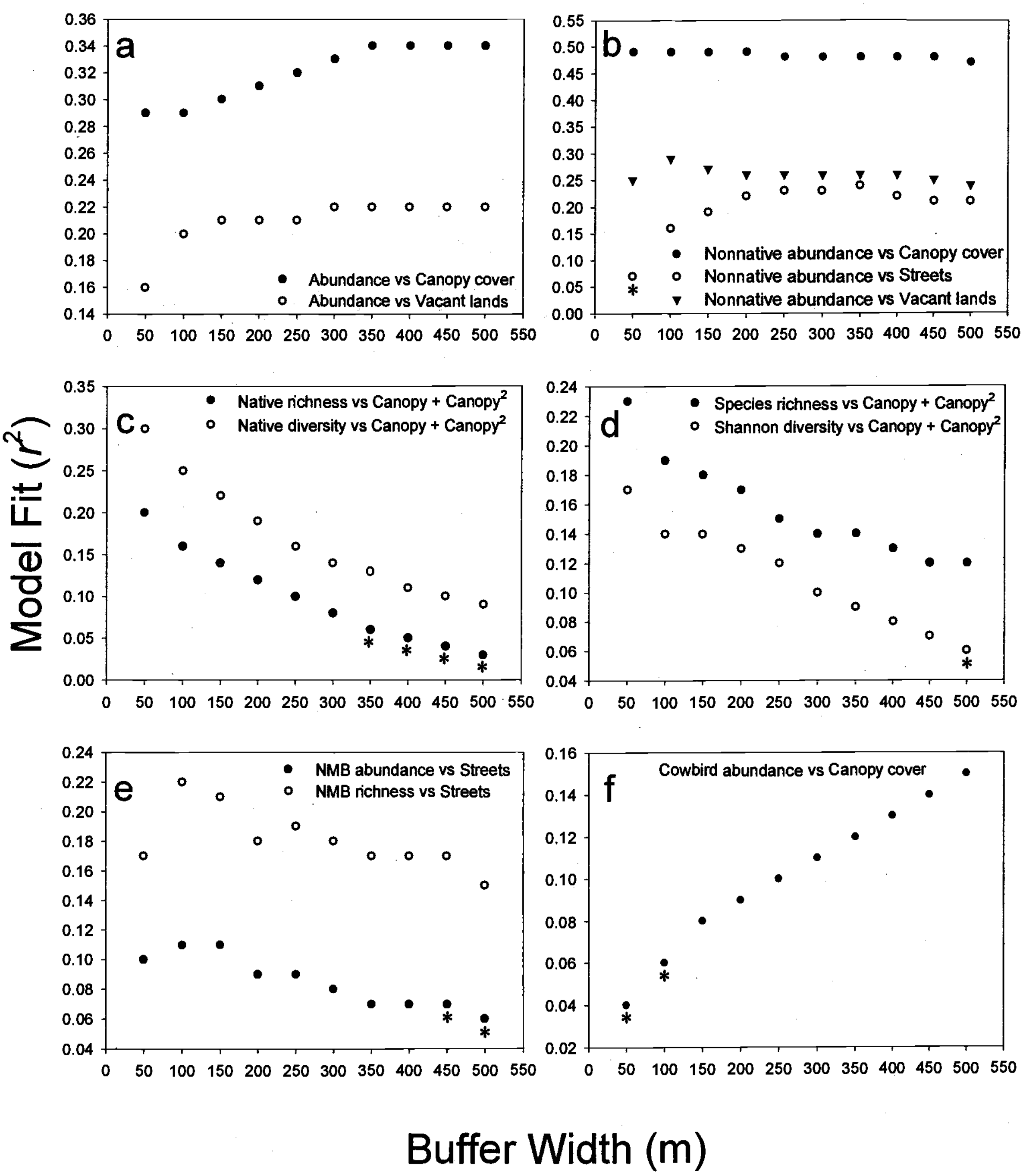

Figure 6. Model fit (r^2) of bird community variables regressed against canopy cover, proportion of vacant lands, and street density for each of ten, 50-m buffers surrounding 54 riparian sites in the Portland, Oregon area, 1999. All relationships are significant ($P < 0.05$) unless denoted with an asterisk (*).

SPECIES-HABITAT RELATIONSHIPS

The occurrence of 32 bird species was related to one or more explanatory variables, most often forest canopy structure or width variables (Table 1). Occurrence of Brown Creepers (*Certhia americana*) and Pacific-slope Flycatchers (*Empidonax difficilis*) was positively associated with FORESTWD, and Winter Wren (*Troglodytes troglodytes*) occurrence was positively associated with DISTEDGE. Conversely, European Starlings, House Finches, and Western Scrub-jays (*Aphelocoma californica*) were negatively associated with FORESTWD, and American Goldfinches (*Carduelis tristis*), Barn Swallows (*Hirundo rustica*), Common Yellowthroats (*Geothlypis trichas*), Black-headed Grosbeaks (*Pheucticus melanocephalus*), and Steller's Jays (*Cyanocitta stelleri*) were negatively associated with DISTEDGE. Steller's Jay occurrence increased with CANCOV, whereas Brown-headed Cowbirds, Violet-green Swallows (*Tachycineta thalassina*), Willow Flycatchers (*Empidonax traillii*) and Yellow Warblers (*Dendroica petechia*) were negatively associated with CANCOV or BUF1CC. Cedar Waxwing (*Bombycilla cedrorum*) occurrence was positively associated with CCDEPTH, but Mourning Dove (*Zenaida macroura*) occurrence was negatively associated with CCDEPTH. Mourning Doves and Bullock's Orioles (*Icterus bullockii*) were positively associated with percent CCALIEN.

The occurrence of eight species was related to shrub characteristics (Table 1). Bewick's Wren, Hutton's Vireo (*Vireo huttoni*), and Mourning Dove occurrence was positively associated with LOWSHRUB. Willow Flycatcher occurrence was positively associated with HIGHSHRUB. Swainson's Thrush (*Catharus ustulatus*) and Western

Table 1. Habitat variables used in logistic regression models for bird species occurrence at 54 riparian sites in the Portland, Oregon urban region, May and June 1999.

Species[a]	Variable(s)[b]	Model X^2	Variable X^2	Sign
American Crow	DISTROAD*[c]	19.54	4.42	-
	TRAIL*		5.40	+
American Goldfinch	DISTEDGE**	20.31	8.28	-
Barn Swallow	DISTEDGE**	22.98	9.59	-
Bewick's Wren	LOWSHRUB**	10.72	6.43	+
Black-headed Grosbeak	DISTROAD*	15.13	5.28	+
	LSHRUBALIEN*		3.87	+
	DISTEDGE*		4.82	-
Brown Creeper	FORESTWD***	40.09	11.39	+
Brown-headed Cowbird	CANCOV*	11.66	4.84	-
Bullock's Oriole	CCALIEN*	5.76	4.76	+
Cedar Waxwing	SLOPE**	12.50	6.01	-
	CCDEPTH*		5.74	+
	SNAGS*		4.36	-
Chestnut-backed Chickadee	SNAGS*	5.04	4.61	+
Common Yellowthroat	DISTEDGE**	30.20	6.58	-
	DISTROAD*		4.41	+
	SLOPE**		6.67	-
Dark-eyed Junco	LEAFLITTER**	10.09	7.90	+
European Starling	FORESTWD*	15.96	5.14	-
House Finch	FORESTWD** [c]	19.53	6.83	-
	DISTROAD**		9.58	-
House Sparrow	HERBALIEN*	30.27	5.27	+
Hutton's Vireo	LOWSHRUB*	5.26	4.36	+

Table 1. Continued.

Species[a]	Variable(s)[b]	Model X^2	Variable X^2	Sign
Mourning Dove	LOWSHRUB**	16.20	6.47	+
	CCDEPTH**		7.93	-
	CCALIEN*		4.62	+
Pacific-slope Flycatcher	FORESTWD*	11.37	5.10	+
Red-breasted Nuthatch	DISTROAD*	8.70	4.45	-
Red-breasted Sapsucker	LSHRUBALIEN**	8.28	6.74	+
Red-winged Blackbird	HERBALIEN***	30.16	14.13	+
Rufous Hummingbird	DISTBLDG**	13.33	6.88	+
Steller's Jay	BUF1CC**	40.27	9.41	+
	DISTEDGE**		7.80	-
	IMPERV*		5.69	-
Swainson's Thrush	SHRUBTOT**	23.20	7.21	+
	DISTBLDG*		4.56	+
Vaux's Swift	IMPERV**	6.34	6.01	+
Violet-green Swallow	BUF1CC***	20.55	12.64	-
Western Scrub-Jay	FORESTWD** [c]	27.20	9.93	-
Western Wood-Pewee	SHRUBTOT**	7.69	6.30	+
Willow Flycatcher	BUF1CC*	8.13	5.45	-
	HIGHSHRUB*		4.89	+
Winter Wren	DISTEDGE***	35.87	10.90	+
Yellow Warbler	BUF1CC**	9.90	7.87	-

[a]Genus and species names listed in Appendix 5. All models are significant ($P < 0.05$).

[b]See Appendix 2 for variable abbreviations and definitions.

[c]Variable significance, *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Wood-pewee (*Contopus sordidulus*) occurrence was positively associated with SHRUBTOT. Black-headed Grosbeak and Red-breasted Sapsucker (*Sphyrapicus ruber*) occurrence was positively associated with LSHRUBALIEN (i.e., Himalayan blackberries).

Two species were associated with HERBALIEN. House Sparrow and Red-winged Blackbird occurrence was positively associated with HERBALIEN, representing lawns for the former, and reed canarygrass (*Phalaris arundinacea*) for the latter.

Four species were associated with other habitat variables including SNAGS, LEAFLITTER or SLOPE. Chestnut-backed Chickadee (*Poecile rufescens*) occurrence was positively associated with SNAGS, whereas Cedar Waxwings were negatively associated with this variable. Dark-eyed Junco (*Junco hyemalis*) occurrence increased with LEAFLITTER. Cedar Waxwings and Common Yellowthroats were negatively associated with SLOPE.

The occurrence of several species was related to human-associated variables (Table 1). American Crow (*Corvus brachyrhynchos*), House Finch, and Red-breasted Nuthatch (*Sitta canadensis*) occurrence was negatively associated with DISTROAD. American Crows were also positively associated with TRAIL. Vaux's Swift (*Chaetura vauxi*) occurrence was positively associated with IMPERV, whereas Steller's Jays were negatively associated with IMPERV. Black-headed Grosbeak and Common Yellowthroat occurrence was positively associated with DISTROAD, despite positive associations with DISTEDGE. Swainson's Thrush and Rufous Hummingbird occurrence increased with DISTBLDG.

Some species occurred either too frequently or too infrequently to analyze using logistic regression, and some simply showed no relationships to the variables I measured. For example, I was unable to assess species-habitat relationships for 39 species because they occurred at too few sites (< ~10 sites) for reliable statistical inference. Song Sparrows, American Robins and Black-capped Chickadees occurred at nearly all sites, thus I was unable to develop presence/absence relationships for these species. Several species, including Bushtits (*Psaltriparus minimus*), Downy Woodpeckers, Northern Flickers (*Colaptes auratus*), Orange-crowned Warblers (*Vermivora celata*), Tree Swallows (*Tachycineta bicolor*), and Warbling Vireos (*Vireo gilvus*) occurred frequently but their occurrence was not related to any of the explanatory variables I measured. I did not assess waterfowl species because they do not regularly vocalize and I was often unable to see the stream, thus detectability for these species was unreliable.

DISCUSSION

Fundamentally, scientists need to know what characteristics of urban habitats cause changes in bird communities to enable effective species conservation in increasingly urbanized landscapes. Along small streams in the Portland region, both habitat and human-associated variables appear to be important. At the community level, habitat characteristics appear most related to bird abundance, nonnative bird abundance, and richness and diversity measures, but human-associated variables appear more important to NMB. These relationships appear to be scale-dependent, with the strongest relationships often occurring within the first 150-200 m of the stream, or within stream buffers of about two site-potential tree heights. At the species level, birds appear to respond differently to urbanization; my data identified species whose occurrence depended on various human-associated variables.

HABITAT IN URBAN ECOSYSTEMS

Habitat characteristics at multiple scales appear to be important to birds in the Portland region. Many urban studies document increased total and nonnative bird abundance with increased urbanization (Penland 1984; Blair 1996; Clergeau et al. 1998), but in my study area decreasing canopy cover was a better predictor of total and nonnative bird abundance than street density or the proportion of developed land around riparian areas; furthermore, these relationships strengthened with increased spatial scale. My PCA analysis revealed relationships between abundance measures and PC1, further supporting the importance of habitat in this urbanized region. Sites with low

PC1 scores had more total and nonnative birds, and these sites tended to have narrow forests with little canopy cover, sparse native shrub cover, reduced canopy depth, and few habitat structures such as logs and snags typically associated with structurally complex forests. Thus bird abundance, particularly nonnative bird abundance (primarily European starlings), was associated with simplified forests in my study area.

The high abundance of European Starlings is probably a function of the configuration of urban habitats. Starlings nest in cavities and occupied many of the natural cavities near forest edges in my study area. Starlings frequently forage on lawns (Fischl and Caccamise 1986; Ehrlich et al. 1988), thus the juxtaposition of forest edge with residential or park lawns may provide ideal starling habitat. Starlings were the most abundant species in my surveys, comprising more than 20% of total birds detected and dominating some sites, and may exert considerable competitive pressure on native birds in my study area.

BIRD COMMUNITY RELATIONSHIPS

Changes in species richness and bird diversity often accompany urbanization, and these changes tend to fall into one of three basic patterns. In the first pattern, species richness and diversity decline linearly with increasing urbanization (e.g., Elmen 1974; Penland 1984; Clergeau et al. 1998). In the second pattern, species richness and diversity peak in moderately developed areas (Blair 1996; Jokimäki and Suhonen 1998). In the third pattern, richness and diversity correlate positively with increases in total or native vegetation volume and/or structural complexity (Guthrie 1974; Lancaster and Rees 1979; Beissinger and Osborne 1982; Goldstein et al. 1986; Maeda 1998; Mills et al. 1991; Fernandez-Juricic 2000). My data appears to represent a hybrid between these second and third patterns, in which species richness and diversity peaked in areas with moderate canopy cover and structural complexity, but did not appear to be strongly related to human-associated variables.

Habitat conditions and urbanization are related. Urban forests typically become fragmented, are structurally and biologically simplified compared to native habitats, and vegetation becomes increasingly nonnative with increasing urbanization (Case 1996; Germaine et al. 1998; Pavlik and Pavlik 2000). Clergeau et al. (1998) found a pattern of increased vegetation volume with decreasing urbanization in major cities on two continents, but vegetation measures such as CANCOV were not correlated with STREETS or VACANT in my study area, perhaps because park sites tend to have more canopy cover than adjacent developed lands. However, nonnative herbs and shrubs were positively correlated with narrow forests in my study.

The convex curve in graphs of species richness and diversity against habitat variables suggest competition from nonnative and generalist bird species, combined with riparian habitat alterations, may influence bird community composition in my study area. Sites with low PC1 scores (i.e., narrow forests with little canopy, sparse native shrub cover, and reduced canopy depth) had low native species diversity (Figure 4). At sites with low PC1 scores, the combination of simplified habitat and competition from nonnative and generalist species probably determines diversity and species richness. At sites with high PC1 scores, native diversity appears to decline and may reflect increasing distance from forest edge and an associated reduction in shrub cover and habitat heterogeneity important to many species. My simple regressions for abundance against FORESTWD and shrub measures support these observations (Appendix 7).

Blair (1996) detected similar convex curves as those I observed for species richness and diversity, and suggested Huston's (1979) dynamic equilibrium hypothesis as a relevant model. This hypothesis predicts high biodiversity in non-equilibrium situations subjected to repeated, unpredictable disturbances, because periodic population reductions and environmental fluctuations hamper the process of competitive exclusion. Proulx (1998) suggested that species richness was related to community productivity for a broad range of organisms, and typically increases with increasing productivity until it reaches a plateau, beyond which further increases in productivity are associated with a decline in species richness. This produces a convex curve similar to those in my species richness and diversity relationships with PC1, canopy cover in all buffers, and FORESTWD and LOWSHRUB.

Diversity and species richness alone may not be appropriate measures of urban biodiversity. The suite of species involved in diversity and richness is important, because similar diversity scores could represent generalist species or habitat specialists (see Blair 1996 for discussion). For example, the widest forests may pick up area or human sensitive species, but diversity may be lower in those sites than in some narrower forests, and therefore fail to reflect the importance of habitat size. Thus, species-habitat or functional guild (i.e., nest type and placement, preferred food, and migratory status) analyses add important information in urban ecosystems.

STREET DENSITY AND NEOTROPICAL MIGRANTS

Neotropical migratory bird abundance, species richness and diversity were related to both human-associated and habitat variables in the Portland area (although simple linear regressions suggested a negative relationship only with STREETS; Appendix 7). In other parts of the U.S., Neotropical migrants tend to respond negatively to human development (Friesen et al. 1995; Nilon et al. 1995) and habitat fragmentation (Martin and Finch 1995; Robinson et al. 1995) to the point that these factors override local habitat characteristics. For example, in Ontario increasing the number of houses surrounding a forest patch reduced NMB species richness and abundance; larger habitat patches were also important (Friesen et al. 1995). In Missouri, forest interior NMB species were most abundant in wildland sites and least abundant in cluster development sites (Nilon et al. 1995). In Pennsylvania, only 2-3% of NMB that were habitat specialists used disturbed habitats during the breeding season, compared to 17-20% in undisturbed areas (Croonquist and Brooks 1991). Other studies reported similar patterns (Gotfryd and Hansell 1986; Theobald et al. 1997; Mancke and Gavin 2000).

Native shrubs are important to various wildlife species because they provide food, shelter, nesting substrate and increased structural diversity. My PCA analyses suggested a positive relationship between NMB and native shrubs, probably because NMB often nest and forage in shrub habitats, which tend to be insect-rich. Eighty percent of the NMB detected on my surveys were also insectivores. Other studies have documented the importance of native shrub cover to NMB and insectivorous species (DeGraaf and Wentworth 1986; Croonquist and Brooks 1991; Reynaud and Thioulouse

2000). Nonnative plants tend to have fewer insects than native plants (Rosenberg et al. 1987). Furthermore, recent evidence suggests that small forest patches may contain lower insect densities than large patches (Burke and Nol 1998).

SPATIAL SCALE

My spatial analysis revealed that most of the variation in forest canopy cover, proportion of vacant lands, and street density occurs within 100 m of the stream (Figure 5), and it is within this zone that the strongest bird community-habitat relationships occurred (Figure 6). The Northwest Forest Plan's recommended riparian buffer widths of two site-potential tree heights (minimum 91 m per side for fish-bearing streams; Forest Ecosystem Management Assessment Team 1993) falls within this zone, adding credence to the importance of this spatial scale for protecting riparian habitats and to the idea that ecological knowledge gained in non-urban systems may also be relevant in urban environments.

Species-habitat relationships and community responses to habitat conditions change depending on the scale through which they are viewed (Wiens 1989; Hansen et al. 1993). I examined community response to canopy cover and development out to 500 m on each side of the stream because beyond that distance, some sites overlapped. A hierarchically nested approach to spatially-explicit ecological questions, arranged on a clearly defined gradient over a long time period, is desirable (Wiens 1989). However, my approach was exploratory, and appears useful because it revealed relatively fine-grained (50-m increment) changes in bird community patterns relating to spatial scale, and in some cases, suggested specific scales of interest. In addition, this approach prevents a loss of information when hierarchical levels are crossed. For example, canopy cover appears most important to bird abundance at the scale of about 350 m, but is important to native species richness at a smaller scale (approximately 50-150 m). My relationship between NMB species richness and road density was weaker, but suggested that road density within 150 m of the stream was most important. For Brown-headed Cowbirds, my study and others suggest that cowbirds respond to canopy cover on a scale larger than 500 m (Hahn and Hatfield 1995; Coker and Capen 1995; Larison et al. 1998). Similar analyses for other species may also reveal new information.

Effective urban habitat conservation will need to include analyses and decisions based on the species or suite of species of interest and associated empirically derived scale(s) of interest. Consideration of multiple spatial scales will also be important because (a) different patterns emerge at different scales; (b) large-scale land use planning is required for habitat connectivity in urban habitats; and (c) regional patterns of urbanization and vegetation cover are likely to influence wildlife communities at smaller scales. For example, a hierarchically-nested scheme appropriate to NMB conservation might include considering watershed- or basin-level fragmentation patterns; street density within 150 m around sites of interest; and on-site habitat variables such as native shrub cover.

SPECIES-HABITAT RELATIONSHIPS

The physical variability of urban environments, combined with prominent human disturbances, may alter species-habitat relationships such that the importance of human-associated variables may override habitat characteristics. Thus, the primary value of my species-habitat relationship analyses was to identify human-bird associations. My data suggest that in urban habitats, some species appear to be adapting to human encroachment, while others appear to avoid humans and their constructs.

In my study two known human associates, American Crow and House Finch, occurred more frequently near roads. Crows were also associated with onsite trails, probably related to enhanced food resources in these park sites. My data indicated two old-growth cavity nesting species (Adams and Morrison 1993; Kaufman 1996) may also be human-associated in the Portland area; Red-breasted Nuthatches and Vaux's Swifts occurred more often near roads or with increasing impervious surfaces, respectively. Vaux's Swifts use a surrogate nest substrate in urban areas in the form of chimneys; nuthatches, while still nesting in natural cavities in urban areas, are common visitors to backyard bird feeders and likely benefit from this association with humans. Other species known to be human-associated, including Barn Swallow, European Starling, House Sparrow and Western Scrub-jay, were positively associated with narrow forests, proximity to forest edge, or increased nonnative herb cover in my study area.

A combination of variables associated with three species (Common Yellowthroat, Steller's Jay, and Black-headed Grosbeak) suggested that these species might be at risk in urban habitats. All three species were associated with edges or narrow forests, where development was more likely to occur, and each species' occurrence was negatively related to human-associated variables. Grosbeaks were also related to LSHRUBALIEN, and may reflect a fondness for blackberries observed during the field season. Common Yellowthroats were associated with low-slope areas, as might be expected because of their use of grassland habitats. Steller's Jays were negatively associated with onsite impervious surfaces.

My data suggests that Winter Wrens, Brown Creepers and Pacific-slope Flycatchers may require larger habitat patches, based on positive relationships with increasing forest width. Another Oregon study suggested that Winter Wrens were sensitive to habitat fragmentation (McGarigal and McComb 1995). In addition, snags and large downed wood provide important nest substrate for Brown Creepers and Winter Wrens (Kaufman 1996), and these structures decline with urbanization in the Pacific Northwest (May et al. 1997). For species that appear to be area-dependent, we need to test whether patch size *per se*, microhabitat variables associated with patch size, or avoidance of humans is most important in urban habitats.

SCOPE AND LIMITATIONS

My study has several limitations. This was an observational study based on correlation statistics, and cannot be used to infer cause and effect relationships. Further, my analyses were based on species abundance and should be followed by studies on avian reproductive success and dispersal, particularly in an urban environment where nest depredation and human disturbance may severely impact reproductive success (Jokimäki and Huhta 2000). I conducted a large number of statistical analyses; based on chance, a few of my results are likely to be spurious. In addition, low r^2 statistics for some relationships, while statistically significant, explain a relatively small amount of the variation in the data; management decisions should probably be based on additional analyses and observations.

My results provide a temporal snapshot consisting of only one breeding season, comparing sites relative to one another. Urbanization impacts may be cumulative over time (Vale and Vale 1976; Soulé et al. 1988; Kattan et al. 1994). Temporal variations in bird populations are not accounted for in my data, thus patterns detected in my field data may change, even if urbanization and forest canopy cover remained the same. Access to data from long-term studies such as Breeding Bird Surveys (Sauer et al. 2000) provides one way to address this problem. Studies of bird migration and wintering use of these habitats would greatly enhance this information. The results of my study should therefore be interpreted with caution and are meant to provide baseline information to guide future studies.

The scope of inference for this study relates to the Portland study area, and the results cannot necessarily be extrapolated to other areas. However, I included the entire available sampling universe for my habitat type within a large study area, thus these results provide a way to evaluate some potential impacts of human development on bird communities in the Portland region and may be relevant to other urbanizing regions within a forested setting.

CONCLUSION

The importance of habitat conditions, spatial scale and human-associated variables are common to nonurban and urban ecosystems. For example, the ecological relevance of two site-potential tree heights to protect perennial streams is used in nonurban Pacific Northwest ecosystems, and appears to be a relevant scale for Portland bird communities. In my study area, bird abundance, community metrics and individual species-habitat relationships were related to riparian habitat and human-associated variables at multiple spatial scales. Individual bird species showed habitat needs similar to those found in nonurban areas but human-associated variables were also sometimes important, suggesting that species respond differentially to habitat, resource availability, and community changes brought about by urbanization. Thus urban ecosystems are subject to the same ecological foundations as other systems but have additional factors of importance, such as development intensity and onsite disturbances.

Several direct actions could enhance bird habitat in the Portland region. My results suggest that the most valuable land management action for most native breeding bird species is to increase native canopy cover. Aiming for native, moderate canopy cover (approximately 40-65%) in as wide a swath as possible around urban streams will reduce nonnative and invasive birds and plants, which compete with their native counterparts for resources. Intermediate canopy levels should also allow sufficient sunlight for development of a shrub layer. Applied regionally, this goal would also increase connectivity among habitat patches as streams are reforested. For NMB, preserving larger roadless areas – both forest and grassland – is likely to enhance the survival prospects for area- and human-sensitive species as urbanization becomes an increasingly dominant influence across many landscapes.

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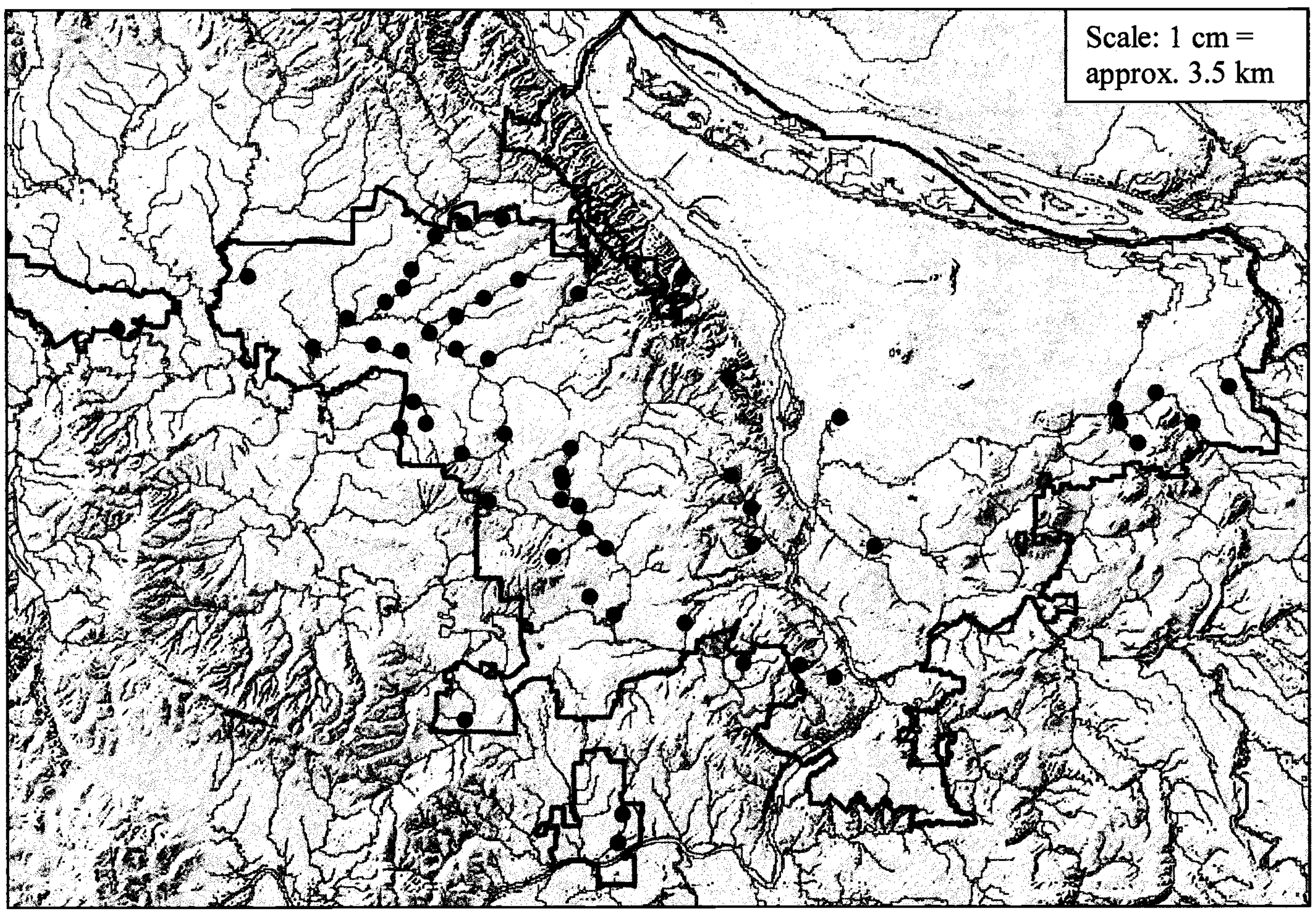
APPENDICES

Appendix 1. Map of study area for bird and vegetation surveys conducted at 54 riparian sites in the Portland, Oregon region during 1999. Study area extends approximately 53 km east-west and 30 km north-south. Black circles are study sites, black line is urban growth boundary, and gray lines are streams. Note stream-deficient area to the east, where streams were piped underground for housing. The confluence of the Columbia and Willamette Rivers is top, center.



Appendix 2. Variables used in regression and Principal Components Analyses of bird communities along 54 riparian sites in the Portland, Oregon area, May and June 1999. Correlations among variables are shown in Appendix 4.

Variable Code	Source	Description
BAREGRND	Vegetation plots	Percent cover of bare ground
BUFCC	GIS/Landsat data	Average canopy cover class (4 classes: 0-25, 25-50, 50-75, 75-100%) in buffers
CANCOV	Vegetation plots	Percent cover of tree canopy
CCALIEN	Vegetation plots	Percent cover of nonnative canopy
CCDEPTH	Vegetation plots	Depth of tree canopy (m)
CCNATIVE	Vegetation plots	Percent cover of native tree canopy
DISTBLDG	Aerial photographs	Distance to nearest building (m)
DISTEDGE	Aerial photographs	Distance to nearest forest edge (m)
DISTROAD	Aerial photographs	Distance to nearest paved road (m)
FORESTWD	Aerial photographs	Forest width (m, log-transformed)
HERB	Vegetation plots	Percent cover of herbaceous plants
HERBALIEN	Vegetation plots	Percent cover of nonnative herbaceous plants
HERBNATIVE	Vegetation plots	Percent cover of native herbaceous plants
HIGHSHRUB	Vegetation plots	Percent cover of high (1.5-7.0 m) shrubs
HSHRUBALIEN	Vegetation plots	Percent cover of high (1.5-7.0 m) nonnative shrubs
HSHRUBNAT	Vegetation plots	Percent cover of high (1.5-7.0 m) native shrubs
IMPERV	Vegetation plots	Percent cover of impervious surfaces in vegetation plots (includes structures)
LEAFLITTER	Vegetation plots	Percent cover of leaf litter
LOGS	Vegetation plots	Percent cover of downed logs > 10 cm DBH
LOWSHRUB	Vegetation plots	Percent cover of low (< 1.5 m) shrubs
LSHRUBALIEN	Vegetation plots	Percent cover of low (< 1.5 m) nonnative shrubs
LSHRUBNAT	Vegetation plots	Percent cover of low (< 1.5 m) native shrubs
SLASH	Vegetation plots	Percent cover of slash (woody debris < 10 cm diameter)
SLOPE	Vegetation plots	Slope (%) from stream bank to far edge of plot
SNAGS	Vegetation plots	Number of standing dead trees > 1 m tall, including stumps
STREETS	GIS streets layer	Density of paved streets within buffers (m/ha)
STRUCT	Vegetation plots	Percent cover of structures (houses, buildings, large sheds, barns)
TOTSHRUB	Vegetation plots	Percent cover of all shrubs
TRAIL	Vegetation plots	Percent cover of trails
VACANT	GIS vacant lands layer	Undeveloped land (including parks)/Total land ratio
VISCAV	Vegetation plots	Number of visible cavities in dead or live trees

Appendix 3. Descriptive statistics for bird community, habitat, and human-associated variables collected at 54 riparian sites in the Portland, Oregon urban region, 1999. Habitat variables are described in Appendix 2.

Variable	Mean	Standard deviation	Minimum	Maximum
Total abundance[a]	11.79	3.11	6.47	20.40
Nonnative abundance	2.11	1.86	0.00	7.83
Native abundance	9.68	2.05	5.25	16.27
Neotropical migrant (NMB) abundance	2.07	0.92	0.67	4.83
Total species richness[b]	6.67	1.14	4.33	9.00
Native species richness	6.11	1.02	3.17	8.50
Neotropical migrant species richness	1.66	0.60	0.67	3.08
Total Shannon diversity[c]	1.68	0.19	1.22	2.05
Native Shannon diversity	1.61	0.20	0.84	2.01
Neotropical migrant Shannon diversity	0.42	0.21	0.09	0.95
BAREGRND	2.75	2.24	0.13	12.00
BUF1CC	2.68	0.80	1.00	4.00
CANCOV	31.98	19.96	0.08	74.60
CCALIEN	1.08	2.08	0.00	11.27
CCDEPTH	8.80	3.54	0.27	14.17
CCNATIVE	30.98	20.36	0.00	74.60
DISTBLDG	68.18	65.00	18.53	389.21
DISTEDGE	28.47	49.37	0.50	316.20
DISTROAD	95.11	80.24	17.00	423.30
FORESTWD	154.80	300.96	3.13	1881.20
HERB	48.59	20.16	12.92	93.40
HERBALIEN	35.86	28.00	0.23	93.33
HERBNATIVE	13.93	15.15	0.04	53.73
HIGHSHRUB	38.57	16.19	0.58	79.73
HSHRUBALIEN	9.59	6.95	0.00	28.40
HSHRUBNAT	30.68	15.74	0.58	69.33
IMPERV	2.90	4.40	0.00	16.87

Appendix 3. Continued.

Variable	Mean	Standard deviation	Minimum	Maximum
LEAFLITTER	1.68	1.51	0.07	7.13
LOGS	0.81	0.74	0.00	2.88
LOWSHRUB	41.25	18.43	0.29	78.60
LSHRUBALIEN	22.82	15.85	0.08	63.30
LSHRUBNAT	20.32	15.31	0.21	59.54
SHRUBTOT	51.96	20.29	0.88	91.67
SLASH	1.23	0.81	0.00	3.92
SLOPE	3.54	3.44	1.00	18.75
SNAGS	0.38	0.31	0.00	1.00
STREETS	27.25	29.07	0.00	119.92
STRUCT	1.05	2.28	0.00	8.67
TRAIL	2.38	2.24	0.00	9.67
VACANT	0.71	0.21	0.32	1.00
VISCAV	0.51	0.72	0.00	4.50

[a]Abundance is number of detections/visit/point count station.
[b]Richness is number of species/visit/point count station.
[c]Shannon diversity (H'; see Magurran 1988:35 for equation) is diversity/visit/point count station.

Appendix 4. Correlation matrix for variables collected for 54 riparian sites in the Portland, Oregon area, 1999. Pearson correlation coefficients are above the diagonal, P-values below the diagonal. Variables are defined in Appendix 2.

Variable	BUF1CC	CANCOV	CCALIEN	CCDEPTH	CCNATIVE	DISTBLDG	DISTEDGE	DISTROAD	FORESTWD	HERB
BUF1CC		0.76	-0.26	0.71	0.77	0.46	0.49	0.42	0.88	-0.48
CANCOV	<0.0001		-0.15	0.81	1.00	0.42	0.52	0.36	0.70	-0.50
CCALIEN	0.06	0.28		-0.15	-0.24	-0.16	-0.16	-0.13	-0.21	0.00
CCDEPTH	<0.0001	<0.0001	0.29		0.81	0.24	0.28	0.23	0.62	-0.65
CCNATIVE	<0.0001	<0.0001	0.08	<0.0001		0.43	0.52	0.37	0.71	-0.49
DISTBLDG	0.00	0.00	0.26	0.08	0.00		0.82	0.93	0.66	0.05
DISTEDGE	0.00	<0.0001	0.24	0.04	<0.0001	<0.0001		0.70	0.70	-0.03
DISTROAD	0.00	0.01	0.36	0.10	0.01	<0.0001	<0.0001		0.63	0.00
FORESTWD[a]	<0.0001	<0.0001	0.12	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		-0.40
HERB	0.00	0.00	1.00	<0.0001	0.00	0.72	0.85	1.00	0.00	
HERBALIEN	<0.0001	<0.0001	0.34	<0.0001	<0.0001	0.02	0.00	0.02	<0.0001	<0.0001
HERBNATIVE	<0.0001	<0.0001	0.06	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.09
HIGHSHRUB	<0.0001	<0.0001	0.27	<0.0001	<0.0001	0.05	0.07	0.02	<0.0001	<0.0001
HSHRUBALIEN	0.87	0.27	0.26	0.57	0.24	0.36	0.06	0.39	0.56	0.00
HSHRUBNAT	<0.0001	<0.0001	0.09	<0.0001	<0.0001	0.03	0.02	0.01	<0.0001	<0.0001
IMPERV	0.00	0.02	0.12	0.09	0.01	0.03	0.10	0.03	0.01	0.55
LEAFLITTER	0.00	<0.0001	0.89	<0.0001	<0.0001	0.02	0.00	0.03	0.00	0.00
LOGS	<0.0001	<0.0001	0.18	<0.0001	<0.0001	0.00	0.00	0.01	<0.0001	0.04
LOWSHRUB	<0.0001	<0.0001	0.16	<0.0001	<0.0001	0.19	0.19	0.11	<0.0001	<0.0001
LSHRUBALIEN	0.12	0.37	0.98	0.03	0.37	0.34	0.23	0.38	0.60	<0.0001
LSHRUBNAT	<0.0001	<0.0001	0.08	<0.0001	<0.0001	0.01	0.00	0.00	<0.0001	0.02
SLASH	<0.0001	<0.0001	0.57	<0.0001	<0.0001	0.08	0.02	0.11	<0.0001	<0.0001
SLOPE	0.00	<0.0001	0.61	<0.0001	<0.0001	0.18	0.04	0.33	0.01	0.02
SNAGS	<0.0001	<0.0001	0.40	0.00	<0.0001	0.04	0.00	0.05	<0.0001	0.01
STREETS	0.09	0.53	0.41	0.72	0.48	0.00	0.07	0.00	0.02	0.41
STRUCT	0.02	0.09	0.82	0.14	0.09	0.07	0.21	0.05	0.01	0.85
TOTSHRUB	<0.0001	<0.0001	0.24	<0.0001	<0.0001	0.13	0.11	0.07	<0.0001	<0.0001
TRAIL	0.18	0.35	0.00	0.18	0.21	0.43	0.54	0.60	0.62	0.13
VACANT	0.00	0.02	0.03	0.26	0.01	<0.0001	0.00	<0.0001	<0.0001	0.94
VISCAV	0.00	0.01	0.55	0.02	0.01	0.90	0.37	0.76	0.01	0.48

[a]Natural log-transformed.

Appendix 4. Continued.

Variable	HERBALIEN	HERBNATIVE	HIGHSHRUB	HSHRUBALIEN	HSHRUBNAT	IMPERV	LEAFLITTER	LOGS	LOWSHRUB
BUF1CC	-0.75	0.72	0.62	-0.02	0.65	-0.44	0.46	0.69	0.63
CANCOV	-0.81	0.81	0.51	-0.15	0.58	-0.32	0.67	0.66	0.53
CCALIEN	0.13	-0.26	-0.15	0.16	-0.23	0.21	-0.02	-0.19	-0.20
CCDEPTH	-0.81	0.61	0.72	0.08	0.73	-0.23	0.60	0.65	0.69
CCNATIVE	-0.81	0.82	0.51	-0.16	0.59	-0.33	0.66	0.66	0.54
DISTBLDG	-0.31	0.64	0.27	-0.13	0.30	-0.30	0.31	0.40	0.18
DISTEDGE	-0.39	0.68	0.24	-0.26	0.32	-0.23	0.41	0.48	0.18
DISTROAD	-0.31	0.57	0.32	-0.12	0.35	-0.29	0.29	0.33	0.22
FORESTWD[a]	-0.70	0.75	0.60	-0.08	0.65	-0.37	0.48	0.67	0.55
HERB	0.84	-0.23	-0.73	-0.38	-0.63	-0.08	-0.40	-0.28	-0.83
HERBALIEN		-0.72	-0.77	-0.14	-0.76	0.12	-0.61	-0.64	-0.79
HERBNATIVE	<0.0001		0.47	-0.24	0.57	-0.32	0.57	0.79	0.37
HIGHSHRUB	<0.0001	0.00		0.31	0.94	-0.19	0.30	0.50	0.84
HSHRUBALIEN	0.33	0.08	0.02		-0.04	0.20	-0.17	-0.19	0.37
HSHRUBNAT	<0.0001	<0.0001	<0.0001	0.77		-0.28	0.38	0.59	0.75
IMPERV	0.38	0.02	0.17	0.14	0.04		-0.26	-0.40	-0.17
LEAFLITTER	<0.0001	<0.0001	0.03	0.23	0.00	0.06		0.48	0.23
LOGS	<0.0001	<0.0001	0.00	0.16	<0.0001	0.00	0.00		0.43
LOWSHRUB	<0.0001	0.01	<0.0001	0.01	<0.0001	0.23	0.09	0.00	
LSHRUBALIEN	0.00	0.49	0.00	<0.0001	0.21	0.49	0.92	0.59	<0.0001
LSHRUBNAT	<0.0001	<0.0001	<0.0001	0.05	<0.0001	0.02	0.02	<0.0001	<0.0001
SLASH	<0.0001	<0.0001	<0.0001	0.94	<0.0001	0.00	<0.0001	<0.0001	<0.0001
SLOPE	<0.0001	<0.0001	0.17	0.81	0.10	0.41	<0.0001	<0.0001	0.14
SNAGS	<0.0001	<0.0001	0.00	0.23	0.00	0.08	0.01	<0.0001	0.01
STREETS	0.88	0.15	0.64	0.47	0.47	0.01	0.74	0.21	0.43
STRUCT	0.38	0.22	0.10	0.80	0.10	<0.0001	0.14	0.09	0.08
TOTSHRUB	<0.0001	0.00	<0.0001	0.02	<0.0001	0.10	0.02	<0.0001	<0.0001
TRAIL	0.96	0.08	0.90	0.28	0.58	<0.0001	0.92	0.03	0.86
VACANT	0.12	0.00	0.08	0.41	0.03	<0.0001	0.19	0.00	0.06
VISCAV	0.02	0.00	0.20	0.18	0.07	0.45	0.21	<0.0001	0.34

[a]Natural log-transformed.

Appendix 4. Continued.

Variable	LSHRUBALIEN	LSHRUBNAT	SLASH	SLOPE	SNAGS	STREETS	STRUCT	TOTSHRUB	TRAIL	VACANT	VISCAV
BUF1CC	0.21	0.57	0.64	0.38	0.65	-0.23	-0.32	0.72	-0.19	0.46	0.39
CANCOV	0.13	0.57	0.64	0.61	0.58	-0.09	-0.23	0.62	-0.13	0.33	0.35
CCALIEN	0.00	-0.24	-0.08	-0.07	-0.12	0.11	0.03	-0.16	0.44	-0.30	-0.08
CCDEPTH	0.29	0.56	0.71	0.51	0.47	0.05	-0.21	0.77	-0.18	0.16	0.31
CCNATIVE	0.13	0.58	0.64	0.61	0.58	-0.10	-0.23	0.62	-0.17	0.35	0.35
DISTBLDG	-0.13	0.38	0.24	0.19	0.29	-0.42	-0.25	0.21	-0.11	0.60	-0.02
DISTEDGE	-0.17	0.42	0.32	0.28	0.46	-0.24	-0.17	0.22	-0.08	0.41	0.12
DISTROAD	-0.12	0.41	0.22	0.13	0.26	-0.49	-0.27	0.25	-0.07	0.59	-0.04
FORESTWD[a]	0.07	0.63	0.56	0.33	0.61	-0.33	-0.36	0.64	-0.07	0.53	0.33
HERB	-0.68	-0.32	-0.51	-0.31	-0.33	-0.11	0.03	-0.85	-0.21	0.01	-0.10
HERBALIEN	-0.43	-0.56	-0.71	-0.53	-0.58	0.02	0.12	-0.87	-0.01	-0.21	-0.32
HERBNATIVE	-0.10	0.59	0.60	0.54	0.62	-0.20	-0.17	0.48	-0.24	0.41	0.43
HIGHSHRUB	0.40	0.62	0.62	0.19	0.39	-0.06	-0.23	0.92	-0.02	0.24	0.18
HSHRUBALIEN	0.70	-0.27	0.01	-0.03	-0.17	0.10	-0.03	0.33	0.15	-0.11	-0.19
HSHRUBNAT	0.17	0.74	0.66	0.23	0.46	-0.10	-0.23	0.85	-0.08	0.29	0.25
IMPERV	0.10	-0.32	-0.40	-0.11	-0.24	0.37	0.70	-0.22	0.53	-0.54	-0.11
LEAFLITTER	0.01	0.31	0.64	0.63	0.34	-0.05	-0.20	0.33	0.01	0.18	0.17
LOGS	-0.07	0.61	0.76	0.52	0.68	-0.17	-0.23	0.51	-0.29	0.41	0.60
LOWSHRUB	0.63	0.60	0.57	0.21	0.35	-0.11	-0.24	0.95	-0.02	0.26	0.13
LSHRUBALIEN		-0.24	0.15	0.15	0.00	0.08	-0.04	0.56	0.07	-0.08	-0.10
LSHRUBNAT	0.08		0.57	0.13	0.45	-0.24	-0.26	0.60	-0.10	0.42	0.27
SLASH	0.26	<0.0001		0.58	0.51	-0.07	-0.29	0.64	-0.27	0.28	0.35
SLOPE	0.29	0.35	<0.0001		0.29	0.14	0.00	0.26	-0.22	0.02	0.23
SNAGS	0.98	0.00	<0.0001	0.03		-0.09	-0.07	0.44	-0.14	0.31	0.53
STREETS	0.56	0.08	0.61	0.31	0.50		0.43	-0.07	-0.08	-0.71	-0.10
STRUCT	0.77	0.06	0.03	0.98	0.64	0.00		-0.26	0.11	-0.45	-0.08
TOTSHRUB	<0.0001	<0.0001	<0.0001	0.06	0.00	0.60	0.06		-0.04	0.24	0.21
TRAIL	0.62	0.48	0.05	0.10	0.32	0.55	0.43	0.79		-0.14	-0.17
VACANT	0.54	0.00	0.04	0.89	0.02	<0.0001	0.00	0.08	0.32		0.15
VISCAV	0.47	0.05	0.01	0.09	<0.0001	0.48	0.57	0.13	0.22	0.29	

[a]Natural log-transformed.

Appendix 5. Bird species detected at 54 riparian sites in Portland, Oregon during May and June, 1999.

Common Name[a]	Scientific Name[a]	Detected at how many sites?	# Birds Detected	% of total detections
Acorn Woodpecker	*Melanerpes formicivorus*	1	1	0.01
American Crow	*Corvus brachyrhynchos*	33	104	1.17
American Goldfinch	*Carduelis tristis*	24	48	0.54
American Kestrel	*Falco sparverius*	1	1	0.01
American Robin	*Turdus migratorius*	53	691	7.76
Anna's Hummingbird	*Calypte anna*	3	6	0.07
Band-tailed Pigeon	*Columba fasciata*	5	61	0.69
Barn Swallow	*Hirundo rustica*	14	626	7.03
Belted Kingfisher	*Ceryle alcyon*	1	1	0.01
Bewick's Wren	*Thryomanes bewickii*	50	285	3.20
Black-capped Chickadee	*Poecile atricapilla*	53	352	3.95
Black-headed Grosbeak	*Pheucticus melanocephalus*	41	165	1.85
Black-throated Gr. Warbler	*Dendroica nigrescens*	8	11	0.12
Brewer's Blackbird	*Euphagus cyanocephalus*	3	11	0.12
Brown Creeper	*Certhia americana*	22	78	0.88
Brown-headed Cowbird	*Molothrus ater*	50	352	3.95
Bullock's Oriole	*Icterus bullockii*	7	23	0.26
Bushtit	*Psaltriparus minimus*	41	218	2.45
California Quail	*Callipepla californica*	3	6	0.07
Canada Goose	*Branta canadensis*	2	14	0.16
Cassin's Vireo	*Vireo cassinii*	2	2	0.02
Cedar Waxwing	*Bombycilla cedrorum*	39	242	2.72
Chestnut-backed Chickadee	*Poecile rufescens*	12	28	0.31
Cliff Swallow	*Petrochelidon pyrrhonota*	1	1	0.01
Common Merganser	*Mergus merganser*	1	1	0.01
Common Yellowthroat	*Geothlypis trichas*	21	83	0.93
Cooper's Hawk	*Accipiter cooperii*	2	2	0.02
Dark-eyed Junco	*Junco hyemalis*	14	23	0.26
Dowitcher species	*Limnodromus species*	1	2	0.02
Downy Woodpecker	*Picoides pubescens*	34	57	0.64
European Starling	*Sturnus vulgaris*	47	1527	17.16
Evening Grosbeak	*Coccothraustes vespertinus*	4	16	0.18
Fox Sparrow	*Passerella iliaca*	1	1	0.01

Appendix 5. Continued.

Common Name[a]	Scientific Name[a]	Detected at how many sites?	# Birds Detected	% of total detections
Golden-crowned Kinglet	*Regulus satrapa*	3	7	0.08
Golden-crowned Sparrow	*Zonotrichia atricapilla*	3	3	0.03
Great Blue Heron	*Ardea herodias*	8	9	0.10
Great Horned Owl	*Bubo virginianus*	1	1	0.01
Green Heron	*Butorides virescens*	1	1	0.01
Hairy Woodpecker	*Picoides villosus*	3	3	0.03
Hammond's Flycatcher	*Empidonax hammondii*	4	5	0.06
Hermit Thrush	*Catharus guttatus*	4	4	0.04
House Finch	*Carpodacus mexicanus*	46	283	3.18
House Sparrow	*Passer domesticus*	26	265	2.98
Hutton's Vireo	*Vireo huttoni*	7	12	0.13
Killdeer	*Charadrius vociferus*	6	9	0.10
Lazuli Bunting	*Passerina amoena*	3	3	0.03
Lincoln's Sparrow	*Melospiza lincolnii*	1	1	0.01
Mallard	*Anas platyrhynchos*	28	193	2.17
Marsh Wren	*Cistothorus palustris*	1	1	0.01
Mourning Dove	*Zenaida macroura*	16	34	0.38
Northern Flicker	*Colaptes auratus*	24	36	0.40
Olive-sided Flycatcher	*Contopus cooperi*	4	8	0.09
Orange-crowned Warbler	*Vermivora celata*	31	66	0.74
Osprey	*Pandion haliaetus*	1	1	0.01
Pacific-slope Flycatcher	*Empidonax difficilis*	23	73	0.82
Pileated Woodpecker	*Dryocopus pileatus*	3	3	0.03
Pine Siskin	*Carduelis pinus*	17	54	0.61
Purple Finch	*Carpodacus purpureus*	3	6	0.07
Red-breasted Nuthatch	*Sitta canadensis*	17	38	0.43
Red-breasted Sapsucker	*Sphyrapicus ruber*	10	14	0.16
Red-tailed Hawk	*Buteo jamaicensis*	3	3	0.03
Red-winged Blackbird	*Agelaius phoeniceus*	19	313	3.52
Ring-necked Pheasant	*Phasianus colchicus*	2	2	0.02
Ruby-crowned Kinglet	*Regulus calendula*	3	3	0.03
Rufous Hummingbird	*Selasphorus rufus*	24	31	0.35
Savannah Sparrow	*Passerculus sandwichensis*	4	5	0.06

Appendix 5. Continued.

Common Name[a]	Scientific Name[a]	Detected at how many sites?	# Birds Detected	% of total detections
Golden-crowned Kinglet	*Regulus satrapa*	3	7	0.08
Golden-crowned Sparrow	*Zonotrichia atricapilla*	3	3	0.03
Great Blue Heron	*Ardea herodias*	8	9	0.10
Great Horned Owl	*Bubo virginianus*	1	1	0.01
Green Heron	*Butorides virescens*	1	1	0.01
Hairy Woodpecker	*Picoides villosus*	3	3	0.03
Hammond's Flycatcher	*Empidonax hammondii*	4	5	0.06
Hermit Thrush	*Catharus guttatus*	4	4	0.04
House Finch	*Carpodacus mexicanus*	46	283	3.18
House Sparrow	*Passer domesticus*	26	265	2.98
Hutton's Vireo	*Vireo huttoni*	7	12	0.13
Killdeer	*Charadrius vociferus*	6	9	0.10
Lazuli Bunting	*Passerina amoena*	3	3	0.03
Lincoln's Sparrow	*Melospiza lincolnii*	1	1	0.01
Mallard	*Anas platyrhynchos*	28	193	2.17
Marsh Wren	*Cistothorus palustris*	1	1	0.01
Mourning Dove	*Zenaida macroura*	16	34	0.38
Northern Flicker	*Colaptes auratus*	24	36	0.40
Olive-sided Flycatcher	*Contopus cooperi*	4	8	0.09
Orange-crowned Warbler	*Vermivora celata*	31	66	0.74
Osprey	*Pandion haliaetus*	1	1	0.01
Pacific-slope Flycatcher	*Empidonax difficilis*	23	73	0.82
Pileated Woodpecker	*Dryocopus pileatus*	3	3	0.03
Pine Siskin	*Carduelis pinus*	17	54	0.61
Purple Finch	*Carpodacus purpureus*	3	6	0.07
Red-breasted Nuthatch	*Sitta canadensis*	17	38	0.43
Red-breasted Sapsucker	*Sphyrapicus ruber*	10	14	0.16
Red-tailed Hawk	*Buteo jamaicensis*	3	3	0.03
Red-winged Blackbird	*Agelaius phoeniceus*	19	313	3.52
Ring-necked Pheasant	*Phasianus colchicus*	2	2	0.02
Ruby-crowned Kinglet	*Regulus calendula*	3	3	0.03
Rufous Hummingbird	*Selasphorus rufus*	24	31	0.35
Savannah Sparrow	*Passerculus sandwichensis*	4	5	0.06

Appendix 6. Principal component (PC) loadings for bird habitat variables measured at 54 riparian sites in the Portland, Oregon area, June and July 1999.

Category	Variable[a]	PC1	PC2	PC3	PC4	PC5	PC6
Herbaceous cover	HERBNATIVE	0.34	-0.09	0.13	0.07	-0.11	0.29
Low shrub cover	LOWSHRUB	0.27	0.41	-0.14	-0.01	-0.03	-0.28
	LSHRUBNAT	0.32	-0.06	0.01	0.22	-0.22	-0.46
	LSHRUBALIEN	0.02	0.55	-0.18	-0.22	0.18	0.14
High shrub cover	HSHRUBNAT	0.33	0.16	0.07	0.06	0.01	-0.41
	HSHRUBALIEN	-0.06	0.50	-0.26	-0.12	-0.02	0.19
Forest structure	FORESTWD	0.35	0.02	-0.08	0.14	-0.02	0.15
	CCDEPTH	0.32	0.24	0.21	-0.08	0.03	0.00
	BAREGRND	0.04	-0.08	0.25	-0.20	0.80	-0.29
	LEAFLITTER	0.24	0.00	0.24	0.08	0.26	0.49
	LOGS	0.35	-0.07	0.12	-0.05	-0.08	0.14
	SNAGS	0.28	-0.03	0.15	0.04	0.03	0.17
Human disturbance	TRAILS	-0.10	0.16	-0.05	0.74	0.30	0.03
	IMPERV	-0.21	0.24	0.23	0.48	-0.08	0.03
	STREETS	-0.13	0.21	0.57	-0.16	-0.31	-0.01
	VACANT	0.23	-0.20	-0.51	0.03	0.05	0.09
	Percent variation explained	38.10	15.40	10.40	8.04	6.75	5.45

[a]See Appendix 2 for variable abbreviations and definitions.

Appendix 6. Principal component (PC) loadings for bird habitat variables measured at 54 riparian sites in the Portland, Oregon area, June and July 1999.

Category	Variable[a]	PC1	PC2	PC3	PC4	PC5	PC6
Herbaceous cover	HERBNATIVE	0.34	-0.09	0.13	0.07	-0.11	0.29
Low shrub cover	LOWSHRUB	0.27	0.41	-0.14	-0.01	-0.03	-0.28
	LSHRUBNAT	0.32	-0.06	0.01	0.22	-0.22	-0.46
	LSHRUBALIEN	0.02	0.55	-0.18	-0.22	0.18	0.14
High shrub cover	HSHRUBNAT	0.33	0.16	0.07	0.06	0.01	-0.41
	HSHRUBALIEN	-0.06	0.50	-0.26	-0.12	-0.02	0.19
Forest structure	FORESTWD	0.35	0.02	-0.08	0.14	-0.02	0.15
	CCDEPTH	0.32	0.24	0.21	-0.08	0.03	0.00
	BAREGRND	0.04	-0.08	0.25	-0.20	0.80	-0.29
	LEAFLITTER	0.24	0.00	0.24	0.08	0.26	0.49
	LOGS	0.35	-0.07	0.12	-0.05	-0.08	0.14
	SNAGS	0.28	-0.03	0.15	0.04	0.03	0.17
Human disturbance	TRAILS	-0.10	0.16	-0.05	0.74	0.30	0.03
	IMPERV	-0.21	0.24	0.23	0.48	-0.08	0.03
	STREETS	-0.13	0.21	0.57	-0.16	-0.31	-0.01
	VACANT	0.23	-0.20	-0.51	0.03	0.05	0.09
	Percent variation explained	38.10	15.40	10.40	8.04	6.75	5.45

[a]See Appendix 2 for variable abbreviations and definitions.

Appendix 7. Regression analyses for bird community variables versus habitat variables with high (> 0.20) loading on principal components for 54 riparian sites in the Portland, Oregon area during 1999. Variables are defined in Appendix 2.

Bird Variable	PC-Loading Variable ($\geq$ 0.20)	Regression Equation			r^2	P-value
		Intercept	Slope	Quadratic[a]		
Bird abundance	HERBNATIVE	13.7	-0.136	N/A	0.44	< 0.0001
	LOWSHRUB	14.8	-7.03	N/A	0.18	0.001
	LSHRUBNAT	13.4	-0.078	N/A	0.15	0.004
	HSHRUBNAT	14.8	-0.098	N/A	0.25	0.002
	LNFWT	17.3	-1.28	N/A	0.22	0.0004
	CCDEPTH	15.5	-0.414	N/A	0.22	0.0005
	LEAFLITTER	13.3	-0.885	N/A	0.19	0.001
	LOGS	13.5	-2.10	N/A	0.25	< 0.0001
	SNAGS	13.7	-5.05	N/A	0.25	0.0001
	IMPERV	11.3	-0.171	N/A	0.06	0.08
	VACANT	16.1	-6.05	N/A	0.16	0.003
Nonnative abundance	HERBNATIVE	3.35	-0.0875	N/A	0.51	< 0.0001
	LOWSHRUB	4.67	-0.0615	N/A	0.37	< 0.0001
	LSHRUBNAT	3.56	-0.0715	N/A	0.35	< 0.0001
	HSHRUBNAT	4.44	-0.0756	N/A	0.42	< 0.0001
	LNFWT	6.65	-1.06	N/A	0.42	< 0.0001
	CCDEPTH	5.08	-0.335	N/A	0.39	< 0.0001
	LEAFLITTER	3.20	-0.638	N/A	0.27	< 0.0001
	LOGS	3.37	-1.55	N/A	0.38	< 0.0001
	SNAGS	3.29	-3.06	N/A	0.26	0.0001
	IMPERV	1.67	0.148	N/A	0.12	0.01
	VACANT	4.28	-4.49	N/A	0.25	< 0.0001

Appendix 7. Continued.

Bird Variable	PC-Loading Variable (≥ 0.20)	Regression Equation			r^2	P-value
		Intercept	Slope	Quadratic[a]		
Species richness	HERBNATIVE	7.10	-0.0311	N/A	0.17	0.002
	LOWSHRUB	6.54	0.0032	N/A	0.003	0.71
	LSHRUBNAT	6.81	-0.0072	N/A	0.009	0.49
	HSHRUBNAT	6.83	-0.0052	N/A	0.005	0.61
	LNFWT	3.19	1.76	-0.206	0.15	0.006
	CCDEPTH	5.27	0.488	-0.0322	0.12	0.02
	LEAFLITTER	0.688	-0.126	N/A	0.03	0.23
	LOGS	0.692	-0.315	N/A	0.04	0.14
	SNAGS	6.97	-0.794	N/A	0.05	0.12
	IMPERV	6.65	0.0071	N/A	0.0008	0.84
	VACANT	7.20	-0.754	N/A	0.02	0.32
Native species richness	HERBNATIVE	6.22	-0.0076	N/A	0.01	0.42
	LOWSHRUB	4.56	0.0726	-0.0007	0.18	0.006
	LSHRUBNAT	5.33	0.0832	-0.0014	0.14	0.02
	HSHRUBNAT	5.00	0.0720	-0.0009	0.09	0.03
	LNFWT	1.87	1.81	-0.181	0.23	0.001
	CCDEPTH	4.36	0.466	-0.0261	0.14	0.009
	LEAFLITTER	6.08	0.0204	N/A	0.00	0.83
	LOGS	6.03	0.0975	N/A	0.01	0.61
	SNAGS	6.10	0.0325	N/A	0.00	0.94
	IMPERV	6.20	-0.0308	N/A	0.02	0.34
	VACANT	5.86	0.351	N/A	0.01	0.61
Shannon diversity	HERBNATIVE	1.71	-0.0022	N/A	0.03	0.22
	LOWSHRUB	1.40	0.0129	-0.0001	0.13	0.01
	LSHRUBNAT	1.67	0.0004	N/A	0.00	0.80
	HSHRUBNAT	1.63	0.0015	N/A	0.02	0.37
	LNFWT	0.980	0.315	-0.0333	0.15	0.007
	CCDEPTH	1.32	0.095	-0.0054	0.16	0.004

Appendix 7. Continued.

Bird Variable	PC-Loading Variable (≥ 0.20)	Regression Equation			r^2	P-value
		Intercept	Slope	Quadratic[a]		
	LEAFLITTER	1.67	0.0028	N/A	0.00	0.87
	LOGS	1.68	0.0015	N/A	0.00	0.97
	SNAGS	1.67	0.0160	N/A	0.00	0.86
	IMPERV	1.68	-0.0000	N/A	0.00	0.99
	VACANT	1.72	0.0459	N/A	0.00	0.67
Native Shannon diversity	HERBNATIVE	1.61	0.0003	N/A	0.00	0.87
	LOWSHRUB	1.20	0.0198	-0.0002	0.32	<0.0001
	LSHRUBNAT	1.43	0.0182	-0.0003	0.15	0.006
	HSHRUBNAT	1.30	0.0193	-0.0002	0.22	0.0006
	LNFWT	0.567	0.430	-0.0405	0.38	< 0.0001
	CCDEPTH	1.18	0.106	-0.0057	0.24	0.0004
	LEAFLITTER	1.59	0.0155	N/A	0.01	0.39
	LOGS	1.57	0.0491	N/A	0.03	0.18
	SNAGS	1.57	0.114	N/A	0.03	0.20
	IMPERV	1.64	-0.0083	N/A	0.03	0.18
	VACANT	1.52	0.127	N/A	0.02	0.34
NMB[b] Species Richness	HERBNATIVE	1.70	-0.0030	N/A	0.01	0.59
	LOWSHRUB	1.53	0.0065	N/A	0.03	0.23
	LSHRUBNAT	1.51	0.0037	N/A	0.01	0.42
	HSHRUBNAT	1.44	0.0072	N/A	0.04	0.17
	HSHRUBALIEN	1.64	0.0022	N/A	0.00	0.87
	CCDEPTH	1.83	-0.0197	N/A	0.01	0.40
	BAREGRND	1.68	-0.0068	N/A	0.00	0.86
	LEAFLITTER	1.79	-0.0788	N/A	0.04	0.15
	IMPERV	1.71	-0.0151	N/A	0.01	0.42
	STREETS	1.89	-0.0085	N/A	0.17	0.002
	VACANT	1.19	0.667	N/A	0.05	0.09