

**EFFECTS OF LANDSCAPE AND LOCAL HABITAT FEATURES ON  
BIRD COMMUNITIES: A STUDY OF AN URBAN GRADIENT IN  
GREATER VANCOUVER.**

by

Stephanie J. Melles

**B.Sc., The University of Toronto, 1994**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR  
THE DEGREE OF MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES  
THE FACULTY OF FORESTRY  
Department of Forest Sciences  
Centre for Applied Conservation Biology

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF ~~BR~~ITISH COLUMBIA  
December, 2000

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Department of Forest Sciences

The University of British Columbia  
Vancouver, Canada

Date Dec 14/2000

## ABSTRACT

Bird species diversity and abundance trends in urban areas can provide evidence to predict the relative importance of local bird habitat under different landscape contexts. I examined the hypothesis that selected species and nesting guilds should be more closely associated with landscape level features, such as proximity to large forested areas ( $< 100$  ha), than with local scale habitat measures ( $< 1$  ha). I collected avian community data during surveys completed over a two year period at 285 point count stations along four linear road transects located in Vancouver and Burnaby, British Columbia. Stations were located along transects bisecting three large parks ( $> 324$  ha) and proceeding away from these parks along residential streets into highly urban and suburban areas. A total of 49 breeding bird species were observed including 36 common species and 13 species that were sighted only once. Canonical correspondence analysis was used to view the main associations between measured habitat variables and species distributions. Species richness declined with increasing urbanization and the gradient (CCA axis one site scores) was dominated by landscape level habitat measures. Park area-by-distance metrics, developed using G.I.S., had the highest correlation with CCA axis one indicating the importance of park area in the vicinity for many species of birds breeding in marginal residential areas. Different land use zones did not neatly separate the urbanization gradient into simple bird habitat categories. Habitat models were created for five nesting guilds and three selected species (Song Sparrow, *Melospiza melodia*, Spotted Towhee, *Pipilo maculatus*, and American Robin, *Turdus migratorius*) with sequential block addition of landscape and local variables. Local variables significantly improved predictability of landscape variable only models, but the difference was slight. Landscape variables alone were often good predictors of presence or absence of most groups of species (guilds), but were less sensitive than local variables at predicting individual species presence. Incidence (percent stations occupied) of several bird species increased with park area in the vicinity as an inverse function of distance. The results of this study suggest that matrix areas surrounding parks and reserves should be integrated into urban planning and development designs.

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## ARCHIVE LOCATION OF ORIGINAL DATA

The original data used in this thesis are not reproduced here. However, archives of all the source data have been provided to the Data Services Department of Walter C. Koerner Library, University of British Columbia. This data may be requested directly from the Data Library or by phone: (604) 822-6742.



## ACKNOWLEDGEMENTS

This project was funded in part with generous support from the Asa -Yohal Graduate Fellowship in Forestry and the Bert Hoffmeister Scholarship in Forest Wildlife. The Centre for Applied Conservation Biology, the Geography department at UBC, and the Canadian Wildlife Service also provided many resources.

I would like to thank my co-supervisors, Professor's Susan Glenn and Kathy Martin. Without Susan Glenn's enthusiasm, trust, generous advice, and theoretical savvy this project would not have been realized; and Kathy Martin, whose scientific ardor and expertise I admire and aspire to, thank you so much for your support and for caring. My other committee members, Professor's Brian Klinkenburg and Tony Sinclair - Brian you were always available to provide insight, humour, and surprisingly quick solutions to all of my GIS related problems. Your help and suggestions were always appreciated. Tony Sinclair, you were particularly instrumental in the beginning of this endeavour, sitting me down and getting right into the nature of how to ask a question. Thank you. Several people at the Centre for Applied Conservation Biology and the Statistical Department at UBC were able to assist me with statistical and data related inquiries, Andreas Hammond, Milosh Ivkovich, Glenn Sutherland, Pierre Vernier, Ralph Wells, and the graduate students of Statistical Consulting, STATS\_500, as well as many others.

When it comes to writing, Glenn Sutherland, I esteem your words and thank you for giving so generously. Finally, to all my good friends, and particularly "The Girls" - Heather and Christine, Anne O', Lisa, Caitlin, Devon, Susan and Susan, and lastly to Milosh: It is with a tremendous amount of sadness that I write these words knowing that the time we have shared has come to pass, and that I may no longer have your friendship so near at hand. My respect for you has only increased with my knowing you and I trust and hope that our friendship will continue always. Special thanks to The favourite Molestics for supreme bits of Hokum.

## INTRODUCTION

Worldwide, urban areas are expanding both in size and number with ever-increasing human populations. By the year 2030, the number of people living in cities is expected to increase by 2 billion inhabitants, reaching an estimated 4.9 billion or 60% of the expected global population (UN Population Division 1999). As a result of urban expansion, native vegetation is reduced and fragmented over a landscape matrix in which both the amount of impervious surface is increased, and the structure and composition of the remaining vegetation is progressively altered (Beissinger and Osborne 1982, Arnold and Gibbons 1996, Germain *et al.* 1998, Marzluff *et al.* 1998). Cities are typically located in coastal areas, close to rivers and estuaries, or near large bodies of inland water (40% of cities with populations greater than ½ million are located on coasts, WRI 1996). Therefore, urbanization is biased to bottomland and riparian systems that often support more species of breeding birds than extensive surrounding upland areas (Knopf *et al.* 1988, Ohmart 1994). Large parks and reserves in urban areas often support high species diversity because these protected areas are the habitat 'fragments' of exceptional ecosystems (Schaefer 1994). Increasing urbanization adjacent to natural areas and parks often results in simplified habitats and this leads to a community of birds with fewer species dominated by superabundant flocks of exotic species (Marzluff *et al.* 1998).

Conservation biologists have been predominantly interested in the protection of natural ecosystems and have placed little importance on urban areas or urban biodiversity overall (Vandermeer 1997, Jules, 1997). Some studies on urban birds have focused on species richness within a patch of native habitat (e.g., a large park) in relation to size of patch and degree of isolation from other contiguous areas of habitat (Tilghman 1987, Diamond 1988, Soulé *et al.*

1988). Other studies of urban avifauna have focused on the habitat associations affecting birds at local spatial scales (2 to <25 ha, Emlen 1974, Weber 1972, Campbell and Dagg 1976, Lancaster and Rees 1979). Citywide surveys are rare (Hadidian *et al.* 1997), and little is known about how the juxtaposition of different habitats (i.e., high density housing and suburban) affects avian diversity both within each habitat type and at varying distances from the edge of a large forested area (Marzluff *et al.* 1998). However, land-use planners may benefit from greater understanding of how urban development affects birds in parks and reserves, in surrounding residential areas, and at the level of entire landscapes.

Land use terms such as, rural, suburban, and urban, pose difficulties for urban bird research because they lack standard definitions and they attempt to define different habitat types along a complex environmental gradient that lacks distinct boundaries (Marzluff *et al.* 1998). There is a need for standard measures that accurately quantify the position of an urban or suburban site along this complex gradient, and to relate these findings to urban bird populations and community ecology (Marzluff *et al.* 1998, Clergeau 1995). Urban areas are generally defined by land use planners as areas having population densities over a minimum of 620 individual humans/km<sup>2</sup> (McDonnell and Pickett 1990) while suburban areas are typically defined as districts located on the edge of a larger urban centre. When these land use categories are examined as different habitat types for birds, the findings from different urban areas are inconsistent. Some suburbs with low levels of development support quite varied bird communities with higher than expected bird species richness, including a mixture of native and non-native species (Emlen 1974, Rosenberg *et al.* 1987; DeGraaf 1991). Suburbs may have potential for land management practices that would enhance the value of these areas for birds (Blair 1996). However, vegetation is invariably altered with urbanization. Suburban areas rarely include the full complement of vertical strata found in natural forests (Beissinger and Osborne 1982), and native

plant species are often removed and/or replaced by exotic ornamentals (Rosenberg *et al.* 1987, Blair 1996). Birds may be responding directly to characteristics of the vegetation within suburban habitats or they may be responding to the proximity of both large forested areas and highly urbanized areas. Suburban areas may be replenished locally by continued immigration of individual birds from more-productive, forested areas nearby, so suburbs could be “sink” habitats where within-habitat reproduction is insufficient to balance local mortality (Pulliam 1988, Robinson *et al.* 1995).

Urban bird community-level dynamics have been investigated in relation to at least three dominant ecological theories:

- 1) Stand level habitat modeling and habitat diversity theories, which examine species assemblage in relation to the structure and composition of resources at the local stand level scale (discussed in Gauch 1973, Shmida and Wilson 1985, McGuinness and Underwood 1986).

- 2) Island biogeography theory, which examines the effects of island isolation and size in relation to species richness, immigration, and extinction rates, and has been applied to habitat patch dynamics in fragmented urban areas (MacArthur and MacArthur 1961, MacArthur and Wilson 1967).

- 3) Spatial structuring theories of ecological communities where local scale habitat features are viewed in relation to larger scale surrounding landscape features (Bolger *et al.* 1997, Germain *et al.* 1998, Rottenborn 1999, Saab 1999). I followed this approach to examine bird communities in relation to features of the entire urban matrix.

Urban bird communities have been examined in relation to the structure and composition of vegetation and food resources at the stand level with areas ranging in size from ~16-50 ha city blocks (Weber 1972, Campbell and Dagg 1976, Lancaster and Rees 1979). Stand level habitat diversity findings have been fairly consistent, demonstrating that species richness (the number of

species) decreased while the relative abundance of common species increased in highly urbanized areas (i.e. commercial and industrial sites) compared to areas with lower residential housing densities (e.g., Emlen 1974, Blair 1996). Relative abundance and species occurrence in a habitat block or stand were related to individual species requirements, such as: weedy lawn cover, number of home feeders (Emlen 1974); foliage height diversity (Lancaster and Rees 1979); woody cover, water (Campbell and Dagg 1976, Edgar and Kershaw 1994); modification of vegetation, and park size (Gavareski 1976). However, the juxtaposition of habitats surrounding each habitat stand was not considered. Lower density residential areas may often be located in close proximity to regional parks, and may also have higher within-habitat diversity, vegetation structure and composition, than more highly urbanized areas with greater housing densities.

Secondly, urban avian diversity in fragmented areas has been correlated with size of remaining habitat areas and, with measures of isolation distance from other 'islands' of habitat. In Springfield, Massachusetts, the diversity of birds correlated *positively* with size of woodland, water, and coniferous tree cover; and *negatively* with distance to the nearest park trail, and building density in areas immediately adjacent to 32 forest 'islands'. Avian richness in these urban forest patches was not related to (isolation) distance to the nearest extensive woods (>400 ha) in multiple regression models (Tilghman 1987). In canyons around the city of San Diego County, California, canyon occupancy by endemic chaparral scrub requiring birds was related to the size of remaining scrub habitat, fragmented by urban development (Soulé *et al.* 1988). In addition, birds dispersing from nearby canyon habitat patches were expected to replace extirpated populations in small habitat patches; species richness was expected to decline inversely with distance from the nearest habitat patch; however, small patches in close proximity to the nearest occupied patch were found unoccupied. The poor dispersal abilities of these

native bird species apparently prevented them from migrating even short distances (<100 meters) through developed areas. However, some of these same species often breed in suburban areas (e.g. Bewick's Wren, *Thryomanes bewicki*, and Spotted Towhee, *Pipilo erythrophthalmus*). Therefore, the absence of these species could have been related to other, unmeasured or missing, habitat features of the larger landscape. Thus, the focus on 'island' isolation of strict habitat patches was perhaps too narrow.

Finally, avian community dynamics can be related to habitat variation at different scales, features of the local habitat are sometimes inadequate to explain species occurrence and surrounding habitats should also be considered (Saab 1999). Previous research demonstrated that urbanization affected bird communities in habitats defined at the site-specific level of city blocks (e.g., Emlen 1974, Campbell and Dagg 1976, Lancaster and Rees 1979), but spatial scale studies indicated that the surrounding landscape features have more predictive power for understanding bird communities at the site level (Blair 1996, Germain *et al.* 1998, Saab 1999). Landscape level characteristics (<100 ha - <30,000 ha) were better predictors of bird species presence/absence, than local, site level (<3 ha) habitat characteristics (Smith and Schaefer 1992, Bolger *et al.* 1997, Germain *et al.* 1998, Rottenborn 1999). Similar studies in other urban areas are necessary to substantiate findings that both the spatial arrangements of the habitat, the physiognomy, and the habitat composition at the level of the landscape, influence the relative abundance and presence of bird species (Bolger *et al.* 1997).

The ecological mechanisms generating community responses to landscape level spatial variability have not been well established (Bolger *et al.* 1997, Marzluff *et al.* 1998, Germain *et al.* 1998). Research on bird dispersal and settlement patterns may help to explain spatial structuring in bird communities. Some evidence suggests that birds search for and select next year's nesting site during post-fledging exploration (Baker 1993). Therefore, habitat area and

proximity to the natal area will affect the occupancy of areas close to successful breeding sites (Baker 1993, Bolger *et al.* 1997, Helzer and Jelinski 1999, Sutherland *et al.* 2000). Dispersal of birds from larger forests of a region may determine bird assemblages of other smaller forest 'patches' (Freemark and Merriam 1986, Hinsley *et al.* 1996).

Two ecological processes that may also help to explain the patterns of species breeding in complex landscapes are complementation and supplementation (Dunning *et al.* 1992).

*Complementation* occurs when species require a complement of non-substitutable, fixed resources that are found in spatially discrete areas or patches. A patch may be defined as any non-linear surface area that differs in appearance from the surrounding areas (Forman and Godron 1986). Regions of the landscape where patches with different types of resources are in close proximity will support more individuals than regions where one patch type is relatively rare. *Supplementation* occurs when species survive in resource patches that are individually too small by supplementing similar resources from the surrounding areas, so long as the supplementary resources are accessible from the local area. Residential sites with foraging areas that are individually too small or of low nutrient quality may still attract birds if individuals can supplement their requirements with resources from nearby foraging patches, or by supplementing their standard food resources with food and complementary water and nesting sites provided by man. Evidently, there is considerable overlap between these ecological processes in urban systems with distance to resources being a potentially critical variable.

Investigations of community assemblage necessarily encompass overlapping alternative hypotheses (Quinn and Dunham 1983). The variation observed in bird abundance and community composition due to urbanization is the result of many ecological factors operating at several observation scales (e.g., habitat area, habitat heterogeneity, isolation distance, food quantity and quality, landscape physiognomy, composition, predator abundance, observer bias,

Clergeau 1995, Ahl and Allen 1996). As a result, several interpretations and predictive models can be tested and applied. Past research relating local bird abundance to stand level habitat factors may be more appropriate under conditions where the local habitat is of excellent quality and where nesting success is high (Brawn and Robinson 1996, Arcese *et al.* 1992), but this perspective, if applied under conditions of poor quality local habitat, neglects to consider the influence of regional 'source pools' or landscape level factors (Sewell and Catterall 1998). Research relating local species occurrence and diversity patterns to island biogeography may apply when the landscape can be classified into suitable and unsuitable habitat. In a complex matrix, though, the presence and detection of individual birds is expected to vary probabilistically with different land use practices and with the overall amount of habitat or forest cover (Trzcinski 1999).

In this study, I use the method of urban gradient analysis (McDonnell and Pickett 1990) to investigate bird species richness, species relative abundance, and groups of birds (by nesting habitat guild) in relation to changes in habitat along four urban transects within the municipalities of Vancouver and Burnaby. My main objective was to quantify the changes in bird abundance and diversity from large urban parks to downtown core areas, and to relate attributes of the bird community to habitat at two scales, the landscape scale (<100 ha) and the local or stand level (measured at <1 ha). I know of only one other study that has examined an urban bird community citywide at different scales (Haddidian *et al.* 1997). Although a few studies have examined the effects of surrounding urbanization on bird species richness in park and riparian fragments, none have looked at the effects of surrounding parks on the community of birds in residential areas. The municipalities of Vancouver and Burnaby are located within the Georgia Basin ecoprovince of British Columbia. The Georgia Basin lies between the Vancouver Island Mountains and the southern Coastal Mountains and represents 3% of the



British Columbia land base (2, 772,571 ha). The region supports the highest diversity of breeding birds in the province, contains three cities, and approximately three-quarters of the provincial population, 2.9 million people on the Canadian side (Demarchi 1996).

Urban areas often have poor quality local habitat for birds and they may not maintain breeding populations of groups of sensitive species over time (Emlen 1974, Bolger *et al.* 1997, Rottenborn 1999). I examine the hypothesis that bird guilds should be more closely associated with landscape level habitat features, measured at scales  $< 100\text{ha}$ , than with local scale habitat measures,  $< 1\text{ ha}$ , under the premise that surrounding habitats may act as resource areas for residential birds and 'source' areas for dispersing birds. I evaluate the following predictions for how patterns of urban bird communities should relate to local and landscape level habitat characteristics and urban land use patterns.

*Prediction 1)* Bird species richness should decline and mean relative abundance of the remaining species should increase with increasing urbanization summarized by a habitat gradient.

*Prediction 2)* Because residential areas outside of parks should have relatively poor quality, local habitat for native birds, they may be 'rescued' by surrounding regional parks with higher bird diversity. Broad scale habitat measures ( $< 100\text{ ha}$ ) should adequately describe the urbanization gradient and should be better predictors of bird species and nesting guild presence than local, site level habitat measures.

*Prediction 3)* Because land use types are often defined by arbitrary boundaries, a continuous gradient should describe the matrix of bird habitat conditions better than categories of urban land use types.

*Prediction 4)* Species incidence (the proportion of sites occupied) should increase with proximity to parks of increasing area if birds are reaching high densities in parks and dispersing from these areas to more marginal nesting locations along residential streets.

These predictions were tested using avian community data from surveys completed over a two year period along roadside transects through Vancouver and Burnaby. The local habitat within 50 meters (m) of point count stations was surveyed, landscape park-distance metrics were developed, and habitat cover variables were estimated at different landscape scales using a G.I.S. and aerial photographs. The urban gradient is summarized using the two scales of habitat variables, and the main associations between bird species distributions with this gradient are examined using canonical correspondence analysis ordination diagrams and regression of ordination axis one scores with species diversity. I produce nesting guild habitat models with logistic regression using sequential addition of local and landscape variables. The bird community was further examined in relation to different geographic areas or habitat types (e.g. suburban and urban parks) in order to determine their position along the urbanization gradient using local and landscape habitat measures. Next, I relate bird incidence (% stations occupied) to the amount of park in the vicinity with the park-distance metrics. I discuss the bird community response in relation to published literature on local and regional effects, avian dispersal, and community dynamics. Finally, I consider conservation implications of urbanization on a global scale.

## METHODS

### Study Area

I conducted this research in the municipalities of Vancouver and Burnaby, hereafter “Greater Vancouver”, British Columbia (49°18' N, 123°12' W, Figure 1) in the Fraser River Lowland area of the Georgia Depression. There are three large parks in this urban area. The campus of the University of British Columbia (UBC) is located on the westernmost peninsula of Vancouver surrounded by a 763 ha forested park, Pacific Spirit Park. Downtown Vancouver is predominantly commercial with the exception of another large park, Stanley Park (405 ha); this park also occupies a peninsula jutting into Burrard Inlet. Industrial areas are located east of the downtown core with residential areas and suburban areas in Burnaby (Figure 1). Simon Fraser University (SFU) campus, like UBC, is a developed piece of land (or ‘encroachment’) surrounded by another large park, Burnaby Mountain Regional Park (324 ha, GVRD Strategic Planning Department 1993). Directly across Burrard inlet, SFU campus faces mountainous watershed reserves along the north shore of Vancouver. The north shore has both residential and commercial development extending partially up the continuously forested mountains.

Vancouver in the 1880's was a small settlement of sawmills, houses, and forest clearings surrounded by continuously forested land (Oke *et al.* 1992). The city has expanded over the past 119 years. The ocean and mountains have tended to constrain or direct Vancouver-Burnaby urban development. A consequence of development was the complete removal of forest and ground cover, later to be replaced with tree plantings along many city streets. Initially, the west-end of Vancouver was planted with native tree species (Oke *et al.* 1992). However, these native species, such as Douglas fir (*Pseudotsuga menziesii*) and Western hemlock (*Tsuga heterophylla*)

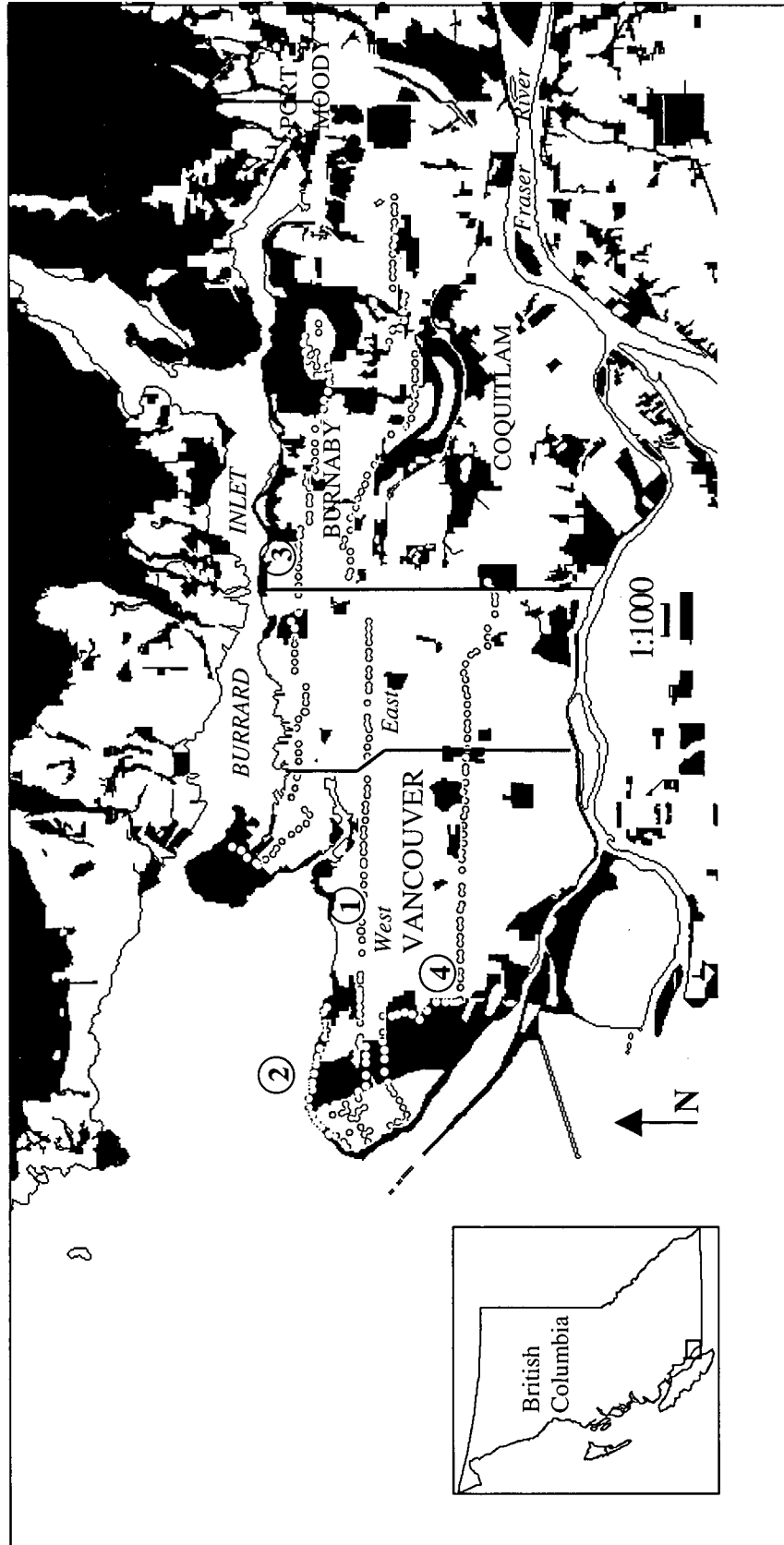


Figure 1. Study area, parks and urban greenspace (black areas), and transect locations (numbers 1-4) for breeding bird and habitat sampling in the Greater Vancouver area, British Columbia. Grey dots are point count stations.

were later deemed unsuitable to urban life since they grew too fast and their root systems buckled the sidewalks. Thus, as the city grew eastward and southward, the tree species planted were largely non-native species, over one-third being cherry or plum (*Prunus sp.*) trees. The result is an uneven distribution and composition of trees that are often larger and more likely native species on the west side than on the east side of the city, which has more deciduous, non-native species in the 'newer' suburbs (Oke *et al.* 1992). These same trends continue to be followed today, although more diverse street tree plantings have replaced planted monocultures of trees.

The Vancouver area has a cool, humid, mesothermal climate. It has cloudy, wet, and mild winters and sunny, dry, and warm summers (Weber 1972, Meidinger and Pojar 1991). Mean daily temperature values recorded during the study period ranged between 14.2-19°C (Appendix I) and were just slightly above normal mean daily temperatures for June-September. Precipitation means were also near normal levels (72 – 108mm at higher elevations or 40-76mm at lower elevations, Appendix I). My study area ranged in elevation from sea level to 370 m.

The Coastal Western Hemlock zone is the dominant biogeoclimatic zone of this region (Green and Klinka 1994). The original vegetation of the area would have resembled a dense coniferous forest, with a shrub-dominated understorey. The climax vegetation of the CWH zone is generally dominated by a canopy of Western red cedar (*Thuja plicata*) and Western hemlock (*Tsuga heterophylla*), with Douglas fir (*Pseudotsuga menziesii*) in drier areas and minor amounts of Sitka spruce (*Picea sitchensis*), Yellow-cedar (*Chamaecyparis nootkatensis*) and Lodgepole pine (*Pinus contorta*). The most prominent species of the original understorey vegetation were Salal (*Gaultheria shallon*), Alaskan blueberry (*Vaccinium alaskaense*), False azalea (*Menziesia ferruginea*), and Red huckleberry (*Vaccinium parvifolium*), with Salmonberry (*Rubus spectabilis*) and Red elderberry (*Sambucus racemosa*) found on wetter sites. The supplanted

herb and dense moss layers were composed of Deer fern (*Blechnum spicant*), Bunchberry (*Cornus canadensis*), and False-lily-of-the-valley (*Maianthemum dilatatum*), Step moss (*Hylocomium splendens*), Lanky moss (*Rhytidiadelphus loreus*), and (*Kindbergia oregana*) Oregon-beaked moss (Weber 1972, Meidinger and Pojar 1991, Demarchi 1996). Pacific Spirit, Stanley, and Central Park, Vancouver, and Burnaby Regional Parks are relatively large areas within this urban context which still contain representative vegetation of the CWH zone; these parks also contain many species of non-native vegetation, such as English holly (*Ilex aquifolium*) and Himalayan blackberry (*Rubus discolor*). Botanical nomenclature follows Pojar and Mackinnon (1994) for vascular plants, Little (1980) for woody plants.

### **Bird Surveys**

I collected data on; species presence and absence, the total number of bird species detected, and the relative abundance of individual bird species at 285 point count locations along four road side transects in Vancouver and Burnaby. Point locations were sampled once within each of three periods (two breeding seasons and one fall season). Breeding season counts were conducted between 24 June-13 July 1997 and 1 May-1 June 1998 and the fall count was from 24 August-11 October 1997. A total of 46 bird surveys were completed, however, only bird census data from the breeding seasons were used for analyses (Appendix II). Point count stations were established along transects with an inter-station distance of 250 meters. Transect placement was subject to the constraint of road length and orientation. The fixed radius point count methodology, with count duration of five minutes, is a commonly used method for bird surveys and was employed to maximize sample size while still ensuring independence (Ralph *et al.* 1993). A 50-meter radius detection area was adopted as DeGraaf *et al.* (1991) found that in urban areas only 6.9% of birds were recorded at distances greater than 46 m from the centre of

street transect lines. I carried out all bird censusing myself, on clear days during the first four hours following sunrise to coincide with peak singing activity (Ralph *et al.* 1993, Robbins 1981).

North American birds have well-known habitat affinities and can be grouped into guilds based on their breeding habitat associations (Haddidian *et al.* 1997, Ehrlich *et al.* 1988). Subsets of species, particularly ground and shrub nesting bird guilds, are of concern to land managers in urban areas because urban residential zones may be currently unsuitable for these groups of species (Rottenborn 1999). Birds were grouped into the following nesting habitat guilds: deciduous tree, coniferous tree, building, ground, shrub, cavity nesters, and ledge/cliff nesters (Ehrlich *et al.* 1988). The ledge/cliff, nesting guild was entirely comprised of gull species. Although, this guild nests on building ledges, it was maintained separately from building nesters since gulls are predominantly restricted to rocky terraces or sandy coasts. Birds were assigned to nesting guilds after Ehrlich *et al.* (1988) with the exception of the Violet-green Swallow (*Tachycineta thalassina*) and the European Starling (*Sturnus vulgaris*) which were assigned to the building nesting guild, since in urban areas they more commonly nest in buildings.

## **Habitat Characteristics**

### Derived Park Area and Locality Measures

I derived four distance by park variables at different radii, 0-260 m, 260-500 m, 500-760 m, 760-1000 m, to summarize the amount and proximity of park-space around each station. A digital map of land-use in the Greater Vancouver Regional District (GVRD Strategic Planning Department 1996) was used to develop a map of green-space in the study area, including parks greater than one hectare, cemeteries, and golf courses (IDRISI Version 4.0 1992, G.I.S. software). Universal Transverse Mercator (UTM) coordinates of the point count stations were registered to the map of urban green-space. Next, I created 20 m distance buffer intervals, in

concentric rings, around each station (Figure 2). Park area within each ring was divided by distance in order to weight parks closer to each station more highly than parks farther away creating a park exposure index. Thus, four composite, park-distance variables were calculated as follows:

$$\begin{array}{l} 1) \text{ Park 0-260m} \\ 2) \text{ Park 260-500m} \\ 3) \text{ Park 500-760m} \\ 4) \text{ Park 760-1000m} \end{array} = \sum_1^k (P / D) * 100$$

where  $P$  = park area within each 20 m 'donut' ring, and  
 $D$  = distance (i.e. 20 m, 40 m, 60 m....)  
 and summed over  $k$  distance rings within each park-distance variable (e.g., for park index 0-260 m, the total radius, 260 m, is divided by 20 m rings  $\Rightarrow 260/20 = 13$  rings,  $k=13$ )

Division by distance assumes that species presence should decrease non-linearly with distance from 'natural' areas. Research suggests that distances dispersed by birds and mammals from their natal areas follow the negative exponential distribution (Sutherland *et al.* 2000). Island biogeography predicts declining rates of immigration and increasing rates of extinction with distance from large natural areas, and spatial structuring predicts that close habitats are visited more frequently than distant ones (Dunning *et al.* 1992).

#### Landscape Habitat Cover

Landscape cover variables were measured from digital aerial photographs to describe the landscape *composition* around each point. These photographs of Vancouver and the Fraser Valley (May/July, 1995 1:30,000), with an orthophoto accuracy registered to TRIM (Terrain Resource Information Management) (1:20,000), and a pixel size of one meter (m), were used to estimate cover of: salt water (SALT500), grass (GRASS500), impervious surface



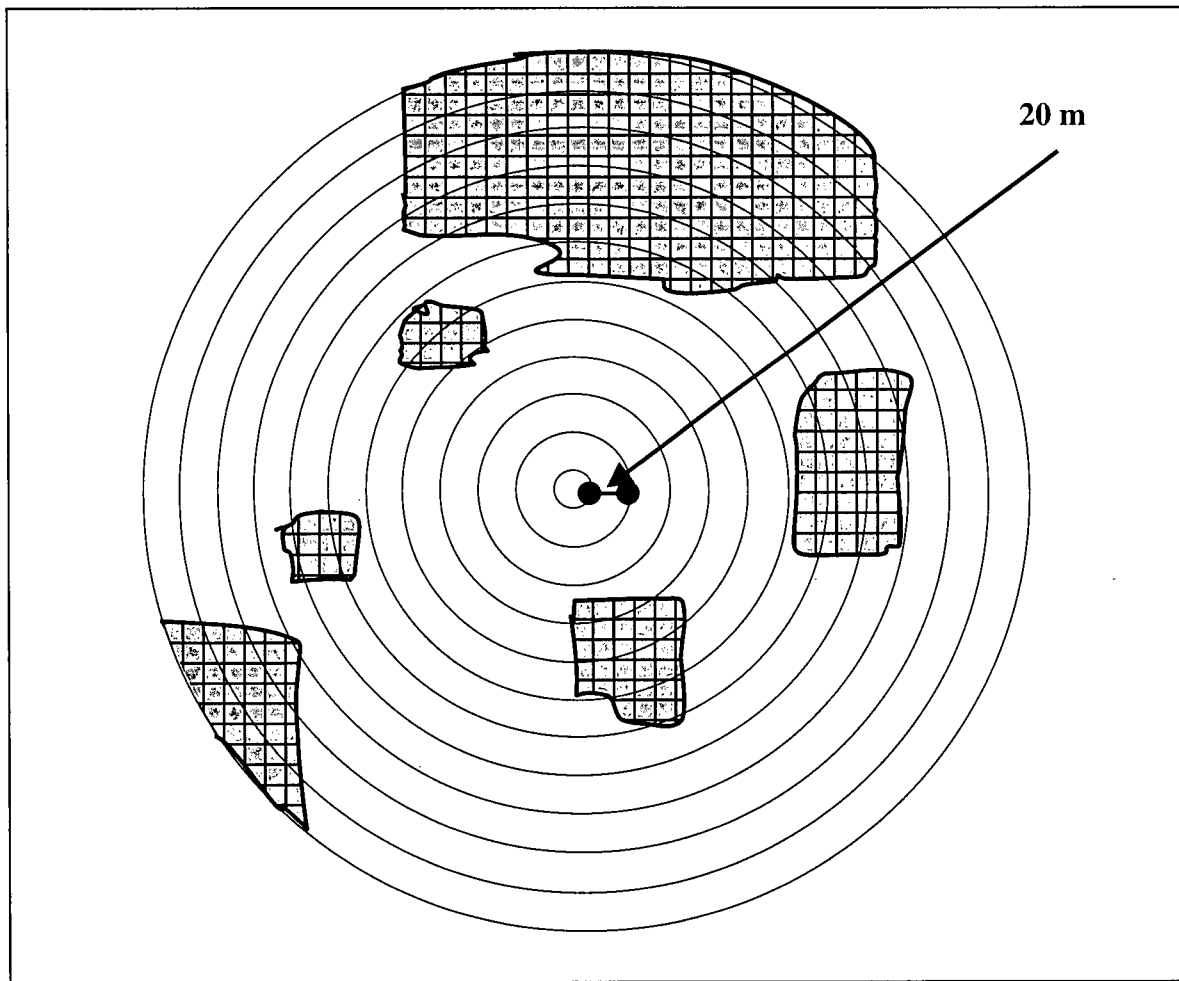


Figure 2. Representation of park-distance variable as the amount and proximity of parkspace around each bird count station in the Greater Vancouver area. Contour lines are at 20 m intervals and the amount of park area within each 20m layer was divided by distance and summed across all radii, creating park exposure indices at different scales (see text).

(IMPERV500), coniferous (CONIF500) and deciduous (DECID500) trees within 500 m of each point count station. I centered an acetate dot-grid overlay representing a 500 m radius circle on each census point located on the aerial photo and recorded the percentage of each of these cover type (Blair 1996, Rottenborn 1999, Germaine *et al.* 1998, Bolger *et al.* 1997).

### Local Vegetation

City zoning base maps were used (1:2,000) to delineate the 50 meter boundaries for vegetation plots (Figure 3). I was able to identify the number of individual house lots (# HOUSE LOTS) within the plot boundary and to record the local habitat variables. The percentage of impervious surface cover changes from 60% for multi-family to 90% for commercial and industrial land uses (Dinicola 1990). When commercial and industrial buildings were present on a plot, fifteen house lot units were added to #HOUSE LOTS and ten units were added if apartment buildings were present.

To assess the local habitat, I measured 30 additional variables around each point count station. The vegetation variables broadly describe land *cover* type (to a maximum of 100% total cover), and vegetation *composition* and *structure*. *Composition* was described simply by tree species richness (SPR), and by the relative proportion of deciduous to coniferous trees and shrubs. A separate category for berry producing trees and/or shrubs was used to assess food plant availability. I recorded the number of standing dead trees (DEAD) and fallen logs or downed wood (DOWN) greater than 15 cm diameter at breast height (dbh -1.3 m). The number of trees in four size classes were counted within 50 m of each station: <15 cm in diameter at breast height (dbh), >15 and <30 cm dbh, between 30 and 60 cm dbh, and > 60 cm dbh (DECID1-4, CONIF1-4). Shrub species > two m in height were considered 'trees' if their stems were distinct enough to be counted. Shrubs were similarly categorized as either deciduous or



coniferous and their numbers were counted within three size classes:  $< 1$  m in height,  $1 - 2$  m, and  $> 2$  m in height (D1-3shrub, C1-3shrub).

I recorded additional local habitat characteristics of importance to birds with the following categorical variables around each 50 m radius point count: the number of street intersections (residential street, residential intersection, thoroughfare intersection), the presence or absence of nest boxes, bird feeders, and water. Water was classified as birdbath, fresh water streams, marine, or both. The percent *cover* of grass was estimated by sketching grass cover onto city zoning base maps for residential lots within the boundaries of each 50 m plot; these maps were later overlain with dot matrix acetate to estimate local grass cover. Developed sites that were completely surrounded by park-space (urban encroachments) were located at different elevations, elevation was estimated using TRIM (Terrain Resource Information Management) maps (1:20,000) with contours generated from a digital elevation model (Ministry of Crown Lands, British Columbia 1993). Finally, ASPECT (north, east, south, west) was recorded at each site.

#### Definition of Landscape Land use Categories

Six different habitat types (e.g., urban, encroachments, suburban) are depicted (Figure 4), as they would occur along an urbanization gradient with decreasing landscape levels of native habitat or vegetation. All 285 point count sites were categorized into these groups in an attempt to simplify the entire gradient of urbanization into land use categories used by land planners, and to later investigate their ecological relevance in relation to bird species distributions. All counts were along roads, so they represent (road) edge habitat in different contexts. Roads through parks were surveyed and point count stations more than 250 meters inside a forested area larger than 300 ha in size were categorized as park sites; there were three large parks in the survey area,

Pacific Spirit (763 ha), Burnaby Mountain Regional (324 ha) and Stanley Park (405 ha). A minimum distance of 250m from the outside edge of these forested areas ensured that sites classified as park, although surveyed along a road edge, had a habitat context of interior forest in all directions (Murcia 1995, Robinson *et al.* 1995). Stations within 250m of the border of one of these large parks were classified as edge sites. Stations within a developed area more than 250m from a park edge *but* completely surrounded in all directions by park were classified as encroachment sites. Stations within urban parks, or parks completely surrounded by the developed matrix (>5ha in size, to avoid tree-lined baseball parks) were classified as urban parks. Within the City of Vancouver, stations were classified as urban sites, with an average population density of 4940 individuals/km<sup>2</sup> and 13.5 properties/ha (GVRD Municipal and Hospital Values 1999). Finally, stations within the politically defined suburban zone of Burnaby, with an average population density of 2150 individuals/km<sup>2</sup> and 6.2 properties/ha (all types), were classified as suburban sites (GVRD Municipal and Hospital Values 1999).

### **Statistical Methods**

A simple correlation matrix was examined and two of the landscape level park-distance variables (Park 260-500 m and Park 760-1000 m) were omitted from further analyses because they were highly correlated with Park 260 m and Park 500-760 m respectively, Pearson correlation coefficients >0.75. These two variables were chosen for omission, one, because the 260-500 m scale was already represented by landscape cover variables (e.g., IMPERV500, CONIF500). Two, the 760 to 1000 m scale level was omitted because it was highly correlated with the next inner ring and I did not want to leave a gap between measurement scales at 500 to 760 m. Next, I calculated descriptive statistics and created frequency distributions for all

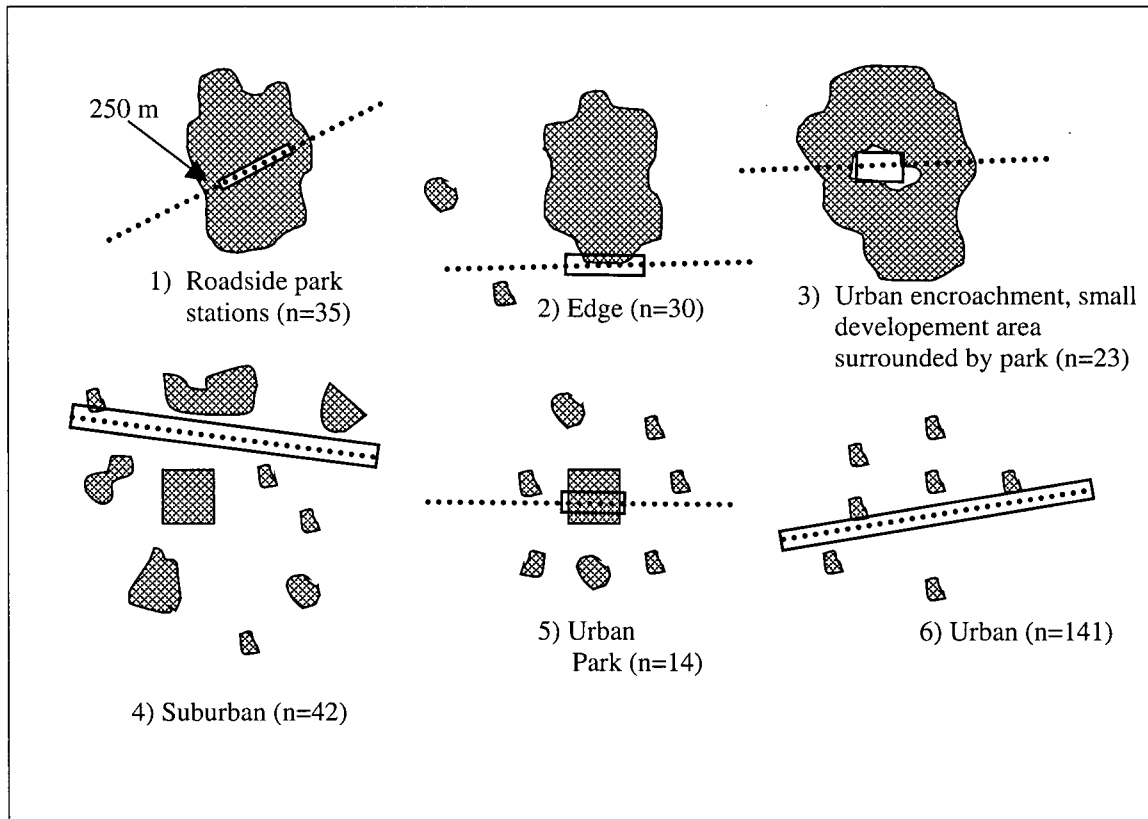


Figure 4. Schematic representation of urban landscape categories (1-6). Stippled areas represent natural area parks. Point count stations along roadside transects through Vancouver and Burnaby were grouped (points within rectangles) into one of these six categories. Stations were 250 m apart along continuous transects.

environmental variables to check for data normality, skewness and kurtosis, and the necessity of data transformations (Sabin and Stafford 1990). Count data, with many values at or close to zero, were log transformed ( $\text{Log}_{10}(X+1)$ ) to better meet the distribution requirements for the explanatory habitat variables used in the analyses (ter Braak 1986, Hosmer and Lemeshow 1989, Jongman *et al.* 1995, Tabachnick and Fidell 1996). Variables with few discrete values were converted to presence/absence variables (i.e., fresh H<sub>2</sub>O 500 m, large berry producing trees (BERRY1 & 2, 15-30 and > 30 cm dbh) and percentage cover variables with non-normal distributions were logit transformed ( $\text{Log}_{10}(p/1-p)$ ) following the recommendations of Sabin and Stafford (1990). I removed species that were observed only once from the analyses to avoid potentially mistaking migrants or wandering individuals for breeding residents. The dimension of the response variables (number of bird species recorded within 50 m of each point count station) was reduced to 36 with the removal of singular sightings from the analyses (Appendix III).

### **Correlation Analysis between Years**

Correlation analysis (CO) was used to check for year effects in relative bird abundance, by nesting guild. Since birds were surveyed later in the 1997-breeding season (24 June to 13 July) than in the 1998 breeding season (1 May - 1 June), I used canonical correlation (CO) analysis to examine the relationships between the relative abundance of different nesting guilds in both years to test for year effects. Both of the year sets contained the following nesting guilds: deciduous tree, coniferous tree, building, ground, shrub, cavity, and ledge/cliff nesters. Canonical correlation finds linear combinations for each set (year in this case) of variables (nesting guilds) in terms of canonical variates such that the correlation between the two variates is maximized (CANCORR procedure, SAS Institute Inc. 1996, Tabachnick and Fidell 1996). The variables in one set, 1997-bird guilds, are linearly combined into single community attribute

or canonical variate and then these are compared with a twin community variate, summarizing the 1998-bird guilds. Thirty-six of the most common species were grouped by nesting guild and included in the analysis. Canonical variate scores produced by a preliminary canonical analysis were examined for normality, linearity, and homoscedasticity using scatter plots of pairs of variates to test for the assumption of multivariate normality. Evidence of failure of normality and homoscedasticity suggested that the data should be  $\log(\log_{10}(X+1))$  transformed (Tabachnick and Fidell 1996, Sabin and Stafford 1990), and transformation improved the scatter plot test for data normality. The analysis was performed on species nesting guilds (Appendix III) since these guild groupings were used in later regression analyses.

### **Canonical Correspondence Analysis**

To examine the prediction that bird species richness and relative abundance may be predicted by a gradient of urbanization, *prediction 1*, I used canonical correspondence analysis (CCA) on the abundance distributions of the 36 species of birds. The method of direct gradient analysis can be used to relate species occurrences directly with landscape or local environmental variables of interest (ter Braak 1986). CCA is akin to direct gradient or regression analysis done in multivariate, species space. Resulting ordination diagrams provide a visual representation of complex relationships between community composition and habitat variables of interest. I examined *prediction 2* with CCA to generate hypotheses for the relative importance of broad scale versus local scale habitat variables as predictors in linear models of the urban gradient system (ter Braak 1986, Jongman *et al.* 1995, Rottenborn 1999). With canonical correspondence analysis one can infer which variables, landscape and/or local, may best explain the variation in species distributions because the most important habitat variables load most highly on the first axis. Identified variables that were highly correlated with CCA axis one were further tested using logistic regression analyses to predict for nesting guilds and species. Axis one scores were



also used in simple linear regression as a predictor of species richness. Species richness for the simple regression analysis was calculated to include 'rare' species (singular sightings) that had been excluded from the CCA. I included these species in richness estimates to avoid underestimating the number of species with low detection probabilities.

Land use categories such as urban and suburban are not expected to fully describe or simplify the urbanization gradient into habitat segments without overlapping features, *prediction*

3. I plotted these site classifications on the CCA urbanization gradient axes in a site ordination plot. The position of these average categories along the urbanization gradient was also quantified and depicted using the landscape and local level variables in radial star plots. Star plots use the average value of a variable in suburbs, for instance, and subtract that value from the mean for all stations sampled. Then, this value is standardized by dividing by the entire sample standard deviation for the variable and is compared as a relative radial length in relation to other variables on the star plot.

For the CCA species ordination, the data consisted of the ( $\text{Log}_{10}(X+1)$ ) number of birds detected for each species recorded at point count stations and the 1997 and 1998 data were pooled by selecting the maximum abundance of the two years. Maximum relative abundance was used instead of an average to avoid the smoothing effect of an average that would result in less detectable bird-habitat trends. Maximum or peak counts are also not influenced by migrating birds because the counts were done during the breeding season. Since point count stations were surveyed only once per season, the number detected at a particular station does not represent an average for that year. Although the maximum value may be an optimistic estimate, this measure is likely to be a more accurate estimate of abundance at a particular site than the mean of one survey in each of two years (Vander Haegen *et al.* 2000). The program ADE-4, a multivariate analysis and graphical display software, was used to perform the CCA (Thioulouse

*et al.* 1997). A randomization test (Monte Carlo) was performed on the projected relationships to test the significance of the CCA ordination of species points; 1000 random permutations were performed on the distribution of species points along the axes using the Projectors: Subspace test (ADE-4 program, Fraile *et al.* 1993). CCA models assume that species have Gaussian (unimodal) response surfaces with respect to compound urbanization gradients that are constrained to be linear combinations of the two-scale habitat variables (ter Braak 1986), an assumption that has not been well tested empirically (Rotenberry and Wiens 1980).

### **Logistic Regression**

I chose a regression design for this study to identify urban bird community patterns in relation to the two scales of habitat investigation by direct gradient analysis. I used a stepwise selection procedure ( $p_{\text{forward}} < 0.20$ ,  $p_{\text{backward}} < 0.25$ ) to effectively screen a large number of variables, and to simultaneously fit a number of logistic regression equations (Hosmer and Lemeshow 1989, Tabachnick and Fidell 1996). Following this stepwise procedure, variables deemed to be of importance either statistically (results from stepwise logistic procedure and CCA) or biologically were entered with sequential logistic regression in three different sets: 1) local level variables only *OR* landscape level variables only, 2) blocks of landscape variables were entered first followed by local level variables, and 3) interaction variables. Sequential addition of variables, landscape followed by local variable sets, answers the question, Do local habitat variables add to prediction of nesting guilds beyond that of landscape habitat variables alone, *prediction 2*? The third sequential block answers the question, does an interaction between habitat variables at the two scales add to prediction beyond that of landscape and local variables? The final logistic equation, the odds ratios, and log likelihood statistics at the end of sequential block entry are the same as would result from standard or direct logistic regression

with all variables entered at once. Thus, the final models are not sensitive to the order of variable entry and the contribution of each predictor can be evaluated as though it entered the equation last - over and above that of the other predictors (Tabachnick and Fidell 1996). Final model residuals were examined for deviations from the assumption of linearity in the logit. All regression analyses were done using SPSS (1996).

### **Species Incidence Functions**

To examine the expectation that species incidence increases in relation to the amount of park-area weighted by inverse distance *prediction 4*, I plotted increasing park distance metrics verses the proportion of sites occupied by different species (incidence) with similar park-distance values. The incidence of a species cannot be higher than one or 100% sites occupied so species incidence should asymptote to one. I used curve estimation regression methods to model these relationships, but for species with very low site incidence values that were not approaching the asymptote of 100% sites occupied, I used a linear regression fit. Bird species with adequate sample sizes ( $n > 10$  sites occupied) were selected on the basis of the CCA avian-habitat associations. The incidences of the three common species selected for logistic regression, American Robins, Spotted Towhees, and Song Sparrows, were also examined for the relationship between park-distance metrics and incidence.

Grouping species into nesting guilds assumes that the nesting habitat of bird species is well known and that species with similar nesting habitat preferences will be found in similar locations. Nesting requirements are constrained for many species (e.g., cavity nesters, Mikusinski and Angelstam 1998), and ground nesters are absent from many urban bird study sites (Lancaster and Rees 1979, Soulé *et al.* 1988, DeGraaf 1991, Rottenborn 1999). So, it is estimated that the best predictors of nesting guild presence in residential areas will be habitat characteristics related to nesting requirements. While grouping species into guilds loses some

information, an examination of individual species makes the assumption that species distributional patterns are completely independent from species to species. In a community of interacting species, this is clearly not the case. Logistic regression uses maximum likelihood methods for parameter estimation, a robust and flexible technique with no assumptions about the distributions of predictor variables (Tabachnick and Fidell 1996).

## RESULTS

### Bird Occurrence and Relative Abundance

A total of 65 bird species were recorded at the 285 point count stations (1997-98, all seasons) on four roadside transects throughout Vancouver and Burnaby, including 62 native and three non-native species (Appendix III). The majority of individuals detected at all sites (~50%) were non-native species (average, 1997-1998), whereas several native species were detected only once (Table 1, Appendix III). The latter species were omitted from most analyses in order to avoid drawing conclusions based on transient or migrating birds and to increase the statistical power to detect bird-habitat trends. The most common species detected were European Starling (*Sturnus vulgaris*), Northwestern Crow (*Corvus caurinus*), House Sparrow (*Passer domesticus*), House Finch (*Carpodacus mexicanus*), American Robin (*Turdus migratorius*), and the Black-capped Chickadee (*Poecile atricapillus*) (Table 1). Building nesters had the highest relative abundance per occupied site as they were detected up to three times more often than the other guilds. In sequence, the deciduous tree and coniferous tree nesters followed building nesters in the number of occupied sites and relative abundance per occupied site. A moderate number of ground and cavity nesters were detected per site occupied, and the ledge/cliff nesters were detected on the least number of sites, while shrub nesters had the lowest relative abundance per occupied site (Table 1).

### Between Year Comparisons of Nesting Guilds

The patterns of bird species diversity and relative abundance that occur in response to urbanization are not likely to change largely from year to year, at least over the two year period of this study, because the urban habitat gradient remains fixed and distinct (Germaine *et al.*

TABLE 1. Detection frequency and nesting guild category for 36 species of breeding birds recorded at 285 point count stations in Greater Vancouver, BC - 1997-1998<sup>1</sup>

Guild	Code	Common name	Scientific name	# Sites detected	Relative abundance on occupied sites <sup>3</sup>
<b>DECIDUOUS TREE</b>	<b>AMRO</b>	<b>American Robin</b>	<i>Turdus migratorius</i>	<b>186</b>	<b>1.06</b>
	BHGR	Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>	2	0.50
	BUSH	Bushtit	<i>Psaltiriparus minimus</i>	57	1.66
	CEWA	Cedar Waxwing	<i>Bombycilla cedrorum</i>	22	0.57
	HOFI	House Finch	<i>Carpodacus mexicanus</i>	190	1.34
	REVI	Red-eyed Vireo	<i>Vireo olivaceus</i>	2	0.75
<b>Guild Total</b>				<b>255</b>	<b>2.75</b>
<b>CONIFEROUS TREE</b>	<b>NOCR</b>	<b>Northwestern Crow</b>	<i>Corvus caurinus</i>	<b>219</b>	<b>1.35</b>
	PISI	Pine Siskin	<i>Carduelis pinus</i>	19	0.68
	RCKI	Ruby-crowned Kinglet	<i>Regulus calendula</i>	8	0.75
	RUHU	Rufous Hummingbird	<i>Selasphorus rufus</i>	12	0.63
	STJA	Stellar's Jay	<i>Cyanocitta stelleri</i>	12	0.63
<b>Guild Total</b>				<b>240</b>	<b>1.89</b>
<b>BUILDING</b>	<b>BASW</b>	<b>Barn Swallow</b>	<i>Hirundo rustica</i>	<b>31</b>	<b>1.35</b>
	EUST <sup>4</sup>	European Starling	<i>Sturnus vulgaris</i>	223	2.76
	HOSP <sup>4</sup>	House Sparrow	<i>Passer domesticus</i>	205	3.09
	RODO <sup>4</sup>	Rock Dove	<i>Columba livia</i>	76	1.83
	VGSW	Violet-green Swallow	<i>Tachycineta thalassina</i>	105	1.42
<b>Guild Total</b>				<b>257</b>	<b>6.95</b>
<b>GROUND</b>	<b>BHCO</b>	<b>Brown-headed Cowbird</b>	<i>Molothrus ater</i>	<b>38</b>	<b>0.82</b>
	CAGO	Canada Goose	<i>Branta canadensis</i>	4	0.88
	DEJU	Dark-eyed Junco	<i>Junco hyemalis</i>	32	0.64
	FOSP	Fox Sparrow	<i>Passerella species</i>	3	0.50
	OCWA	Orange-crowned Warbler	<i>Vermivora celata</i>	15	0.60
	<b>SOSP</b>	<b>Song Sparrow</b>	<i>Melospiza melodia</i>	<b>38</b>	<b>1.08</b>
	<b>SPTO</b>	<b>Spotted Towhee</b>	<i>Pipilo maculatus</i>	<b>87</b>	<b>1.02</b>
	WIWA	Wilson's Warbler	<i>Wilsonia pusilla</i>	5	0.50
<b>Guild Total</b>				<b>124</b>	<b>2.12</b>
<b>SHRUB</b>	<b>AMGO</b>	<b>American Goldfinch</b>	<i>Carduelis tristis</i>	<b>25</b>	<b>0.62</b>
	COYE	Common Yellowthroat	<i>Geothlypis trichas</i>	3	0.50
	SWTH	Swainson's Thrush	<i>Catharus ustulatus</i>	23	0.80
	WCSP	White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	50	0.77
	WIFL	Willow Flycatcher	<i>Empidonax traillii</i>	6	0.50
<b>Guild Total</b>				<b>87</b>	<b>1.45</b>
<b>CAVITY</b>	<b>BCCH</b>	<b>Black-capped Chickadee</b>	<i>Poecile atricapillus</i>	<b>160</b>	<b>1.22</b>
	NOFL	Northern Flicker	<i>Colaptes auratus</i>	3	0.50
	RBNU	Red-breasted Nuthatch	<i>Sitta canadensis</i>	4	0.63
	WIWR	Winter Wren	<i>Troglodytes troglodytes</i>	13	0.65
<b>Guild Total</b>				<b>166</b>	<b>1.83</b>
<b>LEDGE/CLIFF</b>	<b>GWGU</b>	<b>Glaucous-winged Gull</b>	<i>Larus glaucescens</i>		
	MEGU	Mew Gull	<i>Larus canus</i>		
	RBGU	Ring-billed Gull	<i>Larus delawarensis</i>		
<b>Guild Total</b>				<b>54</b>	<b>2.31</b>

<sup>1</sup> Birds were assigned to nesting guilds according to Ehrlich et al., 1988, exceptions of VGSW and EUST, moved from the snag and coniferous tree nesting guilds respectively to building nesting guild since they more commonly nest in building cavities in urban areas. BHCO was moved to the ground nesting guild because it is a nest parasite and SOSP are the most common host species.

<sup>2</sup> Bolded species and guilds were used for logistic regression analysis.

<sup>3</sup> Average of both study years.

<sup>4</sup> Introduced species.

1998, Fernández-Juricic 2000). To examine this assumption for birds over the two years of this study, I used correlation analysis. A simple correlation table comparing the relative abundance of all nesting guilds for 1997 and 1998 (log transformed to achieve multivariate linearity and normality) were examined both between and within years. Correlation between years was significant for six of the seven nesting guilds (Table 2). Within the same year, significant community associations were found between several guilds indicating that certain groups of species were associated with each other. The abundances of ground, shrub and cavity nesters were all positively correlated with each other, and deciduous tree and building nester abundance was also positively correlated. There were significant negative associations between building and three other nesting guilds (Table 2). Further analysis (CO) revealed that the first four pairs of linearly combined nesting guild variates accounted for significant relationships between years (Table 3, 4). There was consistent annual variation between bird nesting guilds, 1997 and 1998. The first test of significance ( $r_c$  0.71,  $p < 0.001$ ) demonstrated that the associations between bird guilds were strong, year to year (Table 3, 4). Stations with a high abundance of building nesters (0.74) and low numbers of ground nesters (-0.81) in 1997 had high building nester abundance (0.80) and low ground nester abundance (-0.83) in 1998. The second test was for all pairs of variates with the first and most important linearly combined pair removed, and so on for the third and fourth tests. The correlation coefficients between variate pairs, two to four, were all significantly different from zero indicating further associations between years. The remaining three canonical correlation coefficients were not significantly different from zero (Table 3,  $p < 0.05$ ). With the exception of canonical variate pair three, there were no year effects either in the global data set or within various guilds. The relative abundance of similar nesting guilds in different years were significantly associated. The third variate pair combines high numbers of

TABLE 2. Simple correlations among (Log10(X+1)) detections of urban bird nesting guilds between the 1997 and 1998 seasons to examine for year effects. Shading identifies the correlation between the same guild in different years.

Guild <sup>1</sup>	DT98	CT98	B98	G98	SB98	CV98	L98	DT97	CT97	B97	G97	SB97	CV97	L97
DT98	----													
CT98	-0.05	----												
B98	0.21**	-0.17**	----											
G98	-0.22**	0.03	-0.47**	----										
SB98	-0.02	-0.07	-0.17**	0.20**	----									
CV98	-0.15*	0.00	-0.22**	0.22**	-0.04	----								
L98	0.10	-0.06	0.09	-0.10	-0.02	-0.05	----							
DT97	0.17**	0.04	0.19**	-0.13*	-0.11	-0.13*	-0.11	----						
CT97	-0.04	0.19**	-0.03	0.05	-0.14*	0.00	-0.08	0.18**	----					
B97	0.26**	-0.08	0.52**	-0.38**	-0.08	-0.20**	0.02	0.23**	-0.12*	----				
G97	-0.21**	0.11	-0.39**	0.56**	0.14*	0.27**	-0.08	-0.11	0.10	-0.34**	----			
SB97	-0.14*	0.03	-0.33**	0.34**	0.24**	0.24**	-0.09	-0.17**	-0.08	-0.26**	0.34**	----		
CV97	0.03	-0.05	-0.10	0.09	0.04	-0.03	-0.03	-0.11	0.00	-0.08	0.07	0.10	----	
L97	0.07	-0.08	0.12*	-0.09	-0.12*	-0.06	0.39**	0.00	0.01	0.06	-0.02	-0.13*	-0.05	----

<sup>1</sup>DT, deciduous tree; L, ledge/cliff; B, building; SB, shrub; G, ground; CT, coniferous tree; CV, cavity nester.

\*\* p ≤ 0.01, \* p ≤ 0.05



building, ground, and coniferous tree nesters with low numbers of shrub nesters in the 1997 variable set and correlates this variate with a combination of ledge/cliff, ground, and coniferous tree nesters in the second variable set, 1998 (Table 4). The two years of data were combined in further analyses because no strong year effects were detected.

### **Bird Community - Habitat Relationships**

Urban bird distributions were expected to follow an overall pattern organized predominantly along an urbanization gradient with decreasing species richness and increasing relative abundance (*prediction 1*). Canonical correspondence analysis was used to depict the main pattern in the relation between the urban bird species community and the observed habitat variables because this method is an ordination technique relating species occurrence and relative abundance to habitat variables (ter Braak 1986). Habitat variables measured or derived at the landscape level were expected to have more explanatory power because they summarize more information about broad scale habitat features. The local urban habitat, in comparison, was expected to have lower habitat value since local urban habitat should be more marginally valuable to native birds (*prediction 2*). None of the local habitat variables were highly correlated with the landscape level variables in simple correlation tables (not shown), and most significant Pearson correlation coefficients were between  $\pm 0.30$  and  $0.50$ , indicating no more than 25% of shared variation. Only four correlation coefficients were higher, local #House Lots correlated both with Park 0-260 m and Impervious surface cover within 500 m ( $r_{\text{Pearson}} = -0.54$  and  $0.72$  respectively), also both local # deciduous trees ( $<30$  cm dbh) and elevation correlated with deciduous tree cover within 500 m ( $r_{\text{Pearson}} = 0.52$  and  $0.59$  respectively).

To examine the relative importance of habitat variables measured at different scales, the correlation coefficients of canonical correspondence analysis were calculated as estimates of the association between each habitat variable and the first and second correspondence axes (Table

TABLE 3. Correlation coefficients, percents of variance, and redundancies between nesting guilds in 1997 and nesting guilds in 1998 with their corresponding variates from canonical correlation analysis.

Pair	Canonical Correlation Coefficient ( $r_c$ )	SE	Percent variance, 1998 guild set	Redundancy <sup>1</sup> in guild set 1	Percent variance, 1997 guild set	Redundancy <sup>1</sup> in guild set 2	$F^2$	dfn <sup>3</sup>	dfd <sup>3</sup>	$p > F$
1	0.71	0.03	0.23	0.09	0.22	0.09	6.9	49	1365	0.0001
2	0.43	0.05	0.14	0.02	0.14	0.02	3.2	36	1184	0.0001
3	0.30	0.05	0.11	0.01	0.12	0.01	2.3	25	1004	0.0004
4	0.27	0.06	0.13	0.01	0.16	0.01	1.9	16	828	0.0150
5	0.17	0.06	0.12	0.00	0.13	0.00	1.1	9	662	0.3928
6	0.07	0.06	0.13	0.00	0.10	0.00	0.4	4	546	0.8163
7	0.02	0.06	0.12	0.00	0.13	0.00	0.1	1	274	0.7894

<sup>1</sup> Redundancy is the amount of variance in a single variate (i.e. the linear combination of 1998 guilds) that has actually been extracted from the set of guilds that it is being correlated with (i.e. 1997 guilds).

<sup>2</sup> Probability of greater  $F$  values

<sup>3</sup> dfn, dfd, degrees of freedom (nominator/denominator)

TABLE 4. Correlation analysis between ( $\text{Log}_{10}(X+1)$ ) detections of urban bird nesting guilds for breeding seasons, 1997 and 1998, with their canonical variates to examine community associations between the two year sets of seven guilds. Shading indicates significant correlations between the original variables and the linearly combined variable set.

Pair	Variable set 1, 1998 bird nesting guilds							Variable set 2, 1997 bird nesting guilds						
	DT98	CT98	B98	G98	SB98	CV98	L98	DT97	CT97	B97	G97	SB97	CV97	L97
1	0.41*	-0.16	0.80*	-0.83*	-0.29*	-0.45*	0.18	0.29*	-0.06	0.74*	-0.81*	-0.61*	-0.11	0.23
2	0.09	0.27*	0.16	0.01	0.08	-0.02	-0.91*	0.40*	0.24	0.29*	0.03	0.06	-0.01	-0.83*
3	0.11	0.37*	0.34*	0.39*	-0.44*	0.02	0.22	0.31	0.53*	0.26	0.50*	-0.24	-0.12	0.43*
4	0.24	-0.44*	0.36	0.21	-0.62*	0.26	0.13	-0.13	-0.62*	0.53*	0.21	0.43*	0.004	0.08
5	0.56	-0.41	-0.19	0.26	-0.07	-0.44	-0.10	0.45	-0.20	-0.07	0.08	-0.10	0.74	0.07
6	0.64	0.53	-0.23	-0.18	0.16	0.20	0.20	0.41	0.32	-0.05	-0.19	0.59	-0.05	0.24
7	-0.14	0.35	0.002	0.09	0.54	-0.70	0.15	-0.53	0.36	0.13	-0.04	0.16	0.65	-0.03

Note: DT, deciduous tree; L, ledge/cliff; B, building; SB, shrub; G, ground; CT, coniferous tree; CV, cavity nester

\* Significant  $r$  value at  $p < 0.05$

5). CCA can also be used to calculate the overall correlation between the species distributions of relative abundance and the first and second axes. These species - habitat correlations provide a measure of how well the variation in species scores can be explained by the combination of habitat variables in the axes. The first axis had a high overall species – habitat correlation (0.85), while the second axis correlation was not as strong (0.49) indicating that overall CCA axis one summarized the gradient of urbanization and the species distributions of relative abundance fairly well. In the following three paragraphs, first I examine the CCA model axes one and two, and then I describe general trends in the bird species distributions as they relate to these axes.

High density sites, as indicated by the number of intersections (INTERSECTIONS) and number of house lots (# HOUSE LOTS) at the local level (< 1 ha) correlated positively with axis one, but with less relative importance than the two landscape park index variables (Park 260 m, Park 500-760 m, Figures 5, 6; Table 5). Moreover, the absence of water and number of small and large deciduous trees (DECID<15 cm and DECID>60cm dbh) correlated positively with this axis (Table 5, right side, Figures 5, 6). The amount of downed wood (DOWN) and grass within 50 meters (LOCGRASS) correlated negatively with the first axis (left side, Figure 5, 6, Table 5). The relative strength of these associations indicate that axis one is an intensity of urbanization gradient characterized largely by landscape habitat variables, the park-distance indices, at the negative (left) extreme, and intersection size, landscape grass cover, large deciduous trees, absence of water, and housing density at the most urban, positive end of axis one.

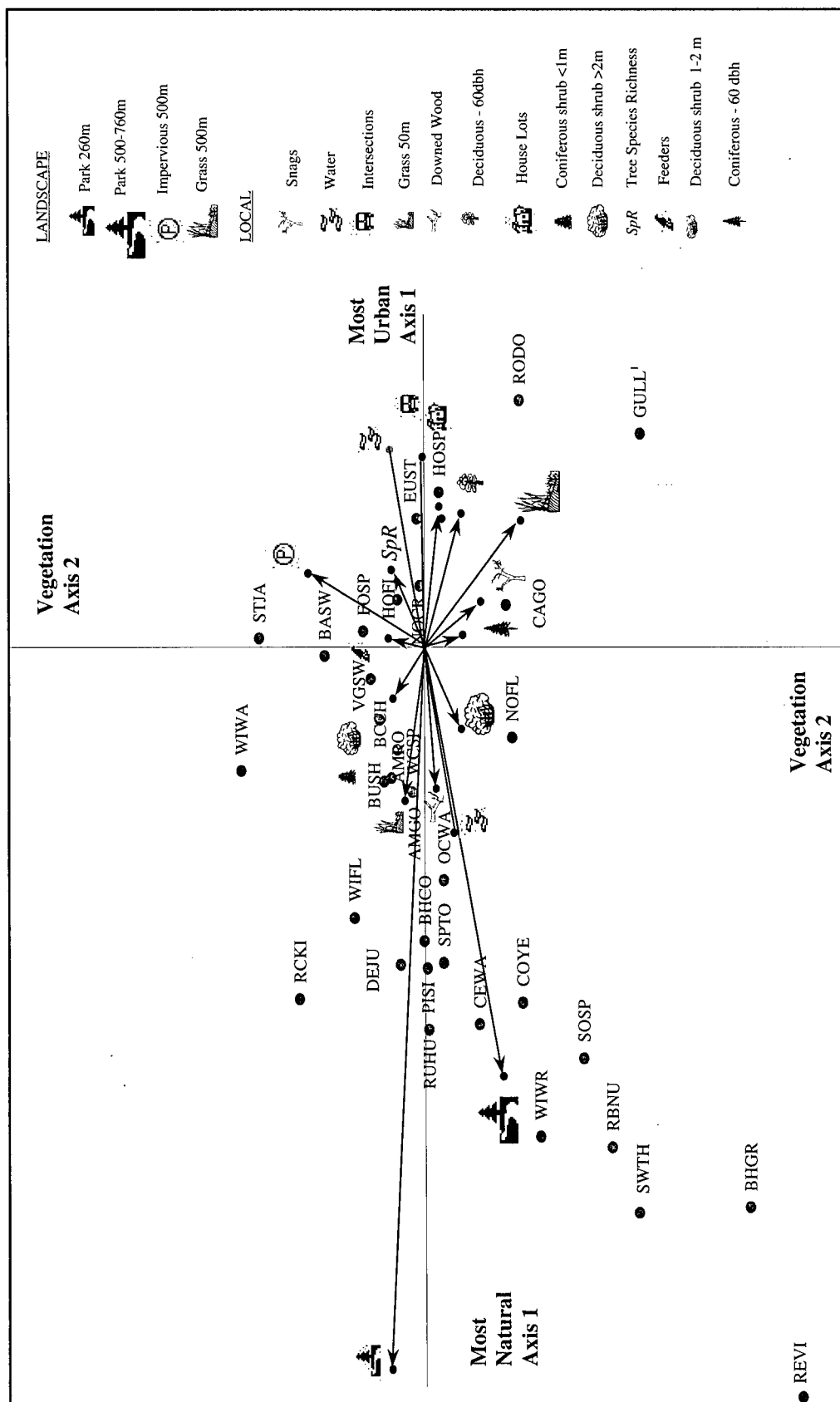
Axis two (vertical) was also partly dominated by landscape level variables, separating sites with high impervious surface cover (IMPERV 500m) from sites with high grass surface cover (GRASS 500m) in the surrounding area (Figure 5 and 6, Table 5). However, this axis explains little variation in the data set and due to the appearance of the ‘arch effect’ (see discussion) will

not be examined in detail (Eigenvalue = 0.09, Table 5). Eigenvalues associated with each axis give a *relative* indication of the ability for that axis to separate or order the species distributions, and can be used to indicate the importance of the variation explained by different sets of explanatory variables.

The ordination diagrams provide a visual representation of complex relationships between community composition and habitat variables (ter Braak 1986, Jongman *et al.* 1995), and depict a joint plot of bird species scores (points) in relation to habitat variables (arrows, Figure 5). Both the length of the habitat arrow on ordination diagrams and the variable correlation coefficients (Table 5) provide an indication of variable relative importance in the model. Landscape level park-distance indices (Park 0-260 m and Park 500-760 m) load most highly on the most natural end of the gradient (axis one) and had the strongest, negative correlation with this axis; they dominated the left side of the ordination. Landscape variables were followed less strongly by local level variables, positively correlated with the most urban end of gradient, axis one (Water, # Intersections, # House Lots, and deciduous trees, <15 cm and > 60 cm dbh, Figure 5, Table 5). Both landscape (impervious surface and grass cover) and local habitat characteristics, such as dead trees, shrubs, and water dominate the vertical axis two. Axis one was four times better at explaining the variation in the data set than axis two (Figure 5). The ordination was significant ( $p < 0.001$ , Projectors - subspace (randomization) test, ADE-4, 1997) indicating that the ordination provides a good approximation of relationships between the observed data on bird species distributions and the two scales of habitat variables. A total of 25 of the 36 species were located on the natural end of the urbanization gradient indicating they are associated with landscape scale habitat (large parks) and supporting the prediction that landscape variables better explain urban bird species distribution patterns (Figure 5, Table 5, *prediction 2*). Two landscape park-distance variables were identified for further hypothesis testing.

CCA axis one scores for each station were used to predict species richness using simple linear regression and curvilinear model fit confirming a significant negative relationship (Figure 7, Table 6,  $F=71.86$ ,  $p<0.001$ , *prediction 1*). Species richness decreased with increasing urbanization along a gradient, however, the amount of variation around the predicted linear relationship was high as evinced by the low r-square ( $r^2 = 0.23$ ) and large, 95% confidence limits. The relationship shows some evidence of non-linearity, but improvement in fit with quadratic and cubic terms was not substantially better ( $r_{\text{linear}}^2 = 0.20$ , Table 6), considering the drawback of having additional parameters in the model (Table 6,  $r^2$  and SSQ, Hilborn 1997).

Overall, the bird community relationships depicted in these results showed generalist and specialist occurrences along an intensity of urbanization gradient (*prediction 1*). All ground (5), shrub (5), and cavity (2) nesting species were found on the left side of the ordination with the exception of Canada Goose (*Branta canadensis*) and Fox Sparrow (*Passerella iliaca*, Figure 5, Table 1). In general, habitat specialists were identified as species associated with very high values of Park 500-760 m, e.g., Winter Wren (*Troglodytes troglodytes*), Song Sparrow (*Melospiza melodia*), Common Yellowthroat (*Geothlypis trichas*), and Cedar Waxwing (*Bombycilla cedrorum*), left side of Figure 5. These species are associated with more (> 100 ha) proximal park area as indicated by high park 500-760 m values (Figure 5, Table 5). There were fewer urban associated species at the extreme right end of this urbanization gradient (Figure 5), and as expected these were also the species with the highest relative abundance per site on average (Table 1, *prediction 1*). They were identified as species associated with higher densities of development, small deciduous trees, less understory vegetation, and more impervious surface cover, e.g. House Finch (*Carpodacus mexicanus*), European Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), and Rock Dove (*Columba livia*).



<sup>1</sup> represents the score of 3 gull species

Figure 5. Canonical correspondence ordination diagram of 36 bird species to examine the strength of association between local and landscape level habitat variables in urban biodiversity study. Points correspond to species scores relative to the axes that are linear combinations of the environmental variables (arrows). Eigenvalues (axis 1 = 0.35, axis 2 = 0.09) for each axis provide an indication of the relative importance of that axis in explaining variation in the data. Refer to Table 1 for definitions of species codes.

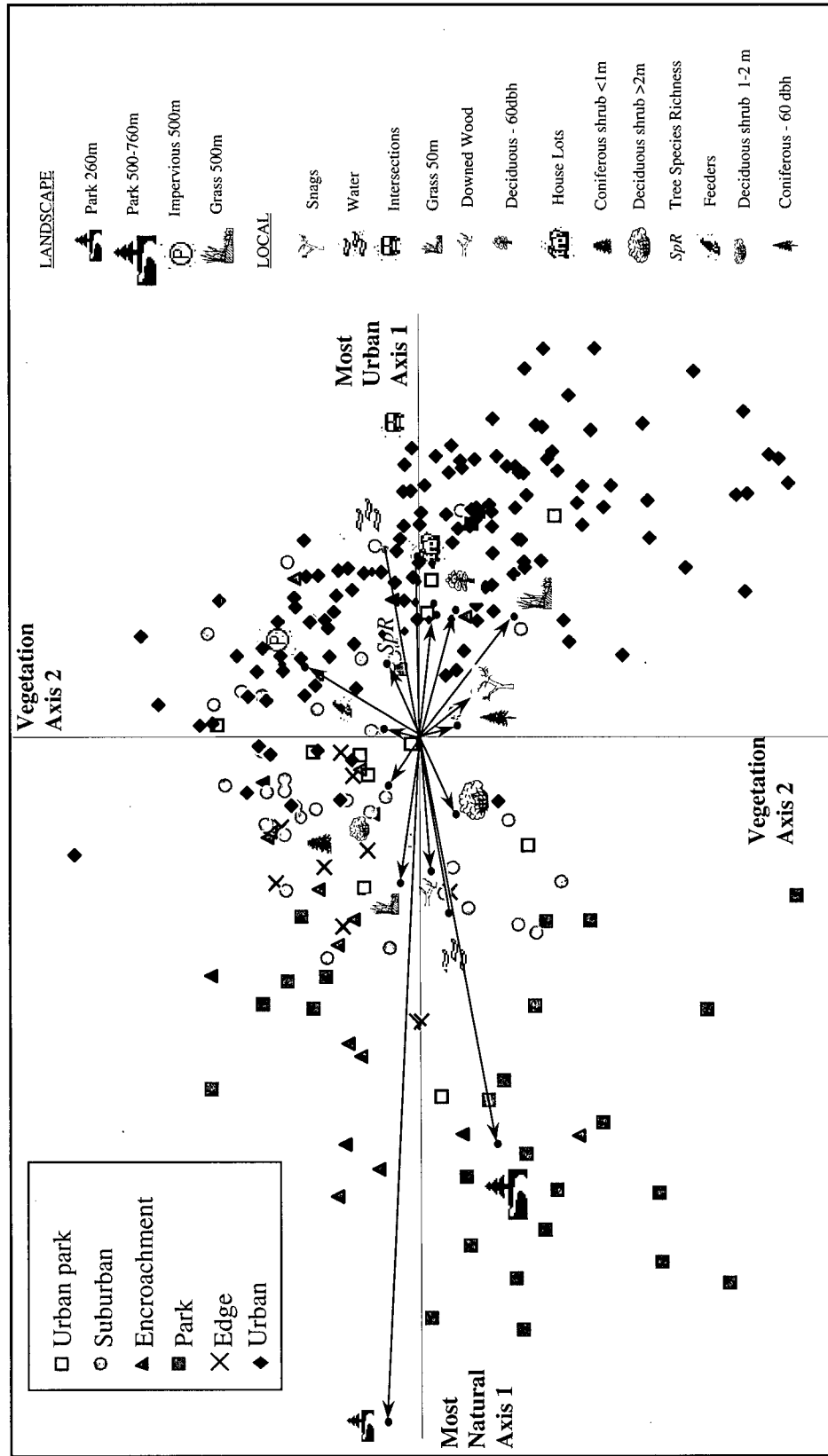


Figure 6. Canonical correspondence ordination diagram showing the distribution of point-count stations categorized by habitat along the axes. Points correspond to station scores as predicted by the axes (arrows are the same as in Figure 10). Refer to Figure 4 for definition of station land use categories.



TABLE 5. Correlation coefficients between habitat variables at local and landscape levels with the first and second canonical correspondence axes in an urban bird biodiversity study in Vancouver - Burnaby, British Columbia.

			Eigenvalues	
			Axis	
			1	2
			0.35	0.09
			Variable Correlation Coefficients	
A) Landscape Level Environmental Variables <sup>a</sup>	<b>Park 260m</b>	Park-distance <260m	<b>-0.76</b>	<b>0.15</b>
	<b>Park 500-760m</b>	Park-distance between 500-760m	<b>-0.45</b>	<b>-0.33</b>
	<b>GRASS 500m</b>	% cover grasses <500m	<b>0.13</b>	<b>-0.41</b>
	<b>IMPERV 500m</b>	% cover impervious <500m	0.08	<b>0.51</b>
	<b>SALT-H2O 500m<sup>c</sup></b>	% cover salt water <500m	0.05	-0.01
	<b>CONIF 500m<sup>d</sup></b>	% cover coniferous trees < 500m	0.04	-0.01
	<b>DECID500m<sup>d</sup></b>	% cover deciduous trees <500m	-0.04	-0.02
	<b>FRESH H<sub>2</sub>O 500m (+/-)</b>	Presence of fresh water <500m	0.00	0.02
B) Local Level Environmental Variables <sup>b</sup>	<b>WATER (1-5)</b>	Presence, water (bath, fresh, marine)	<b>0.21</b>	<b>0.16</b>
	<b>LOCGRASS</b>	% cover of grass at site level	<b>-0.16</b>	0.09
	<b>DOWNwood<sup>c</sup></b>	Amount of downed wood	<b>-0.15</b>	-0.04
	<b>DEAD (trees)<sup>c</sup></b>	# of standing dead trees	0.05	<b>-0.23</b>
	<b># HOUSE LOTS</b>	# of house lots	<b>0.14</b>	-0.07
	<b>SPR (trees)</b>	Species richness of trees	0.08	<b>0.15</b>
	<b>Feeders (+/-)</b>	Presence of bird feeders	0.01	<b>0.16</b>
	<b>BOX(+/-)</b>	Presence of nest boxes	0.00	0.11
	<b>DECID1 (&lt;15 dbh)<sup>c</sup></b>	# of sapling deciduous trees	<b>0.15</b>	-0.06
	<b>DECID2 (15-30 dbh)<sup>c</sup></b>	# of small deciduous trees	-0.02	-0.01
	<b>DECID3 (30-60 dbh)<sup>c</sup></b>	# of medium sized deciduous trees	0.01	-0.01
	<b>DECID4 (&gt;60 dbh)<sup>c</sup></b>	# of large deciduous trees	<b>0.14</b>	<b>-0.15</b>
	<b>CONIF1 (&lt;15 dbh)<sup>c</sup></b>	# of sapling coniferous trees	0.00	0.10
	<b>CONIF2 (15-30 dbh)<sup>c</sup></b>	# of small coniferous trees	0.03	0.11
	<b>CONIF3 (30-60 dbh)<sup>c</sup></b>	# of medium sized coniferous trees	-0.01	0.07
	<b>CONIF4 (&gt;60 dbh)<sup>c</sup></b>	# of large coniferous trees	0.01	<b>-0.16</b>
	<b>D1SHRUB (&lt;1m)<sup>c</sup></b>	# of ground level deciduous shrubs	-0.09	-0.11
	<b>D2 SHRUB (1-2m)<sup>c</sup></b>	# of small deciduous shrubs	-0.05	<b>0.14</b>
	<b>D3SHRUB (&gt;2m)<sup>c</sup></b>	# of large deciduous shrubs	-0.09	<b>-0.15</b>
	<b>C1SHRUB (&lt;1m)<sup>c</sup></b>	# of ground level coniferous shrubs	-0.05	<b>0.16</b>
	<b>C2SHRUB (1-2m)<sup>c</sup></b>	# of small coniferous shrubs	0.00	-0.09
	<b>C3SHRUB (&gt;2m)<sup>c</sup></b>	# of large coniferous shrubs	0.01	-0.10
	<b>B1SHRUB (&lt;1m)<sup>c</sup></b>	# ground level berry shrubs	0.00	-0.10
	<b>B2SHRUB (1-2m)<sup>c</sup></b>	# of small berry shrubs	0.04	-0.11
	<b>B3SHRUB (&gt;2m)<sup>c</sup></b>	# of large berry shrubs	0.00	0.00
	<b>BERRY1 (&lt;15 dbh)<sup>c</sup></b>	# of sapling berry trees	-0.06	0.01
	<b>BERRY2 (15-30 dbh) (1-5)</b>	# of small berry trees	0.00	0.08
	<b>BERRY3 (&gt;30 dbh) (1-3)</b>	# medium sized berry trees	0.01	0.03
	<b>INTERSECTION (1-3)</b>	<b>1, 2, busy street intersection</b>	<b>0.20</b>	0.01
	<b>ELEVATION<sup>c</sup></b>	Elevation (m)	-0.05	0.09

<sup>a</sup> The proportion of impervious surface, grass, salt water, deciduous and coniferous tree cover <a 500 m buffer radii, the presence/absence of fresh water, and 2 composite park variables as an index of park importance <260 m and 760 m radii of each point count station. <sup>c</sup> Log<sub>10</sub>(X+1) transformed, <sup>d</sup> Logit transformed [p/(1-p)], <sup>e</sup> Log<sub>10</sub> transformed.

<sup>b</sup> Variables were measured around each point count station <a 50m radius

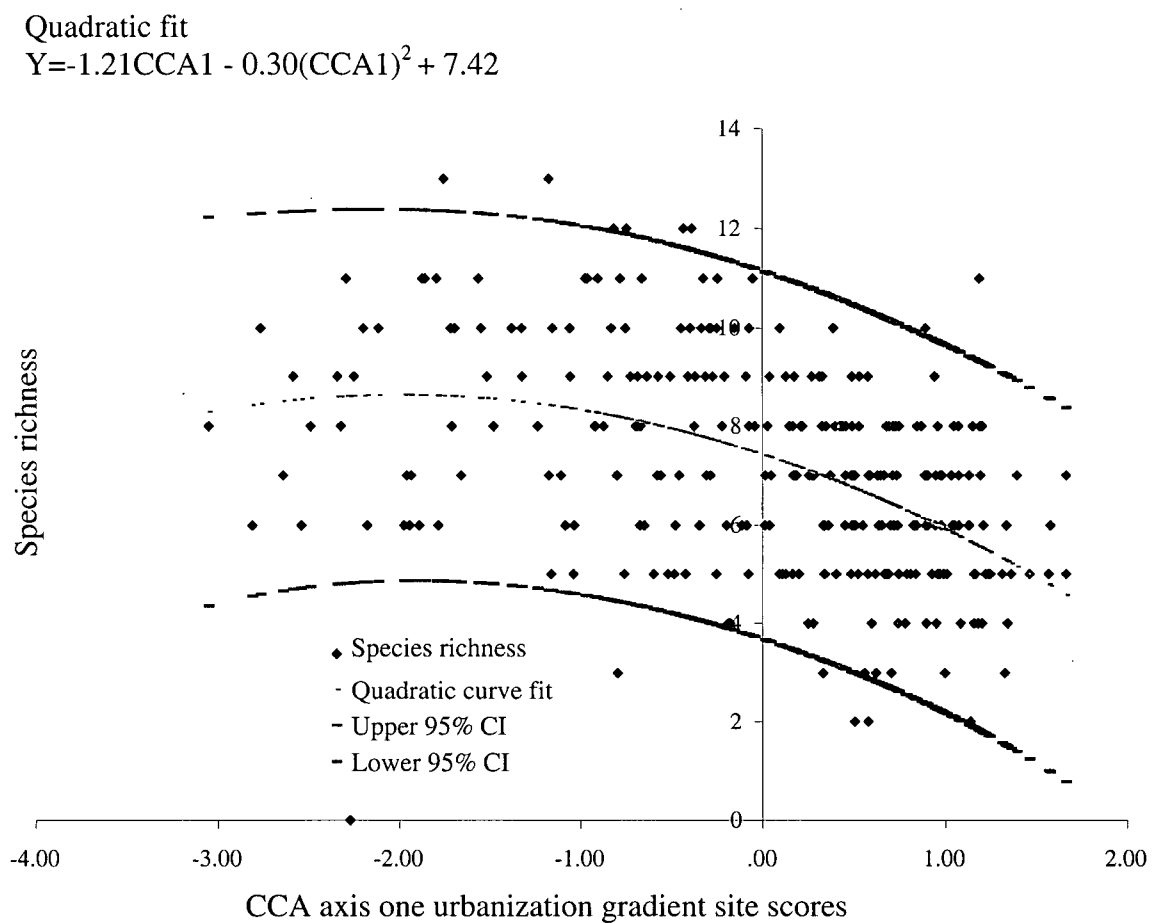


Figure 7. Cuvilinear regression model fit with 95% confidence limits, CCA axis one versus maximum avian species richness at point count stations along four road-side transects in Vancouver and Burnaby.

TABLE 6. Model selection: fit of species richness at road survey sites with CCA axis one (urbanization gradient) Vancouver – Burnaby, British Columbia.

MODEL CCA1 vs. Richness	Variable (m)	Parameter estimate (B)	Standard error of the estimate (B)	T	Sig	n	R <sup>2</sup>	SSQ	SSQ <sub>adjusted</sub> SSQ(m)/ n-2m
Linear Fit F=71.86***	CCA Axis1	-0.95	0.11	-8.48	0.00	283	0.20	<b>265.31</b>	<b>0.94</b>
	Constant	7.11	0.11	62.34	0.00	283			
Quadratic Fit F=30.05***	CCA Axis1	-1.21	0.14	-8.87	0.00	283	0.23	301.97	1.08
	(CCA Axis1) <sup>2</sup>	-0.30	0.09	-3.20	0.00	283			
	Constant	7.42	0.15	49.79	0.00	283			
Cubic Fit F=42.24***	CCA Axis1	-1.51	0.20	-7.73	0.00	283	0.24	318.18	1.15
	(CCA Axis1) <sup>2</sup>	-0.03	0.16	-0.20	0.84	283			
	(CCA Axis1) <sup>3</sup>	0.17	0.08	2.14	0.03	283			
	Constant	7.29	0.16	45.51	0.00	283			

To assess the position of my habitat category sites, e.g., 'urban', 'urban encroachment', and 'suburban', in relation to these CCA model axes of the habitat gradient, the canonical correspondence score of each survey station was plotted along each axis (Figure 6). This figure represents a joint plot ordination of the 285 site score points, with arrows identical to those shown in Figure 5. Each station in this diagram is plotted at the centroid of the species points that were found there, and hence the location of each point indicates which species are likely to be found at a particular site (Figure 6, ter Braak 1986). Urban sites occur predominantly on the lower right hand side of the plot, whereas park, edge, and urban encroachment sites occur largely on the left side of the ordination indicating that some of these categories are useful in simplifying the urbanization gradient, but there is overlap (*prediction 3*). Two thirds of the large park sites occur on the lower left extreme side of the plot, whereas smaller urban parks and edge sites cluster in the mid to upper left half of the plot. This indicates that Park 500-760 m mainly represents the effects of the three large parks in the study area (Burnaby mountain, Pacific Spirit, and Stanley, > 324 ha in size) and Park 260m represents a combination of effects from edges, small (>5 ha) and large parks. So, birds that occurred predominantly along roads bisecting any of the large parks were located at the negative lower end of the CCA plot. Urban encroachment sites scored predominantly in the upper left half of the plot. Suburban stations have a fairly even distribution over the centre of the ordination, indicating that suburban sites constitute the most variability in habitat measures at both scales. This finding confirms that subjectively defined land use categories do not fully simplify the urbanization gradient (*prediction 3*), that is, they are dispersed across a large range of conditions with respect to urban gradient, CCA axis one. Interestingly, suburban stations do cluster more on the positive, upper end of axis two. If this axis can be viewed as a local vegetation or habitat resource gradient, then this indicates that the

best suburban stations had small deciduous and coniferous shrubs (1 to 2 m's), few house lots, and the presence of water, increasing the number of species at suburban sites.

### **Land Use Habitat Positions along the Urbanization Gradient**

To further quantify the position of an average 'urban' and 'suburban' station along the gradient of urbanization, landscape and local level habitat variables have been plotted in relation to each other in star plots for each of the six land use habitat categories (Figure 8). Star plots can be interpreted for each variable such that the magnitude of a star's spike represents a standardized value for a variable, plotted along radial axes in relation to other variables. Habitat types with a larger relative value for a variable will show a greater star spike than corresponding spikes on star plots for other habitat types (Cleveland 1993). Landscape level variables, derived to estimate the importance of parks and reserves close to each survey station, and estimates of landscape composition (i.e., percent cover of trees, impervious surface, water, and grass <100 ha), are shown in Figure 8A. Data on local vegetation, composition and structure, around each point count station (Figure 8B), and non-continuous variables (Figure 8C) are presented and the plots are described and compared in the following three sections.

#### A) Characteristics of Habitat Categories - Landscape Level Features

Urban and suburban areas were defined by their political boundaries and by population density measures in this study (4940 individuals/km<sup>2</sup> and 2150 individuals/km<sup>2</sup> respectively). The average amount of impervious surface cover (landscape, <100 ha) increased with increasing urbanization from parks, edge, urban encroachments, suburban, to urban. However, urban park areas had lower levels of impervious surface cover at the landscape level than suburban areas. The number of house units or lots at the local scale was NIL in parks, low at park edges, and

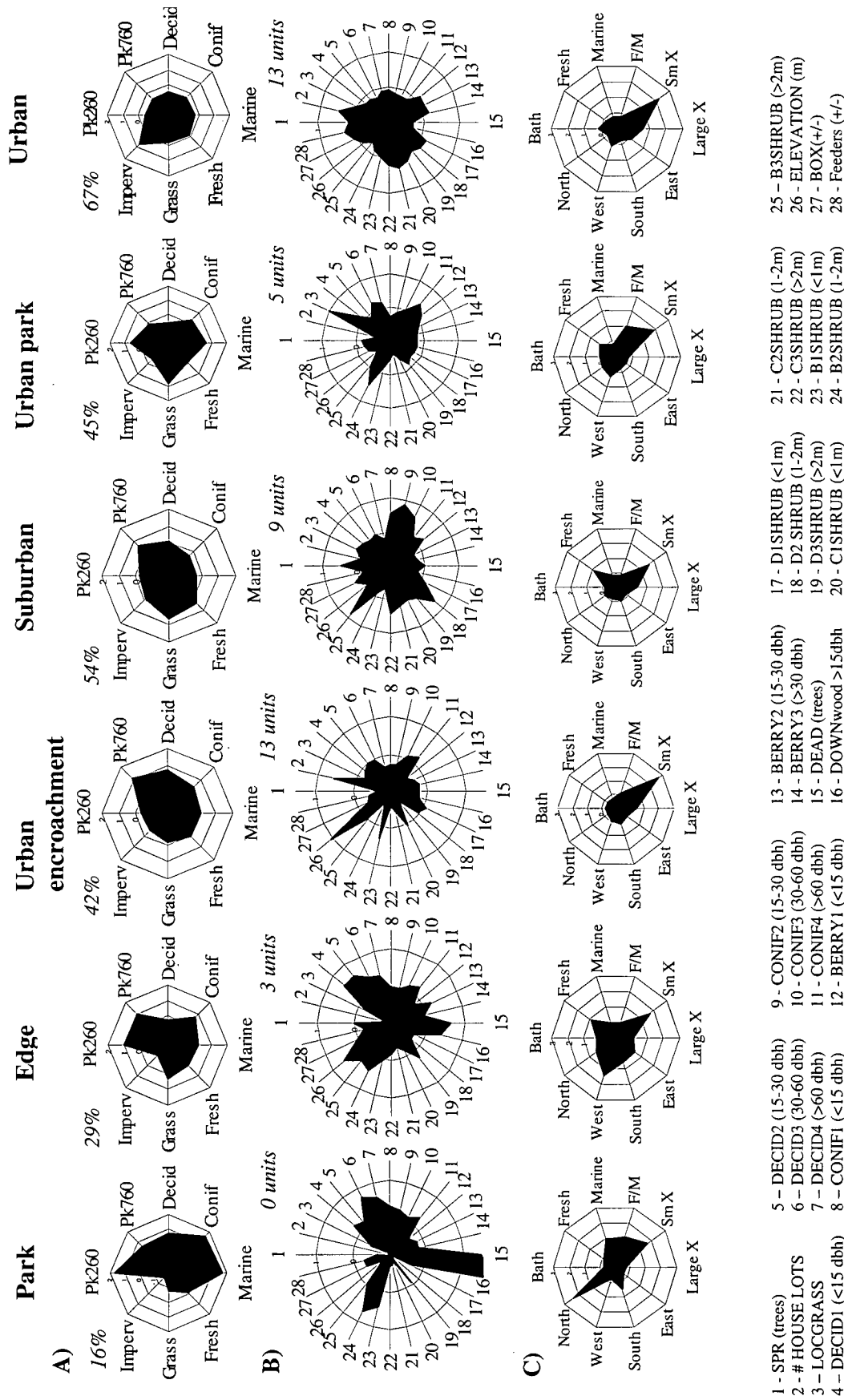


Figure 8. Star plots for A) landscape habitat and, B) local level habitat characteristics and, C) nominal variables, recorded at 285 point count stations (grouped by landscape category) in the Greater Vancouver area, 1997-1998.

highest in urban areas and in urban ‘encroachment’ areas surrounded by parks (*italics*, Figure 8A).

Park sites were often coastal, marine sites; they had less grass cover than any other category (Figure 8A). Edge and park sites were quantified by high park index values (Park 260m and Park 500-760m). Suburban and urban encroachment sites also had high values for park index 500-760m but low values for the park 260m index (Figure 8A). Suburban areas were largely developed in their immediate surroundings, whereas at a larger spatial scale these areas typically had higher values of park index 500-760m than urban areas. The differences between urban encroachment and suburban areas lie mainly with the amounts of grass cover and fresh water, both of which were higher in suburban areas; encroachment sites also had slightly greater marine, coniferous and deciduous tree cover, and Park 500-760 m values (Figure 8A). Conversely, urban park sites had high values for park index 260 m, but had *low* values for the Park 500-760 m index, indicating that urban park areas were surrounded at larger spatial scales by other land uses and further development (Figure 8A).

#### B) Characteristics of Habitat Categories – Local Level Habitat

Local level variable star plots summarize the microhabitat variability within habitat categories (Figure 8B). Suburban areas tended to have the most small deciduous shrubs <1 m to 2 m, similar numbers of coniferous shrubs as urban areas, and a majority of berry producing shrubs >2 m. They also tended to have higher tree species richness, higher numbers of coniferous trees 30 to 60 cm dbh, and lower housing densities (# HOUSE LOTS) than any other areas (Figure 8B). In comparison, urban encroachment sites were characterized by high elevations, large coniferous trees, smaller shrubs, moderate amounts of dead and downed wood, and higher housing densities at the local level (<1ha, Figure 8B). Park areas had typically high levels of dead and downed wood, berry producing shrubs <1 to 2 m, and large numbers of

deciduous trees > 30 to > 60 cm dbh and comparable amounts of coniferous trees to edge areas. Edge sites were similar to park sites but differed in the amount of dead and downed wood, they also tend to have larger berry shrubs (>2m), and the presence of nest boxes (Figure 8B).

Local urban area star plots had diametrically opposite habitat variable high points in comparison with park areas, where parks had habitat maxima, urban areas had habitat minima. Urban areas in this study had high housing densities, high tree species richness and often had bird feeders present. Moreover, they typically had berry producing trees and fewer deciduous and coniferous trees (Figure 8B). Shrub values for the urban stations were comparable to suburban ones, although urban areas tended to have more coniferous than deciduous shrubs (Figure 8B).

### C) Characteristics of Habitat Categories – Nominal variables

The nominal variables are potentially important local habitat variables indicating crucial water resources, the level of disturbance by road intersection size, and aspect; they were treated separately in order to examine them with ease and to reduce the number of variables presented on the local star plots. The most noteworthy differences among habitat categories in relation to aspect, intersection size, and the presence of water at the local scale (<1ha) had to do with the presence of fresh and salt water on park, edge, and suburban sites. Water was typically absent in urban encroachments, urban parks and urban areas. Suburban, encroachment, and urban park areas had more large intersections (Large X, Figure 8C), whereas all of the habitat categories were roughly comparable in terms of the average number of small intersections (Sm X, Figure 8C).



### Bird Nesting Guild-Habitat Relationships

Known nesting guild groupings were confirmed by the species distribution patterns evident in the CCA ordination (Figure 5). Given that ground, shrub and cavity nester species were found on the left side of the ordination, nesting habitat requirements broadly separated the observed distributions of birds. I used groups of nesting guilds to further test the prediction that landscape level habitat features (measured at <100 ha) should be stronger predictors of nesting guild occurrence than local habitat measures (<1 ha, *prediction 2*). I used logistic regression techniques to find the best fitting models that describe bird occurrence using habitat variables measured at landscape and local scales to examine the specific associations between nesting guilds and vegetation structure and composition at both the regional and stand levels. The predictive value and significance of sequential logistic models for seven nesting guilds and three individual species (see below) were compared following entrance of blocks of variables: Block1) local variables only *or* landscape variables only, block 2) local variables were added to landscape variable only models from block 1), and block 3) landscape\*local level variables were added. Of the final nesting guild and bird species models presented, five of seven guilds and all three selected species had good model fit at each block (Hosmer-Lemeshow goodness of fit test,  $p > 0.05$ , Table 7) - indicating that model predictions were not significantly different from the observed data. The exceptions were the local variable only models for building nesters and Spotted Towhee, and the landscape variable only model for American Robins and shrub nesters (Table 7,  $X^2$  goodness of fit,  $p < 0.05$ ). The likelihood ratio test statistic is another test for model goodness of fit comparing the difference in log likelihoods between a model with and without predictive variables to determine if the model fit was significantly improved. All final models in each block (with local and or landscape variables) were better at describing the observed data than null or constant only models (Table 7,  $X^2_{\text{to remove}}$ ,  $p < 0.01$ ).

For guilds that were present at most point count survey stations, such as coniferous and deciduous tree nesters, the models failed to converge and maximum likelihood logistic models could not be obtained. The model for building nesters had low model specificity, or ability to predict absence, probably because there were very few cases where building nesters were absent. Common individual bird species were selected, for which data were sufficient to build robust models. The American robin was selected to represent the deciduous tree nester guild. All of the species in the coniferous tree nester guild had either insufficient number of cases or they were present at almost all sites. I chose to model the occurrence of the two most common ground nesters, Song sparrow and Spotted Towhee, since ground nesters were estimated to have the most specialist habitat requirements. Variables chosen for entry in each model of the sequential regressions were selected based on canonical correspondence analysis results, statistical significance ( $p < 0.20$  in forward stepwise logistic regression), and known habitat associations and requirements. In seven cases out of eight (including 5 nesting guilds, 3 species), the first variable to enter stepwise screening models was a landscape level predictor. In six of those cases this variable was one of either impervious cover  $< 500$  m, or a park-distance variable (Imperv 500 m, Park 260m, Park 500-760m, Table 7). The ledge/cliff nesters were the exception; the number of house lots entered as the first variable for this nesting guild.

When only local level variables were entered into a model, the overall rate of correct classification for building, ground, cavity, and ledge nester guilds was lower than when only landscape variables were modeled (Table 7). This indicates that broad scale measured variables were more specific and/or sensitive predictors of the presence of these four guilds. Conversely, the local variable models for shrub nesters provided more accurate percent correct predictions than the landscape variable only models for these guilds (Table 7). When the five nesting guild models were compared to constant only models, improvement in log likelihood was better for



		Parameter estimate (B)	Odds Ratio	95% CI for Odds Ratio	X <sup>2</sup> to Remove - Likelihood Ratio test	Goodness of Fit	Sig	df	% Correct predictions				
Variable									Absent Specificity	Present - Sensitivity	Overall		
A. Nesting Guild	Shrub nesters (AMGO, COYE, SWTH, WCSP, WIFL) present (n=79) vs. absent (n=188)			LOCAL ONLY	95.29***	7	3.24	0.92	8	91.5	55.7	80.9	
				LANDSCAPE ONLY, BLOCK 1	36.62***	1	19.01	0.01	8	95.7	22.8	74.2	
		<i>Park 500-760m</i>											
			0.03	1.03	1.01	1.04	10.54**	1					
		# HOUSE LOTS	-0.11	0.90	0.85	0.95	19.20***	1					
		WATER(Bath)	1.43	4.19	1.06	16.50	4.17*	1					
		CONIF1(<15dbh) <sup>b</sup>	0.92	2.52	1.28	4.95	7.61**	1					
		D1SHRUB(<1m) <sup>b</sup>	0.85	2.34	1.15	4.74	6.03*	1					
		C3SHRUB(>2m) <sup>b</sup>	-0.96	0.38	0.22	0.65	13.86***	1					
		B1SHRUB(<1m) <sup>b</sup>	-1.40	0.25	0.13	0.49	19.71***	1					
		SPR (Trees)	-0.16	0.86	0.77	0.95	9.66**	1					
		Constant	0.54										
			LANDSCAPE & LOCAL, BLOCK 2	68.03***	7								
		MODEL <sub>(fit vs. constant only)</sub>				104.66***	8	2.14	0.98	8	89.9	57.0	80.2
		MODEL Log-Likelihood	219.66										
		Cavity nesters (BCCH, NOFL, RBNU, WIWR) present (n=166) vs. absent (n=101)				LOCAL ONLY	36.25***	2	7.8	0.45	8	45.7	79.4
				LANDSCAPE ONLY, BLOCK 1	36.28***	1	7.1	0.53	8	66.4	67.1	66.8	
<i>Park 500-760m</i>													
	0.03			1.03	1.01	1.04	19.82***	1					
CONIF2(15-30dbh) <sup>b</sup>	1.02			2.78	1.48	5.25	10.52**	1					
DECID3 (30-60dbh) <sup>b</sup>	0.96			2.62	1.37	5.02	8.72**	1					
Constant	-1.79												
	LANDSCAPE & LOCAL, BLOCK 2			19.64***	2	10.89	0.21	8	62.1	76.8	70.5		
MODEL <sub>(fit vs. constant only)</sub>						55.92***	3						
MODEL Log-Likelihood	314.13												

[illegible]

		Parameter estimate (B)	Odds Ratio	95% CI for Odds Ratio	X <sup>2</sup> to Remove - Likelihood Ratio test	Goodness of Fit	% Correct predictions						
Variable						df	Sig	Absent Specificity	Present - Sensitivity Overall				
B. Species	Song Sparrow present (n=36) vs. absent (n=229)	LOCAL ONLY				5	6.77	0.45	7	95.6	52.8	89.8	
		LANDSCAPE ONLY, BLOCK 1				4	6.86	0.64	8	97.8	50	91.3	
		LANDSCAPE & LOCAL, BLOCK 2				3	10.34	0.24	8	97.4	58.3	92.0	
		CONIF 500m <sup>c</sup>	-1.33	0.26	0.12	0.56	12.48***	1					
		GRASS 500m	-0.08	0.92	0.86	0.99	4.89*	1					
		IMPERV 500m	-0.07	0.93	0.90	0.96	10.30**	1					
		Park 500-760m	0.03	1.03	1.00	1.05	5.00*	1					
		WATER(Fresh)	5.81	333.57	8.62	1.29E+04	14.82**	1					
		WATER(Fresh) <sub>BLK2 estimate</sub>	1.77	5.85	1.63	20.97	7.39**	1					
		C2SHRUB(1-2m) <sup>b</sup>	-1.06	0.35	0.16	0.74	10.55**	1					
		B3SHRUB(>2m) <sup>b</sup>	0.35	1.43	0.64	3.19	0.34	1					
		CONIF 500m <sup>c</sup> * stream	2.19	8.95	1.41	56.61	5.02*	1					
		Constant	-0.98										
		LANDSCAPE, LOCAL, & INTERACTION, BLOCK 3				6.23*	1	7.11	0.52	8	96.5	69.4	92.8
MODEL <sub>(fit vs. constant only)</sub>				102.05***	8								
		MODEL Log-Likelihood				108.25							
American Robin Present (n=175) vs. absent (n=92)	American Robin Present (n=175) vs. absent (n=92)	LOCAL ONLY				4	9.10	0.33	8	43.8	84.0	69.7	
		LANDSCAPE ONLY, BLOCK 1				1	23.75	0.00	8	0.0	100.0	64.6	
		Park 500-760m	0.03	1.03	1.02	1.05	20.89***	1					
		# HOUSE LOTS	-0.06	0.94	0.90	0.99	7.63**	1					
		WATER (Fresh)	0.42	1.53	0.45	5.20	0.53	1					
		WATER(Marine)	-0.15	0.86	0.38	1.93	3.39~	1					
		DECID4 (>60dbh) <sup>b</sup>	1.6	4.95	1.23	19.93	4.26*	1					
		LANDSCAPE & LOCAL, BLOCK 2				28.09**	4						
		MODEL <sub>(fit vs. constant only)</sub>				87.52***	5	5.85	0.66	8	64.6	82.9	76.4
		MODEL Log-Likelihood				285.03							
		LOCAL ONLY				4	9.10	0.33	8	43.8	84.0	69.7	
		LANDSCAPE ONLY, BLOCK 1				1	23.75	0.00	8	0.0	100.0	64.6	
		Park 500-760m	0.03	1.03	1.02	1.05	20.89***	1					
		# HOUSE LOTS	-0.06	0.94	0.90	0.99	7.63**	1					
WATER (Fresh)	0.42	1.53	0.45	5.20	0.53	1							
WATER(Marine)	-0.15	0.86	0.38	1.93	3.39~	1							
DECID4 (>60dbh) <sup>b</sup>	1.6	4.95	1.23	19.93	4.26*	1							
LANDSCAPE & LOCAL, BLOCK 2				28.09**	4								
MODEL <sub>(fit vs. constant only)</sub>				87.52***	5	5.85	0.66	8	64.6	82.9	76.4		
MODEL Log-Likelihood				285.03									

landscape variable only models than for local variable only models ( $X^2_{\text{to remove}}$ , Table 7) with the exception of shrub nesters but all were significant (Model<sub>fit</sub> vs Model<sub>constant</sub>,  $p < 0.001$  Table 7). This indicates that landscape variable only models improved fit more than constant only models with fewer variables (dfs, Table 7) than local variable only models for four of five nesting guilds tested.

The comparison for species is somewhat different. Spotted Towhee, Song Sparrow and American Robin models had better overall rates of correct predictions with local variable only models than landscape variable only models - albeit the local model for Towhees failed the Hosmer-Lemeshow chi-square goodness of fit test (Table 7). When these three species models were compared to constant only models, improvement in log likelihood was again better for landscape variable only models than for local variable only models ( $X^2_{\text{to remove}}$ , Table 7), but the difference was slight. In the case of the Song Sparrow, the difference between chi square log-likelihood to remove for local variables only verses landscape variables only was next to nil in the reverse direction. This indicates that when modeling for individual species as opposed to groups of species, local variables are more precise in terms of correct predictions.

Birds should select local sites that provide adequate nesting habitat conditions during the breeding season and thus their occurrence at point count stations should be related to the local habitat conditions around each station. Following landscape level predictors, microhabitat or local level descriptors significantly improved the predictive ability of the landscape-variable only models, but the overall rate of correct classification increased only minimally (Table 7, Block 2 vs. Block 1). The addition of local variables to the landscape only models for building and cavity nesters was barely significant (Table 7,  $X^2_{\text{to remove}}$   $p \sim 0.10$ ). Point count stations in areas with *both* high quality local habitat *and* a large amount of surrounding regional habitat should have higher than expected guild and species occurrence (presence). A significant

interaction term between local and landscape scales was identified only for Song Sparrows ( $X^2_{\text{to remove}} = 6.23, p < 0.05, df = 8, N = 265$ ). The overall rate of correct classification for the sparrow model with significant interaction term improved only marginally (Table 7).

Six of the eight models included the landscape variable Park 500-760m, implying that distance and the amount of park area in the neighbouring vicinity is a strong predictor of guild and species presence. The odds ratio represents the increase (or decrease if the ratio is less than one) in the odds of finding a guild or species present for every one unit increase in the value of a variable, after adjusting for all other predictors in a model (Tabachnick and Fidell 1996). It is a multiplicative factor, 1.05 for instance represents a 5% increase in odds per unit of the associated predictor value. To make this value more meaningful, the odds ratio is often calculated for greater than one unit increases in predictor values. So, for a *five*-unit (m) increase in the value of Park 500-760 m, the likelihood of ground, shrub, and cavity nester occurrence increased by 25%, 15%, and 15% respectively (Table 7, Odds ratio<sub>Park 500-760 m</sub> = 1.05, 1.03, and 1.03,  $p.001 < p < 0.05$ ). Only the ledge and building nester models did not include this variable as a significant predictor. This finding is consistent with results from canonical correspondence ordinations since all shrub, ground, and cavity nesters were associated with these two habitat variables on the left end of the ordination (Figure 5), while building and ledge nesters were not. Another consistently important landscape predictor was the percent cover of impervious surface (IMPERV 500m). It was included in five of the eight models ( $X^2_{\text{to remove}}, 0.001 < p < 0.05$ ) supporting the use of this variable as an average metric to characterize degree of urbanization (Arnold and Gibbons 1996 and Marzluff *et al.* 1998). American robin was the only species and shrub and cavity nesters were the only nesting guilds that did not include impervious surface as a significant predictor (Table 7).



In general, the best local habitat predictors of nesting guild presence were both habitat structure and composition variables and variables indicative of urban density. The likelihood of finding ground and shrub nesters significantly decreased with increasing housing densities and increasing cover of local grass (LOCGRASS and # HOUSE LOTS). There was an 10% decrease in the likelihood of shrub nester occurrence with each additional housing lot (<1ha) after adjusting for other important local predictors such as numbers of deciduous and coniferous shrubs and water (Table 7, odds ratio<sub>house lots</sub> = 0.90,  $X^2$ <sub>to remove</sub>,  $p < 0.001$ ). The likelihood of finding ground nesters decreased by 50% for every 10% increase in local grass cover (Table 7, odds ratio<sub>local grass</sub> = 0.95 a 5% decrease for every 1% unit change in local grass cover,  $X^2$ <sub>to remove</sub>,  $p < 0.001$ ). The presence of gulls and robins were also found to decrease in likelihood with increases in these variables.

Water was included in all of the models, with the exception of cavity nesters, and the likelihood of finding shrub nesters was four times higher when bird baths were present (Table 7, odds ratio<sub>water bath</sub> = 4.19,  $X^2$ <sub>to remove</sub>  $p < 0.05$ ). The likelihood of finding ledge nesters was seven and one half times higher when salt water was present < 500 m (Table 7, odds ratio<sub>Salt</sub> = 7.46,  $X^2$ <sub>to remove</sub>  $p < 0.01$ ). Song Sparrows were almost six times more likely to occur at sites with fresh water present (Table 7, odds ratio<sub>stream Block 2</sub>) = 5.85,  $X^2$ <sub>to remove</sub>,  $p < 0.01$ ); there were large standard errors in the stream parameter estimate for Block 3), which included an interaction term coniferous<sub>500</sub>X fresh water. This indicates that the interaction term and fresh water have overlapping conditions and since both are good predictors, the iterative process bounces back and forth estimating water and interaction parameters, resulting in large standard error terms (Hosmer and Lemeshow 1989, Tabachnick and Fidell 1996).

Local structural variables such as large deciduous trees (DECID4 (>60dbh)) increased the likelihood of American Robin occurrence (Table 7, odds ratio = 4.95,  $X^2$ <sub>to remove</sub>  $p < 0.05$ ), but

decreased the likelihood of Spotted Towhee occurrence (Table 7, odds ratio = 0.07,  $X^2_{\text{to remove}}$ ,  $p < 0.01$ ), indicating that these two species may have divergent requirements. In addition, increasing numbers of local deciduous and large berry producing shrubs increased the likelihood of ground and shrub nesting species, but this was not true for coniferous and small < 1m berry producing shrubs (Table 7, odds ratios  $_{D1,D3,C3,B3\text{shrubs}}$ ).

### **Bird Species Incidence as a Function of Park-space by Distance**

Species incidence, estimated by the percent of stations (with similar habitat characteristics) occupied, should increase both with area and proximity to parks if parks are 'source' areas for marginal nesting locations along residential streets (*prediction 4*). From the results of the canonical correspondence analysis and ordination, certain bird species were associated with the Park 0 - 260 m index and others were more strongly associated with Park 500-760 m (Figure 5). The percent stations occupied (incidence) of these bird species were plotted as a function of proximity to park if they occurred at more than 10 stations ( $n > 10$ , Figure 9). These graphs indicated that for some species, incidence increases with park area as an inverse function of distance, but the trend, if any, is most apparent with the Park 500 – 760 m index (Figure 9C-D).

According to the results of CCA, Cowbirds and Juncos were associated with Park 0 – 260 m, but their site incidence patterns showed no relationship with this variable (Figure 9A). There were slight increases in the species incidence of Rufous Hummingbirds, Orange-crowned Warblers, and Pine Siskins with increasing values of Park 0 -260 m, but low r-square values indicate that this variable had low predictive ability for these species in urban areas (Figure 9B,  $r^2 = 0.14, 0.21, 0.18$  respectively,  $p < 0.05$ ). The low amount of variation explained by these regressions may also be a function of low sample size for these species. The Winter Wren, Swainson's Thrush, and Cedar Waxwing appeared to have higher incidence in association with

increased values of Park 500-760 m index (Figure 9C-D,  $r^2=0.22, 0.35, 0.43$  respectively,  $0.05 > p < 0.005$ ), indicating that these species occurred at sites with the highest amounts of park area per distance unit at a scale of 500-760 m.

The occurrence of American Robins, Spotted Towhees, and Song Sparrows modeled with logistic regression showed that the variable Park 500-760 m was significant at predicting their distribution. The percent stations occupied with similar values of Park 500-760 m was fit with simple regression (Figure 10a-c). Park 500-760 m explained 50% of the variation in Spotted Towhee incidence, followed by American Robin (45% variation explained) supporting the importance of regional park-space to the residential nesting occurrences of these species (Figure 10a-c,  $p < 0.001$ ). Song Sparrows were not adequately explained by Park 500-760 m index (20% variation explained, Figure 10), indicating the presence of Song Sparrows is not highly associated with this variable. This was not entirely surprising since logistic regression models for Song Sparrows suggested that their presence was more associated with local habitat conditions, particularly riparian habitat. Park 500-760m is a landscape level predictor with an unimpressive level of significance in relation to the other variables in the final logistic model for this species (Table 7). Overall, while Park 500-760 m is a good predictor for groups of nesting bird guilds and some common species such as robins and towhees, it cannot be used as an indicator for all species.

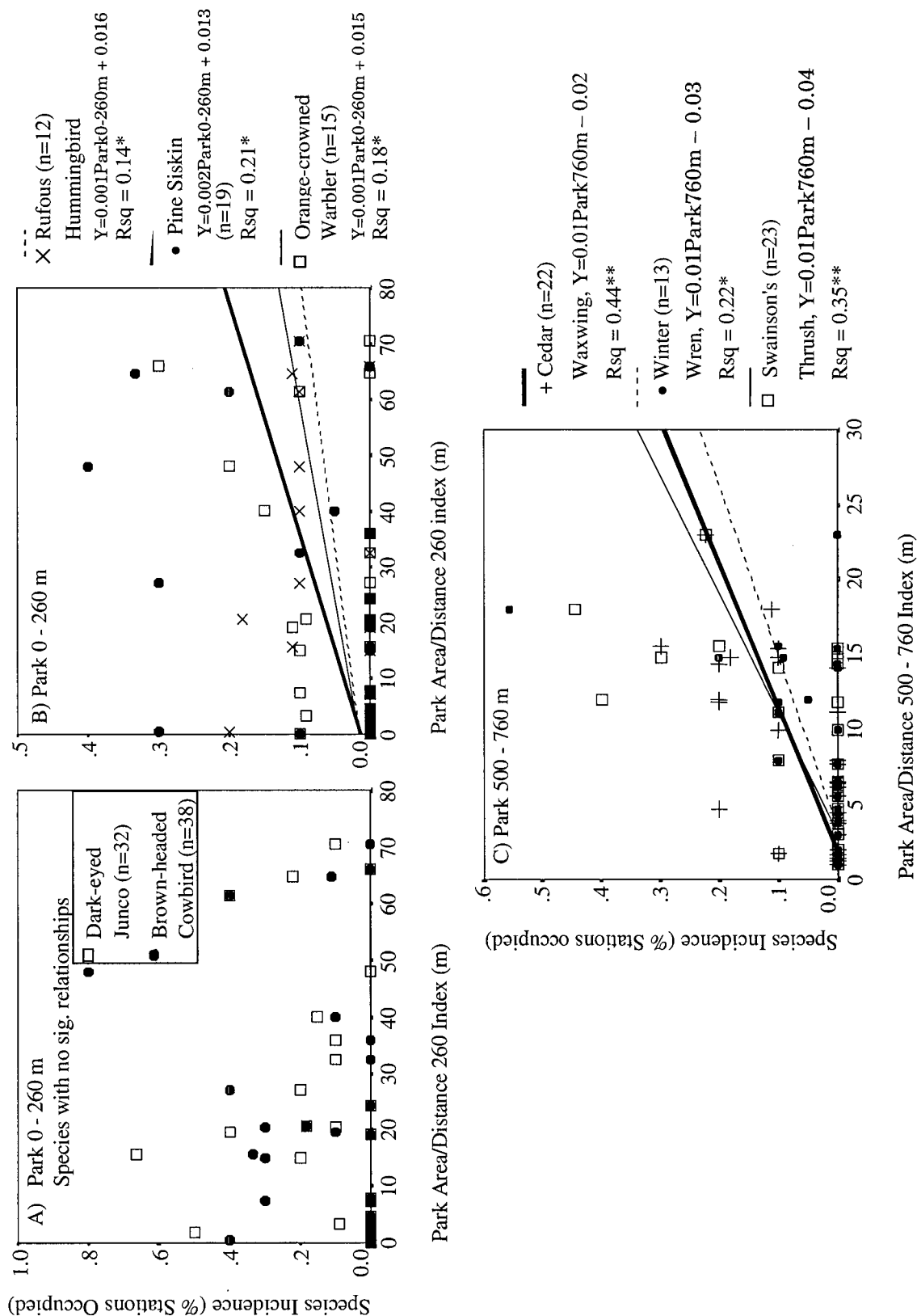


Figure 9. A-B) Predicted incidence (% stations occupied) for common bird species associated with the Park 0 - 260m index (from canonical correspondence analysis, Figure 5). C) Incidence plots for common bird species associated with Park 500-760m (from canonical correspondence analysis, Figure 5). \* $p < 0.05$ , \*\* $p < 0.005$

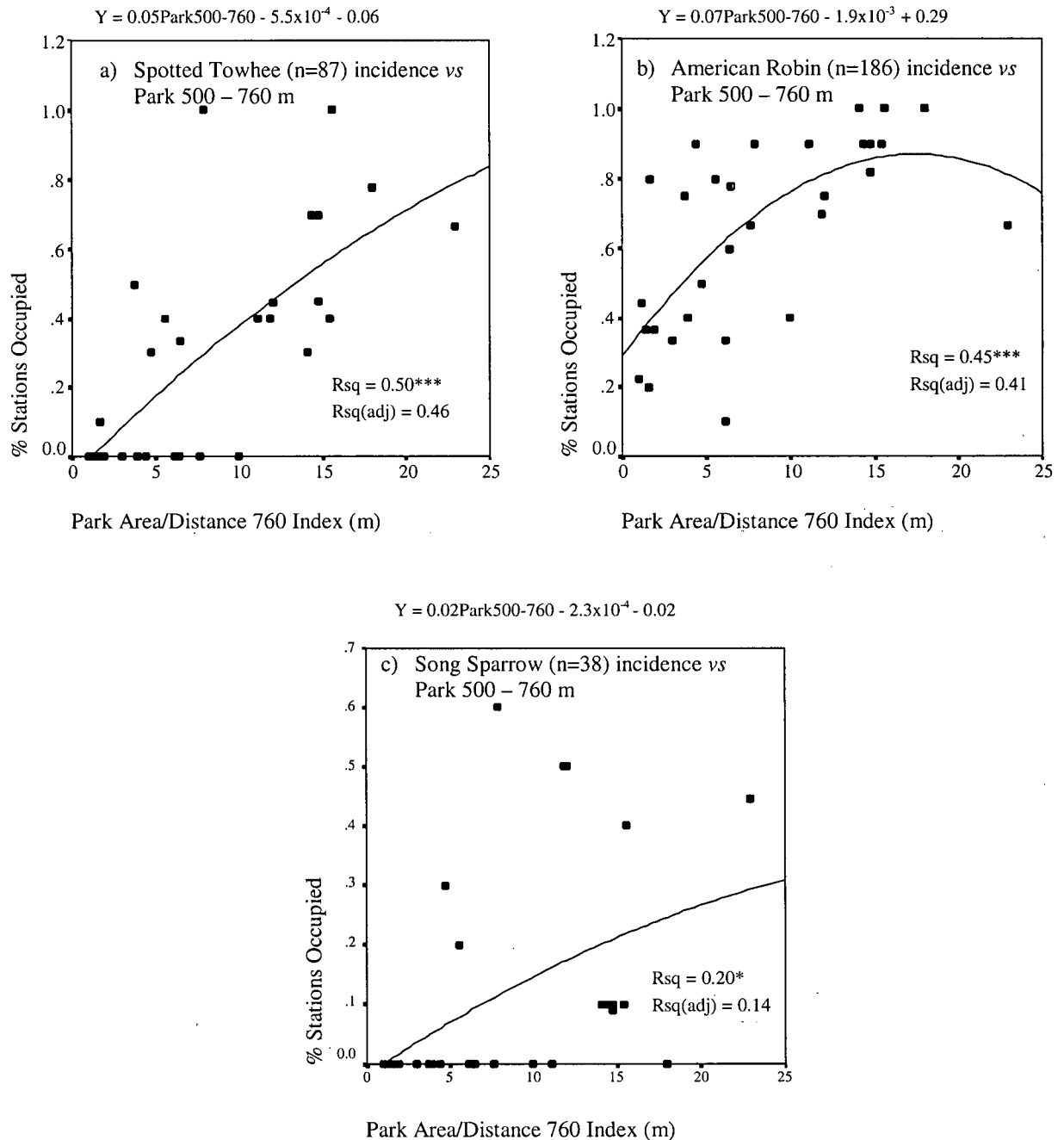


Figure 10a-c). Incidence functions (percent sites occupied) verses Park 500 – 760 m index for three selected bird species, Vancouver – Burnaby, British Columbia (\* $p < 0.05$ , \*\*\* $p < 0.001$ , refer to Table 8 for quadratic fit parameter estimates).

TABLE 8. Curve model fit of Park 500-760 m index as a predictor for the incidence (percent stations with similar Park 500-760 m values occupied) of three selected bird species, Vancouver – Burnaby, British Columbia.

MODEL	Variable (m)	Parameter estimate (B)	Standard error of the estimate (B)	T	Sig.T	n	R <sup>2</sup> (R <sup>2</sup> <sub>adj</sub> )	SSQ
Spotted Towhee Quadratic Fit  F=13.63***	Park 500-760 m	0.05	0.02	1.93	0.06	29	0.50	1.51
	(Park 500-760 m) <sup>2</sup>	-5.5 x 10 <sup>-4</sup>	1.2 x 10 <sup>-3</sup>	-0.44	0.66		(0.47)	
	Constant	-0.06	0.11	-0.54	0.59			
American Robin Quadratic Fit  F=11.09***	Park 500 - 760 m	0.07	0.02	2.96	0.01	29	0.45	0.95
	(Park 500 - 760 m) <sup>2</sup>	-1.9x10 <sup>-3</sup>	1.1x10 <sup>-3</sup>	-1.77	0.09		(0.41)	
	Constant	0.29	0.10	3.03	0.005			
Song Sparrow Quadratic Fit  F=3.46	Park 500 - 760 m	0.02	0.02	1.00	0.32	29	0.20	0.20
	(Park 500 - 760 m) <sup>2</sup>	-2.3x10 <sup>-4</sup>	9.0x10 <sup>-4</sup>	-0.26	0.80		(0.14)	
	Constant	-0.02	0.08	-0.23	0.82			

\*\*\*p<0.001

## DISCUSSION

The avian community in Vancouver and Burnaby, B.C. showed specialist and generalist occurrences along an intensity of urbanization gradient with decreasing species richness and increasing relative abundance (Figure 5, Appendix V), consistent with previous work (Lancaster and Rees 1979, Blair 1996, Haddidian *et al.* 1997). This urbanization gradient was strongly dominated by landscape level measures, so that the amount of park area per distance segment away from point count stations provided the best separation of the observed species distribution patterns. Several local habitat variables, such as housing density, intersection size, water, small and large deciduous trees and tree species richness, dominated the most urban extreme of the gradient (Figure 5). Subjectively defined land use categories such as 'suburban' and 'urban encroachment' did not fully simplify this habitat gradient (Figure 6 and Figure 8). Suburban sites were dispersed across a large range of habitat conditions with respect to the gradient of urbanization.

I have presented several habitat models using logistic regression techniques for five nesting guilds and three selected species, the Song Sparrow, Spotted Towhee, and American Robin, that may be of interest to urban land planners, landscape architects and urban residents. Landscape variable-only models improved the fit more and used fewer variables than did local-variable only models (improvement in log likelihood vs constant only model) for all nesting guilds and species, with two exceptions - shrub nesters and Song Sparrows (Table 7). Contrary to my prediction, however, local models were often more sensitive and/or specific than landscape variables (chi-square goodness of fit test, Hosmer and Lemeshow 1989) in predicting individual species presence/absence. This indicates that when modeling for individual species as opposed

to groups of species, local variables were more precise. The local variable models for cavity and shrub nesters also provided more accurate percent correct predictions than did landscape variable only models (Table 7).

### ***Prediction 1, Bird Species along a Gradient of Urbanization***

The spatially varying effects of urbanization seemed to pattern the corresponding bird communities along a gradient that gradually separated a wide distribution of birds in Greater Vancouver. The bird communities approximated the gradient paradigm described by McDonnell and Pickett (1990) and pioneered by Whittaker (1967) and is the view that spatial patterns in the environment organize the structure and function of populations, communities, or ecological systems. The rate of habitat change in space affects the steepness of the gradient in ecosystem structure and function (Karr and Freemark 1983, McDonnell and Pickett 1990, Keddy 1991). If the spatial patterns of birds were generated by dispersal and settlement biases (Bolger *et al.* 1997), then landscape habitat characteristics such as proximity to natal areas will affect the chances that a bird occurs at a site. The local matrix of habitat conditions will affect how quickly forest species turnover to edge and urban bird species. In my research in Greater Vancouver, parks and reserves augmented avian diversity in the surrounding residential areas along a gradient of urbanization that changed with conditions of the local habitat as well. Habitat specialists are likely to disperse from reserve areas in times of high regional nesting success (Hinsley *et al.* 1996, Helzer and Jelinski 1999) to more marginal nesting areas where they may be exposed to increased predation and competition (Soulé *et al.* 1988, Rottenborn 1999).

Canonical correspondence analysis depicts the overall pattern in the relation between the community of birds and the observed habitat variables along multiple linear regression model



axes. Since the second and third axes are limited by the condition that they be uncorrelated with the first axis, it is possible that the second axis selected is a mathematical construct or polynomial gradient rather than a 'true' second habitat gradient. A modified and folded first axis is a type of polynomial distortion which creates the 'arch effect' (Jongman *et al.* 1995). The arch effect is apparent in my results and is a recognized fault of CCA (Jongman *et al.* 1995), so I have not interpreted the second axis in any detail.

Species points at the edge of ordination diagrams, the Red-eyed Vireo and Black headed Grosbeak, are often species with very low abundance in the data set (Table 1, Figure 5) that ordinate at the extreme edge of the gradient either by chance or because they prefer extreme conditions (Jongman *et al.* 1995). One can only decide between these two possibilities with additional knowledge. Red-eyed Vireos an occasional breeder in the area, their presence at these sites may be a chance occurrence or may indicate breeding summer visitors (Ehrlich *et al.* 1988). The Black-headed Grosbeak is often found in open woodlands and at the forest edge (Ehrlich *et al.* 1988), so their presence may be related to park-space (Park 500-760m). However, species at the extreme ends of the CCA ordinations have little influence on the analysis (Jongman *et al.* 1995). Another shortcoming of the method of weighted averaging is that species at the very centre of the diagram (Steller's Jay, Violet-green and Barn Swallow) may either be unimodal with optima at the centre, or bimodal, or unrelated to the ordination axes. The preferred habitat of Steller's Jays is successional forest edges and neighborhoods with suburban vegetation characteristics, consistent with their position in the canonical correspondence ordination (Figure 5, Sieving and Willson 1998). Violet-green and Barn Swallows may be expected to have optima at the centre of the axes, as they are prevalent throughout many areas of the city and they nest in building cavities.

The results of CCA on these data support the hypothesis that landscape variables are better able to explain the variability in the Greater Vancouver urban bird community than the local habitat, but the resulting bird-habitat trends are exploratory. In general, the ordination diagrams of individual species (Figure 5) and point count stations (Figure 6), and the logistic regression analysis (Tables 7) on nesting guilds, are largely consistent. The same landscape and local variables showed significant relationships with bird species and nesting guild occurrence in logistic regression. Given that the results of the canonical correspondence analysis and the regression analysis are similar, we can be confident that the important environmental variables have been examined in the survey (Jongman *et al.* 1995).

### ***Prediction 2, Landscape verses Local Habitat Predictors***

The distance from large potential 'source' and resource habitat areas was one of the most important variables in determining the distribution of breeding birds in Greater Vancouver. Similar results were found by Munyenyembe *et al.* (1989) and Germaine *et al.* (1998), but results from multiple scale studies have not consistently shown that landscape level effects are significant. Neither the occurrence of individual breeding bird species, nor species richness, was related to any measure of landscape context in foothill shrub avian communities of Colorado (Berry and Brock 1998). They suggested that bird species in the foothill shrub could have evolved tolerance for habitat fragmentation because it represents the natural state of the landscape in which these birds occur. Clergeau *et al.* (1998) found that local site level features were more important than landscape level features along an urban-rural gradient in two cities, Rennes, France and Québec City, Canada. However, they did not quantify the surrounding landscape 'setting' and excluded all natural areas such as parks and woodlots from their analysis, examining only the percent of vegetated open areas under different land uses. So, it is possible

that they were unable to detect landscape level effects because they did not capture variation in habitat at the landscape level in their study.

In urban areas, there is more support for landscape level effects, but the perspective is generally that urbanization around habitat patches and riparian areas affects birds within these areas, rather than residential bird communities being 'rescued' by their surroundings, as in this study. Bird species richness in urban riparian corridors in Alachua County, Florida was negatively correlated with housing densities in areas adjacent to these corridors (Smith and Schaefer 1992). Urbanization on lands adjacent ( $< 78$  ha) to intact riparian woodlands ( $\sim 1$  ha width) in Santa Clara Valley, CA, had a substantial impact on the riparian bird communities. The number of bridges within 500 m of a plot was significantly related to decreasing species richness in regression models (Rottenborn 1999). Saab (1999) had similar findings for breeding birds in riparian forests, South Forks, Idaho. Examining the effects of land cover types around study plots, Germaine *et al.* (1998) found that the abundance of 17 of 21 bird species were associated with land cover variables ( $> 3$  ha) such as housing density at the landscape level in Tuscon, Arizona. Landscape descriptors ( $< 20$ -3000 ha) were often better predictors than local habitat variables ( $< 3$  ha) for the abundance of 10 of 20 bird species in San Diego County, California (Bolger *et al.* 1997).

My local variable-only models for individual species and for cavity and shrub nesters were often more sensitive or specific predictors than landscape variable-only models. The cavity and shrub nesting guilds contain species that are known to nest under a variety of conditions along an urbanization gradient, Black-capped Chickadees, Northern Flickers and White-crowned Sparrows for instance. The scale of response for these groups of species acts more at a local level along the urbanization gradient probably because many of these species have adapted to landscape habitat fragmentation and are cueing into local habitat variation. American Robins are

a ubiquitous species, known to be very robust to changes in broad scale urbanization, so it is not surprising that they were more associated with local variables than landscape variables. Spotted Towhees were insensitive to landscape level habitat fragmentation in other studies as well (Bolger *et al.* 1997, Berry and Bock 1998). Although the occurrence of Towhees and Robins were better predicted by local habitat conditions, their incidence (% stations occupied) was associated with the amount of park area over distances within 500 to 760m at the landscape scale. It would be interesting to investigate nesting success and post-natal dispersal of these resident species in relation to distance to the edge of a large forested area. The incidence of Song Sparrow in my study was associated with local variables more than with the landscape variable, Park 500-760 m. Other research has shown that this ground nester appears to display a high degree of site fidelity - the observed maximum distances dispersed by Song Sparrows were shorter on average (72% less) than predicted values (Sutherland *et al.* 2000). In another urban bird study, Song Sparrow abundance was related to the (local) presence of, or increases in, shrub stratum on one ha sample plots in Montreal, Quebec parks over a 15-year period (Morneau *et al.* 1999), and this was confirmed in Vancouver as well.

Demographic differences in reproduction and survival success at the local site level are strongly associated with nearby native habitat resources that may be acting as sources of species immigrants and visitors (Pulliam 1988). The overall avian community response may be related to a combination of several factors, such as, differences in rates of competition, predation, nest parasitism, immigration and emigration, nesting success, and resource abundance. Each of these mechanisms operates at the site level and each has features associated with the surrounding landscape, so landscape level variables may integrate a combination of factors. Landscape variables are likely to have more information than the variables measured at smaller scales. This would explain the inconsistency between the results for ground nesters (landscape models were

better predictors) and two individual species of ground nesters, Song Sparrows and Spotted Towhees, with occurrence patterns better predicted by local level variables. Landscape models seem to be better able to predict for presence species groups rather than for individual species. If the landscape variables explain more variation, it may not indicate that bird communities are mechanistically associated with landscape measures, it may simply mean that we can predict bird distributions better with measurements made at the level of the landscape.

In a study on the impacts of urbanization on riparian bird communities, the abundance of ground nesters was highly correlated with measures of the local habitat such as native and total vegetation volume within 10 meters. Landscape measures such as the overall degree of urbanization or disturbance within 500 meters of a plot were also correlated with ground nester abundance (Rottenborn 1999). Cats and other predators were the suggested long-term mechanism keeping the numbers of ground nesters in his study low; although the density of cats was estimated, however, it was not a significant variable in his final multiple linear regression models (Rottenborn 1999). My results agree with those of Rottenborn, but I would suggest that habitat may be more important than the number of cats when it comes to nest site selection for some ground nesters (i.e., Towhees). Still, cat predation could be impacting nesting success after birds have already invested nesting time at a location, but further study would be required to examine cat predation of native birds in urban areas close to parks and in suburbs. A single pet cat was responsible for the deaths of at least 62 individual birds over a period of 18 months in Michigan (Bradt 1949 cited in Soulé *et al.* 1988).

### ***Prediction 3, Urban Land Use Categories, a Poor Indicator of Bird Habitat Types?***

Many studies have focused directly on 'suburban' birds, but fail to define the term, suburban, in more than a general sense (e.g., Vale and Vale 1976, Rosenberg *et al.* 1987, DeGraaf 1991,

Sodhi 1992, Zalewski 1994). Land use terms (suburban, rural, commercial) have different meanings in different cultural contexts, where they also change with societal gradients (i.e., changes in economic status, socio-cultural differentiation, land use and housing density changes) and societal gradients may or may not represent parallel habitat gradients of importance to birds. Nonetheless, the utility of the terms, urban and suburban, lies in their (presumed) ability to simplify a complex gradient into discrete groupings that represent an easily understood habitat type of significance to birds and land-use planners. So, standard measures that accurately quantify the position of an urban or suburban site along a complex urbanization gradient would be useful (Marzluff *et al.* 1998). However, according to my results in Greater Vancouver, land use categories were not *accurate or precise* ways to delineate bird habitat and perhaps such subjective habitat groupings should be avoided.

Some studies have found that species diversity and bird biomass peaked in suburban areas with slight levels of development, rather than at the most natural site (Batton 1972, Lancaster and Rees 1979, Blair 1996). Star plots of Burnaby suburbs in this study showed that suburban areas had intermediate levels of impervious surface cover (54%) and intermediate levels of vegetation at different scales (Figure 8A-C). The finding that species richness peaks in suburbs or at low levels of diversity has been related to the hypotheses of intermediate disturbance theory (Connell 1978, Collins *et al.* 1997, *as in* Blair 1996). According to this theory, superior competitors are assumed to be susceptible to intermediate conditions of disturbance and, thus, they do not achieve dominance, while less competitive species co-exist because they are assumed to be relatively tolerant of intermediate disturbance conditions (spatial in this case, Collins *et al.* 1997). Although the results of this study agree with this hypothesis, because species richness seemed to peak at intermediate levels of the urbanization gradient, CCA axis

one, the relationship showed a large amount of variation and could be modeled both curvilinearly and linearly (Table 6).

Combined with park-distance metrics (see below), impervious surface cover may be a better habitat quality indicators for bird species distributions. The amount of impervious surface cover in the surrounding area (<500 m) was an important and frequent predictor of bird occurrence in this study. American Robin was the only species and shrub and cavity nesters were the only nesting guilds that did not include impervious surface as a significant predictor (Table 7). However, Robins, Towhees and shrub nesters did include the number of local level house lots as a significant predictor, and the number of house lots had the highest correlation with landscape-level impervious surface cover (Pearson's  $r = 0.72$ ). Geologists and hydrologists have used percent impervious surface cover to assess water cycle and infiltration changes associated with urbanization (Stankowski 1972 cited in Arnold and Gibbons 1996). They suggest using impervious surface cover as an integrative environmental indicator of complex urban environmental issues, such as cumulative water resource impacts with many nonpoint sources of pollution. The relative amount of impervious cover seems to be a relevant indicator for bird species distributions as well, because many native species have declining abundance with the increasing percent area paved (e.g., Munyenyembe *et al.* 1989, Germaine *et al.* 1998).

#### **Prediction 4, Species Incidence as a Function of Park Area and Distance**

Area and distance from parks explained species incidence, and six of the eight final logistic regression models produced, included the landscape variable Park 500-760m. This park by distance index also explained 35 to 50 percent of the variation in the site occurrences (incidence) of Swainson's Thrush, Cedar Waxwing, American Robin and Spotted Towhee (Figure 9 and 10).

Thus, park area weighted inversely by distance away was a significant predictor for the presence of several bird species in Greater Vancouver, and species incidence increased with the amount and proximity to parks. Only the ledge and building nester regression models did not include Park 500 – 760 m as a significant predictor. This was not surprising given that building and ledge nester guilds included many urban generalist species. The building nester guild included non-native species such as European Starling, House Sparrow, and Rock Dove and these species generally nest on building ledges, eaves, and building cavities, within highly urbanized areas where they can find adequate food (Ehrlich *et al.* 1988). Although the presence of Violet-green and Barn Swallows should be related to park habitat nearby, given their known habitat requirements, the relationship may be a weak one in Greater Vancouver and could have been masked by the occurrence patterns of the other species included in the building nester guild. Barn Swallows are often found near open fresh water ponds, and Violet-green Swallows breed in areas with coniferous or deciduous open forests (Ehrlich *et al.* 1988). Three species of gulls were included in the ledge nester guild, however the most frequently sighted species was the Glaucous-winged Gull. The gulls were wide ranging and their presence was probably more an indication of food availability rather than nesting occurrence.

In another urban bird study, decreasing weights were assigned to the amount of developed land within increasing concentric rings at different spatial scales around bird survey points, coastal southern California (Bolger *et al.* 1997). They assigned an inverse weighting scheme to the proportion of developed land within each concentric ring around point counts located in 'islands' of natural habitat, creating an urban exposure index. However, when this variable was entered in logistic regression models, urban exposure was significant in only two of twenty species occurrence habitat models. More significant variables were the non-weighted proportions of edge and natural areas around 'island' survey sites. My results agree with those



of Bolger *et al.* (1997), but I did not use the proportion of natural area within concentric rings around each bird survey station, rather I used park area within each ring directly and divided that area by distance away. Dividing park area by distance weights habitat farther away with an exponentially declining importance. The use of the proportional natural area within each concentric ring around a site also gives habitat areas farther away a declining importance, because the outermost rings will be much larger than the innermost ring (as in Bolger *et al.* 1997). My inverse of distance weighting scheme perhaps relates more directly to the theoretical expectation that species and guild occurrence should decrease non-linearly with distance from 'natural' areas, given known natal dispersal trends for birds (Sutherland *et al.* 2000). Moreover, if species are using park habitat as a resource for complementary habitat, or if they are supplementing these areas with resources that are lacking in residential urban areas, then close habitats should be visited more frequently than distant ones.

### **Speculation - Dispersal from Natal Area?**

Several studies have found declining species richness and declining site incidence with increasing distance from native habitats (Munyenymbe *et al.* 1989, Bolger *et al.* 1997, Germaine *et al.* 1998). My research confirms these findings, but the decline in species richness may be an isolation effect or could it be related to the quality of the local habitat in urban areas. Many urban and forest dwelling bird species are migratory and are not likely to be severely limited by their dispersal abilities (Tilghman 1987, Soulé *et al.* 1988). Birds can probably move with relative ease through sparsely treed and patchy areas to local sites with good nesting habitat characteristics. There is evidence to suggest that birds do not generally disperse far from their natal area and that the number of individuals dispersing decreases exponentially with distance from parental nesting sites (Sutherland *et al.* 2000). Published data on natal the dispersal

movements for 77 bird species indicates that most dispersers move relatively short distances (30% of species moved median distances of  $< 1$  km and just over 60% of species examined moved  $< 10$  km). In their survey of published dispersal literature, the maximum distances dispersed were 28.4 km for migratory bird species and 24 km for resident species. If the local (matrix) habitat is highly unsuitable and/or if the birds do not survive their dispersal movements, then the number of individuals at particular distances from natal areas would be low (Sutherland *et al.* 2000). If the local (urban matrix) habitat has an abundance of breeding sites, albeit of a lower quality, than potentially overcrowded, high quality natal sites, then birds may disperse to lower quality sites to breed (Pulliam 1988, Brawn and Robinson 1996). The finding that bird species incidence is related to inverse distance weighted park-space seems to agree with their findings. If dispersal decreases exponentially with distance from natal area, then you would expect the percent of sites occupied to be highest close to large forested areas (assuming that large parks are high quality natal areas for many species) and to decrease inversely with distance. High quality local habitat may remain unoccupied if it is too far away.

### **Study Design Critique**

I conducted point counts only once per breeding season over each of two years. This may limit inferences I can make about community trends. Because urban areas have large amounts of impervious surface cover, they have large distances over which resources experience their full range of variability. Many of the bird species living in these areas have small territories and relatively high densities in relation to the changes in habitat. This combination of factors is ideal for detecting species-habitat relations at the level of the landscape (Goodinson 2000). So, replication in space rather than performing multiple point counts at fewer locations can be an advantage rather than a disadvantage in urban areas because replication in space leads to more

certainty about the species – habitat associations at the expense of certainty about a particular species presence at any individual point (Bolger *et al.*, 1997, Goodinson 2000).

Data were collected earlier in the 1998-breeding season than in the 1997-breeding season and included some late spring migrants from May 1998. While data were screened by omitting species that were sighted only once, this screening process was not sufficient enough to screen migrant species such as Ruby-crowned Kinglets ( $n=8$ ) and Fox Sparrows ( $n=3$ ), species that are known to breed farther north in British Columbia (Campbell *et al.* 1997). I avoided underestimating the number of species with low detection probabilities but included some migrant individuals in the analysis. Vagrant individuals of two gull species, the Mew Gull and the Ring-billed Gull, were also included in the analysis although they do not breed in the area (Campbell *et al.* 1997). These species are known to occur in the Vancouver area year round, but do not breed here (Campbell *et al.* 1997). Twelve species were omitted from the breeding season analysis because they were recorded only once (Appendix III). Most of these birds were recorded within one of the three large parks and thus would have been placed at the left end of the CCA ordination. By removing these species, the ordination and logistic regression model results would have slightly underestimated the landscape effects of park area by distance.

I classified species into nesting guilds according to their known habitat affinities across North America (Ehrlich *et al.* 1988), but species are known to change their nesting preferences depending on the availability of suitable nesting sites (Wiens 1989). The general nesting preference across North America may not apply directly to Vancouver and Burnaby. I will mention a few species in particular that could be grouped into different nesting guilds. House Finches, Bushtits and American Robins were grouped into the deciduous tree nesting guild, but also commonly nest in buildings. Song Sparrows were grouped into the ground-nesting guild,

but Song Sparrows are commonly a shrub nesting species as well. Black-capped Chickadees and Red-breasted Nuthatches are cavity nesters that commonly excavate cavities in coniferous trees. These two species could be grouped into the cavity nesting guild or the coniferous tree, nesting guild.

Because of the inherent arbitrariness in the method of guild classification, resultant guild - habitat 'patterns' are consequences of imposing an arbitrary arrangement on a community that may actually be structured ecologically in some other way altogether - or not structured at all (Wiens 1989). Given that the known nesting guild groupings were at least broadly confirmed by the species distribution patterns evident in my CCA ordination, I have some evidence that this is not a problem in my results. Moreover, when Chickadees and Nuthatches were moved from the coniferous tree, nesting guild to the cavity nester guild because this made more sense biologically, logistic regression model results were qualitatively similar. Landscape level variables, and in particular the park-distance variable, Park500-760m, was a significant predictor in both models. The parameter values in the model changed quantitatively when species with similar nesting requirements were added or removed from a guild, but the general trends remained consistent. This was also true when Brown-headed Cowbirds were moved from the deciduous tree, nesting guild to the shrub-nesting guild in order to place this nesting parasite with its most common host, the Song Sparrow.

I was able to sample a large number of plots over an extensive area, allowing more analytical power to detect species – habitat trends at the level of the landscape. Urban Vancouver and Burnaby are exceptional cities due to three large (>324 ha) natural area park remnants in close proximity to different residential sections, providing resource variability at a landscape level. Transect placement was subject to the constraint of road length and orientation, yet it is unlikely

that road orientation and length would introduce any bias in the sampled populations of birds since these roads were typical of urban residential streets (Appendix IV).

I found clear patterns of landscape and local level bird-habitat associations along an urbanization gradient, but it cannot be assumed that these patterns of species occurrence reflect ecological success along this gradient (Van Horne 1983 cited in Berry and Bock 1998). It is possible that residential areas close to parks are attracting species to marginal nesting habitat in times of high regional species densities, but whether or not birds can nest successfully in these locations is unknown, especially considering potentially higher rates of predation and disturbance. Still, the patterns of habitat occurrence provide a framework for future investigations into breeding success, dispersal, and species-species relationships in urban areas.

## CONSERVATION IMPLICATIONS

Ninety percent of all bird species known to occur in and sixty percent of the species known to breed in British Columbia (Demarchi, 1996) are found in the Lower Mainland and the Georgia Basin area, an area under extreme urban development pressure. In addition, the Basin may be of national significance to breeding landbirds with the highest number of species breeding and over-wintering in Canada (Demarchi, 1996). Currently, only five percent of the Lower Mainland (80,000 ha of 1.58 million ha) is set aside as parkland (GVRD Strategic Planning Department 1996). Although a large portion of the Lower Mainland maintains some natural character under forest management and agricultural reserves, more than 1.2 million additional people are expected to live in the Greater Vancouver Region alone by the year 2021 (GVRD Strategic Planning Department 1993).

The results of my thesis suggest that matrix areas surrounding parks and reserves should be integrated into urban planning and development designs. Recommendations for urban planners, particularly in Vancouver, developing on the verge of continuously forested areas would include minimizing impervious surface cover and house size, keeping grass cover to a minimum, maintaining native tree cover and berry shrubs, and integrating new ponds, and natural fresh water sources, into planning designs. Recommendations to home-owners living close to large parks and continuously forested areas may include keeping cats indoors because although cats were not investigated in this study, it is reasonable to assume that they could have a significant impact on ground and shrub nesters in these areas. Peripheral residential areas have a high likelihood of recruiting sensitive nesting species and will probably experience frequent visits by different species from nearby parks and could be managed as potential sink habitats.

Investigations at larger spatial scales allow us to study the response of bird species to landscape level habitat heterogeneity, a scale often neglected in the past by local habitat land use classifications and diversity investigations. Ecologists have become increasingly aware of the importance of examining ecological processes at multiple spatial scales and it is perhaps non-trivial that this direction coincides with the use of geographic spatial analysis technologies. It may be pertinent to consider where these bearings are taking us because although landscape level studies detect and predict patterns, local level and demographic studies are necessary to determine many of the mechanisms involved in population and community change. I would recommend that urban bird studies examine a few key landscape measures, such as distance to, and size of, large natural park areas with potentially good habitat for birds. Then, ecologically meaningful landscape metrics can be developed using the negative exponential of distance as an

indicator of species occurrence patterns. I would also recommend that impervious surface be measured at different spatial scales.

Habitat variability at different spatial scales is the most important, easily measured and controlled, factor affecting bird communities in urban systems. Nonetheless, changing ecosystem processes resulting from human development (altered fire, water, radiant energy flows, nutrient and pollutant cycling) may have the greatest, long-term impact (Marzluff *et al.* 1998). Higher ambient temperatures in urban environments, alone, have been related to shifts in the availability of invertebrate foods, affecting egg-laying dates and the breeding biology of magpies (*Pica pica*) in Britain (Eden 1985). In the face of inevitable urban expansion there *are* many local vegetation changes that we can make, but the impact on the bird community may be expected to decline with distance from large continuously forested areas and increasing impervious surface cover. Providing complementary habitat resources such as, small backyard habitat ponds, different types of feeding resources, berry producing shrubs, and cover options would increase the likelihood of several species of shrub and ground nesters, White-crowned Sparrows, Common Yellowthroats, American Goldfinch, Spotted Towhees and Dark-eyed Juncos. Perhaps we may even hear the swirling song of a Swainson's Thrush, but residential areas on the extreme end of the urbanization gradient may never have the pleasure.

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## APPENDIX I

### TEMPERATURES DURING STUDY PERIOD, COMPARED TO NORMALS (1977-1991) AND (1992-1996).

Normal daily mean temperatures in the city vary from 3°C in January to 17°C during July and August, with an annual mean of 10°C. Temperatures during the study period averaged above the 30-year normal for the same time periods, while precipitation means during the study period were above normal to near normal in 1997, and below normal in 1998 (Environment Canada, Climate Data Services).

STUDY PERIOD (1997-1998) (Celcius)										NORMALS (1977-91) Burnaby SFU (Celcius)	NORMALS (1977-91) Vancouver Int'l Airport (Celcius)	NORMALS (1992- 1996) Burnaby SFU (Celcius)	NORMALS (1992- 1996) Vancouver Int'l Airport (Celcius)
Month	Mean Daily			Mean Daily			Mean			Mean Daily Max	Mean Daily Max	Mean Daily Max	Mean Daily Max
	SFU	Air- port	SFU	Air- port	SFU	Air- port	SFU	Air- port	Air- port				
June	18.3	19.1	10.1	12.0	14.2	15.6	17.3	10.5	19.3	11.2	19.3	11.0	20.0
July	21.2	21.6	12.3	13.7	16.8	17.7	20.2	12.7	21.7	13.1	21.9	12.9	22.0
Aug	23.9	23.2	14.0	14.8	19.0	19.0	20.5	13.3	22.0	13.4	21.5	13.0	21.8
Sept	19.3	19.8	11.9	12.0	15.6	15.9	17.2	11.2	18.5	10.4	19.0	11.3	19.0
Oct	11.4	13.2	6.0	7.8	8.7	10.5	12.1	7.4	13.6	6.5	12.6	7.2	13.8
May							14.5	7.7	16.3	8.4	17.7	8.7	17.7
June							17.3	10.5	19.3	11.2	19.3	11.0	20.0
													11.9
													16.0
													18.0
													17.7
													14.9
													10.6
													13.6
													16.0

# APPENDIX I continued.

## PRECIPITATION (mm) DURING STUDY PERIOD, COMPARED TO NORMALS (1977-1991) AND (1992-1996).

Normal (30 year) monthly precipitation in winter varies between means of 115 mm and 109 mm for October and March respectively, to a maximum mean of 178 mm for December. Summer normal monthly precipitation varies between means of 75 mm and 64 mm for April and September respectively, to a minimum mean of 36 mm in July. *Annual* mean precipitation at the Vancouver International Airport is 1167 mm, with little falling as snow (Environment Canada, Climate Data Services).

STUDY PERIOD (1997-98)			NORMALS (1977-91) Burnaby SFU	NORMALS (1977-91) Vancouver Int'l Airport	NORMALS (1992-1996) Burnaby SFU	NORMALS (1992-1996) Vancouver Int'l Airport	NORMALS (1991-96) Oakridge	NORMALS (1996) Trafalgar
Month	SFU	Air- port	Oak- ridge	Trafa- lgar				
June, 1997	155.2	94.8	119.7	104.0	98.1	54.4	108.2	59.7
July, 1997	80.5	89.6	85.8	71.4	72.1	33.8	57.0	32.9
Aug, 1997	59.9	43.8	42.4	46.2	72.4	45.2	73.0	32.7
Sept, 1997	181.0	103.5	118.1	128.8	103.3	63.2	94.1	40.2
Oct, 1997	220.3	166.8	214.7	204.0	181.2	95.4	329.3	137.2
May, 1998					118.1	71.8	91.1	51.1
June, 1998					98.1	54.4	108.2	59.7
								76.3
								20.6
								24.0
								Not available
								79.8
								313.4
								75.6
								20.6



## APPENDIX II

## TIMES AND WEATHER CONDITIONS DURING POINT COUNT SURVEYS IN THE GREATER VANCOUVER AREA.

Date	Time	Temperature	Weather conditions	Survey points
24-Jun-97	5:13-9:04	~15-18C	Cloudy, very light rain	1-30A
25-Jun-97	5:23-9:04	~20C	Sunny and warm	31-36A, 1-20B
28-Jun-97	5:07-9:24	~20C	Sunny	37-65A
29-Jun-97	5:37-7:54	~15-18C	Overcast, light rain possible	1-16C
30-Jun-97	5:51-8:35	~18C	Sunny, Partial Cloud	17-36C
2-Jul-97	5:43-9:30	~16C	Sunny	37-60C
3-Jul-97	5:37-8:58	~18C	Sunny	61-77C
4-Jul-97	5:45-9:22	~20C	Sunny	1-25D
5-Jul-97	5:51-8:35	~22C	Sunny	26-44D
7-Jul-97	6:35-9:10	~16-18C	A bit cooler, overcast	44a-63D, 66A
12-Jul-97	5:40-9:45	~17C	Partly cloudy	68-89A
13-Jul-97	6:01-9:38	~16C	Partly cloudy	90-111A
16-Jul-97	6:31-8:37	~22-24C	Sunny	66-81D
20-Aug-97	6:27-9:32	~22C	Fair	1-6D, 44-57D
22-Aug-97	7:52-9:36	~20C	Slightly overcast	7-16D
23-Aug-97	6:47-10:22	~18C	Cloudy, slight drizzle	17-44D
24-Aug-97	7:00-10:30	~18C	Cloudy	58-81D
2-Sep-97	9:17-9:22	~15C	Some clouds	37-49A
3-Sep-97	7:40-9:25	~16C	Partly cloudy	53-65A
4-Sep-97	7:25-9:01	~17C	Sunny with part cloud	50-52A, 33-36C
6-Sep-97	7:27-8:42	~13-15C	Sunny, Clear, Crisp	25-32C
7-Sep-97	6:15-9:17	~14C	Crisp & Clear	1-24C
8-Sep-97	7:05-9:45	~15C	Sunny	1-20B
9-Sep-97	7:52-9:17	~15C	Cloudy	1-12A
11-Sep-97	6:43-9:13	~15C	Cloudy & Windy	37-59C
12-Sep-97	7:18-10:28	~15C	Partly cloudy	67-85A
20-Sep-97	8:18-9:12	~13-14C	Cool, Crisp, Sunny	23-30A
26-Sep-97	7:37-8:33	~15C	Slightly overcast, chance of drizzle	13-22A
11-Oct-97	9:26-10:10	~10C	Sunny & Brisk	31-36A
12-Oct-97	9:25-10:50	~8C	Partly cloudy	60-77C
1-May-98	6:28-8:57	~16-18C	Sunny	60-81D
2-May-98	6:23-9:13	~12C	Mostly sunny, breezy	1-4D
3-May-98	6:07-9:34	~16C	Sunny	5-28D
6-May-98	5:19-8:52	~14C	Sunny and breezy	30-36A, 1-18B
10-May-98	6:11-9:50	~16C	Cloudy	86-111A
12-May-98	5:50-9:20	~15C	Cloudy and cool	62-85A
16-May-98	6:36-9:05	~16C	Sunny	1-21A, 23A
18-May-98	6:30-9:00	~15C	Overcast, light rain, breezy	19-20B, 22A, 24A
19-May-98	7:05-8:35	~16C	Partly cloudy	29-39D
20-May-98	5:58-9:15	~17C	Sunny	37-61A
24-May-98	7:40-8:52	~12C	Cloudy and overcast	1-8C
29-May-98	6:06-9:40	~19C	Sunny	55-77C
30-May-98	6:00-9:28	~18C	Sunny	9-16C, 43-54C
31-May-98	5:58-9:33	~16C	Some cloud, overcast	17-42C

LIST OF BIRD SPECIES (CAMPBELL *ET AL.* 1997), AND NESTING GUILD (EHRlich *ET AL.* 1988),  
RECORDED AT POINT COUNT STATIONS IN THE GREATER VANCOUVER AREA, 1997-1998 (N=65).

4-Letter Code	Common Name	Scientific Name	GUILD Nesting
AMGO	American Goldfinch	<i>Carduelis tristis</i>	SB
AMRO	American Robin	<i>Turdus migratorius</i>	DT
BASW	Barn Swallow	<i>Hirundo rustica</i>	B
BCCH	Black-capped Chickadee	<i>Poecile atricapillus</i>	CV
BHCO	Brown-headed Cowbird	<i>Molothrus ater</i>	G
BHGR	Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>	DT
*BOWA <sup>2</sup>	Bohemian Waxwing	<i>Bombycilla garrulus</i>	CT
*BRBL <sup>2</sup>	Brewer's Blackbird	<i>Euphagus cyanocephalus</i>	CT
*BRCR <sup>2</sup>	Brown Creeper	<i>Certhia americana</i>	CT
*BTPI <sup>1</sup>	Band-tailed Pigeon	<i>Columba fasciata</i>	CT
*BTGWA <sup>3</sup>	Black-throated gray Warbler	<i>Dendroica nigrescens</i>	CT
BUSH	Bushtit	<i>Psaltiriparus minimus</i>	DT
CAGO	Canada Goose	<i>Branta canadensis</i>	G
*CBCH <sup>2</sup>	Chestnut-back Chickadee	<i>Poecile rufescens</i>	CV
CEWA	Cedar Waxwing	<i>Bombycilla cedrorum</i>	DT
*COHA <sup>2</sup>	Cooper's Hawk	<i>Accipiter cooperii</i>	DT
*CORA <sup>3</sup>	Common Raven	<i>Corvus corax</i>	L
COYE	Common Yellowthroat	<i>Geothlypis trichas</i>	SB
DEJU	Dark-eyed Junco	<i>Junco hyemalis</i>	G
EUST	<u>European Starling</u>	<u><i>Sturnus vulgaris</i></u>	<u>DT</u>
FOSP	Fox Sparrow	<i>Passerella species</i>	G
*GCSP <sup>3</sup>	Golden-crowned Sparrow	<i>Zonotrichia atricapilla</i>	G
GWGU	Glaucous-winged Gull	<i>Larus glaucescens</i>	L
*HETH <sup>2</sup>	Hermit Thrush	<i>Catharus guttatus</i>	G
HOFI	House Finch	<i>Carpodacus mexicanus</i>	DT
HOSP	<u>House Sparrow</u>	<u><i>Passer domesticus</i></u>	<u>B</u>
*HOWR <sup>2</sup>	House Wren	<i>Troglodytes aedon</i>	DT
*HUVI <sup>3</sup>	Hutton's Vireo	<i>Vireo huttoni</i>	DT
*KILL <sup>3</sup>	Killdeer	<i>Charadrius vociferus</i>	G
*MALL <sup>3</sup>	Mallard	<i>Anas platyrhynchos</i>	G
*MERL <sup>2</sup>	Merlin	<i>Flaco columbarius</i>	DT
MEGU	Mew Gull	<i>Larus canus</i>	L
*MODO <sup>3</sup>	Mourning Dove	<i>Zenaida macroura</i>	DT
NOCR	Northwestern Crow	<i>Corvus caurinus</i>	CT
NOFL	Northern Flicker	<i>Colaptes auratus</i>	CV
OCWA	Orange-crowned Warbler	<i>Vermivora celata</i>	G
*OSFL <sup>2</sup>	Olive-sided Flycatcher	<i>Contopus borealis</i>	CT
PISI	Pine Siskin	<i>Carduelis pinus</i>	CT
RBGU	Ring-billed Gull	<i>Larus delawarensis</i>	L
RBNU	Red-breasted Nuthatch	<i>Sitta canadensis</i>	CV
RCKI	Ruby-crowned Kinglet	<i>Regulus calendula</i>	CT
REVI	Red-eyed Vireo	<i>Vireo olivaceus</i>	DT
RODO	<u>Rock Dove</u>	<u><i>Columba livia</i></u>	<u>B</u>
*RTHA <sup>3</sup>	Red-tailed Hawk	<i>Buteo jamaicensis</i>	DT
RUHU	Rufous Hummingbird	<i>Selasphorus rufus</i>	CT
*RWBL <sup>3</sup>	Red-winged Blackbird	<i>Agelaius phoeniceus</i>	R
*SORA <sup>3</sup>	Sora	<i>Porzana carolina</i>	R
SOSP	Song Sparrow	<i>Melospiza melodia</i>	G
SPTO	Spotted Towhee	<i>Pipilo maculatus</i>	G
STJA	Steller's Jay	<i>Cyanocitta stelleri</i>	CT
SWTH	Swainson's Thrush	<i>Catharus ustulatus</i>	SB
*VATH <sup>2</sup>	Varied Thrush	<i>Ixoreus naevius</i>	CT
VGSW	Violet-green Swallow	<i>Tachycineta thalassina</i>	CV
WCSP	White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	SB
*WETA <sup>2</sup>	Western Tanager	<i>Piranga ludoviciana</i>	CT
WIFL	Willow Flycatcher	<i>Empidonax traillii</i>	SB
WIWA	Wilson's Warbler	<i>Wilsonia pusilla</i>	G
WIWR	Winter Wren	<i>Troglodytes troglodytes</i>	CV
*WEFL <sup>1</sup>	Western Flycatcher	<i>Empidonax difficilis</i>	DT
BAEA <sup>4</sup>	Bald Eagle	<i>Haliaeetus leucocephalus</i>	CT
BLSW <sup>4</sup>	Black Swift	<i>Cypseloides niger</i>	L
GBHE <sup>4</sup>	Great Blue Heron	<i>Ardea herodias</i>	DT
NOHA <sup>4</sup>	Northern Harrier	<i>Circus cyaneus</i>	G
PIWO <sup>4</sup>	Pileated Woodpecker	<i>Dryocopus pileatus</i>	CV
SAVS <sup>4</sup>	Savannah Sparrow	<i>Passerculus sandwichensis</i>	G

\*Species excluded from the analysis (n=29).

Species censused in: <sup>1</sup> 1997 breeding only (n=2); <sup>2</sup> 1997 fall migration only (n=11); <sup>3</sup> 1998 breeding only (n=10); <sup>4</sup> Species recorded > 50 m from point count stations (n=6).

NEST is nesting guild where SB=shrub, CV=Cavity, G=ground, R=riparian, L=Ledge/Cliff, CT=coniferous tree, DT=deciduous tree, and B=building nesting species.

Underlining indicates non-native species

PHYSICAL CHARACTERISTICS OF TRANSECT POINT COUNT STATIONS (N=285)  
IN THE GREATER VANCOUVER AREA.

Tran- sect	Point #	UTM lat	UTM long	Elev- ation	Address	Urban Category	Aspect	Water
A	1	5456873	489903	35	8th and Granville	Urban	n.a.	None
	2	5456885	489553	35	8th and Burrard	Urban	n.a.	None
	3	5456889	489270	30	Cypress and 8th	Urban	n.a.	None
	4	5456898	489033	40	8th and Arbutus	Urban	n.a.	None
	5	5456907	488676	35	8th and Yew	Urban	n.a.	None
	6	5456916	488406	30	8th and Balsam	Urban	n.a.	None
	7	5456922	488203	30	2545 W 8th	Urban	n.a.	None
	8	5456928	487930	30	2745 W 8th	Urban	n.a.	None
	9	5456942	487665	30	8th and Bayswater	Urban	n.a.	None
	10	5456942	487382	30	3136 W 8th	Urban	n.a.	bath
	11	5456943	487180	40	3358 W 8th	Urban	n.a.	bath
	12	5456975	486960	40	3584 W 8th	Urban	n.a.	None
	13	5456958	486720	40	8th at Dunbar	Urban	n.a.	None
	14	5456965	486526	40	8th at Highbury	Urban	90	None
	15	5456973	486315	60	3894 W 8th	Urban	90	None
	16	5456979	486080	65	4026 W 8th	Urban	90	bath
	17	5456982	485738	70	4186 W 8th	Urban	90	None
	18	5456986	485498	75	1/2 way up hill	Urban	90	bath
	19	5456985	484854	75	8th at Sasamat	Urban	90	None
	21	5457001	484682	80	8th at Tolmie	Urban	n.a.	None
	22	5457009	484450	95	8th at Blanca	Urban	n.a.	bath
	23	5457017	484380	95	At Bus Loop	Edge	90	None
	24	5456829	484272	95	University Blvd., outside Golf Course	Edge	180	bath
	25	5456820	484018	95	University Blvd., Club House	Edge	180	None
	26	5456808	483773	100	University Blvd.	Edge	180	None
	27	5456793	483399	95	University Blvd., outside Golf course	Edge	180	None
	28	5456825	483073	90	University Blvd.	Edge	180	None
	29	5457031	482877	95	University Chapel	Edge	180	None
	30	5457041	482679	100	Acadia and Toronto	Fragment	n.a.	None
	31	5456899	482400	95	Allison and Toronto	Fragment	n.a.	None
	32	5457062	482262	90	On Allison	Fragment	n.a.	None
	33	5457119	482092	90	Gate 1 UBC	Fragment	n.a.	None
	34	5456984	481772	90	At East Mall	Fragment	n.a.	None
	35	5456896	481569	90	Main Mall and University Blvd	Fragment	n.a.	None
	36	5456784	481332	85	At Lower Mall	Fragment	270	None
	37	5456874	490020	35	1443 W 8th at Granville	Urban	n.a.	None
	38	5456866	490270	40	1245 W 8th	Urban	n.a.	None
	39	5456860	490510	40	1081 W 8th at Spruce	Urban	n.a.	Fresh
	40	5456855	490760	40	905 W 8th at Laurel	Urban	n.a.	None
	41	5456845	491010	35	795 W 8th and Willow	Urban	n.a.	None
	42	5456840	491280	30	W 8th at Ash	Urban	n.a.	None
	43	5456830	491530	25	8th at Yukon	Urban	n.a.	None
	44	5456812	491780	20	8th at Manitoba	Urban	n.a.	None
	45	5456785	492060	20	8th at Ontario	Urban	n.a.	None
	46	5456782	492260	25	8th at Scotia	Urban	n.a.	Fresh
	47	5456770	492530	30	8th at Prince Edward	Urban	n.a.	None
	48	5456757	493050	40	8th at St. George	Urban	n.a.	None
	49	5456734	493560	40	8th and Fraser	Urban	n.a.	None
	50	5456730	493793	30	8th and St. Catherine	Urban	n.a.	None
	51	5456728	494072	20	8th and Glen	Urban	n.a.	None
	52	5456783	494233	20	7th and Keith	Urban	270	None
	53	5456878	494680	25	1365 E. 7th at McLean	Urban	270	None
	54	5456835	494780	25	1523 E 8th and Woodland	Urban	n.a.	None
	56	5456734	494942	25	8th and N. Greenview at Rail greenway	Urban park	n.a.	None
	57	5456720	495290	45	8th past Victoria	Urban	n.a.	None
	58	5456714	495500	45	8th At Lakewood	Urban	n.a.	None
	59	5456715	495750	45	8th and Garden	Urban	n.a.	None
	60	5456685	496000	45	8th and Kamloops	Urban	270	None
	61	5456688	496300	55	2651 E 8th	Urban	270	None

Tran- sect	Point #	UTM lat	UTM long	Elev- ation	Address	Urban Category	Aspect	Water
<b>A</b>	62	5456683	496550	60	8th and Kaslo	Urban	270	None
	63	5456682	496800	55	2936 E 8th at Renfrew	Urban	90	None
	64	5456684	497020	55	3098 E 8th at Lillouet	Urban	90	None
	65	5456682	497240	50	3198 E 8th at Windmere	Urban	90	None
	66	5456649	497690	60	At 8th past Rupert	Urban	n.a.	None
	68	5457303	498853	40	2nd and MacDonald	Urban	n.a.	None
	69	5457265	499017	40	Halifax and Chalet Cabinets	Urban	n.a.	None
	70	5457256	499353	40	4305 Halifax	Suburban	n.a.	None
	71	5457246	499637	45	4430 Halifax	Suburban	n.a.	None
	72	5457483	499811	50	4560 Brentlawn	Suburban	n.a.	None
	73	5457438	500050	50	4645 Brentlawn	Suburban	n.a.	None
	74	5457277	500295	55	4806 Brentlawn	Suburban	n.a.	None
	75	5457240	500680	55	Halifax and Woodway	Suburban	n.a.	Fresh
	76	5457073	501040	35	54 Broadway	Suburban	n.a.	Fresh
	77	5457020	501290	35	5695 Broadway	Suburban	n.a.	None
	78	5456921	501530	30	Parkcrest Plaza	Suburban	n.a.	None
	79	5456825	501750	30	6205 Broadway	Suburban	n.a.	None
	80	5456740	502000	25	6385 Broadway	Suburban	n.a.	None
	81	5456545	502359	25	Broadway and Kensington	Suburban	n.a.	Fresh
	82	5456055	503292	45	Coventry and Collister	Suburban	n.a.	None
	83	5455592	503548	40	Buffalo and Lyndale	Suburban	n.a.	None
	84	5455458	503813	40	Between Philips and Chrisdale - Colleen	Suburban	180	None
	85	5455456	504060	38	7511 Colleen	Suburban	n.a.	None
	86	5455344	504260	25	7572 Government	Suburban	n.a.	None
	87	5455341	504510	25	7750 Government	Suburban	n.a.	Fresh
	88	5455341	504730	30	Government and Piper	Suburban	n.a.	None
	89	5455340	505000	35	7986 Government	Suburban	n.a.	None
	90	5455339	505240	40	8121 Government	Suburban	n.a.	Fresh
	91	5455333	505530	35	8243 Government	Suburban	n.a.	Fresh
	92	5455337	505770	30	AT Dalebright	Suburban	n.a.	None
	93	5456097	506190	45	East Lake at ADT	Suburban	360	None
	94	5456010	506508	40	East Lake and Centaurus	Suburban	360	Fresh
	95	5455761	506580	35	East Lake and turn off	Suburban	360	None
	96	5455636	506847	40	Cameron and Kensington	Suburban	180	Fresh
	97	5455627	507120	50	Cameron and Beaverbrook	Suburban	180	None
	98	5455630	507380	60	Cameron Towers	Suburban	n.a.	None
	99	5455625	507601	80	Walmart and Cameron	Suburban	n.a.	None
	100	5456000	507855	100	Foster and Ebert	Suburban	n.a.	None
	101	5456000	508150	100	Foster almost at Austin	Suburban	n.a.	Fresh
	102	5456000	508400	100	605 Foster	Suburban	n.a.	None
	103	5456000	508630	120	Foster and Florence	Suburban	n.a.	None
	104	5455972	508880	120	Foster and Sprice	Suburban	n.a.	None
	105	5455963	509150	140	827 Foster	Suburban	n.a.	Fresh
	106	5455955	509400	140	Foster and Hailey	Suburban	n.a.	None
	107	5455944	509650	140	Foster and MacIntosh	Suburban	n.a.	None
	108	5455944	509900	145	Porter on Foster	Suburban	n.a.	None
	109	5455938	510150	140	1207 Foster	Suburban	n.a.	None
	110	5455935	510400	140	1410 Foster	Suburban	n.a.	None
	111	5455932	510650	140	Foster and Berry	Suburban	n.a.	None
<b>B</b>	1	5457359	481173	70	Gate 4, Museum of Anthropology	Edge	0	Marine
	2	5457491	481358	70	At P3 and Info Sign	Edge	0	Marine
	3	5457728	481515	65	Newton on NW Marine	Park	0	Marine
	4	5457936	481582	60	NW Marine	Park	0	Fresh
	5	5458126	481790	40	NW Marine	Park	0	Marine
	6	5458313	481965	30	Acadia	Park	0	Marine
	7	5458442	482156	10	NW Marine	Park	0	Marine
	8	5458538	482420	10	NW Marine / Parking Lot	Park	0	Fresh/Marine
	9	5458510	482697	10	NW Marine	Park	0	Fresh/Marine
	10	5458413	482939	10	NW Marine	Park	0	Fresh/Marine
	11	5458416	483189	10	NW Marine	Park	0	Fresh/Marine

Tran- sect	Point #	UTM lat	UTM long	Elev- ation	Address	Urban Category	Aspect	Water
<b>B</b>	12	5458377	483460	10	NW Marine	Park	0	Fresh/Marine
	13	5458325	483717	7	At Spanish Banks Food Stand	Park	0	Fresh/Marine
	14	5458254	483951	7	NW Marine	Park	0	Marine
	15	5458203	484211	7	NW Marine	Park	0	Marine
	16	5458061	484536	7	NW Marine /Tolmie	Park	0	Fresh/Marine
	17	5457975	484793	7	NW Marine at Sasamat	Urban park	n.a.	Fresh/Marine
	18	5458020	485012	7	At Corner NW Marine	Urban park	n.a.	Fresh/Marine
	19	5458069	485313	7	At Parking Lot/Jericho beach	Urban park	n.a.	Fresh/Marine
	20	5457985	485526	10	Jericho Park.	Urban park	n.a.	Fresh/Marine
<b>C</b>	1	5460782	490453	30	Stanley Park Aquarium	Fragment	90	Fresh/Marine
	2	5460542	490324	20	Parking lot fork	Fragment	180	Fresh/Marine
	3	5460359	490119	10	On Bridge	Edge	n.a.	Fresh/Marine
	4	5460111	489951	10	At Alberni and Chilco	Edge	315	Fresh/Marine
	5	5460005	489886	15	Chilco on Barclay	Edge	n.a.	None
	6	5459823	490052	15	Barclay and Denman	Urban	n.a.	None
	7	5459592	490231	15	Barclay at Cadero	Urban	n.a.	None
	8	5459488	490380	25	Barclay at Broughton	Urban	n.a.	None
	9	5459293	490586	40	Barclay and Bute	Urban	n.a.	None
	10	5459043	490827	35	Barclay at Thurlow	Urban	n.a.	None
	11	5458792	490988	30	Burrard and Hornby on Smithe	Urban	n.a.	None
	12	5458583	491181	30	Granville and Seymour	Urban	n.a.	None
	13	5458452	491432	30	On Homer between Smithe and Robson	Urban	n.a.	None
	14	5458620	491607	25	Homer at Georgia in front of library	Urban	n.a.	None
	15	5459028	492004	15	Homer and Cordova	Urban	n.a.	None
	16	5458901	492266	15	Cordova and Abbott	Urban	n.a.	None
	17	5458842	492579	15	Cordova and Columbia	Urban	n.a.	None
	18	5458836	492780	15	Cordova and Main	Urban	n.a.	None
	19	5458825	493087	20	Dunlevy and Cordova	Urban	n.a.	None
	20	5458818	493375	20	Cordova and Princess	Urban	n.a.	None
	21	5458809	493642	15	Cordova and Hawks	Urban	n.a.	None
	23	5458809	493642	15	Cordova and and Campbell	Urban	n.a.	None
	24	5458846	494150	15	Franklin and Glen	Urban	n.a.	None
	25	5458622	494638	15	E Pender and Mclean	Urban	n.a.	None
	26	5458617	494899	15	Commercial and Pender	Urban	n.a.	None
	27	5458605	495127	20	Pender and Salsbury	Urban	270	None
	28	5458600	495398	25	Pender and Semlin	Urban	270	None
	29	5458600	494645	30	Pender and Templeton	Urban	n.a.	None
	30	5458917	495925	40	Franklin and Nanaimo	Urban	n.a.	None
	31	5458911	496195	45	Penticton and Franklin	Urban	n.a.	None
	32	5458909	496471	50	Franklin at Slocan	Urban	n.a.	None
	33	5458907	496749	45	Franklin at Renfrew	Urban	n.a.	None
	34	5458915	496998	35	PNE Parking Lot	Urban park	n.a.	None
	35	5458908	497240	35	PNE Park	Urban park	n.a.	bath
	36	5459058	497459	35	PNE Park	Urban park	n.a.	None
	37	5458812	497773	60	3400 Franklin at Cassiar	Urban	270	None
	38	5458811	498289	80	Franklin and Boundary	Urban	n.a.	None
	39	5458808	498603	95	Albert and Ingleton	Urban	n.a.	None
	40	5458805	498855	95	Albert and MacDonald	Urban	n.a.	None
	41	5458801	499152	90	Albert at Carleton	Urban	n.a.	None
	42	5458795	499398	90	Albert at Madison	Urban	n.a.	None
	43	5458796	499648	85	Albert at Rosser	Urban	n.a.	None
	44	5458785	499867	75	Confederation Community Centre	Urban park	n.a.	None
	45	5458783	500122	90	Beta and Albert	Urban park	270	None
	46	5458780	500369	100	Albert at Gama	Urban	270	None
	47	5458481	500560	100	Frances and Delta	Urban	n.a.	None
	48	5458481	500815	100	Frances and Springer	Urban	n.a.	None
	49	5458479	501146	100	Frances and Howard	Urban	n.a.	None
	50	5458478	501369	100	Frances at Holdom	Urban	n.a.	None
	51	5458502	501614	100	At Gate to park on Frances	Urban park	n.a.	Fresh
	52	5458569	501785	100	Frances/Union Bike Route	Urban park	270	None

Tran- sect	Point #	UTM lat	UTM long	Elev- ation	Address	Urban Category	Aspect	Water
<b>C</b>	53	5458517	501991	100	At Kennsington/Burnaby Sec. School	Urban	n.a.	None
	54	5458331	502202	100	Union and Brooklyn	Urban	n.a.	None
	55	5458331	502458	100	Union and Duncan	Urban	n.a.	None
	56	5458333	502728	90	Union at Cliff	Urban	n.a.	None
	57	5458332	503008	90	Union and Calvin	Urban	n.a.	None
	58	5458326	503434	100	Union and Duthie	Urban	270	None
	59	5458050	503704	110	Curtis and Duthie	Urban	270	None
	60	5458048	504058	130	Curtis Cul de Sac	Edge	270	Fresh
	61	5458060	504368	190	Road to SFU	Park	270	Fresh
	62	5457937	504631	200	Road to SFU	Park	200	Fresh
	63	5457892	504879	220	Road to SFU	Park	200	Fresh
	64	5457885	505129	240	Road to SFU at Discovery sign	Park	200	Fresh
	65	5457940	505376	250	Road to SFU at SFU sign	Park	270	Fresh
	66	5458096	505140	260	Road to SFU	Park	270	Fresh
	67	5458269	505134	280	Road to SFU	Park	270	Fresh
	68	5458240	505377	290	Road to SFU	Park	270	None
	69	5458293	505618	300	SFU campus	Park	270	Fresh
	70	5458275	505847	300	Road SFU campus at Central stores	Park	0	Fresh
	71	5458458	505959	300	Science Portables	Fragment	n.a.	None
	72	5458585	505851	300	WAC Bennet Library	Fragment	180	None
	73	5458663	506115	300	Strand Hall sign	Fragment	n.a.	None
	74	5458588	506347	300	Parking lot C23	Fragment	n.a.	None
	75	5458219	506745	300	Parking lot G24	Fragment	n.a.	None
	76	5458186	506433	300	Parking lot B26	Fragment	n.a.	None
	77	5458547	505560	300	Residences/Daycare	Fragment	n.a.	None
<b>D</b>	1	5453970	488490	60	2292 W 37th at Yew	Urban	n.a.	None
	2	5453978	488182	60	2527 W 37th at Larch	Urban	n.a.	None
	3	5453982	487936	60	2736 W 37th	Urban	n.a.	None
	4	5453981	487689	60	2915 W 37th	Urban	n.a.	None
	5	5453981	487427	60	3091 W 37th	Urban	n.a.	None
	6	5453984	487166	60	3294 W 37th	Urban	n.a.	None
	7	5453986	486930	60	37th and Collingwood	Urban	n.a.	None
	8	5453998	486630	55	37th at Dunbar	Urban	n.a.	None
	9	5453998	486370	50	3835 37th at Highbury	Edge	n.a.	None
	10	5454003	486140	50	3959 W 37th	Edge	n.a.	None
	11	5454007	485749	40	37th at Camosun	Edge	90	None
	12	5454219	485680	50	35th at Camosun	Edge	90	bath
	13	5454426	485684	65	33rd and Camosun	Edge	90	None
	14	5454720	485688	75	30th and Camosun	Edge	90	None
	15	5455090	485691	80	28th and Camosun	Edge	n.a.	None
	16	5454981	485373	80	29th and Kevin	Edge	0	None
	17	5455222	485138	80	Doncaster Way	Park	n.a.	None
	18	5455408	485302	80	Imperial	Park	n.a.	None
	19	5455652	485351	80	Along Imperial	Park	n.a.	None
	20	5455892	485271	80	Along Discovery	Park	n.a.	None
	21	5456052	485230	80	5m and boy w/ ball sign	Park	n.a.	None
	22	5456292	485220	80	15th and Discovery	Edge	n.a.	None
	24	5456300	484720	90	15th up from Sasamat	Edge	n.a.	None
	25	5456309	484470	90	4348 W 15th	Edge	n.a.	None
	26	5456239	484166	90	Along 16th	Park	180	None
	27	5456243	483906	90	Along 16th	Park	180	None
	28	5456243	493507	90	Along 16th	Park	180	None
	29	5456150	483184	90	16th and Salish Trail	Park	180	None
	30	5456073	483016	90	16th and Wyndham Hall	Park	n.a.	None
	31	5455988	482850	90	Along 16th	Park	n.a.	None
	32	5455838	482597	90	Along 16th and Thunderbird field	Edge	n.a.	None
	33	5455730	482373	90	East Mall	Edge	270	None
	34	5455611	482162	90	Outside Botanical Garden at GATE	Edge	180	bath
	35	5455645	481956	70	Over Botanical Garden tunnel	Edge	270	bath
	36	5455848	481972	70	Gate 8	Edge	270	None

Tran- sect	Point #	UTM lat	UTM long	Elev- ation	Address	Urban Category	Aspect	Water
<b>D</b>	37	5456075	481870	80	Along West Mall	Fragment	n.a.	None
	38	5456726	481653	85	Engineering Annex	Fragment	n.a.	None
	39	5456336	481602	90	Brock Hall	Fragment	n.a.	None
	40	5457281	482070	90	College Highroad and Wesbrook Cres	Fragment	n.a.	None
	41	5457386	482286	95	Allison and College Way	Fragment	n.a.	None
	42	5457554	482222	95	1856 Allison	Fragment	n.a.	None
	43	5457835	482162	90	1616 Acadia	Fragment	n.a.	None
	44	5457444	482512	85	College Highway and Acadia	Edge	n.a.	None
	44a	5453940	488680	70	37th and Maple	Urban	n.a.	None
	45	5453961	488969	80	1868 W 37th at Pine	Urban	n.a.	None
	46	5453951	489215	80	1705 W 37th at Marguerite	Urban	n.a.	None
	47	5453932	489775	100	1530 W 37th and Granville	Urban	n.a.	bath
	48	5453929	490034	108	1408 W 37th and Cartier	Urban	n.a.	bath
	49	5453914	490281	100	1250 W 37th	Urban	n.a.	bath
	50	5453897	490533	90	1076 W 37th and Osler	Urban	n.a.	None
	51	5453887	490799	90	928 W 37th	Urban	n.a.	None
	52	5453870	491117	90	Baillie and 37th	Urban	n.a.	None
	53	5453853	491368	100	Manson and 37th	Urban	n.a.	bath
	54	5453836	491608	100	37th and Cambie	Urban	n.a.	None
	55	5453821	491868	100	280 W 37th and Elizabeth	Urban	n.a.	None
	56	5453857	492148	100	88 W 37th and Manitoba	Urban	n.a.	None
	57	5453846	492451	95	82 E 37th and Quebec	Urban	n.a.	None
	58	5453826	492746	90	37th and Sophia	Urban	n.a.	None
	59	5453830	492952	85	37th and Prince Edward	Urban	n.a.	None
	60	5453821	493205	80	Bone Yard	Urban	n.a.	None
	61	5453760	493496	85	758 37th and Chester	Urban	n.a.	bath
	62	5453758	493806	90	966 37th and Sommerville	Urban	n.a.	bath
	63	5453749	494095	100	37th and Ross	Urban	n.a.	None
	64	5453790	494320	95	1333 E 37th at Colloden	Urban	n.a.	None
	65	5453782	494590	90	1488 E 37th	Urban	n.a.	None
	66	5453775	494868	85	1726 E 37th	Urban	270	None
	67	5453776	495121	85	1928 E 37th	Urban	n.a.	None
	68	5453801	495373	85	2097 E 37th	Urban	n.a.	None
	69	5453799	495630	85	2262 E 37th	Urban	n.a.	None
	70	5453857	495877	85	St. Margarets and 37th	Urban	n.a.	None
	71	5453851	496139	85	Chambers and 37th	Urban	n.a.	None
	72	5453676	496427	90	Earles and 38th	Urban	n.a.	None
	73	5453485	496544	90	40th and Killarney	Urban	n.a.	None
	74	5453155	496672	95	Lancaster and 43rd	Urban	n.a.	None
	75	5453139	496949	95	McKinnon and 43rd	Urban	n.a.	None
	76	5453148	497258	105	43rd and Latta	Urban	n.a.	None
	77	5452500	497707	115	3441 E 45th	Urban	n.a.	None
	78	5452500	498023	120	3550 E 45th	Urban	n.a.	None
	79	5452500	498275	120	Boundary and 45th	Urban	270	None
	80	5452501	498499	125	Corner Parking lot/Swangard Stadium	Urban park	0	None
	81	5453166	498678	125	Central Park	Urban park	n.a.	Fresh

A) DISTRIBUTION OF MAXIMUM AVIAN SPECIES RICHNESS FOR POINT COUNT STATIONS ALONG FOUR ROADSIDE TRANSECTS IN GREATER VANCOUVER, 1997-1998. B) as in A), distribution of simpson's diversity index ( $1/\sum p_i^2$ ) where  $p_i$  is the proportional abundance of each species by station. Simpson's diversity index is relative measure of diversity that weights each species by its relative abundance (Ricklefs 1990).

