# ABSTRACT

**HULL, JAMIE REBEKAH**. Can urban greenways provide high quality avian habitat? (Under the direction of Christopher E. Moorman and George R. Hess.)

As natural areas are converted to urban or suburban development, landscape and urban planners are pressed to integrate wildlife habitat into a rapidly changing landscape. Urban greenways provide a broad range of social, economic and environmental benefits, and consequently are enjoying worldwide popularity as a developing form of urban openspace protection. One of the goals of greenway development often is to provide habitat for wildlife. If landscape and urban planners are to strategically design greenways so as to maximize their value to wildlife, they need information on the specific environmental characteristics in and surrounding urban greenways that contribute to their value as wildlife habitat.

I investigated how forested corridor width, land use context, and greenway composition and vegetation structure affected avian community composition in urban greenways in Raleigh and Cary, North Carolina, USA. I surveyed breeding bird communities at 34 greenway study sites using 50-m fixed-radius point counts located at the center of 300m long greenway segments. Each greenway segment's forested corridor width and surrounding land use were determined in ArcGIS. Greenway composition (proportion of mature forest, young forest, managed area, and stream in the greenway study site) and vegetation structure were measured in the field.

Total bird abundance increased with increasing canopy cover in the adjacent landscape and increasing shrub cover within the greenway. Neotropical migrant, insectivore and forest-interior species richness decreased with increasing amounts of managed area, such as trail and other mowed or maintained surfaces, within a greenway. Neotropical migrant species richness and forest-interior species richness and abundance decreased with increasing amounts of building in the adjacent landscape. Insectivore species richness increased with increasing lawn cover in the adjacent landscape, and insectivore abundance increased with increasing amounts of canopy in the adjacent landscape. White-eyed Vireos were recorded only in greenways wider than 300m; Wood Thrushes and Indigo Buntings were recorded only in greenways wider than 100m; and Blue-gray Gnatcatchers, Downy Woodpeckers and Red-eyed Vireos were recorded only in greenways wider than 50m. Urban-adaptors such as Common Grackles and European Starlings were more common in narrower greenways.

Landscape and urban planners can maximize native bird diversity and abundance by minimizing the width of the greenway trail and associated mowed and landscaped surfaces adjacent to the trail, maintaining vegetative structure within the greenway, and giving priority to the protection of greenways in areas of lower development intensity. Greenways wider than 50m provide habitat for a diversity of bird species, but many species of conservation concern require much wider greenways.

# Can Urban Greenways Provide High Quality Avian Habitat?

by

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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Masters of Science

**FISHERIES AND WILDLIFE SCIENCE**

Raleigh

2003

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## BIOGRAPHY

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## ACKNOWLEDGEMENTS

I would like to thank Chris Moorman and George Hess for advice and instruction in all aspects of this project, and Heather Cheshire for advice and instruction on issues of GIS, GPS and air photo analysis. I thank Marcia Gumpertz and Janet Bartz for advice and guidance on statistical analysis. I thank Nathan Tarr for an immense amount of work locating and marking study sites and conducting bird surveys. I thank Jim Hines for modifying program SPECRICH2 to process multiple input files for use with my data. I thank the City of Raleigh, Town of Cary, Hemlock Bluffs Nature Preserve, and William B. Umstead State Park for graciously allowing us to conduct research on their lands. I thank Wake County GIS, City of Raleigh GIS and Town of Cary GIS for provision of geographic data. Finally, I thank the North Carolina State University Department of Forestry and the U.S. Forest Service for providing the funds and resources to make this research possible.

# TABLE OF CONTENTS

## LIST OF TABLES

Page

## LIST OF FIGURES

Page

# CHAPTER 1 LITERATURE REVIEW

## The Greenway Movement

By 2025, the United Nations predicts, the human population in urban areas will equal today's global population of 6 billion (United Nations 1998). As urbanization progresses, landscape and urban planners will be pressed to maintain natural areas in a rapidly changing landscape. Recently, greenways have become a popular means of mitigating urbanization effects (Searns 1995). "Greenway" is a generic term used to refer to linear protected lands. Greenways vary from paths several feet wide meandering through neighborhoods to larger miles-wide "conservation corridors." Greenways may be manicured and park-like, or managed to enhance "naturalness" and ecosystem quality. Historically, the purpose of greenways has been to provide recreation and alternative means of transportation to urban residents (Fabos 1995; Searns 1995). However, greenways also increase property value and spur economic growth, improve aesthetics and quality-of-life, provide buffers between adjacent land uses, improve water quality, protect a variety of natural, cultural and historical resources, offer opportunities for urban residents to experience and connect with nature, and provide habitat for wildlife (Ahern 1995; Fabos 1995; Searns 1995).

The popularity of greenways is evidenced by the volume of projects and proposals currently underway in the United States. In 1987, the President's Commission on American Outdoors recommended "a living network of greenways…threading through cities and countrysides like a giant circulation system" (President's Commission 1987; cited by Fabos 1995). As of 1990, more than 500 greenway projects were completed or underway in North America (Searns 1995). Several books have been published on the greenway movement, including Charles Little's 1990 *Greenways for America*, Smith and Hellmund's 1993 *Ecology of Greenways*, and Fabos and Ahern's 1995 *Greenways: The Beginning of an International Movement*.

**Greenways in the Raleigh-Durham, North Carolina Metropolitan Area**

The rapidly growing Raleigh-Durham metropolitan area, in the Piedmont of North Carolina, has long been a national leader in the development of urban greenways. According to U.S. Census data for the Raleigh-Durham area, the urban population increased by 200% and urbanized land increased by 900% during 1950-1990 (North Carolina Chapter of the American Planning Association 2002). The greenway systems in both the Capital City of Raleigh and the neighboring Town of Cary are intended to be multi-functional, providing recreational opportunities, economic benefits, natural and cultural resource protection, quality-of-life enhancement, development buffers and urban beautification, and both cities' greenway plans name wildlife habitat as one of the many benefits of urban greenways (City of Raleigh 2001; Town of Cary 2001). Greenway development in the Raleigh-Durham area has been met with great public support, as evidenced by the existence of local greenway advocacy groups such as the Triangle Greenways Council (Triangle Greenways Council 2001).

The City of Raleigh began to acquire greenways in 1976 and currently has a 43-mile, 2100-acre greenway system, consisting of 24 trails. Eight additional trails are under construction and "aggressively pursuing land acquisition and development of the trail system" is part of the City's Comprehensive Plan (City of Raleigh 2001). Several more miles of interconnected greenways are planned.

The Town of Cary is a rapidly growing suburb neighboring Raleigh. The population of Cary doubled during the 1980s and grew by 82% between 1990 and 1996. In 1979, Cary began developing its greenway system, and the town currently has 11 miles of publicly-owned greenways and 25 miles of privately-owned greenways (Town of Cary 2001). Like Raleigh, the Town of Cary is expanding its greenway system, and has plans for 15 additional greenway miles (Town of Cary 2001).

**Birds and Urbanization**

Urbanization converts natural areas, such as forests, grasslands and wetlands, into residential, commercial, institutional or industrial development. With the conversion of natural areas to human developments comes dramatic change to wildlife habitat, and consequently potential endangerment and local extinction of numerous species of wildlife (Miller and Hobbs 2002). Native wildlife species richness typically declines as urbanization increases, and the magnitude of these declines is directly related to the magnitude of urbanization (Nilon et al.1994; Freisen et al. 1995; Savard et al. 2000; Marzluff and Ewing 2001).

Birds in the urban environment can be assigned into one of two groups; omnivorous species adapted to urban environments and their unique food resources, or specialized species that find the resources that they normally require in more natural habitats in the urban landscape (Clergeau et al.1998). In urban environments, avian community composition shifts from specialist to generalist species (Blake and Karr 1987; Nilon et al. 1995). Bird communities in urban environments are characterized by high densities of a few, dominant exotic species, high abundance of granivores and omnivores, and few insectivorous migrant species (Beissinger and Osborne 1982; DeGraff 1987; Blair 1996). Often, total bird abundance increases in the urban environment because food provided by humans allows habitat generalists and granivorous and omnivorous species to maintain extremely high abundances (Lancaster and Rees 1979).

Within urbanizing landscapes, remnant forest patches and riparian forest corridors provide avian habitat. Riparian forest corridors, especially, contain a high diversity of species and protection of riparian corridors can secure critical habitat (Naiman et al. 1993). Urban conservation efforts that focus on protecting habitat and resources for development-sensitive specialist species, such as neotropical migrants, insectivores and forest-interior specialists, are most likely to succeed in conserving native species diversity.

Bird diversity within remnant forest patches is largely influenced by the size or width of the woods, with larger or wider woodlands providing habitat for a greater diversity of species (Tilghman 1987; Rottenborn 1999). The diversity and abundance of neotropical migrants within a remnant forest increases with increasing forest patch size (Friesen et al. 1995). Bird diversity within remnant forest patches also decreases when areas of high building density are adjacent to the woods (Tilghmann 1987). Neotropical migrants decrease in diversity and abundance with increasing intensity of adjacent development (Friesen et al. 1995).

**Birds and Vegetation**

Bird communities within urban remnant woodlots and corridors are influenced by the vegetation structure of the woods. Bird species richness and density increase with increasingly complex vegetative structure and total vegetation volume in urban environments, as in natural habitats (Lancaster and Rees 1979; Tilghman 1987; Mills et al. 1989; Rottenborn 1999). Forest patches with well-developed shrub layers have higher bird species richness and diversity (Tilghman 1987). Avian species richness and density are lowest in coniferous forests with high tree density, low canopy height and low tree species richness (James and Wamer 1982). Avian species richness is highest in multi-layered deciduous woodlots containing an abundance of dead and downed wood (Mortberg 1998; Marzluff and Ewing 2001). Dead and downed wood serve as habitat for many important bird food sources, such as decomposers, invertebrates and small mammals. Dead wood also provides nesting sites for cavity-nesting species (Lanham and Guynn 1996). In addition, removal and control of exotic plant species and maintenance of native vegetation within remnant woodlots and riparian corridors is necessary to conserve native bird diversity (Rottenborn 1999; Marzluff and Ewing 2001).

## Birds and Edge Effects

Edges are areas of transition between two or more habitat types (Keyser 2002). Many avian species are common near habitat edges, most likely because of more complex vegetation structure and simultaneous access to two or more different habitat types and their associated resources (Robinson 1988). However, other species appear to avoid edges or require forest-interior habitat. Fragmentation and the creation of edge decrease habitat availability to forest-interior or area-sensitive species (Villard 1998). Edge effects may entirely penetrate small remnant woodlots and narrow corridors, limiting the potential of the areas as breeding habitat for forest-interior bird species. Edges created by streams and other natural features, and by trails and other human-made features are present within greenways. These edges may affect avian community composition and rates of nest depredation (Miller et al. 1998; Miller and Hobbs 2000).

The increased vegetation complexity at edges may provide better cover and protection of nests (Yahner 1988; Burhans 1997). However, the effect of edge on nest predation rates is related to the type of adjacent habitats and may vary by region (Donovan et al. 1997; Keyser 2002). Nest predation rates often increase nearer to edges, especially in developed and agricultural landscapes (Gates and Gysel 1978; Andren and Angelstam 1988; Keyser 2002). Within forested landscapes, nest predation rates are not higher near edges as compared to farther into the forests (Yahner and Wright 1985; Ratti and Reese 1988; Hanski et al. 1996; Keyser 2002; Moorman et al. 2002). The probability of brood parasitism by Brown-headed Cowbirds is higher near edges, reducing clutch sizes and nest success (Moorman et al. 2002).

**Greenways as a Conservation Strategy**

Greenways are considered valuable to wildlife because they serve as a type of "conservation corridor." Corridors have been the subject of much recent ecological research and have been found to provide many benefits to wildlife (Beier and Noss 1998; Hess and Fischer 2000; Marzluff and Ewing 2001). Forman and Godron (1986) summarized the six ecological functions of corridors as habitat, conduit, filter, barrier, source and sink. On a smaller scale, urban greenways have the potential to perform the same functions as larger "conservation corridors." However, the utility of a greenway to wildlife is constrained by the unique conditions of habitat fragmentation and alteration in the surrounding landscape. Little is known about the extent to which urban greenways perform the aforementioned ecological functions. My research addresses only the first possible ecological function of greenways: habitat. Although investigation of how urban greenways function as a conduit, filter, barrier, source or sink for wildlife is beyond the scope of this project, further scientific investigation is needed.

**Research on Greenways as Wildlife Habitat**

Despite the growing popularity of greenways as an urban landscape form and the assertion that greenways provide wildlife habitat, very little research has been conducted by biologists on the value of urban greenways as wildlife habitat. Urban greenway corridors are often designated opportunistically on undevelopable land, such as stream corridors, steep slopes and utility right-of-ways with little or no explicit consideration of wildlife habitat quality (Fabos 1995). If urban and landscape planners are to successfully incorporate the needs of wildlife into greenway planning and design, they must have some idea of which characteristics and environmental factors contribute to their wildlife habitat value. Most of the literature on the greenway movement and greenway planning is conceptual in nature, and biological field research on greenways is scare. Additional scientific research on the subject of urban greenways is needed to direct future greenway planning towards strategic conservation of wildlife.

Urban greenways, especially along riparian corridors, can provide habitat for diverse avian communities and potentially even rare species (Mortberg and Wallentinus 2000, Manifold 2001). Greenway segments in the southeastern United States with more forest cover, greater widths, greater amounts of adjacent natural habitat, and greater connectivity to nonadjacent natural areas are more likely to harbor fox and deer (Schiller and Horn 1997). Wider greenways generally have greater density and diversity of birds, but narrow greenways can still provide habitat for many of the same birds founds in larger forests (Manifold 2001). In Washington state, greenways narrower than 40m had lower densities of ground and foliage foragers, residents and neotropical migrants (Manifold 2001). Greenways wider than 100m harbored greater numbers of interior species and greater bird diversity when compared to narrower greenways (Manifold 2001). Landscape context surrounding greenways also influences the composition of avian communities within the corridors. Increasing human development in the adjacent landscape increases the abundance of generalist species (Sodhi et. al 1999).

Human recreation and the edges created by recreational trails also affect the avian community within a greenway. In Colorado greenways, the presence of recreational hiking trails affected the vulnerability of artificial bird nests to predation (Miller and Hobbs 2000). Specifically, mammalian predators were less likely to depredate nests near trails, presumably because the scent of domestic dogs on the trails deterred predators. Generalist birds were more abundant near recreational trails in both forest and grassland ecosystems in Colorado, while specialist birds were less common (Miller et. al 1998).

These studies indicate that a complex set of interacting variables influences the wildlife value of urban greenways. Greenway width, landscape context, connectivity to larger areas of natural habitat, vegetation structure and composition, and the intensity of human activity are important factors that can affect the quality of a greenway as wildlife habitat. No research has been conducted comparing the wildlife habitat value of greenway systems to that of larger nature preserves, although municipalities must often make the choice between devoting resources to the acquisition and management of greenway systems or larger nature preserves. The paucity of scientific literature on the wildlife value of urban greenways clearly indicates that there is a need for well-designed, rigorous studies on this subject.

## Conclusion

Urban greenways provide a broad range of social, economic and environmental benefits, and consequently are enjoying great popularity as a developing urban landscape form. Municipalities worldwide are funneling resources into the design and implementation of greenway systems. One of the goals of greenway development is to provide habitat to wildlife. However, little scientific research has been conducted on the specific environmental characteristics in and surrounding urban greenways that contribute to their value as wildlife habitat. If landscape and urban planners are to be expected to strategically design greenways so as to maximize their value to wildlife, rigorous scientific research is needed in this area.

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# CHAPTER 2

# DESIGNING URBAN GREENWAYS TO PROVIDE HIGH QUALITY FOREST BIRD HABITAT

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For Submission to *Landscape and Urban Planning*
June 2003

# ABSTRACT

Greenways provide a broad range of social, economic and environmental benefits in rapidly urbanizing landscapes, and consequently are enjoying worldwide popularity as a developing form of urban openspace protection. If landscape and urban planners are to strategically design greenways so as to maximize their value to wildlife, they need information on the specific environmental characteristics in and surrounding urban greenways that contribute to their value as wildlife habitat. We investigated how forested corridor width, landscape context, and greenway composition and vegetation structure affect avian community composition in urban greenways in Raleigh and Cary, North Carolina, USA. We surveyed breeding bird communities at 34 greenway study sites using 50-m fixed-radius point counts located at the center of 300m-long greenway segments. Each greenway segment's forested corridor width and surrounding land use were determined in ArcGIS. Greenway composition (proportion of mature forest, young forest, managed area, and stream in the greenway study site) and vegetation structure were measured in the field. Total bird abundance increased with increasing canopy cover in the adjacent landscape and increasing shrub cover within the greenway. Neotropical migrant, insectivore and forest-interior species richness decreased with increasing amounts of managed area, such as trail and other mowed or maintained surfaces, within a greenway. Neotropical migrant species richness and forest-interior species richness and abundance decreased with increasing amounts of building in the adjacent landscape. Insectivore species richness increased with increasing lawn cover in the adjacent landscape, and insectivore abundance increased with increasing amounts of canopy in the adjacent landscape. White-eyed Vireos were recorded only in greenways wider than 300m; Wood Thrushes and Indigo Buntings were recorded only in greenways wider than 100m; and Blue-gray Gnatcatchers, Downy Woodpeckers and Red-eyed Vireos were recorded only in greenways wider than 50m. Urban-adaptors such as Common Grackles and European Starlings were most common in greenways 50m or narrower. Landscape and urban planners can maximize native bird diversity and abundance by minimizing the width of the greenway trail and associated mowed and landscaped surfaces adjacent to the trail, maintaining vegetative structure within the greenway, and giving priority to the protection of greenways in areas of lower development intensity. Greenways wider than 50m can provide habitat for a diversity of bird species, but many species of conservation concern require much wider greenways.

**Keywords:** birds, corridor width, greenway design, landscape context, North Carolina, urban planning

# INTRODUCTION

By 2025, the United Nations predicts, the human population in urban areas will equal today's global population of 6 billion (United Nations 1998). Urbanization converts natural areas, such as forests, grasslands and wetlands into residential, commercial, institutional or industrial development. With the conversion of natural areas to human developments comes dramatic change to wildlife habitat, and consequently potential endangerment and local extinction of numerous species (Miller and Hobbs 2002). Native bird species richness typically declines as urbanization increases, and the magnitude of these declines is directly related to the magnitude of urbanization (Nilon et al.1994; Freisen et al. 1995; Savard et al. 2000). As development intensity and habitat fragmentation increase, bird community structure shifts from development-sensitive specialists to urban-adaptive generalists (Blake and Karr 1987; Nilon et al. 1994). Bird communities in urban environments are commonly characterized by high densities of exotic species and resident granivores and omnivores, and few insectivorous migrant species (Lancaster and Rees 1979; Beissinger and Osborne 1982; DeGraff 1987; Blair 1996). Urban conservation efforts that focus on protecting habitat and resources for development-sensitive species, such as neotropical migrants, insectivores and forest-interior specialists, are most likely to succeed in conserving native bird diversity.

Recently, greenways have become a popular means of mitigating some of the negative effects of urbanization (Searns 1995). "Greenway" is a generic term used to refer to linear protected lands. Greenways vary from paths several feet wide meandering through neighborhoods to larger miles-wide “conservation corridors.” Greenway systems generally are developed with the ultimate goal of creating an interconnecting network of openspace within an urban landscape, linking together larger parks and natural areas (Ahern 1995; Fabos 1995; Searns 1995). Greenways often are conserved along riparian corridors, largely due to the natural connectivity of stream networks and existing floodplain protection regulations requiring stream and river buffers. Riparian corridors contain a high diversity of species and protection of riparian greenways can secure critical habitat (Naiman et al. 1993). Greenways provide a range of benefits, including recreation and transportation, urban beautification, increased property value, development buffers, floodplain protection, preservation of historical, cultural and environmental resources, and wildlife habitat (Ahern 1995; Fabos 1995; Searns 1995). As of 1990, more than 500 greenway projects were completed or underway in North America (Searns 1995).

Despite the growing popularity of greenways as an urban landscape form and the assertion that greenways provide wildlife habitat, very little research has been conducted by biologists on the value of urban greenways as wildlife habitat. Urban greenway corridors usually are designated opportunistically on undevelopable land, such as stream corridors, steep slopes and utility right-of-ways with little or no explicit consideration of wildlife habitat quality (Fabos 1995). If urban and landscape planners are to successfully incorporate the needs of wildlife into greenway planning and design, they must know which characteristics and environmental factors contribute to a greenway’s wildlife habitat value. The current scientific literature suggests that greenway width and landscape context (the adjacent land use) are likely the dominant factors affecting a greenway's value as wildlife habitat (Schiller and Horn 1997, Rottenborn 1999, Manifold 2001). Because these two factors are under direct control of government planning organizations, they have potential to be managed to maximize the wildlife habitat value of urban greenways. Vegetation structure and composition and the intensity of human activity are important factors that also can affect the quality of a greenway as wildlife habitat.

Our objectives were (1) to determine how landscape and environmental characteristics of greenways, including forested corridor width, landscape context, and vegetation structure and composition, affect avian community composition, and (2) to develop recommendations for the design and management of urban greenways as high quality habitat for development-sensitive birds such as neotropical migrants, insectivores and forest-interior specialists.

# METHODS

## Study Area

We studied greenways in the cities of Raleigh and Cary, North Carolina, USA (Figure 1). Raleigh and Cary are part of the Triangle Region of North Carolina, within the larger physiographic region of the Central Appalachian Piedmont. This region consists mostly of urban-suburban land use within a forested matrix, with areas of urban-rural interface into agricultural land use. In recent decades, intense population growth within the region has resulted in urban and suburban growth, replacing forests with residential, commercial, institutional and industrial development and infrastructure. According to U.S. Census data for the Raleigh-Durham area, the urban population increased by 200% and urbanized land increased by 900% during 1950-1990 (North Carolina Chapter of the American Planning Association 2002). The Town of Cary is a rapidly growing suburb neighboring Raleigh. The population of Cary doubled during the 1980s and grew by 82% between 1990 and 1996 (Town of Cary 2001).

**Study Site Selection**

We sampled birds in 34 forested "segments" of publicly-owned greenway, each 300m long and separated by at least 75m (Figure 1). All greenway segments were bottomland riparian corridors bisected by a stream or river. The 34 greenway segments were selected to ensure a distribution of samples across of range of width and context combinations, in order to investigate the effects of greenway forested corridor width and adjacent development intensity on bird use. We selected only segments with relatively homogenous width and similar land use on both sides. Sites in industrial or manufacturing landscape contexts were excluded from our study because of the unique and potentially severe impacts of this land use. We also excluded sites adjacent to lakes, because lakes could provide unique resources and habitat types not available at other study sites. A greenway's width was considered to be the width of the forested corridor, which sometimes extended beyond the legal or protected bounds of the greenway. Greenway forested-corridor width and landscape context were determined on digital aerial photography in ArcView (Figure 2). Digital data were obtained from Wake County, the City of Raleigh and the Town of Cary.

### Measuring Landscape Context

We quantified the land use surrounding each site by analyzing 1999 leaf-off aerial photography using ArcView 3.2. Aerial photography was obtained from Wake County GIS (Wake County Geographic Information System Services 2001). Two 300mX300m squares were drawn on either side of the study site, adjacent and parallel to the forested corridor (Figure 2). Each square was populated with a systematic grid containing100 points, using the Samples 3.03 extension in ArcView. At each point, we recorded the land use in the following categories; canopy, pavement, building, lawn, water, agriculture, and bare earth. Because photography was leaf-off, we recorded points that fell within a deciduous tree crown as canopy. At points where pavement, building, lawn, water or agriculture could be seen beneath a tree crown or canopy, both land use categories were recorded for that point. We used these observations to calculate the proportion of each of the above land use categories in each study site's adjacent context.

### Bird Surveys

We quantified bird use of the greenways in Raleigh and Cary during the breeding season of 2002. Two observers surveyed breeding birds using 50-m fixed-radius point counts of 8-min duration (Ralph et al. 1993; Hamel et al. 1996). We recorded all birds seen or heard within the 50-m radius plot during the 8-min point count. Birds detected outside the

50-m plot or flying over the plot were recorded but not included in analysis. All point counts were conducted between May 15$^{th}$ and June 30$^{th}$, in the mornings between 6-11am, and under fair weather conditions. A point count was discarded if disrupted by rain, strong gusts of wind, construction or maintenance equipment, or any other significant disturbance. Point counts were conducted repeatedly throughout the breeding season so that each point count station was visited four times. All 34 greenway segments were visited before a new round of surveys began. The order in which study sites were visited was rotated, to avoid bias due to time of day. Each site was visited during the early, mid-, and late morning at some point during the study. Observers were rotated, so that each site was visited twice by each of the two observers who conducted the surveys.

Point count stations were located approximately at the center of each greenway segment. Segment centers were identified on aerial photography in ArcView 3.2, and located and flagged in the field using GeoExplorer II, a global positioning device (Trimble Navigation Limited 1996). We recorded point count station coordinates in the field, downloaded and differentially corrected the coordinates using Pathfinder, and verified the locations on aerial photography. We surveyed birds in the center of each greenway segment's forested corridor in order to detect any forest-interior specialist species in the greenway. At all study sites, the 50-m radius point count included or was adjacent to a stream, and would therefore be considered riparian habitat.

## Guilds

Each bird species encountered during our research was assigned to foraging, nesting, migratory and habitat guilds (Hamel et al. 1982; Ehrlich et al. 1998; Moorman and Guynn 2001) (Appendix 1). Foraging guilds were insectivore, carnivore, granivore, nectarivore and omnivore. Nesting guilds were building/ledge nester, brood parasite, canopy nester, shrub nester, ground nester and cavity nester. Migratory guilds were exotic, neotropical migrant, short-distance migrant and resident. We defined short-distance migrants as those species with winter ranges that do not include the Raleigh-Durham metro area, but do include some portion on the southeastern region of the United States. Habitat guilds were edge, interior, interior-edge, open area, urban and water. We refer to development-sensitive species as those that fall in the neotropical migrant, insectivore or forest-interior guilds (DeGraff 1987; Blair 1996; Villard 1998).

## Greenway Microhabitat Surveys

We visited each greenway segment during September 2002 to characterize the greenway composition and vegetation within the 50-m radius point count plot. To account for habitat variability and edges within plots, we recorded greenway composition as the percentages of each 50-m radius plot covered by mature forest, young forest, managed area and stream. Mature forest was defined as any area covered by trees taller than 6m. Young forest included woody vegetation 1-6m tall. Managed area included mowed and maintained surfaces, roads, parks, trails, and ballfields. The type of managed area and the predominant management ground cover were recorded when applicable. Percent covers for each class (mature forest, young forest, managed area and stream) summed to 100% for each plot. Because we measured the proportion of managed area within our 50-m radius point count plots, greenways with forested corridor widths narrower than the 100m diameter of our point count plot often had higher amounts of managed area because the 50-m plots extended beyond the greenway boundary onto the adjacent landscape. However, greenway width and managed area were not highly correlated (Pearson correlation coefficient = -0.45), so these variables were treated independently and in fact behaved differently in analyses.

All 50-m radius plots contained areas of mature forest cover, and most plots were dominated by this cover type. Within the mature forest cover class, percent canopy cover, canopy height, percents pine and hardwood, percent vine cover, percent shrub cover, and percent ground cover were recorded. Percents vine cover, shrub cover and ground cover were visually estimated for the whole plot and recorded as 0 = absent, 1 = 1-20%, 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, or 5 = 81-100%. Percent canopy cover was measured by standing at a single location within the mature forest and averaging four spherical densiometer readings, one in each cardinal direction. Percents pine and hardwood within the mature forest cover were visually estimated to the nearest whole number for the entire plot. Canopy height was measured by reading the height of the tallest canopy tree within the plot using a sonar hypsometer.

At each plot, we recorded distance from the plot center to the stream edge and stream width. We recorded presence of a trail and distance from the plot center to the trail's edge, trail surface type (paved, gravel or dirt), trail width, and managed width. Managed width included the trail and any mowed or maintained area adjacent to the trail. We counted the number of snags within the 50-m radius plot, defining snags as standing dead wood taller than 2m and greater than 10cm in diameter.

**Data Analysis**

Using 50-m fixed-radius point count data for each of the four visits, we compiled a species list and presence/absence of each species for each study site. We calculated total species richness for each study site as the total number of bird species recorded at the site over all four point counts. We calculated guild species richness values for each guild as the number of species of a particular guild recorded at the site over all four point counts. We corrected total and guild species richness values using SPECRICH2, a program that uses the jackknife estimator from program CAPTURE to compute corrected species richness values based on presence-absence data over multiple visits (White et al. 1978; Rexstad and Burnham 1991; ComDyn 2002). We calculated individual species abundances as the average number of adult males of a species seen over all four visits to a single plot. Total bird abundance and guild abundances were calculated as the sum of individual abundances.

We performed correlation analysis using PROC CORR in SAS 8.2 to identify correlation among all independent variables, including forested corridor width, landscape context, and greenway composition and vegetation structure measures. Correlation among independent variables violates the assumption of colinearity necessary for regression analysis. We considered a pair of variables highly correlated if the Pearson correlation coefficient was greater than 0.6. We removed one member of each highly correlated pair of variables, making an effort to remove the variable which we considered less useful or meaningful in greenway planning and management. The reduced set of independent variables used in analysis contained the variable AverageWidth, seven landscape context variables, and ten microhabitat variables (Table 1). We performed backwards stepwise multiple regression on square-root transformed total bird abundance and corrected species richness and guild abundance and corrected species richness values using PROC REG in SAS 8.2.

Because guilds are a crude attempt to group bird species with similar life history traits, analyses using guilds can be confounded individual species responses. For example, a guild analysis may appear non-significant, but one species within the guild may have responded positively to a treatment while another species responded negatively. The two species in this case cancelled each other out when lumped into a guild class. Therefore, we used chi-square tests of independence to determine if the presence of an individual species was independent of greenway forested corridor width and landscape context classes. Study sites were classified in the following landscape context classes: low-density residential (1-5lots/acre), high-density residential (>5lots/acre), and office/institutional. The office/institutional class contained commercial, office, school and other institutional land uses. We determined landscape context classes using zoning and land use data in ArcView. Study sites were classified into the following forested corridor width classes: ≤50m, 51-100m, 101-150m, 151-300m and >300m. We defined width and context classes such that each class contained an approximately equal number of study sites (Table 2). The significance level for all statistical analyses was set at $\alpha$ = 0.05.

# RESULTS

We recorded 48 species during our point counts of breeding birds (Table 2). Of these species, there were 33 insectivores, 11 omnivores, two carnivores, one granivore and one nectarivore. There were 18 cavity nesters, 13 canopy nesters, 12 shrub nesters, four ground nesters and one brood parasite. Thirty-one of the species were year-round residents of the North Carolina Piedmont, while 11 were neotropical migrants, four were short-distance migrants, and two were exotic species. Seventeen of these species were classified in the interior-edge habitat guild, 15 as forest-edge specialists, nine as forest-interior specialists, one as an open habitat dweller, three as water dwellers, and three as urban specialists.

No independent variables were included in the regression model for total corrected avian species richness ($R^2$ = 0), while total avian abundance increased with increasing amounts of canopy cover in the adjacent landscape and increasing amounts of shrub cover within the greenway (Table 3). The amount of managed area within the greenway study site was the most significant factor affecting neotropical migrant, insectivore and forest-interior species richness (Table 3). The number of these development-sensitive species decreased with increasing amounts of managed area within the greenway. Neotropical migrant species richness decreased with increasing amounts of bare earth in the surrounding landscape (Table 3). Neotropical migrant species richness and forest-interior species richness and abundance decreased with increasing amounts of building in the adjacent landscape. Insectivore species richness increased with increasing lawn cover in the adjacent landscape, and insectivore abundance increased with increasing amounts of canopy in the adjacent landscape (Table 3). Greenway forested corridor width was not significantly correlated with any of the bird groupings examined.

The presence of several species was not independent of greenway forested corridor width (Table 2). White-eyed Vireos were recorded only in greenways wider than 300m ($p < 0.05$); Wood Thrushes and Indigo Buntings were only recorded in greenways wider than 100m ($p < 0.05$); and Blue-gray Gnatcatchers ($p < 0.025$), Downy Woodpeckers ($p < 0.025$) and Red-eyed Vireos ($p < 0.005$) were recorded only in greenways wider than 50m (Table 2). Tufted Titmice were uncommon in greenways 50m or narrower ($p < 0.025$). European Starlings ($p < 0.05$) and Common Grackles ($p < 0.025$) were more common in narrower greenways, especially in greenways 50m or narrower. Several development-sensitive species, including Ovenbird, Louisiana Waterthrush, Prothonotary Warbler, Scarlet Tanager, Hairy Woodpecker, Pileated Woodpecker and Acadian Flycatcher were recorded only in wider greenways (Table 2). However, these species did not occur at a sufficient number of sites to statistically determine if species presence was independent of greenway forested corridor width. Ground-nesting songbirds were extremely rare in our study sites. Ovenbird and the Louisiana Waterthrush were the only ground-nesting songbirds recorded during point counts, and these species were found only in wide greenways (Table 2). Ovenbirds were recorded only at Black Creek 3, a 225-m-wide site. Louisiana Waterthrush and Scarlet Tanager were recorded only at Swift Creek 3, a 405-m-wide site with a forested corridor containing Hemlock Bluff Nature Preserve. Prothonotary Warblers were recorded only at Lower Walnut 2, a 600-m-wide site. Hairy Woodpeckers were recorded only in four study sites, all wider than 100m (Table 2). Acadian Flycatchers and Pileated Woodpeckers were recorded only in greenways wider than 50m (Table 2).

The Red-shouldered Hawk was the only species tested for which presence was not independent of landscape context ($p < 0.025$). Red-shouldered Hawks were recorded only in greenways in a low-density residential land use context (Table 2).

Many common species were recorded over all greenway widths and contexts, including American Goldfinches, American Robins, Brown-headed Cowbirds, Carolina Chickadees, Carolina Wrens, Gray Catbirds, Northern Cardinals, Red-bellied Woodpeckers, and White-breasted Nuthatches (Table 2). Northern Cardinals were recorded at all 34 study sites.

# DISCUSSION

## Microhabitat Effects

The amount of managed area, such as trail and other mowed or maintained surfaces, within a greenway study site was the most significant factor in predicting neotropical migrant, insectivore and forest-interior species richness. Increasing amounts of managed area within a greenway correspond to decreasing richness of these development-sensitive guilds. Vegetation is removed to build and maintain greenway trails and managed surfaces adjacent to trails. Canopy openings are created and shrub and ground cover is removed. Bird abundance and diversity are strongly correlated with vegetation volume (Lancaster and Rees 1979; Tilghman 1987; Mills et al. 1989; Rottenborn 1999). Narrow trails with no adjacent managed area do not break up the forest canopy overhead. However, wide trails and wide managed areas adjacent to trails create edges and breaks within the greenway canopy that deter forest-interior and area-sensitive species (Villard 1998). The wide managed areas essentially divide the once contiguous forested corridor into two much narrower corridors. Furthermore, sites closer to the greenway trail edge contained fewer insectivores, indicating that insectivorous species avoid trial edges in favor of more interior forest habitat. Other research has similarly shown that generalist birds are more abundant near recreational trails in both forest and grassland ecosystems, while specialist birds are less common (Miller et. al 1998).

Minimizing managed area within a greenway is essential to providing habitat for development-sensitive species. Greenways containing little or no managed area may provide habitat for up to twice as many development-sensitive bird species compared to greenways containing 2-3m wide trails with adjacent mowed areas. However, the goal of minimizing managed area within a greenway may conflict with the goal of providing recreation and transportation opportunities to urban residents. Trails 2-4m wide often are constructed within urban greenways to accommodate access and shared use of paths by bikers, pedestrians, strollers, and wheelchairs. Additional mowed areas are maintained to accommodate benches and equipment, or merely for aesthetic purposes. This conflict may be resolved by placing greenway trails along one edge of the forested corridor, rather than directly down the middle of the corridor, minimizing the effect of greenway trail management and edge on "interior" forest. However, this solution also requires that the greenway corridor be wide enough to contain a substantial amount of forest not adjacent to a trail or forested corridor edge.

Total bird abundance increased with increasing shrub cover within a greenway. Other studies have similarly found that bird species richness and density increase with increasingly complex vegetative structure and total vegetation volume (Lancaster and Rees 1979; Tilghman 1987; Mills et al. 1989). Therefore, shrub or understory layer removal for aesthetics, safety concerns, or improved access could decrease the total number of birds using a greenway as habitat. Shrub cover and vegetation structure in greenways may increase following openings of the canopy by storms and other temporary natural disturbances.

Total bird abundance and insectivore species richness declined with increasing hardwood cover in the greenways. As percents hardwood and pine summed to one, a decrease in percent hardwood correlates perfectly to an increase in percent pine. Typically, avian species richness and density are lower in coniferous than in deciduous woodlots (James and Wamer 1982; Mortberg 1998; Marzluff and Ewing 2001). However, all of our study sites were located in bottomland hardwood habitats. Study sites some containing pine may have attracted additional resident insectivorous species, such as nuthatches and woodpeckers, not found in exclusively hardwood sites.

**Landscape Context Effects**

Total bird abundance was highest in greenways with high canopy cover in the adjacent landscape, but many neotropical migrant and forest-interior species were absent in greenways with bare earth or high building cover in the adjacent landscape. Other studies have similarly shown that in areas of high development intensity adjacent to remnant woods, total bird diversity and neotropical migrant diversity and abundance decrease (Tilghman 1987; Friesen et al. 1995). Insectivore species richness was positively correlated with lawn cover in the adjacent context, indicating that insectivorous species are more common in greenways in a residential land use context where lawns predominate than in a commercial or institutional land use context where lawns are absent. If conservation of development-sensitive bird species is a goal, priority should be given to the protection of greenways located in areas of low-density residential development with high canopy cover and little or no bare earth.

The Red-shouldered Hawk was the only individual species tested that demonstrated a statistically significant response to landscape context class. Red-shouldered Hawks were recorded only in greenways surrounded by low-density residential land use (1-5 lots/acre). As a carnivore, the Red-shouldered Hawk may respond to habitat factors within the landscape at a broader scale than other bird species. Landscape context surrounding greenways may be particularly important for species occupying higher trophic levels.

**Forested Corridor Width Effects**

Contrary to our expectation, development-sensitive species richness and abundance measures were not significantly correlated with greenway forested corridor width. However, the presence of several individual bird species was not independent of greenway width. Many of these species, including the White-eyed Vireo, Wood Thrush and Blue-gray Gnatcatcher, are listed on the North Carolina Partners in Flight Watch List of birds requiring conservation attention. Greenways narrower than 50m did not provide habitat for these and other development-sensitive bird species. In Washington state, greenways narrower than 40m had lower densities of ground and foliage foragers, residents and neotropical migrants (Manifold 2001). Greenways wider than 100m harbored greater numbers of interior species and greater bird diversity when compared to narrower greenways (Manifold 2001).

While greenways as narrow as 50m provided habitat for a diversity of bird species, many development-sensitive species required wider greenways. The necessary width of a greenway corridor depends on the species that are to be conserved. In order to protect ground nesting songbirds, it may be necessary for greenways to be over 200m wide. Forest-interior species, such as the Scarlet Tanager and Prothonotary Warbler may require greenways 600m or wider. Wider greenways also were less likely to contain nest predators such as Common Grackles and aggressive exotic species such as European Starlings in their interiors. The absence of these species may contribute to higher nest success rates for development-sensitive species. Because our point count plots were located at the greenway center, point counts in wide greenways were conducted farther away from the greenway edge. While European Starlings and Common Grackles were not common in the centers of wide greenways, it is likely that they could be found at the greenway edges. Internal edges created by trails and other openings also may provide habitat for edge species within wide greenways.

The peripheral areas of most of the greenways we studied were owned by private homeowners and businesses. Wider publicly-owned greenways would require greater forethought, planning and expenditure of public funds. As greenways of this width are not a realistic option for many urban municipalities, typical urban greenways may not suffice to conserve certain development-sensitive, forest-interior bird species. Larger nature preserves or public parks likely are necessary to conserve these species.

**Further Research Needs**

Human recreation and the edges created by recreational trails may affect avian nest success within a greenway. The effect of edge on nest predation rates is related to the type of adjacent habitats and may vary by region (Donovan et al. 1997; Keyser 2002). Nest predation rates often increase nearer to edges, especially in developed and agricultural landscapes (Gates and Gysel 1978; Andren and Angelstam 1988; Keyser 2002). The probability of brood parasitism by Brown-headed Cowbirds also is higher near edges, reducing clutch sizes and nest success (Moorman et al. 2002). However, in Colorado greenways, the presence of recreational hiking trails decreased the vulnerability of artificial bird nests to predation, presumably because the scent of domestic dogs on the trails deterred mammalian predators (Miller and Hobbs 2000). The potentially large amount of forest edge in urban greenways raises questions about predation rates and nest success. Nest predators, such as raccoons, opossums, corvids, squirrels, rodents and domestic cats are common in urban greenways (Sinclair et al. 2003). Corvids, such as American Crows, Common Grackles and Blue Jays, have been photographed depredating artificial bird nests at our greenway study sites (Sinclair 2003). However, nest predators were less common in the interior of wide greenways, where development-sensitive bird species were most common. Wide greenways may provide interior habitat for development-sensitive species while contributing to low nest predation rates due to low density of nest predators. Further investigation is needed on nest success in urban greenways, to determine if urban greenways act as “ecological traps,” providing habitat in which birds establish territories but do not reproduce successfully.

Greenways may act as important stopover sites for birds during migration, though little research has been conducted on stopover habitat use in urban remnant woods and corridors. We encountered several migratory species within the greenways during spring migration of 2002, including American Redstart, Blackpoll Warbler, Black-throated Blue Warbler, Chestnut-sided Warbler, Common Yellowthroat, Eastern Wood-pewee, Hooded Warbler, Prairie Warbler, Veery, Yellow Warbler, Yellow-billed Cuckoo, Yellow-breasted Chat, Yellow-throated Vireo and Yellow-throated Warbler. Although many of these species breed in the area, none were recorded during our point counts and most likely use the greenways only as stopover habitat. Research is needed to assess the adequacy of urban greenways as stopover habitat for migratory birds.

# MANAGEMENT RECOMMENDATIONS

Based on our results, the following guidelines may be useful to urban and landscape planners in design and management of greenways as high quality habitat for development-sensitive bird species:

1. *Be creative in finding ways to minimize managed area within a greenway.* Mow less, make paved trails narrower, leave certain trails within the system unpaved, and locate trails at the greenway edge to maximize forest interior. If vegetation

removal is necessary for sight lines on steep terrain, leave forest litter rather than planting grass or ornamentals. These efforts will encourage use of greenways by a greater number of neotropical migrants, insectivores, and forest-interior species.

2. *Maintain vegetative structure within the greenway by leaving ground cover and understory shrubs.* Removal of the understory or shrub layer could decrease bird diversity and abundance.
3. *Conserve wider greenways.* Greenways wider than 50m provide habitat for many species, but greenways as wide as 200-600m may be necessary to conserve certain development-sensitive species, especially forest-interior specialists and ground-nesting songbirds. When greenways of this width are not realistic, larger non-linear reserves are needed to provide habitat for these species.
4. *Give priority to the conservation of greenways in areas of lower development intensity.* Greenways surrounded by residential areas with high canopy cover, low building density, and little or no bare earth likely contain the greatest diversity and abundance of birds.

## ACKOWLEDGMENTS

We thank Marcia Gumpertz and Janet Bartz for advice and guidance on statistical analysis. We thank Jim Hines for modifying program SPECRICH2 to process multiple input files for use with our data. We thank Nathan Tarr for an immense amount of work locating and marking study sites and conducting bird surveys. We thank the City of Raleigh, Town of Cary, Hemlock Bluffs Nature Preserve, and William B. Umstead State Park for graciously allowing us to conduct research on their lands. We thank Wake

County GIS, City of Raleigh GIS and Town of Cary GIS for provision of geographic data. Finally, we thank the North Carolina State University Department of Forestry and the U.S. Forest Service for providing the funds and resources to make this research possible.

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**Table 1.** Greenway width, landscape context and microhabitat measures used in multiple regression analysis on total species richness and abundance and guild species richness and abundance measures from Raleigh and Cary, NC greenways (2002).

| Variable | Description |
|---|---|
| **Width** | |
| AvgWidth | Average width, in meters, of the greenway forested corridor. |
| **Landscape Context** | |
| ContextCanopy | Proportion of canopy cover in 2 300mX300m areas adjacent to study site. |
| ContextBuilding | Proportion of building cover in 2 300mX300m areas adjacent to study site. |
| ContextPavement | Proportion of pavement cover in 2 300mX300m areas adjacent to study site. |
| ContextLawn | Proportion of lawn cover in 2 300mX300m areas adjacent to study site. |
| ContextEarth | Proportion of bare earth in 2 300mX300m areas adjacent to study site. |
| ContextAg | Proportion of agriculture in 2 300mX300m areas adjacent to study site. |
| ContextWater | Proportion of water in 2 300mX300m areas adjacent to study site. |
| **Microhabitat** | |
| TrailDistance | Distance in meters from the study site center to the trail edge. |
| YoungForest% | Percent of study site covered in young forest (1-6m). |
| Managed% | Percent of study site covered by human management (lawn, trail, etc.). |
| StreamWidth | Width in meters of greenway stream or river. |
| CanopyCover | Canopy cover in the mature forest portion of the study site. |
| Hardwood% | Percent of the mature forest portion of the study site composed of hardwood cover. |
| CanopyHieght | Height in meters of the tallest tree in the study site, as measured by sonar hypsometer. |
| VineCover | Index of percent vine cover in study site forest, recorded in 20% interval (1-5). |
| ShrubCover | Index of percent shrub cover in study site forest, recorded in 20% interval (1-5). |
| GroundCover | Index of percent ground cover in study site forest, recorded in 20% interval (1-5). |

**Table 2.** Breeding bird species occurrences in greenway landscape context and width classes, Raleigh and Cary, NC (2002).

| | **Context** | | | **Width (m)** | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species** | **L D R** | **H D R** | **O F C** | **≤ 50** | **51-100** | **101-150** | **151-300** | **>300** |
| **Number of sites** | 10 | 11 | 13 | 7 | 6 | 7 | 8 | 6 |
| Scarlet Tanager (*Piranga olivacea*) | X | | | | | | | X |
| Louisiana Waterthrush (*Seirus motacilla*) | | | X | | | | | X |
| White-eyed Vireo (*Vireo griseus*) * | | | X | | | | | X |
| Prothonotary Warbler (*Protonotaria citrea*) | | | X | | | | | X |
| Ovenbird (*Seiurus aurocapillus*) | | X | | | | | X | |
| Summer Tanager (*Piranga rubra*) | | X | X | | | X | | X |
| Hairy Woodpecker (*Picoides villosus*) | X | X | | | | X | X | X |
| Wood Thrush (*Hylocichla mustelina*) * | X | X | X | | | X | X | X |
| Indigo Bunting (*Passerina cyanea*) * | X | | X | | | X | X | X |
| Acadian Flycatcher (*Epidomax virscens*) | X | X | X | | X | X | X | X |
| Blue-gray Gnatcatcher (*Polioptila caerulea*) * | X | X | X | | X | X | X | X |
| Downy Woodpecker (*Picoides pubescens*) * | X | X | X | | X | X | X | X |
| Pileated Woodpecker (*Dryocopus pileatus*) | X | X | X | | X | X | X | X |
| Red-eyed Vireo (*Vireo olivaceus*) * | X | X | X | | X | X | X | X |
| Red-shouldered Hawk (*Buteo lineatus*) ** | X | | | | X | X | | X |
| Ruby-throated Hummingbird (*Archilochus colubris*) | X | | X | | X | X | | X |
| Belted Kingfisher (*Megaceryle alcyon*) | | X | X | | | X | X | |
| American Robin (*Turdus migratorius*) | X | X | X | X | X | X | X | X |
| Brown-headed Cowbird (*Molothrus ater*) | X | X | X | X | X | X | X | X |
| Carolina Chickadee (*Parus carolinensis*) | X | X | X | X | X | X | X | X |
| Carolina Wren (*Thryothorus ludovicianus*) | X | X | X | X | X | X | X | X |
| Eastern Towhee (*Pipilo erythrophthalmus*) | X | X | X | X | X | X | X | X |
| Gray Catbird (*Dumetella carolinensis*) | X | X | X | X | X | X | X | X |
| Great-crested Flycatcher (*Myiarchus crinitus*) | X | X | X | X | X | X | X | X |
| Northern Cardinal (*Cardinalis cardinalis*) | X | X | X | X | X | X | X | X |
| Red-bellied Woodpecker (*Melanerpes carolinus*) | X | X | X | X | X | X | X | X |
| Tufted Titmouse (*Parus bicolor*) * | X | X | X | X | X | X | X | X |
| White-breasted Nuthatch (*Sitta carolinensis*) | X | X | X | X | X | X | X | X |
| Common Grackle (*Quiscalus quiscula*) * | X | X | X | X | X | X | | X |
| Fish Crow (*Corvus ossifragus*) | | X | X | X | X | | | X |
| Northern Flicker (*Colaptes auratus*) | X | X | | X | X | | X | X |
| Red-headed Woodpecker (*Melaneres erythrocephalus*) | X | | X | X | X | | | X |
| Pine Warbler (*Dendroica pinus*) | X | X | | X | | | | X |
| Blue Jay (*Cyanocitta cristata*) | X | X | X | X | X | X | X | |
| Chipping Sparrow (*Spizella passerine*) | X | X | X | X | X | X | X | |
| House Finch (*Carpodacus mexicanus*) | X | X | X | X | X | X | X | |
| European Starling (*Sturnus vulgaris*) * | X | X | X | X | X | | X | |
| Barn Swallow (*Hirundo rustica*) | | | X | X | | | X | |
| House Wren (*Troglodytes aedon*) | X | X | X | X | X | | X | |
| Mallard (*Anas fulvigula*) | | X | X | X | | X | X | |
| Mourning Dove (*Zenaida macroura*) | X | X | X | X | X | | X | |
| Canada Goose (*Branta canadensis*) | | | X | X | | | X | |
| Chimney Swift (*Chaetura pelagica*) | X | X | X | X | X | X | | |
| Northern Mockingbird (*Mimus polyglottos*) | X | X | X | X | X | X | | |
| Eastern Bluebird (*Sialia sialis*) | | X | | | X | X | | |
| Brown Thrasher (*Toxostoma rufum*) | X | X | | X | X | | | |
| Brown-headed Nuthatch (*Sitta pusilla*) | X | X | X | X | | | | |
| House Sparrow (*Passer domesticus*) | | | X | X | | | | |

* Species presence not independent of greenway width ($p < 0.05$)
** Species presence not independent of landscape context ($p < 0.05$)

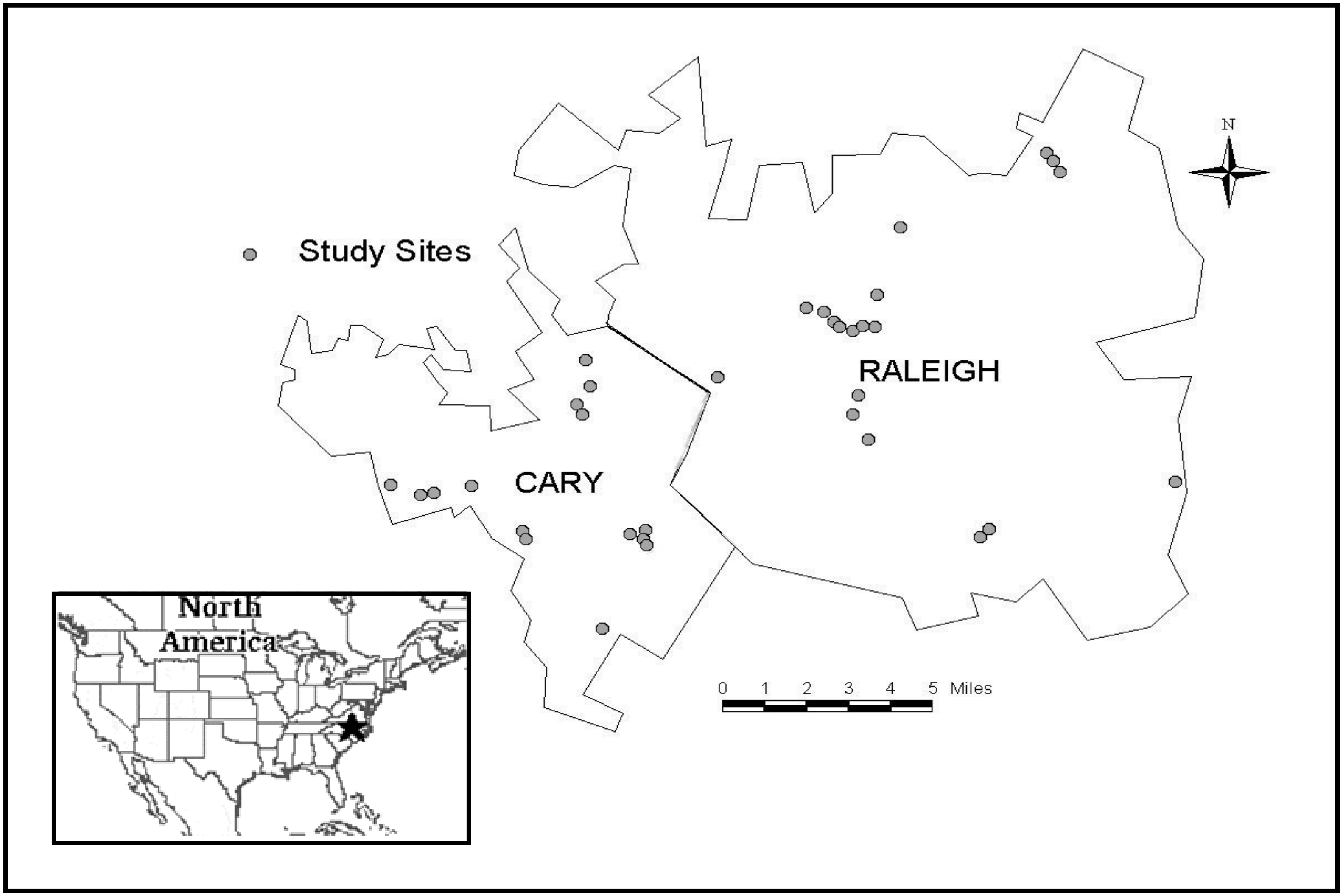
**Table 3.** Regression models, reported with coefficients and partial F-statistic significance levels for included variables for greenways in Raleigh and Cary, NC (2002). Significance levels set at α = 0.05 for variable inclusion in models.

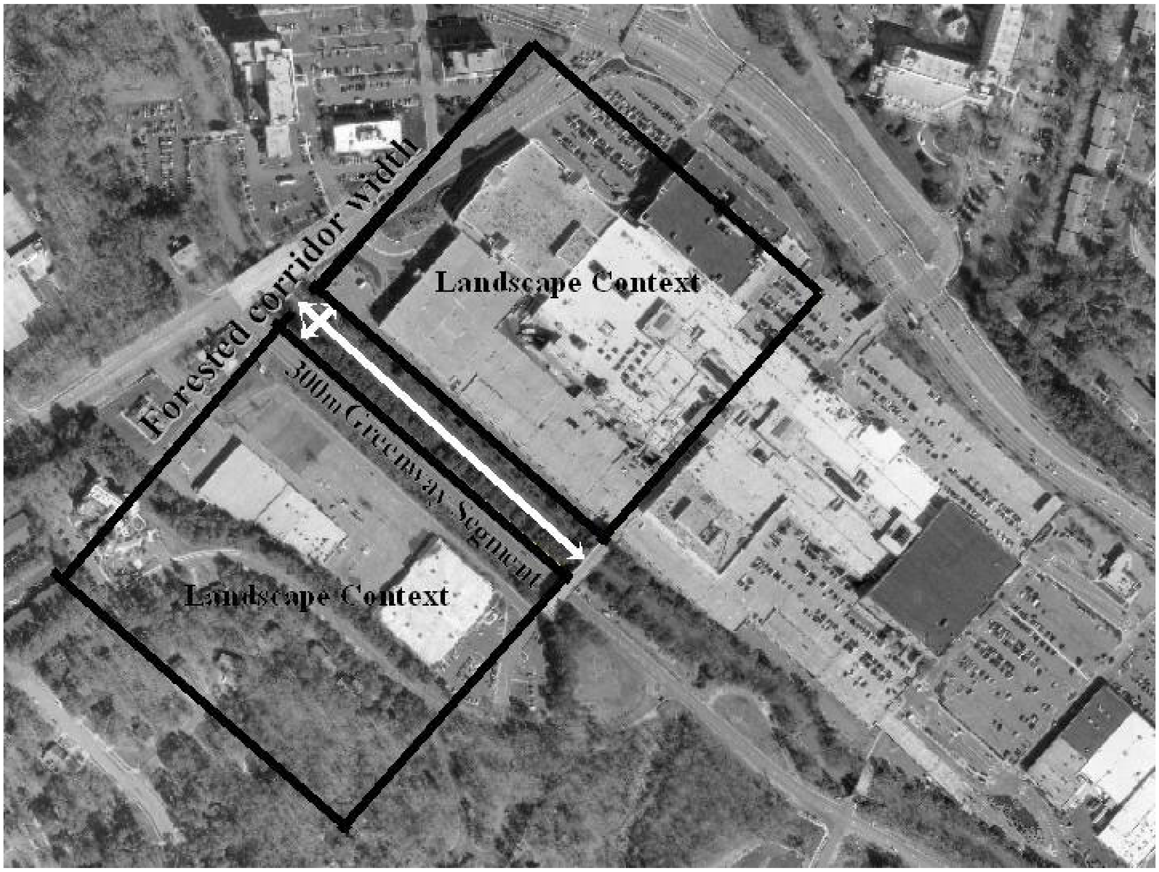
| | | | **Microhabitat Variables** | | | | **Landscape Context Variables** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Breeding Bird Measure** | **$R^2$** | **Intercept** | **%Hardwood** | **Shrubcover** | **Managed%** | **TrailDistance** | **Context Canopy** | **Context Building** | **Context Earth** | **Context Lawn** |
| Total Species Richness | 0 | | | | | | | | | |
| Total Abundance | 0.3821 | 2.44867 | –0.68064<br>p = 0.0117 | +0.18084<br>p = 0.0128 | | | +0.88573<br>p=0.0027 | | | |
| Neotropical Migrant Species Richness | 0.5916 | 2.50158 | | | – 3.13377<br>p = <0.0001 | | | –3.377203<br>p=0.0212 | –20.02917<br>p=0.0142 | |
| Neotropical Migrant Abundance | 0.3953 | 1.10119 | | | –2.34463<br>p = <0.0001 | | | | | |
| Insectivore Species Richness | 0.6586 | 3.90813 | – 0.74364<br>p = 0.0093 | | – 1.75664<br>p = 0.0005 | +0.00218<br>p = 0.0295 | | | | +1.42527<br>p=0.0074 |
| Insectivore Abundance | 0.2874 | 1.94310 | | | | | +1.05598<br>p=0.0011 | | | |
| Forest-Interior Species Richness | 0.4491 | 1.77279 | | | – 2.31272<br>p = 0.0020 | | | –3.25662<br>p=0.0433 | | |
| Forest-Interior Abundance | 0.4642 | 1.09569 | | | – 1.31620<br>p = 0.0022 | | | –2.14164<br>p=0.0217 | | |

# FIGURE CAPTIONS

**Figure 1.** Distribution of greenway study sites in Raleigh and Cary, North Carolina, USA (2002).

**Figure 2.** Forested corridor width and landscape context were measured for each 300m greenway segment using aerial photography in ArcGIS. Width was measured perpendicular to the greenway orientation, and context was measured in two 300mX300m areas on either side of the forested corridor.


Study Sites
RALEIGH
CARY
N
0 1 2 3 4 5 Miles
North
America


Forested corridor width
Landscape Context
300m Greenway Segment
Landscape Context

# CHAPTER 3 APPENDICES

# Appendix 1. Breeding bird species list and guild classifications

| Species | Foraging | Nesting | Migratory | Habitat |
|---|---|---|---|---|
| Acadian Flycatcher | I | C | N | I |
| American Crow | O | C | R | E |
| American Goldfinch | I | S | R | E |
| American Robin | I | C | R | E |
| Belted Kingfisher | C | V | R | W |
| Blue Jay | O | C | R | E |
| Blue-gray Gnatcatcher | I | C | S | IE |
| Brown Thrasher | O | S | R | E |
| Brown-headed Cowbird | O | P | R | E |
| Brown-headed Nuthatch | I | V | R | IE |
| Canada Goose | O | G | R | W |
| Carolina Chickadee | I | V | R | IE |
| Carolina Wren | I | V | R | IE |
| Chipping Sparrow | I | C | R | E |
| Common Grackle | O | S | R | E |
| Downy Woodpecker | I | V | R | IE |
| Eastern Bluebird | I | V | R | O |
| Eastern Towhee | I | S | R | E |
| European Starling | O | V | E | U |
| Fish Crow | O | C | S | IE |
| Gray Catbird | I | S | S | E |
| Great-crested Flycatcher | I | V | N | IE |
| Hairy Woodpecker | I | V | R | I |
| House Finch | O | S | R | U |
| House Sparrow | O | V | E | U |
| House Wren | I | V | R | E |
| Indigo Bunting | I | S | N | E |
| Louisiana Waterthrush | I | G | N | I |
| Mallard | O | G | R | W |
| Mourning Dove | G | S | R | E |
| Northern Cardinal | I | S | R | IE |
| Northern Flicker | I | V | R | E |
| Northern Mockingbird | I | S | R | E |
| Ovenbird | I | G | N | I |
| Pileated Woodpecker | I | V | R | I |
| Pine Warbler | I | C | R | IE |
| Prothonotary Warbler | I | V | N | I |
| Red-bellied Woodpecker | I | V | R | IE |
| Red-eyed Vireo | I | C | N | IE |
| Red-headed Woodpecker | I | V | R | IE |
| Red-shouldered Hawk | C | C | R | I |
| Ruby-throated Hummingbird | N | C | N | IE |
| Scarlet Tanager | I | C | N | I |
| Summer Tanager | I | C | N | IE |
| Tufted Titmouse | I | V | R | IE |
| White-breasted Nuthatch | I | V | R | IE |
| White-eyed Vireo | I | S | S | IE |
| Wood Thrush | I | S | N | I |

**KEY**

| | | | |
|---|---|---|---|
| I = Insectivore | P = Brood Parasite | E = Exotic | E = Edge |
| N = Nectarivore | C = Canopy | N = Neotropical | I = Interior |
| O = Omnivore | G = Ground | R = Resident | IE = Interior-Edge |
| C = Carnivore | S = Shrub | S = Short-distance | O = Open |
| G = Granivore | V = Cavity | | U = Urban |
| | | | W = Water |

## Appendix 2. Breeding bird species lists for study sites

**Beaver Dam 1** (Average Width = 55m, Context Class = LDR):
American Goldfinch, American Robin, Blue Jay, Carolina Chickadee, Carolina Wren, Common Grackle, Gray Catbird, House Finch, House Wren, Northern Cardinal, Northern Flicker, Red-bellied Woodpecker, Red-eyed Vireo, Red-shouldered Hawk, Tufted Titmouse
*Species Richness = 15*

**Beaver Dam 3** (Average Width = 40m, Context Class = HDR):
American Robin, Blue Jay, Brown-headed Nuthatch, Chipping Sparrow, Common Grackle, Eastern Towhee, Gray Catbird, House Wren, Northern Cardinal, Red-bellied Woodpecker
*Species Richness = 10*

**Black Creek 3** (Average Width = 225m, Context Class = OFC/INS)
Acadian Flycatcher, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Great-crested Flycatcher, Northern Cardinal, Red-eyed Vireo, Wood Thrush
*Species Richness = 8*

**Black Creek 5** (Average Width = 162.5m, Context Class = LDR)
Acadian Flycatcher, American Goldfinch, American Robin, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Hairy Woodpecker, Northern Cardinal, Pileated Woodpecker, Red-bellied Woodpecker, Red-eyed Vireo, Tufted Titmouse, Wood Thrush
*Species Richness = 14*

**Black Creek 8** (Average Width = 500m, Context Class = HDR)
Acadian Flycatcher, American Goldfinch, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Hairy Woodpecker, Northern Cardinal, Ovenbird, Red-bellied Woodpecker, Red-eyed Vireo, Summer Tanager, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 13*

**Black Creek 9** (Average Width = 160m, Context Class = HDR)
American Goldfinch, Carolina Chickadee, Carolina Wren, Chipping Sparrow, Downy Woodpecker, Eastern Towhee, Gray Catbird, House Wren, Northern Cardinal, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch, Wood Thrush
*Species Richness = 13*

**Crabtree 1** (Average Width = 40m, Context Class = OFC/INS)
American Crow, American Goldfinch, American Robin, Canada Goose, Carolina Chickadee, Gray Catbird, House Finch, Northern Cardinal, Tufted Titmouse
*Species Richness = 9*

**Crabtree 2** (Average Width = 32.5m, Context Class = OFC/INS)
American Crow, American Goldfinch, American Robin, Canada Goose, Carolina Chickadee, Common Grackle, Fish Crow, House Finch, Mallard, Mourning Dove, Northern Cardinal
*Species Richness = 11*

**Crabtree 3** (Average Width = 40m, Context Class = OFC/INS)
American Goldfinch, American Robin, Carolina Wren, Common Grackle, European Starling, Gray Catbird, House Finch, House Sparrow, Mourning Dove, Northern Cardinal
*Species Richness = 10*

**Durant 1** (Average Width = 50m, Context Class = LDR)
American Crow, American Robin, Brown-headed Cowbird, Brown-headed Nuthatch, Brown Thrasher, Blue Jay, Carolina Chickadee, Carolina Wren, Common Grackle, Chipping Sparrow, Eastern Towhee, European Starling, House Finch, House Wren, Northern Cardinal, Northern Flicker, Northern Mockingbird, Red-bellied Woodpecker, Red-headed Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 21*

**Durant 2** (Average Width = 50m, Context Class = OFC/INS)
American Goldfinch, American Robin, Brown-headed Nuthatch, Carolina Chickadee, Carolina Wren, Common Grackle, Chipping Sparrow, Eastern Towhee, European Starling, Gray Catbird, Great-crested Flycatcher, Mourning Dove, Northern Cardinal, Northern Mockingbird, Red-bellied Woodpecker, Red-headed Woodpecker, White-breasted Nuthatch
*Species Richness = 17*

**Durant 3** (Average Width = 80m, Context Class = HDR)
American Goldfinch, American Robin, Blue-gray Gnatcatcher, Brown Thrasher, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Common Grackle, Chipping Sparrow, Eastern Bluebird, Fish Crow, House Wren, Mourning Dove, Northern Cardinal, Northern Flicker, Pileated Woodpecker, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 18*

**Gardner 1** (Average Width = 35m, Context Class = HDR)
American Goldfinch, American Robin, Brown-headed Cowbird, Blue Jay, Carolina Chickadee, Carolina Wren, Common Grackle, European Starling, House Finch, House Wren, Mourning Dove, Northern Cardinal, Northern Flicker, Pine Warbler, Red-bellied Woodpecker, White-breasted Nuthatch
*Species Richness = 16*

**Hinshaw 2** (Average Width = 160m, Context Class = LDR)
American Robin, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Eastern Towhee, Gray Catbird, Great-crested Flycatcher, Indigo Bunting, Northern Cardinal, Red-bellied Woodpecker, Red-eyed Vireo, Tufted Titmouse, White-breasted Nuthatch, Wood Thrush
*Species Richness = 16*

**Ironwood 2** (Average Width = 182.5m, Context Class = LDR)
Acadian Flycatcher, American Goldfinch, American Robin, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Eastern Towhee, Great-crested Flycatcher, Indigo Bunting, Mourning Dove, Northern Cardinal, Northern Flicker, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch, Wood Thrush
*Species Richness = 17*

**Loblolly 3** (Average Width = 1300m, Context Class = LDR)
American Robin, Brown-headed Cowbird, Blue Jay, Carolina Chickadee, Carolina Wren, Common Grackle, Great-crested Flycatcher, Indigo Bunting, Northern Cardinal, Northern Flicker, Pileated Woodpecker, Pine Warbler, Red-bellied Woodpecker, Red-eyed Vireo, Red-headed Woodpecker, Red-shouldered Hawk, Scarlet Tanager, Tufted Titmouse, Wood Thrush
*Species Richness = 19*

**Lower Walnut 1** (Average Width = 400m, Context Class = OFC/INS)
American Goldfinch, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Eastern Towhee, Fish Crow, Indigo Bunting, Northern Cardinal, Pileated Woodpecker, Red-bellied Woodpecker, Red-eyed Vireo, Tufted Titmouse, White-eyed Vireo
*Species Richness = 14*

**Lower Walnut 2** (Average Width = 650m, Context Class = OFC/INS)
Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Common Grackle, Downy Woodpecker, Eastern Towhee, Gray Catbird, Northern Cardinal, Prothonotary Warbler, Red-eyed Vireo, Tufted Titmouse
*Species Richness = 11*

**Neuse 6** (Average Width = 600m, Context Class = LDR)
Acadian Flycatcher, American Crow, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Indigo Bunting, Northern Cardinal, Pine Warbler, Red-bellied Woodpecker, Red-eyed Vireo, Red-shouldered Hawk, Ruby-throated Hummingbird, Tufted Titmouse
*Species Richness = 14*

**North Hills 3** (Average Width = 210m, Context Class = OFC/INS)
American Goldfinch, American Robin, Belted Kingfisher, Blue-gray Gnatcatcher, Blue Jay, Canada Goose, Carolina Wren, Downy Woodpecker, European Starling, Indigo Bunting, Gray Catbird, House Finch, Mallard, Northern Cardinal, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 17*

**North Hills 4** (Average Width = 135m, Context Class = OFC/INS)
Acadian Flycatcher, American Goldfinch, American Robin, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Common Grackle, Indigo Bunting, Mallard, Northern Cardinal, Pileated Woodpecker, Red-bellied Woodpecker, Red-eyed Vireo, Ruby-throated Hummingbird, Summer Tanager, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 18*

**Oak Park 1** (Average Width = 200m, Context Class = OFC/INS)
Acadian Flycatcher, American Robin, Belted Kingfisher, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Wren, Eastern Towhee, House Finch, Indigo Bunting, Northern Cardinal, Red-eyed Vireo, Tufted Titmouse
*Species Richness = 12*

**Oak Park 2** (Average Width = 150m, Context Class = HDR)
Acadian Flycatcher, American Goldfinch, American Robin, Belted Kingfisher, Blue Jay, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Common Grackle, Downy Woodpecker, Eastern Towhee, Great-crested Flycatcher, Hairy Woodpecker, Mallard, Northern Cardinal, Red-bellied Woodpecker, Red-eyed Vireo, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 20*

**Parkway 1** (Average Width = 77.5m, Context Class = OFC/INS)
American Robin, Blue-gray Gnatcatcher, Brown-headed Cowbird, Brown-headed Nuthatch, Carolina Chickadee, Carolina Wren, Common Grackle, Eastern Towhee, Fish Crow, Gray Catbird, House Finch, House Wren, Mourning Dove, Northern Cardinal, Northern Mockingbird, Red-headed Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 18*

**Pirate's Cove 1** (Average Width = 150, Context Class = HDR)
American Goldfinch, American Robin, Blue Jay, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Eastern Towhee, Great-crested Flycatcher, Northern Cardinal, Red-eyed Vireo, Tufted Titmouse, Red-bellied Woodpecker, White-breasted Nuthatch
*Species Richness = 13*

**Pirate's Cove 2** (Average Width = 152.5, Context Class = HDR)
American Robin, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Downy Woodpecker, House Wren, Northern Cardinal, Red-eyed Vireo, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 10*

**Pirate's Cove 3** (Average Width = 150, Context Class = LDR)
American Goldfinch, American Robin, Blue Jay, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Common Grackle, Eastern Towhee, Gray Catbird, Hairy Woodpecker, Northern Cardinal, Tufted Titmouse, White-breasted Nuthatch, Wood Thrush
*Species Richness = 14*

**Sawmill 2** (Average Width = 100, Context Class = LDR)
Acadian Flycatcher, American Goldfinch, American Robin, Blue Jay, Blue-gray Gnatcatcher, Carolina Chickadee, Carolina Wren, Great-crested Flycatcher, House Wren, Northern Cardinal, Red-bellied Woodpecker, Red-eyed Vireo, Red-shouldered Hawk, Ruby-throated Hummingbird, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 16*

**Swift Creek 3** (Average Width = 405, Context Class = OFC/INS)
American Robin, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Common Grackle, Downy Woodpecker, Louisiana Waterthrush, Great-crested Flycatcher, Northern Cardinal, Red-bellied Woodpecker, Red-eyed Vireo, Summer Tanager, Tufted Titmouse, White-eyed Vireo
*Species Richness = 15*

**Tarbert 1** (Average Width = 85, Context Class = LDR)
American Robin, Blue Jay, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Eastern Towhee, Great-crested Flycatcher, Northern Cardinal, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 13*

**Tarbert 2** (Average Width = 137.5, Context Class = HDR)
American Crow, American Goldfinch, Carolina Chickadee, Carolina Wren, Chipping Sparrow, Downy Woodpecker, Eastern Towhee, Great-crested Flycatcher, House Finch, Northern Cardinal, Red-bellied Woodpecker, Red-eyed Vireo, Tufted Titmouse, White-breasted Nuthatch, Wood Thrush
*Species Richness = 15*

**White Oak 1** (Average Width = 127.5, Context Class = HDR)
American Goldfinch, Carolina Chickadee, Carolina Wren, Downy Woodpecker, Gray Catbird, Northern Cardinal, Northern Mockingbird, Red-bellied Woodpecker, Tufted Titmouse, Wood Thrush
*Species Richness = 10*

**White Oak 4** (Average Width = 130, Context Class = HDR)
American Goldfinch, American Robin, Blue-gray Gnatcatcher, Brown-headed Cowbird, Carolina Wren, Chipping Sparrow, Common Grackle, Eastern Bluebird, Eastern Towhee, House Finch, Northern Cardinal, Red-bellied Woodpecker, Tufted Titmouse, White-breasted Nuthatch
*Species Richness = 14*

**White Oak 1** (Average Width = 85, Context Class = OFC/INS)
American Goldfinch, Blue Jay, Brown-headed Cowbird, Carolina Wren, Common Grackle, Eastern Towhee, European Starling, Gray Catbird, House Finch, Northern Cardinal, Northern Mockingbird, Red-bellied Woodpecker, Tufted Titmouse
*Species Richness = 13*

## Appendix 3. Additional bird species recorded in greenways during spring migration, 2002.

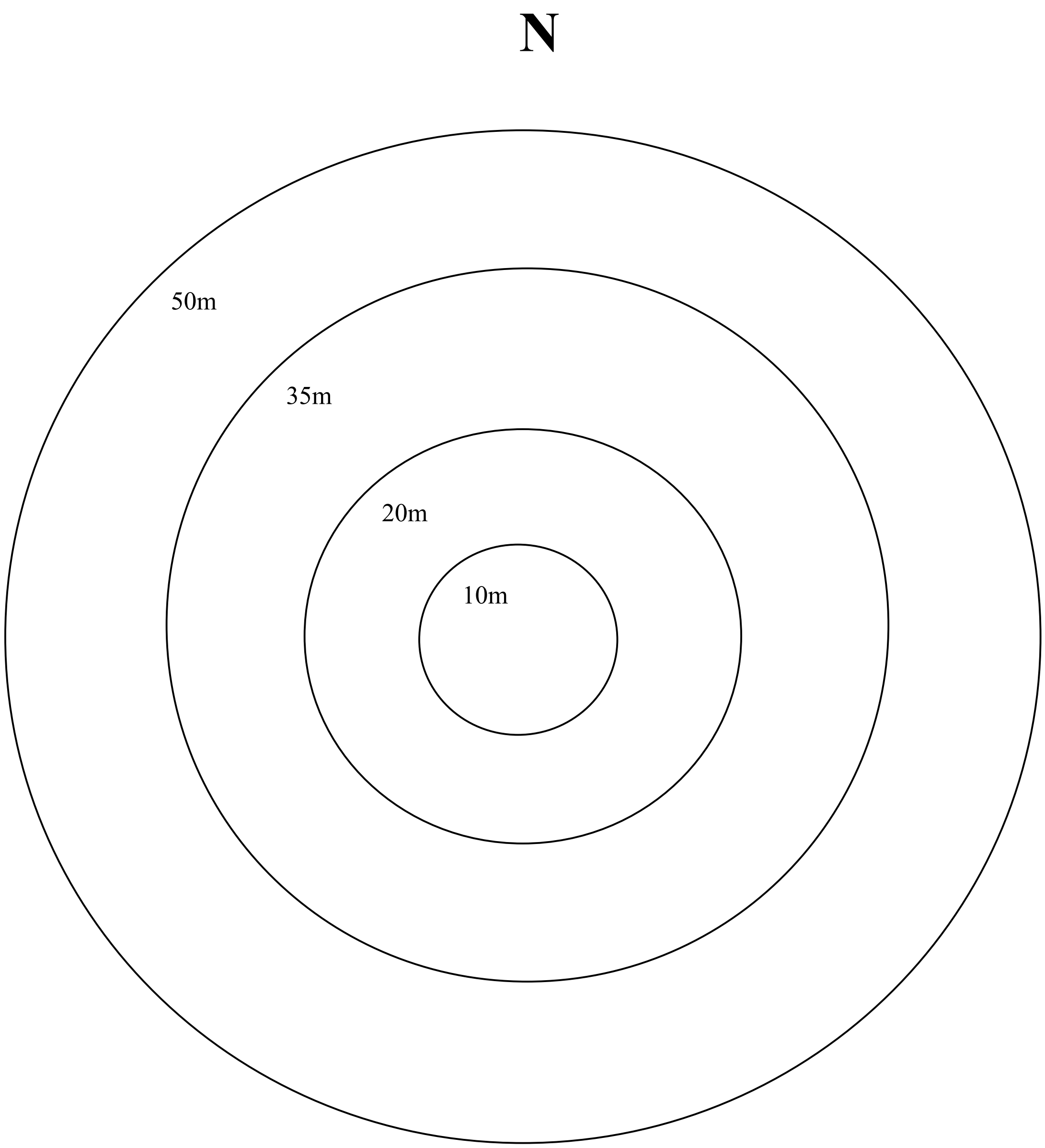
American Redstart (*Setophaga ruticilla*)
Baltimore Oriole (*Icterus galbula*)
Barred Owl (*Strix varia*)
Black-and-white Warbler (*Mnoitilta varia*)
Blackpoll Warbler (*Dendroica striata*)
Black-throated Blue Warbler (*Dendroica caerulescens*)
Broad-winged Hawk (*Buteo platypterus*)
Cedar Waxwing (*Bombycilla garrulus*)
Chestnut-sided Warbler (*Dendroica pensylvanica*)
Common Yellowthroat (*Geothlypis trichas*)
Eastern Kingbird (*Tyrannus tyrannus*)
Eastern Phoebe (*Sayornis phoebe*)
Eastern Wood-pewee (*Contopus virens*)
Field Sparrow (*Spizella pusilla*)
Great Blue Heron (*Ardea herodias*)
Hermit Thrush (*Catharus guttatus*)
Hooded Warbler (*Wilsonia citrine*)
Killdeer (*Charadrius vociferus*)
Northern Parula (*Parula americana*)
Orchard Oriole (*Icterus spurious*)
Prairie Warbler (*Dendroica discolor*)
Red-tailed Hawk (*Buteo jamaicensis*)
Ruby-crowned Kinglet (*Regulus calendula*)
Veery (*Catharus fuscescens*)
White-throated Sparrow (*Zonotrichia albicollis*)
Wood Duck (*Aix sponsa*)
Yellow Warbler (*Dendroica petechia*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Yellow-breasted chat (*Icteria virens*)
Yellow-rumped Warbler (*Dendroica coronata*)
Yellow-throated Vireo (*Vireo flavifrons*)
Yellow-throated Warbler (*Dendroica dominica*)

## Appendix 4. Point count data sheet

| Date: | Observer: | Site: |
|---|---|---|
| **Begin Time:** | **End Time:** | **Air Temperature:** |

**Weather Conditions: circle appropriate codes**

| Code | Sky Condition | Code | Wind Condition |
|---|---|---|---|
| 0 | Clear or only a few clouds | 0 | < 1 mph; smoke rises vertically |
| 1 | Partly cloudy or variable | 1 | 1-3 mph; smoke drifts with wind |
| 2 | Broken clouds or overcast | 2 | 4-7 mph; wind felt on face, leaves rustle |
| 3 | Fog | 3 | 8-12 mph; leaves and small twigs in constant motion |
| 4 | Drizzle (DON'T SURVEY) | 4 | 13-18 mph; moves small branches, raises dust and looses paper (TOO WINDY TO SURVEY) |
| 5 | Showers (DON'T SURVEY) | 5 | 19-24 mph, small trees in leaf sway (TOO WINDY) |



## Appendix 5. Vegetation and composition data sheet

Segment Name ____________________________________________

Location of circle: flag / other

Date __________ Observer(s) ____________________ Photos # __________

Verbal description of circle (i.e. topographic position, disturbance, context):

___________________________________________

___________________________________________

___________________________________________

Trail Yes No

Surface type __________

Distance circle center to trail edge __________ m

Trail width __________ m

Managed width __________ m

Stream Yes No

Distance circle center to stream edge __________ m

Snag Count (50m-radius): __________

| | Mature forest | Young forest | Managed area | Stream | Other |
|---|---|---|---|---|---|
| % of total area | | | | Width = m | |

| | | |
|---|---|---|
| Canopy cover | L | |
| (384-L) | D | |
| % pine | | |
| % hardwood | | |
| Canopy height (m) | | |
| Vine cover index (0-5) | | |
| Shrub density index (0-5) | | |
| Ground cover density index (0-5) | | |

| | |
|---|---|
| Management type | |
| Predominant ground cover | |
| Average veg. height | |

Young Forest:

| |
|---|
| Vine |
| Shrub |
| Ground |

## Appendix 6. Study site coordinates

| Study Site | Longitude | Latitude |
|---|---|---|
| Beaver Dam 1 | -78.672491 | 35.812266 |
| Beaver Dam 3 | -78.674577 | 35.805355 |
| Black Creek 3 | -78.787730 | 35.826051 |
| Black Creek 5 | -78.785491 | 35.816246 |
| Black Creek 8 | -78.791160 | 35.809319 |
| Black Creek 9 | -78.788960 | 35.805351 |
| Crabtree Valley 1 | -78.682577 | 35.840313 |
| Crabtree Valley 2 | -78.680000 | 35.838468 |
| Crabtree Valley 3 | -78.674472 | 35.836991 |
| Durant 1 | -78.592202 | 35.904286 |
| Durant 2 | -78.589502 | 35.900966 |
| Durant 3 | -78.586688 | 35.896861 |
| Gardner Street 1 | -78.668327 | 35.795727 |
| Hinshaw 2 | -78.768767 | 35.759822 |
| Ironwood 2 | -78.664258 | 35.850589 |
| Loblolly 3 | -78.731823 | 35.819510 |
| Lower Walnut Creek 1 | -78.617255 | 35.761509 |
| Lower Walnut Creek 2 | -78.621260 | 35.758544 |
| Neuse River 6 | -78.538763 | 35.779050 |
| North Hills 3 | -78.665388 | 35.838250 |
| North Hills 4 | -78.670327 | 35.838641 |
| Oak Park 1 | -78.686697 | 35.844205 |
| Oak Park 2 | -78.694366 | 35.845583 |
| Parkway 3 | -78.835738 | 35.778425 |
| Pirates' Cove 1 | -78.762528 | 35.761342 |
| Pirates' Cove 2 | -78.763356 | 35.758092 |
| Pirates' Cove 3 | -78.762097 | 35.755646 |
| Sawmill 2 | -78.654122 | 35.876222 |
| Swift Creek 3 | -78.780784 | 35.723991 |
| Tarbert-Gatehouse 1 | -78.814538 | 35.761139 |
| Tarbert-Gatehouse 2 | -78.812781 | 35.758169 |
| White Oak 1 | -78.869797 | 35.778990 |
| White Oak 4 | -78.857443 | 35.774995 |
| White Oak 5 | -78.851897 | 35.775633 |

## Appendix 7. SAS code used in regression analysis

```
* Read excel file into SAS;
PROC IMPORT OUT= WORK.birds
DATAFILE= "A:\gw_data1.xls"
DBMS=EXCEL2000 REPLACE;
GETNAMES=YES;
run;
* Clean up data;
Data gwbirds;
set birds;
if _N_ > 148 then delete;
run;
* Keep only replicate one;
data gwbirds1;
set gwbirds;
where replicate=1;
run;
*Delete duplicate trails and transform species richness data;
data gwbirds2;
set gwbirds1;
if ID = 12 then delete;
if ID = 27 then delete;
if ID = 30 then delete;
sqrtNeotropical___corrected = sqrt(Neotropical___corrected);
sqrtInsectivore___Total__corr = sqrt(Insectivore___Total__corrected_);
sqrtInterior___corrected = sqrt(Interior___corrected);
sqrtNeotrop_naive = sqrt (Neotropical___na_ve);
sqrtInsectivore_naive = sqrt(Insectivore___Total__na_ve_);
sqrtInterior_naive = sqrt(Interior___na_ve);
sqrtCanopy = sqrt(Canopy___corrected);
sqrtCanopy_naive = sqrt(Canopy___na_ve);
sqrtShrub = sqrt(Shrub___corrected);
sqrtShrub_naive = sqrt(Shrub___na_ve);
sqrtGround = sqrt(Ground);
sqrtSppRich_corrected = sqrt(Corrected_Spp_Richness);
canopy_width=Average_Width__m_* __Canopy;
building_width=Average_Width__m_*__Building;
paved_width=Average_Width__m_*__paved;
run;
*Perform preliminary regression analysis for Neotropical Migrant
Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtNeotropical___corrected = Context_class Average_Width__m_ /
solution;
run;
*Plot Width vs. Neotropical Corrected Species Richness;
proc gplot data=gwbirds2;
plot  sqrtNeotropical___corrected * Average_Width__m_;
plot  Neotropical___corrected * Average_Width__m_;
run;
*Examine Residuals;
proc reg data=gwbirds2;
```

```
model Neotropical___corrected = Average_Width__m_ / r influence dw
partial;
output out=residuals rstudent=rstar h=v cookd=cookd dffits=dffits
covratio=covratio;
plot (rstudent. )*p.;
plot (rstudent. )*nqq.;
run;
*Regression for Neotropical Migrant Species Richness all with
Covariates;
proc reg data=gwbirds2;
model sqrtNeotropical___corrected =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___  StrmWidth
CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtNeotropical___corrected =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtNeotropical___corrected =  MatureFor___ YoungFor___
CanHeight __Earth;
run;
*Regression for NAIVE Neotropical Migrant Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtNeotrop_naive = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
model sqrtNeotrop_naive = MatureFor___ YoungFor___
CanHeight  __Earth ;
run;
*Regression for Insectivore Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtInsectivore___Total__corr = Context_class Average_Width__m_ /
solution;
run;
proc reg data=gwbirds2;
model sqrtInsectivore___Total__corr =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover  Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtInsectivore___Total__corr =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
```

```
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtInsectivore___Total__corr =  TrailWidth Managed___
PercentHardwood __Canopy ;
run;
*Regression for NAIVE Insectivore Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtInsectivore_naive = Context_class Average_Width__m_ /
solution;
run;
proc reg data=gwbirds2;
model sqrtInsectivore_naive =
MatureFor___  Managed___   PercentHardwood  __Lawn __Earth ;
run;
*Regression for Interior Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtInterior___corrected = Context_class Average_Width__m_ /
solution e;
run;
proc reg data=gwbirds2;
model sqrtInterior___corrected =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtInterior___corrected =
Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood CanHeight Vinecover Shrubcover
Groundcover __Canopy __Building __Paved __Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtInterior___corrected =  __Building  Snags;
run;
proc glm data=gwbirds2;
class Context_Class;
model sqrtInterior___corrected =  Context_Class PercentHardwood   Snags
/ solution e;
run;
*Regression for NAIVE Interior Species Richness;
proc reg data=gwbirds2;
model sqrtInterior_naive = Average_Width__m_ TrailWidth __Earth __Paved
Snags  __Building;
run;
*Regression for Canopy-nesting Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtCanopy = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
```

```
model sqrtCanopy = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover  _Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtCanopy = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtCanopy = TrailDist StreamDist Snags  Wetland___ StrmWidth
Groundcover __Earth;
run;
*Regression for NAIVE Canopy-nesting Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtCanopy_naive = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
model sqrtCanopy_naive =  StreamDist Snags   Wetland___ StrmWidth
Groundcover __Earth ;
run;
*Regression for Shrub-nesting Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtShrub = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
model sqrtShrub = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover  _Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtShrub = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtShrub =  __Canopy StrmWidth  Vinecover;
run;
*Regression for NAIVE Shrub-nesting Species Richness;
proc glm data=gwbirds2;
class Context_Class;
model sqrtShrub_naive = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
model sqrtShrub_naive = PercentHardwood Vinecover Shrubcover __Canopy;
run;
*Regression for Ground Species Richness;
```

```
proc glm data=gwbirds2;
class Context_Class;
model sqrtGround = Context_class Average_Width__m_ / solution;
run;
proc reg data=gwbirds2;
model sqrtGround = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover   Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds2;
model sqrtGround = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds2;
model sqrtGround = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags  Wetland___ StrmWidth  CanHeight Groundcover  __Lawn
__Water  __Earth;
run;
* Correlation Analysis with Covariates;
proc corr data=gwbirds2;
var Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn;
run;
* Correlation Analysis with All Variables;
proc corr data=gwbirds2;
var Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn
Neotropical___corrected Insectivore___Total__corrected_
Neotropical___na_ve Insectivore___Total__na_ve_ Interior___na_ve
Canopy___corrected Canopy___na_ve Shrub___corrected Shrub___na_ve
Interior___corrected Ground;
run;
* Computing means over the four visits;
proc sort data=Gwbirds;
by id;
proc means data=Gwbirds;
by id;
id Greenway trail Context_class;
output out=birdmeans mean=;
run;
* Delete duplicate trails and transform abundance data;
data gwbirds3;
set birdmeans;
drop  type   freq ;
if ID = 12 then delete;
if ID = 27 then delete;
```

```
if ID = 30 then delete;
sqrtNeotrop_ab = sqrt(Neotrop_ab);
sqrtInsectivore_ab = sqrt(Insectivore_ab);
sqrtInterior_ab = sqrt(Interior_ab);
sqrtTotal_ab = sqrt(Total_Abundance);
sqrtShrub_ab = sqrt(Shrub_ab);
sqrtCanopy_ab = sqrt(Canopy_ab);
run;
* Correlation Analysis with All Variables;
proc corr data=gwbirds3;
var Average_Width__m_ TrailDist TrailWidth ManagWidth StreamDist
Snags MatureFor___ YoungFor___ Managed___ Stream___ Wetland___
StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn Neotrop_ab Insectivore_ab Interior_ab Blue_gray_Gnatcatcher
Brown_headed_Nuthatch Ovenbird Red_headed_Woodpecker Northern_Flicker
Eastern_Towhee Gray_Catbird Wood_Thrush Acadian_Flycatcher Shrub_ab
Canopy_ab;
run;
* Regression for Neotropical Migrant Abundance;
proc glm data=gwbirds3;
class Context_Class;
model sqrtNeotrop_ab =  Average_Width__m_ Context_Class / solution e;
run;
proc reg data=gwbirds3;
model sqrtNeotrop_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds3;
model sqrtNeotrop_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds3;
model sqrtNeotrop_ab = Snags PercentHardwood Vinecover;
run;
* Regression for Insectivore Abundance;
proc glm data=gwbirds3;
class Context_Class;
model sqrtInsectivore_ab = Average_Width__m_ Context_Class  / solution
e;
run;
proc reg data=gwbirds3;
model sqrtInsectivore_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds3;
```

```
model sqrtInsectivore_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
  Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds3;
model sqrtInsectivore_ab =  StreamDist   Wetland___ Vinecover __Paved
  Earth;
run;
* Regression for Interior Species Abundance;
proc glm data=gwbirds3;
class Context_Class;
model sqrtInterior_ab =  Average_Width__m_ Context_Class / solution e;
run;
proc reg data=gwbirds3;
model sqrtInterior_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds3;
model sqrtInterior_ab = Average_Width__m_ TrailDist TrailWidth
ManagWidth StreamDist Snags MatureFor___ YoungFor___ Managed___
Stream___ Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds3;
model sqrtInterior_ab =    Managed___  __Building;
run;
* Regression for Shrub-nesting abundance;
proc glm data=gwbirds3;
class Context_Class;
model sqrtShrub_ab =  Average_Width__m_ Context_Class  / solution e;
run;
proc reg data=gwbirds3;
model sqrtShrub_ab = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds3;
model sqrtShrub_ab = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
  Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds3;
model sqrtShrub_ab = MatureFor___ CanHeight Vinecover Shrubcover ;
run;
* Regression for Canopy-nesting abundance;
proc glm data=gwbirds3;
class Context_Class;
```

```
model sqrtCanopy_ab =  Average_Width__m_ Context_Class  / solution e;
run;
proc reg data=gwbirds3;
model sqrtCanopy_ab = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth / selection=b SLS=.05;
run;
proc rsquare data=gwbirds3;
model sqrtCanopy_ab = Average_Width__m_ TrailDist TrailWidth ManagWidth
StreamDist Snags MatureFor___ YoungFor___ Managed___ Stream___
Wetland___ StrmWidth CanopyCov___  PercentHardwood
CanHeight Vinecover Shrubcover Groundcover __Canopy __Building __Paved
__Lawn __Water __Ag __Earth;
run;
proc reg data=gwbirds3;
model sqrtCanopy_ab =  StrmWidth __Canopy  Groundcover PercentHardwood;
run;
*Final Regression for Neotropical Migrant Species Richness with reduced
set of variables;
proc reg data=gwbirds2;
model sqrtNeotropical___corrected = Average_Width__m_ TrailDist
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood CanHeight Vinecover Shrubcover Groundcover __Canopy
__Building __Paved __Lawn __Earth __Ag __Water / selection=b SLS=.05;
run;
*Final Regression for Neotropical Migrant Abundance with reduced set of
variables;
proc reg data=gwbirds3;
model sqrtNeotrop_ab = Average_Width__m_ TrailDist
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood  CanHeight Vinecover Shrubcover Groundcover __Canopy
__Building __Paved __Lawn __Ag __Water / selection=b SLS=.05;
run;
*Final Regression for Insectivore Species Richness with reduced set of
variables;
proc reg data=gwbirds2;
model sqrtInsectivore___Total__corr = Average_Width__m_ TrailDist
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood  CanHeight Vinecover Shrubcover Groundcover  __Canopy
__Building __Paved __Lawn __Earth __Ag __Water / selection=b SLS=.05;
run;
*Final Regression for Insectivore Abundance with reduced set of
variables;
proc reg data=gwbirds3;
model sqrtInsectivore_ab = Average_Width__m_ TrailDist
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood CanHeight Vinecover Shrubcover Groundcover __Canopy
__Building __Paved __Lawn __Ag __Water / selection=b SLS=.05;
run;
*Final Regression for Interior Species Richness with reduced set of
variables;
proc reg data=gwbirds2;
model sqrtInterior___corrected = Average_Width__m_ TrailDist
```

```
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood  CanHeight Vinecover Shrubcover Groundcover __Canopy
__Building __Paved __Lawn __Earth __Ag __Water / selection=b SLS=.05;
run;
*Final Regression for Interior Abundance with reduced set of variables;
proc reg data=gwbirds3;
model sqrtInterior_ab = Average_Width__m_ TrailDist
YoungFor___ Managed___  Wetland___ StrmWidth CanopyCov___
PercentHardwood CanHeight Vinecover Shrubcover Groundcover   Canopy
__Building __Paved __Lawn __Ag __Water / selection=b SLS=.05;
run;
```