Available online at www.sciencedirect.com
ScienceDirect
Landscape and Urban Planning 80 (2007) 153–164
LANDSCAPE AND URBAN PLANNING
This article is also available online at:
www.elsevier.com/locate/landurbplan

Designing suburban greenways to provide habitat for forest-breeding birds

Jamie Mason [1], Christopher Moorman *, George Hess, Kristen Sinclair [2]

Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695, USA

Received 6 March 2006; received in revised form 25 May 2006; accepted 10 July 2006
Available online 22 August 2006

Abstract

Appropriately designed, greenways may provide habitat for neotropical migrants, insectivores, and forest-interior specialist birds that decrease in diversity and abundance as a result of suburban development. We investigated the effects of width of the forested corridor containing a greenway, adjacent land use and cover, and the composition and vegetation structure within the greenway on breeding bird abundance and community composition in suburban greenways in Raleigh and Cary, North Carolina, USA. Using 50 m fixed-radius point counts, we surveyed breeding bird communities for 2 years at 34 study sites, located at the center of 300-m-long greenway segments.

Percent coverage of managed area within the greenway, such as trail and other mowed or maintained surfaces, was a predictor for all development-sensitive bird groupings. Abundance and richness of development-sensitive species were lowest in greenway segments containing more managed area. Richness and abundance of development-sensitive species also decreased as percent cover of pavement and bare earth adjacent to greenways increased. Urban adaptors and edge-dwelling birds, such as Mourning Dove, House Wren, House Finch, and European Starling, were most common in greenways less than 100 m wide. Conversely, forest-interior species were not recorded in greenways narrower than 50 m. Some forest-interior species, such as Acadian Flycatcher, Hairy Woodpecker, and Wood Thrush, were recorded primarily in greenways wider than 100 m. Others, including ground nesters such as Black-and-white Warbler, Louisiana Waterthrush, and Ovenbird, were recorded only in greenways wider than 300 m.

Landscape and urban planners can facilitate conservation of development-sensitive birds in greenways by minimizing the width of the trail and associated mowed and landscaped surfaces adjacent to the trail, locating trails near the edge of greenway forest corridors, and giving priority to the protection of greenway corridors at least 100 m wide with low levels of impervious surface (pavement, buildings) and bare earth in the adjacent landscape.

Keywords: Breeding birds; Corridor width; Forested greenways; North Carolina; Urban planning

1. Introduction

There is increasing recognition that landscapes dominated by human populations cannot be ignored in the quest to conserve biodiversity (Dale et al., 2000; Miller and Hobbs, 2002). Most of the increase in human population for the coming decades is expected to occur in and around urban areas (United Nations, 2004). Some 150 major cities around the world are located near biodiversity hotspots (Myers, 1990; Cincotta and Engelman, 2000), and in the United States urbanization is a primary cause for species decline (Czech et al., 2000). As human populations spread, people convert forests, grasslands, and wetlands into developed landscapes of residential, commercial, institutional, or industrial buildings and associated infrastructure. This land use change alters wildlife habitat and can lead to endangerment and local extinction of numerous species (Dale et al., 2000; Miller and Hobbs, 2002).

Native bird species richness typically declines as the density of human development increases (Nilon et al., 1994; Friesen et al., 1995; Savard et al., 2000). These effects are seen in areas developed at even relatively low "exurban" densities (<0.25 houses/ha) and become increasingly apparent at suburban (2.5–10 houses/ha) and urban (>10 houses/ha) levels (Lancaster and Rees, 1979; Beissinger and Osborne,

* Corresponding author at: Department of Forestry and Environmental Resources, Campus Box 8003, North Carolina State University, Raleigh, NC 27695-8003, USA. Tel.: +1 919 515 5578; fax: +1 919 515 6883.
E-mail address: chris_moorman@ncsu.edu (C. Moorman).
[1] Present address: 1262 Avon Street N., St Paul, MN 55117, USA.
[2] Present address: The North Carolina Natural Heritage Program, NCDENR, 1601 Mail Service Center, Raleigh, NC 27699-1601, USA.

0169-2046/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.landurbplan.2006.07.002

1982; DeGraff, 1987; Blair, 1996, 2004; Melles et al., 2003; Fraterrigo and Wiens, 2005). As development density and habitat fragmentation increase, bird community structure shifts from development-sensitive specialists to development-adaptive generalists (Nilon et al., 1994). Bird communities in urban environments are characterized by high abundances of exotic species, resident granivores and omnivores, and few insectivorous, migrant species. 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 in developed landscapes.

Greenways have become a popular means of mitigating some of the negative effects of development, with hundreds of projects completed or underway in North America (Searns, 1995; Jongman and Pungetti, 2004; Bryant, 2006). "Greenway" is a generic term used to refer to linear protected lands composed of natural vegetation, or at least vegetation that is more natural than in surrounding areas (Smith and Helmund, 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; Jongman and Pungetti, 2004). Although often stated as a benefit of greenways in urban and suburban settings, the contribution of greenways to wildlife conservation is unclear (Schiller and Horn, 1997; Sinclair et al., 2005). If urban and landscape planners are to successfully incorporate the needs of wildlife into greenway planning, design, and management, they must know which characteristics and environmental factors contribute to a greenway's wildlife habitat value. Ecologists and conservation biologists can play an important role in this endeavor by conducting research on wildlife–greenway relationships and disseminating their findings among land use planners (Miller and Hobbs, 2000; Broberg, 2003; Jongman and Pungetti, 2004).

Research to date suggests that greenway width, habitat quality within the greenway, and adjacent land use and cover are likely the dominant factors affecting a greenway's value as wildlife habitat (Schiller and Horn, 1997; Rottenborn, 1999; Manifold, 2001; Rodewald and Bakermans, 2006). In the United States, these factors are regulated, to varying degrees, by municipal and county governments through planning and zoning processes. Research findings on the effect of these factors on the quality of wildlife habitat can be applied by governments and other organizations during the planning, design, and management of greenways, and when designating adjacent zoning districts.

Our objectives were (1) to determine how forested corridor width, adjacent land use and cover, and greenway vegetation structure and composition affect avian community composition in greenways, and (2) to develop recommendations for the design and management of urban greenways as habitat for development-sensitive birds such as neotropical migrants, insectivores, and forest-interior specialists.

2. Methods

2.1. Study area

We studied greenways in the cities of Raleigh and Cary, North Carolina, USA (Fig. 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 forest–agriculture mosaic. In recent decades, population growth within the region has resulted in urban and suburban growth, replacing forests and fields with residential, commercial, institutional, and industrial development and infrastructure. The urban population in the region increased by 200%, and the area of urbanized land increased by 900% during 1950–1990 (North Carolina Chapter of the American Planning Association, 2002).

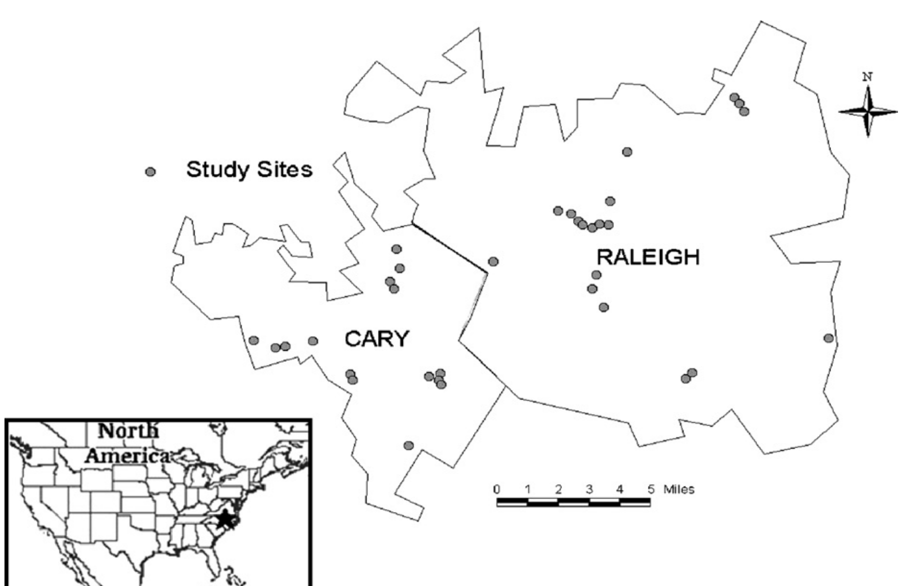

Fig. 1. Distribution of greenway segments in Raleigh and Cary, North Carolina, USA (2002).

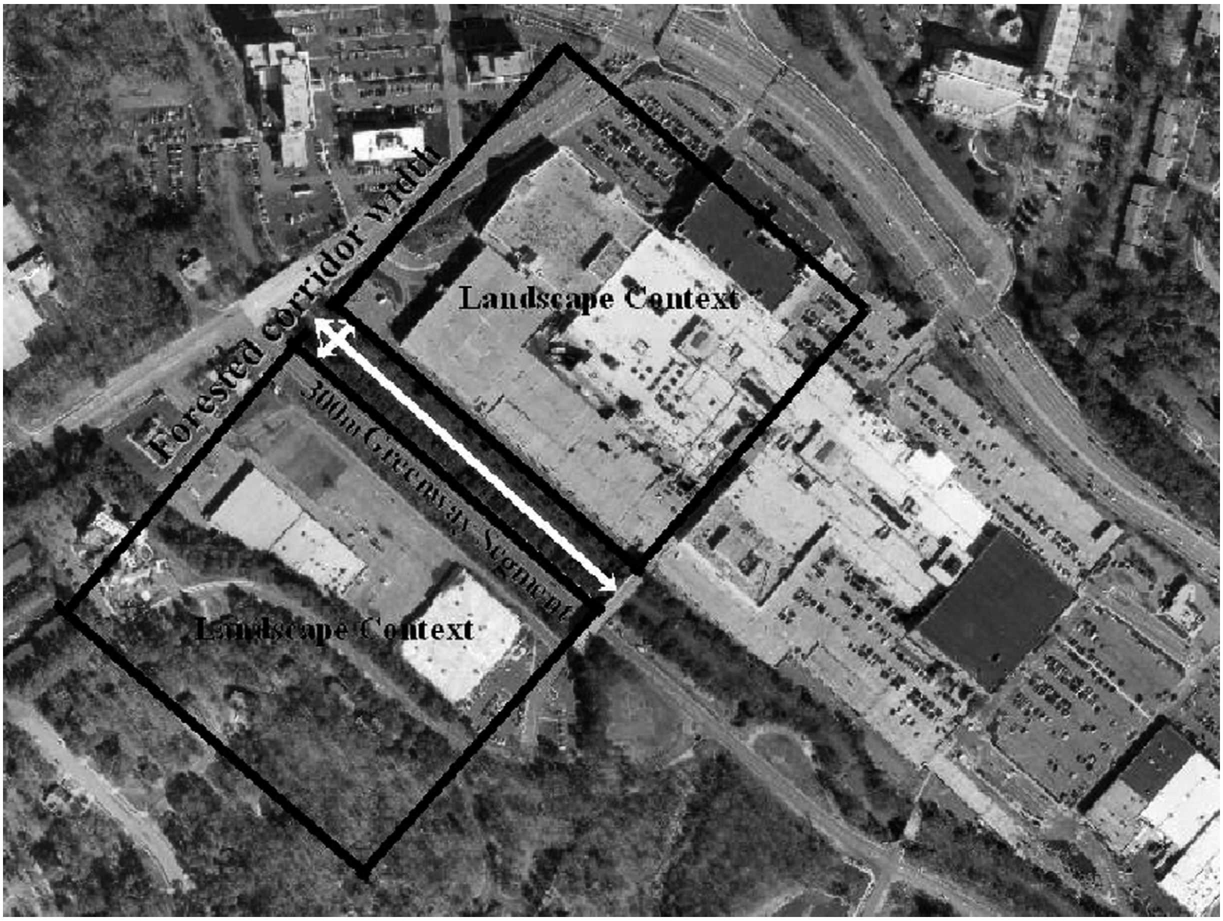

Fig. 2. Forested corridor width and landscape context were measured for each 300 m greenway segment using aerial photography in ArcGIS. Width was measured perpendicular to the greenway orientation and context was measured in two 300 m × 300 m areas on either side of the forested corridor.

2.2. Study site selection: forested corridor width and adjacent land use

We sampled birds in 34 forested "segments" of publicly-owned greenway, each 300 m long and separated by at least 75 m. All greenway segments were mature-forest, riparian corridors bisected by a stream or river (minimum stream width = 1 m; maximum = 40 m; mean = 6.59 m). The 34 greenway segments were selected to ensure a distribution of samples across a broad range of forested corridor width (minimum = 32.5 m; maximum = 1300 m; mean = 207.57 m) and adjacent land use combinations. We selected segments with relatively homogenous width and similar land use on both sides. Categories of adjacent land use we sampled were low-density residential (≤7.5 lots/ha), high-density residential (>7.5 lots/ha), and office/institutional, corresponding to zoning categories in Raleigh and Cary. A greenway's width was considered to be the width of the forested corridor including the stream and both sides of the waterway, which sometimes extended beyond the legal or protected bounds of the greenway. Greenway forested-corridor width and adjacent land use were determined using digital aerial photography and land-use and zoning maps. Digital data were obtained from Wake County, the City of Raleigh, and the Town of Cary (Fig. 2).

2.3. Adjacent land cover

Because land cover varies within land use zones, we further quantified the land cover adjacent to each segment by analyzing 1999 leaf-off digital aerial photography. Two 300 m × 300 m squares were drawn on either side of the study segments, adjacent and parallel to the forested corridor (Fig. 2). Each square was populated with a systematic grid containing 100 points. At each point, we recorded the land cover 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 cover categories were recorded for that point. We used these observations to calculate the proportion of each land cover category adjacent to each study site.

2.4. Bird surveys

Using 50 m fixed-radius point counts of 8 min duration, we surveyed breeding birds from 15 May to 30 June 2002 and 2003 (Ralph et al., 1993; Hamel et al., 1996). Point counts were situated at the midpoint of the 300 m segments, so the centers of all count circles were separated by at least 375 m. Each point count center was located at the approximate center of the greenway segment's forested corridor because our goal was to detect any forest-interior specialist species in the greenway. Counts in wider greenways did not sample edge habitat and likely provided poor measures of edge-dwelling birds there. Conversely, the 50 m radius count circles placed at the center of narrow greenways (<100 m) extended beyond the forest boundary often into residential or commercial grounds characterized by ornamental landscapes and managed lawn. Therefore, point counts in narrow greenways recorded the entire bird community within the greenway, including edge-dwelling species and any forest-interior species present. At all segments, the point count included or was adjacent to a stream, and would therefore be considered riparian habitat. Segment centers were identified on aerial photography and were located and flagged in the field using a global positioning device. We recorded point count station coordinates in the field using a global positioning device and verified the locations on aerial photography.

Two observers surveyed each segment a total of four times in 2002 and one observer surveyed each segment twice in 2003. In 2002, the two observers were rotated, so that each site was visited twice by each of the observers. All 34 greenway segments were visited before a new round of surveys began. All point counts were conducted in the mornings between 6:00 and 11:00 a.m., and under fair weather conditions. The order in which segments were visited was rotated to avoid bias because of time of day. Each site was visited during the early, mid-, and late morning at some point during the study. Birds detected outside the 50 m count circle or flying over the plot were not included in analyses. A point count was discarded if disrupted by rain, strong gusts of wind, construction or maintenance equipment, or any other significant disturbance that made it difficult to hear birds. Because mature forest was the surveyed habitat type at all segments, we did not expect differences in detectability across sites.

2.5. Guilds

Each bird species encountered during our research was assigned to foraging (breeding season), nesting, migratory, and habitat guilds (Appendix A; Hamel et al., 1982; Ehrlich et al., 1988; Moorman and Guynn, 2001). We defined short-distance migrants as those species with winter ranges that do not include the Triangle Region of North Carolina, but do include some portion on the southeastern region of the United States. 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).

2.6. Greenway composition and vegetation structure

We visited each greenway segment during September 2002 to characterize the greenway composition and vegetation structure within the 50 m radius point count plot. We recorded greenway composition as the percentages of each 50 m radius plot covered by mature forest, young forest, managed area, and stream. We defined mature forest as any area covered by trees taller than 6 m. Young forest included woody vegetation 1–6 m tall. Managed area included mowed and maintained surfaces, roads, parks, trails, and ball fields. Percent covers for each class (mature forest, young forest, managed area, and stream) summed to 100% for each plot. Greenways with forested corridor widths narrower than 100 m 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. We visually estimated percents vine cover, shrub cover, and ground cover 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%. We measured percent canopy cover 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. We measured canopy height 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 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 2 m and greater than 10 cm in diameter.

2.7. Data analysis

We calculated total species richness for each greenway segment as the total number of bird species recorded during each year, and guild species richness values were calculated as the number of species of a particular guild recorded during each year. Individual species abundances were calculated as the average number of adult males of a species recorded during all visits within a year. We calculated total bird abundance and guild abundances as the sum of individual abundances. Because relationships between dependent and independent variables were similar between years, we performed all analyses on the average abundance and richness values for the 2 years.

We tested for correlation among all independent variables, including forested corridor width, landscape context, and greenway composition and vegetation structure measures. Strong correlation among independent variables would violate the assumption of non-collinearity necessary for regression analysis. We considered a pair of variables highly correlated if the Pearson correlation coefficient (r) was greater than 0.6. We removed one member of each pair of highly correlated variables, making an effort to remove the variable which we considered less use-

Table 1
Greenway forested corridor width, landscape context, and greenway composition and structure measures used in multiple regression analyses on total species richness and abundance, and guild species richness and abundance measures from Raleigh and Cary, NC greenways (2002–2003)

Variable	Description
Corridor width	Average width (m) of the greenway forested corridor
Landscape context (in two 300 m × 300 m areas adjacent to either side of the segment)	
Canopy	Proportion of canopy
Building	Proportion of building
Paved	Proportion of pavement
Lawn	Proportion of lawn cover
Earth	Proportion of bare earth
Water	Proportion of water
Greenway composition and structure	
TrailDist	Distance (m) from the point count center to trail edge
YoungFor	Percent of count area covered in young forest (1–6 m)
Managed	Percent of count area covered by human management (lawn, trail, etc.)
StrWidth	Width (m) of greenway stream or river
Hardwd	Percent of the mature forest in count area composed of hardwoods
CanHt	Height (m) of tallest tree in count area as measured by sonar hypsometer
Vine	Index of percent vine cover in count area in 20% intervals (1–5)
Shrub	Index of percent shrub cover in count area in 20% intervals (1–5)
Ground	Index of percent ground cover in count area in 20% intervals (1–5)

ful in greenway planning and management. Distance to stream ($r = 0.22$) and distance to trail ($r = 0.25$) were not correlated with forested corridor width; therefore, these variables likely did not contribute to differences in bird communities between narrow and wide greenways. The reduced set of independent variables used in analysis was average corridor width, six landscape context variables, and nine greenway composition and structure variables (Table 1). We performed backwards stepwise multiple regression on total bird abundance and species richness and guild abundance and species richness values. All dependent variables were square-root transformed for regression analysis.

Because guilds represent a crude attempt to group bird species with similar life history traits, analyses using guilds can be confounded by individual species' responses. For example, a guild analysis may appear non-significant, because one species within the guild may have responded positively to a treatment while another species responded negatively. The two species in this case cancel 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 adjacent land use classes. Segments were classified in the following land use classes: low-density residential (≤7.5 lots/ha), high-density residential (>7.5 lots/ha), and office/institutional. Previous studies have indicated thresholds in bird response to varying corridor widths at approximately 50 m (Manifold, 2001; Dickson et al., 1995), 100 m (Hodges and Krementz, 1996; Keller et al., 1993), and wider (Kilgo et al., 1998). Therefore, we assigned segments to the following forested corridor width classes to reflect these known breakpoints and ensure even distribution of greenway segments among classes: ≤50, 51–100, 101–150, 151–300 and >300 m (Table 2). The significance level for all statistical analyses was set at $\alpha = 0.05$.

3. Results

We recorded 53 species during our point counts of breeding birds (Table 2). Of these species, 38 were insectivores, 11 were omnivores, 2 were carnivores, 1 was a granivore, and 1 was a nectivore. There were 18 cavity nesters, 16 canopy nesters, 13 shrub nesters, 5 ground nesters, and 1 brood parasite. Thirty-one of the species were year-round residents of the North Carolina Piedmont, 16 were neotropical migrants, 4 were short-distance migrants, and 2 were exotic species. Nineteen of these species were classified in the interior-edge habitat guild, 17 as edge specialists, 11 as forest-interior specialists, 3 as water dwellers, and 3 as urban specialists.

Forested corridor width was retained only in the final model for forest-interior richness. The number of these width-sensitive species was highest in wider greenways (Table 3).

The amount of managed area within the greenway was the most consistently retained variable in regression models. Total avian richness, neotropical migrant richness and abundance, insectivore richness and abundance, and forest-interior species richness and abundance all decreased with increasing amounts of managed area within the greenway (Table 3). Percent hardwood overstory was the other consistently retained composition variable (Table 3). Total avian richness and abundance and insectivore richness and abundance decreased as percent hardwood increased. Neotropical migrant abundance and forest-interior richness increased as stream width increased. Three variables representing adjacent land cover were retained in various final models (Table 3). Total bird abundance, neotropical migrant richness, and insectivore richness and abundance declined as percent of the adjacent landscape covered by pavement and bare earth increased. Forest-interior richness also declined with increasing bare earth in the adjacent landscape. Neotropical migrant species richness and abundance decreased with increasing building coverage in the adjacent landscape. The relationships between birds and vegetation structure were inconsistent (Table 3).

Although greenway forested corridor width was a predictor for only forest-interior guild richness, the presence of several individual bird species was dependent on greenway forested corridor width (Table 2). No forest-interior species were recorded in greenways ≤50 m wide, and Acadian Flycatcher (see scientific names in Table 2), Hairy Woodpecker, and Wood Thrush were most commonly detected in greenways wider than 100 m. Other forest-interior birds, including Black-and-white Warbler, Louisiana Waterthrush, Ovenbird, Prothonotary Warbler, Scarlet Tanager, and Yellow-throated Warbler, were recorded only in wider (>300 m) greenways (Table 2). However, these species did not occur at a sufficient number of sites to statistically determine

Table 2
Breeding bird species occurrences in greenway shown by adjacent land use and width classes (*n*), Raleigh and Cary, NC (2002–2003)

	Adjacent Land Use			Forested Corridor Width (m)				
	LDR	HDR	OFC	≤50	51-100	101-150	151-300	>300
Species	(10)	(11)	(13)	(7)	(6)	(7)	(8)	(6)
Forest-interior Species								
Acadian Flycatcher (*Epidonax virescens*)[a]	5	2	5		1	2	5	4
Black-and-white Warbler (*Mniotilta varia*)	1							1
Hairy Woodpecker (*Picoides villosus*)[a]	4	3	3			3	5	2
Louisiana Waterthrush (*Seiurus motacilla*)			1					1
Ovenbird (*Seiurus aurocapillus*)		1						1
Pileated Woodpecker (*Dryocopus pileatus*)	2	1	2		1	1	1	2
Prothonotary Warbler (*Protonotaria citrea*)			1					1
Red-shouldered Hawk (*Buteo lineatus*)[a,b]	4		1		3			2
Scarlet Tanager (*Piranga olivacea*)	1							1
Wood Thrush (*Hylocichla mustelina*)[a]	5	3	2			3	5	2
Yellow-throated Warbler (*Dendroica dominica*)			1					1
Interior-edge Species								
Blue-gray Gnatcatcher (*Polioptila caerulea*)[a]	8	7	8		4	6	7	6
Brown-headed Nuthatch (*Sitta pusilla*)	4	5	5	2	4	4	2	2
Carolina Chickadee (*Poecile carolinensis*)	10	10	11	5	5	7	8	6
Carolina Wren (*Thryothorus ludovicianus*)	10	11	12	6	6	7	8	6
Downy Woodpecker (*Picoides pubescens*)[a]	6	5	5		2	3	7	4
Tufted Titmouse (*Baeolphus bicolor*)[a]	10	9	10	2	6	7	8	6
Eastern Wood-Pewee (*Contopus virens*)		1				1		
Fish Crow (*Corvus ossifragus*)		2	3	2	2			1
Great Crested Flycatcher (*Myiarchus crinitus*)	7	5	6	2	4	3	4	5
Northern Cardinal (*Cardinalis cardinalis*)	10	11	13	7	6	7	8	6
Northern Parula (*Parula americana*)	3	1	1	1	1		1	2
Pine Warbler (*Dendroica pinus*)	3	1		2				2
Red-bellied Woodpecker (*Melanerpes carolinus*)[b]	10	10	7	4	5	7	6	5
Red-eyed Vireo (*Vireo olivaceus*)[a]	6	5	6		2	4	5	6
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	2		1	2				1
Ruby-throated Hummingbird (*Archilochus colubris*)	2		1		1	1		1
Summer Tanager (*Piranga rubra*)		1	2			1		2
White-breasted Nuthatch (*Sitta carolinensis*)	7	9	5	3	4	6	6	2
White-eyed Vireo (*Vireo griseus*)[a]			2					2
Edge Species								
American Crow (*Corvus brachyrhynchos*)[b]	4	1	9	5	3	1	2	3
American Goldfinch (*Carduelis tristis*)	6	9	8	6	4	6	5	2
American Robin (*Turdus migratorius*)	9	9	11	7	5	7	7	3
Blue Grosbeak (*Passerina caerulea*)			1			1		
Blue Jay (*Cyanocitta cristata*)	7	5	4	3	5	4	2	2
Brown Thrasher (*Toxostoma rufum*)	2	3	2	3	3		1	
Brown-headed Cowbird (*Molothrus ater*)	2	2	5	3	3	2	1	
Chipping Sparrow (*Spizella passerina*)	1	5	2	2	1	2	2	1
Common Grackle (*Quiscalus quiscula*)	5	5	10	6	4	4	2	4
Eastern Bluebird (*Sialia sialis*)[b]		3			1	2		
Eastern Towhee (*Pipilo erythrophthalmus*)	7	7	7	4	4	5	5	3
Gray Catbird (*Dumetella carolinensis*)	6	3	7	5	4	2	3	2
House Wren (*Troglodytes aedon*)[a]	3	5	1	3	4		2	
Indigo Bunting (*Passerina cyanea*)[a]	3	1	4			1	3	4
Mourning Dove (*Zenaida macroura*)[a]	3	3	5	6	3	1	1	
Northern Flicker (*Colaptes auratus*)[b]	4	5		2	2	2	2	1

Table 2 (*Continued*)

Northern Mockingbird (*Mimus polyglottos*)	2	4	2	3	2	3	
Urban Species							
European Starling (*Sturnus vulgaris*) [a]	1	1	5	5	1		1
House Finch (*Carpodacus mexicanus*) [a]	3	6	8	6	4	4	3
House Sparrow (*Passer domesticus*)	1		1	1	1		
Water Species							
Belted Kingfisher (*Ceryle alcyon*)		1	2			1	2
Canada Goose (*Branta canadensis*)			3	2			1
Mallard (*Anas platyrhynchos*)		1	3	1		2	1

Adjacent land use abbreviations are: LDR = low-density residential (≤7.5 lots/ha), HDR = high-density residential (>7.5 lots/ha), OFC = office/institutional. Each cell contains the number of segments in the corresponding greenway class in which the species was recorded during the 2002 and 2003 breeding seasons. [a]Species presence not independent of greenway width ($P < 0.05$). [b]Species presence not independent of landscape context ($P < 0.05$).

if species presence was independent of greenway forested corridor width. Ground-nesting songbirds were rare in our segments. Ovenbird, Black-and-white Warbler, and Louisiana Waterthrush were the only ground-nesting songbirds recorded during point counts, and these species were found only in greenways wider than 300 m. Several interior-edge species, including Blue-gray Gnatcatcher, Downy Woodpecker, and Red-eyed Vireo, also were most common in wider (>50 m) greenways. White-eyed Vireo was recorded only in greenways wider than 300 m. Indigo Bunting, an edge species, only was detected in greenways wider than 100 m.

European Starling, House Finch, House Wren, and Mourning Dove, all edge or urban-adapter species, were more common in narrower greenways, especially in greenways ≤50 m wide. Many common species were recorded over all greenway widths and land use classes; Northern Cardinal, American Robin, Carolina Chickadee, Carolina Wren, and Tufted Titmouse were recorded in 29 or more of the 34 segments (Table 2).

Red-shouldered Hawk, Northern Flicker, and Red-bellied Woodpecker were least common in greenway segments with adjacent office/institutional land use. Conversely, American Crows were most commonly detected in segments surrounded by suburban office complexes (Table 2).

4. Discussion

4.1. Greenway composition and vegetation structure

The amount of managed area, such as trail and other mowed or maintained surfaces, within a greenway segment was the most consistent factor in predicting neotropical migrant, insectivore, and forest-interior species richness. The number of development-sensitive species decreased as the amount of managed area increased. Most greenway trails in Raleigh and Cary are collocated with sewer lines. Vegetation was removed during construction, and managed surfaces adjacent to trails and relatively wide canopy openings usually were created. The wide managed areas essentially divided the once contiguous forested corridor into two narrower corridors, decreasing the habitat value for development-sensitive species (Villard, 1998). Other research has similarly shown that generalist birds are more abundant near recreational trails in forest and grassland ecosystems, while development-sensitive 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 2–4 m wide paved trails with adjacent mowed areas. The goal of minimizing managed area within a greenway, however, may conflict with the goal of providing recreation and transportation opportunities to urban residents. Trails 2–4 m wide often are constructed within 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, to keep tree roots from breaking up paved paths, or for aesthetics and safety. These conflicts might be resolved by placing greenway trails along one edge of a wide forested corridor, rather than directly down the middle of the corridor, minimizing the effect of greenway trail management and edge on “interior” forest.

Several bird groupings declined with increasing hardwood cover in the greenways. Typically, avian species richness and density are lower in coniferous than in deciduous woodlots (James and Wamer, 1982; Mortberg, 1998; Marzluff and Ewing, 2001). All of our segments were located in streamside hardwood habitats. Segments containing some pine may have attracted additional resident insectivorous species, such as Brown-headed Nuthatch and Pine Warbler, not found in exclusively hardwood sites.

4.2. Adjacent land use and cover

If conservation of development-sensitive bird species is a goal, priority should be given to the protection of greenways located in areas adjacent to low-density residential development that maintains vegetative cover. Many neotropical migrant and forest-interior species were absent in greenways with bare earth, pavement, or high building cover in the adjacent landscape. Other studies have similarly shown that total bird diver-

Table 3
Final regression models, reported with coefficients and partial F-statistic significance levels for included variables for greenways in Raleigh and Cary, NC (2002–2003)

Dependent variable[a]	R^2	Intercept	Width	Greenway composition and structure						Landscape context		
				Managed	Hardwd	StrWidth	Shrub	Ground	Vine	Paved	Earth	Building
Total richness	0.439	4.432		−1.023, $P=0.003$	−0.934, $P<0.001$							
Total abundance	0.550	3.458			−0.832, $P<0.001$		+0.187, $P=0.002$			−1.374, $P=0.002$	−7.654, $P=0.041$	
Neotropical richness	0.685	2.568		−1.502, $P=0.005$						−1.748, $P=0.014$	−16.540, $P=0.004$	−4.052, $P<0.001$
Neotropical abundance	0.689	1.754		−1.562, $P=0.001$		+0.020, $P=0.036$	−0.146, $P=0.045$	+0.132, $P=0.026$	−0.165, $P=0.030$			−2.651, $P=0.010$
Insectivore richness	0.815	4.304		−2.101, $P<0.001$	−0.693, $P<0.001$					−1.805, $P=0.005$	−9.812, $P=0.001$	
Insectivore abundance	0.725	3.595		−1.197, $P<0.001$	−0.673, $P=0.001$				+0.113, $P=0.026$	−1.871, $P<0.001$	−11.896, $P<0.001$	
Forest-interior richness	0.698	0.353	+0.001, $P=0.002$	−1.889, $P<0.001$	+0.612, $P=0.031$						−10.710, $P=0.030$	
Forest-interior abundance	0.593	0.722		−1.960, $P<0.001$		+0.019, $P=0.009$						

Significance levels set at $\alpha=0.05$ for variable inclusion in models.
[a] All dependent variables were square-rooted transformed in regression analyses.

sity and neotropical migrant diversity and abundance decrease in areas of high development intensity adjacent to remnant woods (Tilghman, 1987; Friesen et al., 1995; Rodewald and Bakermans, 2006). Human development can have several negative effects on birds in remnant forest areas, including but not limited to: concentration of natural and exotic predators and parasites; increased competition with exotic and human-associated bird species; removal of resources; and disruption of behavior and movement by human activities (Marzluff and Ewing, 2001). Exotic plants are more likely to colonize riparian forest reserves within more urban landscapes (Borgmann and Rodewald, 2005), and birds that nest in exotic plants may experience increased net failure (Schmidt and Whelan, 1999; Borgmann and Rodewald, 2004).

Adjacent land use may be particularly important for wide-ranging species. In our study, no passerine species was dependent on the land cover adjacent to greenways, possibly because the territories of the relatively small birds are contained entirely within the greenway forested corridor. Conversely, Red-shouldered Hawk, American Crow, and two woodpecker species demonstrated a response to adjacent land use class. Red-shouldered Hawks were recorded primarily in greenways surrounded by low-density residential land use (≤7.5 lots/ha), typically with high levels of canopy cover. As a carnivore, the Red-shouldered Hawk may respond to habitat factors within the landscape at a broader scale than other bird species, and areas with extensive hardwood canopy typically are preferred as breeding habitat by Red-shouldered Hawks (Moorman and Chapman, 1996). Red-bellied Woodpeckers were less common and Northern Flicker was absent in greenway segments surrounded by office/institutional land use, possibly because of the low canopy cover in those areas. Conversely, American Crow was most common in segments with adjacent office/institutional land use. Crows are generalists that most commonly feed on the ground in open habitats like that found on the grounds of suburban office complexes (Verbeek and Caffrey, 2002).

4.3. Forested corridor width

Forest-interior species richness was correlated positively with greenway forested corridor width, and no forest-interior species were observed in the narrowest greenways. Several interior-edge species and Indigo Bunting, an edge species, also were most common in greenways wider than 50 m. Other studies have shown that neotropical migrant species richness increases with increasing riparian forest corridor width (Keller et al., 1993; Hodges and Krementz, 1996; Kilgo et al., 1998). In Washington state, greenways narrower than 40 m had low densities of ground and foliage foragers, residents, and neotropical migrants (Manifold, 2001). Greenways wider than 100 m harbored greater numbers of interior species and greater bird diversity when compared to narrower greenways (Manifold, 2001). Rodewald and Bakermans (2006) concluded that the landscape matrix surrounding Ohio riparian forests was a more important predictor of the bird community than forest width alone, and suggested that traditional management strategies that focus solely on maximizing forest corridor width are insufficient. They did not, however, survey forest tracts <60 m because the linear habitats generally lacked forest-dwelling birds, which agrees with our findings that few development-sensitive species occurred in greenways less than 50 m wide.

While greenways as narrow as 50 m provided habitat for a diversity of birds, most were common edge species or urban adapters that rank low in terms of conservation priority (Hunter et al., 1993). Development-sensitive species were found only in wider greenways. The necessary width of a greenway corridor depends on the species that are to be conserved. To protect ground-nesting songbirds and some forest-interior species, greenways more than 300 m wide might be needed. Wider greenways were less likely to contain nest parasites such as Brown-headed Cowbirds and aggressive exotic species such as European Starlings in their interiors. 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 starlings and cowbirds 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 within wide greenways may provide habitat for these edge-dwelling species.

One appealing approach to increase the suitability of narrow greenways for development-sensitive species might be to embed them in areas of low-density development. During initial statistical analyses, however, we failed to document interactions between greenway forested corridor width and adjacent land use (i.e., bird communities in narrow greenways surrounded by low-density development were similar to those in narrow greenways surrounded by high-density development). Further, forest-interior birds were absent in narrow greenways regardless of adjacent land use and cover, and unequal abundances of individual species among greenway segments was explained by greenway width alone in most cases. Yet, greenway forested corridor width and adjacent land cover each affected abundance or richness of some species or guilds, indicating that additional investigation of width–context interactions might be warranted.

Human recreation and the edges created by recreational trails might 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 some edges, reducing clutch sizes and nest success (Moorman et al., 2002). In Colorado greenways, however, 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 nest predators (Miller and Hobbs, 2000).

The potentially large amount of forest edge in linear, suburban greenways suggests that nest predation rates may be high there. In a complementary study using the same greenways segments as used in this study, Sinclair et al. (2005) determined that nest predators, such as raccoons, opossums, squirrels, and domestic cats, were common. Corvids, such as American Crows and Blue Jays, and Common Grackles have been photographed depredating artificial bird nests at our greenway study sites (Novotny, 2003). Mammalian and avian nest predators were less abundant in the interior of wide greenways (Sinclair et al., 2005), where development-sensitive bird species were most common. Wide greenways should provide interior habitat for development-sensitive species while contributing to low nest predation rates because of low density of nest predators.

We did not measure success of real nests in greenways (Burhans and Thompson, 2006). If birds present in suburban greenway segments experience low survival and reproductive success, then greenway habitats could be acting as sinks (Pulliam, 1988). Further, if birds preferentially choose to breed in linear greenway habitats that are poorer in quality than other potential breeding sites (e.g., non-linear parks or reserves), greenways could be acting as ecological traps (Battin, 2004). Further investigation is needed to determine if greenways act as sinks or ecological traps, providing habitat in which birds establish territories but do not survive or reproduce successfully.

The land adjacent to most of the greenways we studied was owned by private homeowners and businesses. In the cases of many of the widest greenways, only a small portion of forested corridor was comprised of land protected legally as "greenway." Wider publicly-owned greenways would require greater forethought, planning, and expenditure of public funds. As greenways wider than 50 m are not a realistic option for many municipalities, typical urban and suburban 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.

5. Management recommendations

Based on our results, the following guidelines may be useful to urban and landscape planners in the design and management of greenways as 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. Recommendations for specific maximum trail widths are difficult to formulate because of regional variations in bird communities and environmental factors. Instead, we suggest that trails and the associated managed areas be narrow enough that the forest canopy remains relatively unbroken.
2. *Conserve wider greenways*. Greenways of at least 100 m wide provide habitat for some development-sensitive species, but greenways as wide as 300–600 m may be needed to conserve certain 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. These might be located as "nodes" along greenways.

3. *Encourage developers of property adjacent to greenways to minimize pavement, building, and bare earth cover*. Through education and outreach, developers and landowners can be motivated to participate in the conservation of development-sensitive bird species by limiting impervious surface and retaining native vegetation on the privately-owned lands surrounding greenways.

Acknowledgments

We thank Marcia Gumpertz and Janet Bartz for advice and guidance on statistical analysis. We thank Nathan Tarr for an immense amount of work locating and marking study sites and conducting bird surveys; 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; and 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 Environmental Resources and the USDA Forest Service for providing the funds and resources to make this research possible.

Appendix A. Breeding bird species recorded during our study, classified into four different guilds

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
Black-and-white Warbler	I	G	N	I
Blue Grosbeak	I	S	N	E
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	E
Eastern Towhee	I	S	R	E
Tufted Titmouse	I	V	R	IE
Eastern Wood-Pewee	I	C	N	IE
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
Northern Parula	I	C	N	IE
Ovenbird	I	G	N	I
Pileated Woodpecker	I	V	R	I

Appendix A (*Continued*)

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
White-breasted Nuthatch	I	V	R	IE
White-eyed Vireo	I	S	S	IE
Wood Thrush	I	S	N	I
Yellow-throated Warbler	I	C	N	I

Key

Foraging guilds	Nesting guilds	Migratory guilds	Habitat guilds
I = Insectivore	P = Brood Parasite	E = Exotic	E = Edge
N = Nectivore	C = Canopy	N = Neotropical	I = Forest-interior
O = Omnivore	G = Ground	R = Resident	IE = Interior-edge
C = Carnivore	S = Shrub	S = Short-distance	U = Urban
G = Granivore	V = Cavity		W = Water

References

Ahern, J., 1995. Greenways as a planning strategy. Landsc. Urban Plann. 33, 131–155.

Andren, H., Angelstam, P., 1988. Elevated predation rates as an edge effect in habitat islands: experimental evidence. Ecology 69, 544–547.

Beissinger, S.R., Osborne, D.R., 1982. Effects of urbanization on avian community organization. Condor 84, 75–83.

Blair, R.B., 1996. Land use and avian species diversity along an urban gradient. Ecol. Appl. 6, 506–519.

Blair, R., 2004. The effects of urban sprawl on birds at multiple levels of organization. Ecol. Soc. 9 (5), 2 [online] URL: http://www.ecologyandsociety.org/vol19/iss5/art2.

Battin, J., 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conserv. Biol. 18, 1482–1491.

Borgmann, K.L., Rodewald, A.D., 2004. Nest predation in an urbanizing landscape: the role of exotic shrubs. Ecol. Appl. 14, 1757–1765.

Borgmann, K.L., Rodewald, A.D., 2005. Forest restoration in urbanizing landscapes: interactions between land uses and exotic shrubs. Restor. Ecol. 13, 334–340.

Broberg, L., 2003. Conserving ecosystems locally: a role for ecologists in land-use planning. BioScience 53, 670–673.

Bryant, M.M., 2006. Urban landscape conservation and the role of ecological greenways at local and metropolitan scales. Landsc. Urban Plann. 76, 23–44.

Burhans, D.E., Thompson, F.R., 2006. Songbird abundance and parasitism differ between urban and rural shrublands. Ecol. Appl. 16, 394–405.

Cincotta, R.P., Engelman, R., 2000. Nature's Place: Human Population and the Future of Biological Diversity. Population Action International, Washington, DC.

Czech, B.P., Krausman, R., Devers, P.K., 2000. Economic associations among causes of species endangerment in the United States. BioScience 50, 593–601.

Dale, V.H., Brown, S., Haueber, R.A., Hobbs, N.T., Huntly, N., Naiman, R.J., Riebsame, W.E., Turner, M.G., Valone, T.J., 2000. Ecological principles and guidelines for managing the use of land. Ecol. Appl. 10, 639–670.

DeGraff, R.M., 1987. Urban wildlife habitat research—application to landscape design. Proc. Natl. Symp. Urban Wildlife, 107–111.

Dickson, J.G., Williamson, J.H., Conner, R.N., Ortego, B., 1995. Streamside zones and breeding birds in eastern Texas. Wildlife Soc. Bull. 23, 750–755.

Donovan, T.M., Jones, P.M., Annand, E.M., Thompson, F.R., 1997. Variation in local-scale edge effects: mechanisms and landscape context. Ecology 78, 2064–2075.

Ehrlich, P.R., Dobkin, D.S., Wheye, D., 1988. The Birder's Handbook: A Field Guide to the Natural History of North American Birds. Simon and Schuster Inc., New York.

Fabos, J.G., 1995. Introduction and overview: the greenway movement, uses and potentials of greenways. Landsc. Urban Plann. 33, 1–13.

Fraterrigo, J.M., Wiens, J.A., 2005. Bird communities of the Colorado Rocky Mountains along a gradient of exurban development. Landsc. Urban Plann. 71, 263–275.

Friesen, L.E., Eagles, P.F.J., Mackay, R.J., 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conserv. Biol. 9, 1408–1414.

Gates, J.E., Gysel, L.W., 1978. Avian nest dispersion and fledging success in field-forest ecotones. Ecology 59, 871–883.

Hamel, P.B., LeGrand, H.E., Lennartz, M.R., Gauthreaux, S.A., 1982. Bird–habitat relationships on southeastern forest lands. U.S. Department of Agriculture, Forest Service, General Technical Report SF-22. Southeastern Forest Experiment Station, Asheville, NC.

Hamel, P.B., Smith, W.P., Twedt, D.J., Woehr, J.R., Morris, E., Hamilton, R.B., Cooper, R.J., 1996. A land manager's guide to point counts of birds in the Southeast. U.S. Department of Agriculture, Forest Service, General Technical Report SO-120. Southern Research Station, New Orleans, LA.

Hodges, M.F., Krementz, D.G., 1996. Neotropical migratory bird communities in riparian forests of different widths along the Altamaha River, Georgia. Wilson Bull. 108, 496–506.

Hunter, W.C., Pashley, D.N., Escano, R.E.F., 1993. Neotropical migratory landbird species and their habitats of special concern within the southeast region. In: Finch, D.M., Stangel, P.W. (Eds.), Status and Management of Neotropical Migratory Birds. U.S. Department of Agriculture, Forest Service, General Technical Report RM-229. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, pp. 159–171.

James, F.C., Wamer, N.O., 1982. Relationships between temperate forest bird communities and vegetation structure. Ecology 63, 159–171.

Jongman, R., Pungetti, G. (Eds.), 2004. Ecological Networks and Greenways: Concept, Design, Implementation. Cambridge University Press.

Keller, C.M.E., Robbins, C.S., Hatfield, J.S., 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. Wetlands 13, 137–144.

Keyser, A.J., 2002. Nest predation in fragmented forests: landscape matrix by distance from edge interactions. Wilson Bull. 114, 186–191.

Kilgo, J.C., Sargent, R.A., Chapman, B.R., Miller, K.V., 1998. Effect of stand width and adjacent habitat on breeding bird communities in bottomland hardwoods. J. Wildlife Manage. 62, 72–83.

Lancaster, R.K., Rees, W.E., 1979. Bird communities and the structure of urban habitats. Can. J. Zool. 57, 2358–2368.

Manifold, S., 2001. Bird communities in urban greenway trail corridors. MS Thesis. Western Washington University, Bellingham, WA.

Marzluff, J.M., Ewing, K., 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restor. Ecol. 9, 280–292.

Melles, S., Glenn, S., Martin, K., 2003. Urban bird diversity and landscape complexity: species–environment associations along a multiscale habitat gradient. Ecol. Soc. 7 (1), 5 [online] URL: http://www.ecologyandsociety.org/vol7/iss1/art5/.

Miller, J.R., Hobbs, N.T., 2000. Recreational trails, human activity and nest predation in lowland riparian areas. Landsc. Urban Plann. 50, 227–236.

Miller, J.R., Hobbs, R.J., 2002. Conservation where people live and work. Conserv. Biol. 16, 330–337.

Miller, S.G., Knight, R.L., Miller, C.K., 1998. Influence of recreational trails on breeding bird communities. Ecol. Appl. 8, 162–169.

Moorman, C.E., Chapman, B.R., 1996. Nest site selection by woodland hawks in a managed forest in the Georgia Piedmont. Wilson Bull. 108, 357–368.

Moorman, C.E., Guynn, D.C., 2001. Effects of group-selection opening size on breeding bird habitat use in a bottomland forest. Ecol. Appl. 11, 1680–1691.

Moorman, C.E., Guynn, D.C., Kilgo, J.C., 2002. Hooded warbler nesting success adjacent to group-selection and clearcut edges in a southeastern bottomland forest. Condor 104, 366–377.

Mortberg, U., 1998. Bird species diversity in urban forest remnants: landscape pattern and habitat quality. In: Key Concepts in Landscape Ecology. Preston, IALE, UK.

Myers, N., 1990. The biodiversity challenge: expanded hot-spot analysis. Environmentalist 10, 243–256.

Nilon, C.H., Long, C.N., Zipperer, W.C., 1994. Effects of wildland development on forest bird communities. Landsc. Urban Plann. 32, 81–92.

North Carolina Chapter of the American Planning Association, 2002. URL=http://www.nc-apa.org/urbanized_area_stats.htm, viewed October 9, 2002.

Novotny, K.E., 2003. Mammalian nest predators respond to greenway width, habitat structure, and landscape context. MS Thesis. North Carolina State University, Raleigh, NC.

Pulliam, H.R., 1988. Sources, sinks, and population regulation. Am. Naturalist 132, 652–661.

Ralph, C.J., Geupel, G.R., Pyle, P., Martin, T.E., DeSante, D.F., 1993. Handbook of field methods for monitoring landbirds. General Technical Report. PSW-GTR-144. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA.

Rodewald, A.D., Bakermans, M.H., 2006. What is the appropriate paradigm for riparian forest conservation? Biol. Conserv. 128, 193–200.

Rottenborn, S.C., 1999. Predicting the impacts of urbanization on riparian bird communities. Biol. Conserv. 88, 289–299.

Savard, J.P.L., Clergeau, P., Mennechez, G., 2000. Biodiversity concepts and urban ecosystems. Landsc. Urban Plann. 48, 131–142.

Schiller, A., Horn, S.P., 1997. Wildlife conservation in urban greenways of the mid-southeastern United States. Urban Ecosyst. 1, 103–116.

Schmidt, K.A., Whelan, C.J., 1999. Effects of exotic *Lonicera* and *Rhamnus* on songbird nest predation. Conserv. Biol. 13, 393–402.

Searns, R.M., 1995. The evolution of greenways as an adaptive urban landscape form. Landsc. Urban Plann. 33, 65–80.

Sinclair, K.E., Hess, G.R., Moorman, C.E., Mason, J.H., 2005. Mammalian nest predators respond to greenway width, landscape context, and habitat structure. Landsc. Urban Plann. 71, 277–293.

Smith, D.S., Helmund, P.C., 1993. Ecology of Greenways: Design and Function of Linear Conservation Areas. University of Minnesota Press, Minneapolis.

Tilghman, N., 1987. Characteristics of urban woodlands affecting breeding bird diversity and abundance. Landsc. Urban Plann. 14, 481–495.

United Nations, 2004. World Urbanization Prospects: The 2003 Revision (ST/ESA/SER.A/237). United Nations, Department of Economic and Social Affairs, Population Division, New York.

Verbeek, N.A.M., Caffrey, C., 2002. American crow (*Corvus brachyrhynchos*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, No. 647. The Birds of North America Inc., Philadelphia, PA.

Villard, M.A., 1998. On forest-interior species, edge avoidance, area sensitivity and dogmas in avian conservation. Auk 115, 801–805.