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## Avian use of suburban greenways as stopover habitat

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1 **Abstract** Greenways may provide stopover habitat for migrating birds in otherwise inhospitable  
2 suburban landscapes. We examined the effect of greenway forested corridor width, vegetation  
3 composition and structure, and adjacent land cover on the species richness and abundance of  
4 migrating songbirds during spring and fall migration in Raleigh and Cary, North Carolina, USA.  
5 Migrant species richness increased with forest corridor width in spring and fall. During spring,  
6 richness and abundance increased with tree height and percent hardwood tree composition, and  
7 abundance increased with shrub density. During fall, migrant songbird abundance increased  
8 with decreasing canopy cover and increasing shrub density. Forest-interior migrant richness was  
9 not correlated with corridor width in either season, but these species were more abundant in  
10 greenways bordered by less bare earth and pavement cover in the spring. Although migrants  
11 used greenways of all widths, forested corridors wider than 150m should be conserved whenever  
12 possible to provide stopover habitat for forest-interior migrants. Shrub cover should be retained  
13 to maintain vegetative complexity. Habitat for the greatest diversity of migrants can be provided  
14 by constructing greenways in areas of lower development intensity and encouraging residents to  
15 retain shrubs and trees on properties bordering greenways.

16  
17 **Keywords** Greenways · Migration · Neotropical migrants · Stopover · Urbanization  
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## 21 **Introduction**

22  
23 The conversion of forested land to urban uses in the United States has accelerated in recent  
24 decades (Alig et al. 2004), and the resulting fragmentation and alteration of habitat are major  
25 concerns for biological conservation. Migratory bird species are of particular concern, and their  
26 widely documented declines have prompted extensive investigation of the contributing factors  
27 (e.g. Graber and Graber 1963, Robbins et al. 1989, Askins et al. 1990, Hagan et al. 1992).  
28 Although most research has focused on the availability and condition of breeding and wintering  
29 habitat, recent studies have focused on the conditions and events during migration that might  
30 contribute to migrant songbird declines (Newton 2006). Effective conservation measures must  
31 address all life history phases, including migration (Hagan and Johnston 1992, Moore et al. 1993,  
32 Moore 2000, Faaborg 2002).

33 Neotropical migrants are vulnerable during migration, perhaps more so than during any  
34 other time of the year (Sillert and Holmes 2002). During this energetically demanding time,  
35 migrants must find suitable stopover habitat in which to replenish fat stores and rest while  
36 avoiding predation (Blem 1980, Moore et al. 1995). The availability and quality of stopover  
37 habitat can have profound consequences for avian survival. Yet, the precise mechanisms by  
38 which birds choose habitats during migration and the specific habitat requirements for species  
39 are poorly understood (see Moore and Aborn 2000, Chernetsov 2006 for reviews). Breeding  
40 birds have been the primary focus of urban bird studies (e.g. Emlen 1974, Bessinger and Osborne  
41 1982, Friesen et al. 1995, Mason et al. 2007). Much less is known about bird use of stopover  
42 habitat in urban areas (Hostetler 2005, Rodewald and Matthews 2005).

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4 43 Greenways have become popular in attempts to mitigate the effects of habitat alteration  
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6 44 and fragmentation associated with urbanization (Hay 1991). Greenways are multipurpose,  
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9 45 linear, protected open spaces that link natural areas while providing recreation opportunities and  
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11 46 alternative transportation (Little 1990, Hay 1991, Flink and Searns 1993, Searns 1995).  
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14 47 Greenways can vary greatly in forested corridor width and in the land uses that border them –  
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16 48 factors that can be controlled to some degree by city planners. If properly designed, greenways  
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19 49 might be a cost effective means of providing stopover habitat in rapidly developing areas where  
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21 50 land is expensive.

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24 51 We studied migrating songbirds in greenways to: 1) determine the influence of greenway  
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26 52 forested corridor width and adjacent land cover on migrating bird abundance and species  
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29 53 richness, and 2) provide recommendations to urban planners for the design of greenways as  
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31 54 migratory bird stopover habitat.

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## 37 38 57 **Methods**

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### 42 43 59 **Study Area**

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48 61 We studied migrating bird use of greenways in the City of Raleigh and Town of Cary, Wake  
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50 62 County, North Carolina, USA, located in the Central Appalachian Piedmont. Wake County is  
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53 63 experiencing rapid population growth and suburban development. Wake County's population  
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55 64 increased by 24% to 786,522 people between 2000 and 2006, and is expected to reach nearly 1.5  
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58 65 million people by 2030; much of this growth is in Raleigh and Cary (Wake County 2008). Both

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4 66 municipalities are developing relatively extensive greenway systems. Raleigh's public  
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7 67 greenways total 86.9 km in length (City of Raleigh 2006), and Cary has 17.8 km of greenways  
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9 68 (Town of Cary 2006). Hardwood trees dominate greenway canopies, including red maple (*Acer*  
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11 69 *rubrum*), sweetgum (*Liquidambar styraciflua*), tulip-poplar (*Liriodendron tulipifera*), and  
12  
13 70 various oaks (*Quercus* spp.). Loblolly (*Pinus taeda*), shortleaf (*P.echinata*), and Virginia pine  
14  
15 71 (*P. virginiana*) are also common. Native understory vegetation includes eastern redbud (*Cercis*  
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17 72 *canadensis*), blackberry (*Rubus* spp.), sumac (*Rhus* spp.), wax myrtle (*Myrica cerifera*),  
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19 73 greenbrier (*Smilax* spp.), and wild grape (*Vitis* spp.). Exotic understory vegetation includes  
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21 74 privet (*Ligustrum* spp.), olive (*Elaeagnus* spp.), Japanese honeysuckle (*Lonicera japonica*), and  
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23 75 Japanese stiltgrass (*Microstegium vimineum*). We also surveyed three reference sites along trails  
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25 76 in William B. Umstead State Park. The park is largely composed of second and third growth  
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27 77 woodlands, and is situated in an urban matrix just west of Raleigh. It is the largest contiguous  
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29 78 forested area (2,201 ha) nearest the study greenways and is connected to Raleigh's greenway  
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31 79 system. Dominant hardwood species include oaks, hickory (*Carya* spp.), tulip-poplar, and red  
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33 80 maple.  
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#### 43 82 Study site selection

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48 84 We sampled migrating birds in 47 forested segments of public greenway (Fig. 1). The 200-m  
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50 85 long greenway segments followed streams and were chosen to represent a range of greenway  
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52 86 forested corridor widths and adjacent land uses. Segments were separated by at least 200m with  
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54 87 one exception (192m); most were separated by more than 250m. Many of the segments overlap  
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4 88 those used by Sinclair et al. (2005) and Mason et al. (2007). In Umstead State Park, we chose  
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6 89 three 200-m long reference segments of trail that paralleled a stream.  
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9 90 We used criteria similar to Sinclair et al. (2005) and Mason et al. (2007) to choose  
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11 91 segments. We examined leaf-off US Geological Survey 2003 high-resolution, digital  
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13 92 orthoimages and digital land use and zoning maps in a geographic information system and chose  
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15 93 segments in the following land use categories: low density residential ( $\leq 7.5$  lots/hectare), high  
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17 94 density residential ( $> 7.5$  lots/hectare), and office/institutional (businesses, schools, etc.). A  
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19 95 segment's assigned category was based on the zoned land use within 200 m of the forested  
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21 96 corridor on both sides of the segment (Fig. 2). We attempted to choose locations that had similar  
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23 97 land use on both sides, but the use with the highest degree of development was chosen to  
24  
25 98 represent the site if the sides differed. Narrow (0-75 m), medium (76-150 m), and wide ( $> 150$   
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27 99 m) greenways were represented within each of the land use categories, and we chose segments  
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29 100 with relatively constant forested widths. Greenway width was considered to be the average  
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31 101 width of the forested corridor containing the greenway path and was not limited to the legal  
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33 102 boundary of the greenway.  
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41 103  
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43 104 Land cover variables  
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48 106 We quantified cover in the land bordering each segment by analyzing leaf-off aerial  
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50 107 photography. For each study site, two 200-m x 200-m squares were drawn on each side of the  
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52 108 forested corridor (Fig. 2). Each square was populated with a systematic grid of 100 points. At  
53  
54 109 each point, we assigned the land cover to the following categories: canopy, pavement, building,  
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56 110 lawn, water, agriculture, and bare earth. In the leaf off photos, points that fell within a deciduous  
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4 111 tree canopy were considered canopy. If land cover below a tree's canopy could be determined,  
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6 112 both categories were recorded for the point. For each segment, we calculated the percentage of  
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9 113 each land cover category by averaging the values calculated from the two adjacent squares.  
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14 115 Avian surveys

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19 117 We surveyed birds during spring migration (15 April-14 May), 2004, fall migration (3  
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21 118 September- 27 October), 2004, and spring migration (1 April-15 May), 2005. We performed our  
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23 119 surveys along transects, the technique considered most effective for estimating abundance and  
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26 120 richness of migrating songbirds (Wilson et al. 2000, Rodewald and Brittingham 2004). We used  
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28 121 200-m long, one-sided, belt-transects along the mowed edge, if present, or greenway path as the  
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31 122 line of travel. We surveyed the side of the path with the widest forested area; if the two sides  
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33 123 had roughly equal forested area, we surveyed the side with the stream.

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36 124 We traversed each transect slowly, pausing when flocks were encountered to ensure that  
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38 125 all birds were counted. Surveys lasted at least 10 min and averaged 16 min. We counted all  
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40 126 birds seen and heard in the survey side within 25 m of the line of travel to minimize detectability  
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43 127 bias between greenways that have more shrubs and those that may be more open (Rodewald and  
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45 128 Brittingham 2004). Flyovers were not counted. To minimize bias associated with weather, we  
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48 129 did not survey during rainy or windy (>21 km/hr) conditions.

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50 130 There were two observers during spring 2004. We rotated observers among greenways in  
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52 131 different width and land use classes to minimize observer bias. During fall 2004 and spring  
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55 132 2005, there was one observer. During spring and fall 2004, we conducted surveys between 07:00  
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58 133 and 19:00 EST. To limit bias associated with the time of day, each transect was surveyed  
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4 134 multiple times during each of the following time periods: 07:00-10:00; 10:00-13:00; 13:00-  
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7 135 16:00; 16:00-19:00. We visited each greenway segment and reference site on independent  
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9 136 rotations within each time period to cover the range of corridor width and land use combinations.  
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11 137 Preliminary analysis of spring 2004 data revealed that the majority of migrant bird detections  
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13 138 occurred in the earlier part of the day, so during spring 2005 we conducted surveys between  
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16 139 07:00 and 13:00. For consistency, we included only the surveys conducted before 13:00 in  
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19 140 spring 2004 analyses. Because sample sizes were low during fall counts, we included surveys  
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21 141 during all time periods in fall analyses.  
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26 143 Guilds

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31 145 We included Neotropical and short-distance migrants in our analyses, and we excluded any  
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33 146 species present year-round in Wake County. Determining the migratory status of an individual  
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36 147 bird was not possible, so Neotropical migrants included both transients and species that breed  
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38 148 locally. Many of the locally breeding Neotropical migrant species recorded during surveys,  
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41 149 however, rarely breed in the greenways, or breed only in the widest (>300m) greenways (Mason  
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43 150 et al. 2007). Only three of the greenway segments in this study exceeded 300m.  
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45 151 We divided species into three guilds based on area sensitivity during the breeding season  
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48 152 (Poole 2005): 1) forest-interior species that prefer large contiguous habitats with interior  
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51 153 woodland away from forest edges; 2) forest-edge species that use forest habitats near edges; and  
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53 154 3) field-edge species that prefer scrub-shrub habitat and woodland edge (Table 1).  
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4 155 We calculated migrant bird species richness as the average number of migrant species  
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7 156 detected per visit for each season. We calculated species richness and abundance for the forest-  
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9 157 interior, forest-edge, and field-edge guilds in the same manner.

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14 159 Vegetation surveys15  
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19 161 We chose points along each transect at 25, 75, 125, and 175m to survey greenway vegetation  
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21 162 during summer 2004. Each point was located 20m from the transect survey line within the area  
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23 163 surveyed for birds. We estimated shrub density, canopy cover, canopy height, and percentage of  
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25 164 pine and hardwood trees, and averaged the values for each of these variables across the four  
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28 165 survey points for each transect.

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31 166 We estimated shrub density using a density board that was 2.5m tall and 30.48cm wide  
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33 167 and divided equally into five boxes alternating black and white (Nudds 1977). We made four  
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35 168 shrub density readings at each survey point in four directions: two parallel to and two  
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37 169 perpendicular to the greenway path. For each reading, we placed the board 15m from the point  
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40 170 and estimated the percentage of each box obscured by vegetation in quintiles from 1-5; boxes  
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42 171 that were completely uncovered were assigned a score of zero. We averaged scores for each of  
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44 172 the five boxes in each direction and then averaged the four directions for a mean shrub density  
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47 173 score for each survey point.

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50 174 We estimated canopy cover using a concave spherical densiometer. The observer stood  
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52 175 on the survey point and estimated canopy cover while facing each of the cardinal directions and  
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54 176 then averaged the four readings. Using a hypsometer, we estimated canopy height by measuring  
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57 177 three of the tallest canopy trees in the vicinity of the survey point and then averaging their  
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4 178 heights. We visually estimated the percentage of pine and hardwood trees within a 15-m radius  
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6 179 circle centered on the survey point.  
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9 180        Though not within the area surveyed for birds, we measured the width of the path and  
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11 181 mowed edge (together, the managed area) at 25, 75, 125, and 175m along the survey line to  
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13 182 evaluate whether the opening created by the managed portion of the greenway influenced the  
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15 183 birds found in the forested portion of the greenway. The four measurements were averaged for  
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17 184 each transect.  
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23 186 Statistical analyses  
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28 188 Our dependent variables were the spring and fall square-root transformed species richness and  
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30 189 abundance values for the migrant bird, forest-interior, forest-edge, and field-edge guilds. Our  
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32 190 independent variables were greenway forested corridor width, vegetation measurements, and  
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34 191 measurements of land cover in the landscape immediately adjacent to the greenway segments.  
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38 192        We tested for correlation among all independent variables (PROC CORR, SAS Institute  
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40 193 Inc. 2001) and considered two variables highly correlated if the Pearson correlation coefficient  
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42 194 ( $r$ ) was  $\geq 0.6$ . We eliminated one variable from each highly correlated pair, retaining the  
43  
44 195 variable most useful for greenway planning and management. The reduced set of variables  
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46 196 consisted of forested corridor width, five greenway vegetation measures (canopy cover, canopy  
47  
48 197 height, managed area, percent hardwoods, and shrub density), and five measures of adjacent land  
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50 198 cover (bared earth, building, canopy, lawn, pavement). We averaged the species richness and  
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52 199 abundance data for the two spring seasons for final analyses, because preliminary analysis of  
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54 200 each of the spring seasons yielded similar results.  
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4 201 For each season, each of the eight dependent variables was regressed against the reduced  
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6 202 set of independent variables in stepwise multiple linear regression analysis using SAS (PROC  
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9 203 REG, SAS Institute, Inc. 2001). Only variables significant at  $\leq 0.05$  were used in the final  
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11 204 regression models.

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14 205 For each season, we calculated average guild richness and abundance for each greenway  
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16 206 width category and compared them to the average guild richness and abundance for the three  
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19 207 reference segments using a one-way ANOVA with Tukey's post-hoc test (Fig. 3).  
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## 23 210 **Results**

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31 212 We recorded 43 migrant species in the greenways and reference sites during the spring and fall  
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33 213 migration surveys; 20 were forest-interior species, 16 were forest-edge species, and seven were  
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36 214 field-edge species (Table 1).  
37

38 215 During spring migration periods, 82% of surveys detected migrants; during fall, only  
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40  
41 216 31% of surveys recorded migrants. During spring, surveys in which migrants were detected  
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43 217 averaged three migrant species and four individuals. Blue-gray gnatcatcher, red-eyed vireo, and  
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46 218 gray catbird (scientific names in Table 1) were the most common migrants during spring.  
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48 219 During fall, surveys in which migrants were detected averaged 1.6 species and 2.1 individuals.  
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51 220 The species detected most frequently during the fall were gray catbird and ruby-throated  
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53 221 hummingbird; few forest-interior species were recorded.  
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4 222 Spring and fall migrant species richness, fall migrant abundance, spring forest-edge  
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6 223 species richness and abundance, and fall field-edge richness and abundance increased with  
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9 224 increasing forested corridor width (Tables 2, 3).  
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11 225 During spring, species richness of migrants and species richness and abundance of forest-  
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14 226 edge and forest-interior species were highest in greenways with taller trees and a greater  
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16 227 percentage of hardwoods (Table 2). During fall, forest-interior richness and abundance increased  
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19 228 with increasing canopy height while migrant richness and abundance were higher in greenways  
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21 229 with less canopy cover (Table 3). Spring migrant abundance, fall migrant richness, and spring  
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23  
24 230 field-edge richness and abundance increased with increasing shrub density (Tables 2, 3).  
25

26 231 Only three adjacent land cover variables were retained in the models. Spring migrant  
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29 232 richness and field-edge species richness and abundance increased with increasing building cover  
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31 233 (Table 2), while fall forest-edge richness and abundance increased with decreasing building  
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33  
34 234 cover (Table 3). Spring forest-interior richness and abundance were lowest in greenways  
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36 235 surrounded by more pavement and bare earth (Table 2).  
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38 236 Average species richness and abundance of migrants during spring and fall migration  
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41 237 were higher in the reference sites than in our widest greenways (>150m wide, Fig. 3). We  
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43 238 detected more forest-interior species in the reference sites than in greenways of all widths during  
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46 239 spring and fall migration. Forest-edge species richness and abundance were similar in wide  
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48 240 greenways (>150 m) and in the reference sites during spring. We detected more field-edge  
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51 241 species in the greenways than in the reference sites.  
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4 **245 Discussion**

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9 247 Forested corridor width

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14 249 Migrant richness during spring and richness and abundance during fall were highest in the widest  
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16 250 greenway forested corridors, suggesting that wider greenways are more attractive to migrants.

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19 251 This is consistent with the findings of several studies of the effect of patch size on migrating  
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21 252 songbirds (Martin 1980, Blake 1986, Somershoe and Chandler 2004). Martin (1980)

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24 253 demonstrated that migrant species richness and abundance increased with increasing area in  
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26 254 shelterbelts on the Great Plains. Blake (1986) recorded greater species richness in larger

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29 255 woodlots during migration in Illinois, and Somershoe and Chandler (2004) observed a greater  
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31 256 diversity and abundance of migrants in large hammocks than small hammocks in coastal South

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34 257 Carolina. Similarly, breeding migrants often are more abundant in wider corridors (Hodges and  
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36 258 Krementz 1996, Mason et al. 2007).

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38 259         Though species that are area-sensitive during the breeding season also might prefer larger  
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40 260 patches during migration, some area-sensitive migrants use smaller habitat patches as stopover

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43 261 even when larger patches are available (Petit 2000). We routinely documented forest-interior

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46 262 migrants in greenways narrower than those in which they were found breeding (Mason et al.

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48 263 2007). Louisiana waterthrush, ovenbird, prothonotary warbler, scarlet tanager, and yellow-

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51 264 throated warbler did not breed in greenways less than 300m wide in our study area (Mason et al.  
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53 265 2007), yet we recorded all of these species in greenways less than 300m wide during migration.

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55 266 However, we detected more forest-interior migrants in the reference sites, suggesting that these  
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58 267 birds may prefer larger forest patches during stopover to linear habitats such as greenways.

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4 268           Although migrants used narrow greenways, it is unclear whether these areas offer  
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6 269           sufficient resources to meet migrant birds' energetic needs (Graber and Graber 1983, Blake  
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9 270           1986). Birds that used a New York City park as stopover habitat showed significant mass gain,  
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11 271           indicating that urban green spaces are places where migrants can replenish energy reserves  
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14 272           (Seewagen and Slayton 2008). Unlike small habitat patches completely surrounded by  
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16 273           development, greenways frequently offer connectivity to other habitat patches and can provide  
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18 274           migrants with a conduit for seeking additional habitat. In fact, Petit (2000) recorded more fall  
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21 275           migrants in habitat fragments that were connected by corridors than in isolated fragments of  
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24 276           similar size. Thus, migrants are not forced to remain in narrow habitats that may have fewer  
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26 277           resources and can more easily travel to alternate locations.  
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#### 29 278 30 31 279   Greenway vegetation

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36 281   Vegetation characteristics within the greenways were better predictors of migrant species  
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38 282   richness and abundance than the characteristics describing land cover adjacent to the surveyed  
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41 283   greenway segments. Though habitat use during migration can vary with bird species, geographic  
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43 284   location, and season, habitats with heterogeneous vegetative structure often are those that support  
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46 285   the most diverse and abundant migrant community (see Petit 2000 for review). During spring,  
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48 286   migrant richness and abundance were highest in hardwood-dominated greenways with taller  
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51 287   canopies and higher shrub density. During the fall, migrant richness was greater in greenways  
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53 288   with more open canopies and higher shrub density. Rodewald and Brittingham (2007) also  
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55 289   documented higher temperate migrant abundances in urban woodlots with tall trees, open  
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58 290   canopies, and heterogeneous horizontal structure.  
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4 291           Vegetation structure was important to migrants using greenways in both seasons, but the  
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6 292   selection of greenways with more open canopies during fall suggests a seasonal shift to habitats  
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9 293   with more shrub cover. Other researchers have documented heavier use of shrub and scrub  
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11 294   habitats during fall migration (Suthers et al. 2000, Swanson et al. 2003, Rodewald and  
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14 295   Brittingham 2004). Canopy gaps or sparse canopy coverage allow sunlight to reach the forest  
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16 296   and stimulate understory growth. Migrants may be attracted to these open areas because they  
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19 297   provide greater arthropod abundances and more fruiting plants in the fall. Gaps with dense shrub  
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21 298   or midstory growth also may offer protection from predators during migration, a period when  
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23  
24 299   birds are especially vulnerable (Bowen et al. 2007).

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26 300           Although forest-interior breeding birds were least abundant in greenways with more  
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29 301   extensive managed area (path and mowed edge) along the recreational trails (Mason et al. 2007),  
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31 302   we failed to document a similar relationship during migration. Trail management activities may  
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34 303   benefit migrants because the greenway path and mowed edges create a canopy opening for  
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36 304   sunlight that promotes the growth of shrubs and saplings along the path. Rodewald and  
37  
38 305   Brittingham (2002) documented the highest species richness and abundance of fall migrants  
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41 306   along forest edges with high densities of shrubs and saplings. Similarly, Rodewald and  
42  
43 307   Brittingham (2007) recorded more spring migrants in mature, edge-dominated forests.

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45 308           Maintaining shrubs and other understory vegetation within a greenway is a balance  
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48 309   between conserving habitat, maintaining aesthetics, and providing safe public spaces (Luymes  
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51 310   and Tamminga 1995, Ivy 2001). Removing bushes and shrubs, especially those that produce  
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53 311   fruit in the fall, could reduce the quality of greenways as stopover habitat by reducing the  
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55 312   amount of food and cover available. Restricting greenway shrub pruning and removal to areas of  
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58 313   short sight lines can increase safety for people and maximize habitat potential for wildlife, and  
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4 314 can be offset by planting native fruiting shrubs elsewhere in the greenway. During the  
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6 315 construction of a new greenway path, clearing should be reduced to the minimum necessary for  
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9 316 activities such as grading, paving, and bridge construction.  
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14 318 Adjacent land use15  
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19 320 Adjacent land cover was a poor predictor of migrant species richness and abundance. Although20  
21 321 adjacent building cover was retained in final models, several relationships were inconsistent.22  
23 322 During spring, we recorded more migrant species and higher field-edge species richness and24  
25 323 abundance in greenways with higher adjacent building cover, but forest-edge species richness26  
27 324 and abundance increased with decreasing building cover adjacent to the greenways in the fall.28  
29 325 Similarly, Rodewald and Matthews (2005) found no statistical relationship between migrants and30  
31 326 the percentage of urban land within one kilometer of their study sites. During spring migration,32  
33 327 however, we recorded fewer forest-interior species and individuals in greenways with high34  
35 328 adjacent pavement and bare ground cover, which are indicators of intense development. This36  
37 329 suggests that some migrants may avoid stopping in greenways located in built-up areas.  
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41 331 Fall Surveys42  
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45 333 Fewer migrants were encountered during fall surveys; thus, fall models should be interpreted46  
47 334 with caution. Detection can be more difficult in fall when migrants are cryptically colored and48  
49 335 less vocal. We performed point counts using playbacks of Eastern Screech-owl (*Otus asio*)50  
51 336 vocalizations and chickadee and titmouse mobbing calls in an attempt to increase detections  
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4 337 (Turcotte and Desrochers 2002). The counts with playback rarely detected additional migrants,  
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6 338 and we did not use them in the analysis.

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## 10 11 340 Design and Management Recommendations

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16 342 Conserving migratory birds requires conserving diverse habitats that can accommodate them

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18 343 during multiple phases of their annual cycle. Many of the associations between birds and

19  
20 344 greenway characteristics are the same during migration and breeding seasons. Greenways might

21  
22 345 be able to accommodate migrants during both the breeding and non-breeding season, if designed

23  
24 346 using the following recommendations:

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26  
27 347 1. Conserve greenways wherever possible, even narrow ones. Migrant birds used even the

28  
29 348 narrowest greenways as stopover habitat, even in areas of dense development. These

30  
31 349 narrow greenways are most valuable if they have complex vegetative structure, including

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33 350 well-developed canopy, midstory, and shrub layers.

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36 351 2. Conserve wider greenways. Even the widest greenways we surveyed, on average,

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38 352 harbored fewer migrants than the reference sites in Umstead Park. Greenways with

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40 353 forested corridors wider than 150m should be conserved wherever possible, benefiting

41  
42 354 both breeding and migrating forest birds. When entire corridors of this width cannot be

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44 355 protected, conserving some sections that are at least 150m wide may be possible.

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46  
47 356 3. Construct new greenways in areas where there is lower development intensity and

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49 357 encourage those who own property adjacent to greenways to retain canopy and shrubs.

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4 358 4. Do not limit open space planning to greenways. Large forested habitat patches, such as  
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6 359 Umstead Park, support more species, especially forest-interior species, and can be  
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8  
9 360 located as “nodes” along greenways as part of a larger open space network.  
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19 364 **Acknowledgments**  
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## Figure Captions

**Fig. 1** Greenway segment and reference site locations in Raleigh and Cary, North Carolina, USA

**Fig. 2** Forested corridor width and adjacent land use were determined for each 200-m greenway segment in ArcGIS. Land cover variables were measured in two 200-m x 200-m areas on either side of the forested corridor

**Fig. 3** Mean richness and abundance of migrating birds using reference sites in Umstead State Park and Raleigh and Cary, NC greenways of differing forested corridor width categories during spring (2004-2005) and fall (2004) shown with standard deviation bars. (a) migrant species richness, (b) migrant abundance, (c) field-edge species richness, (d) field-edge abundance, (e) forest-edge species richness, (f) forest-edge abundance, (g) forest-interior species richness, (h) forest-interior abundance. Richness and abundance were calculated as average number of migrant bird species and individuals detected per survey per segment per category. Bars with the same letter are not significantly different ( $P < 0.05$ , Tukey post-hoc test)

**Table 1** Migrant bird species recorded in greenways and reference sites, presented by adjacent land use and width categories.

Each cell contains the number of segments in the corresponding category in which the species was recorded during spring migration (S) (2004-2005) or fall migration (F) (2004). Adjacent land use categories are: LDR, low-density residential ( $\leq 7.5$  lots/hectare); HDR, high-density residential ( $> 7.5$  lots/hectare); OFC, Office/Institutional. Reference segments are indicated by REF

Guild/Species	Adjacent Land Use						Forested Corridor Width (m)						REF	
	LDR		HDR		OFC		0-75		76-150		>150		REF	
	Number of Sites													
	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Field-edge Species														
Blue Grosbeak ( <i>Guiraca caerulea</i> )					1				1					
Blue-winged Warbler ( <i>Vermivora pinus</i> )				1									1	
Common Yellowthroat ( <i>Geothlypis trichas</i> )	11	2	8	2	12	5	6	1	15	4	10	4	1	
House Wren ( <i>Troglodytes aedon</i> )	4		4		2		2		7		1			
Indigo Bunting ( <i>Passerina cyanea</i> )	3		1		2		1		2		3			
Prairie Warbler ( <i>Dendroica discolor</i> )	2						1		1					
Yellow-breasted Chat ( <i>Icteria virens</i> )					1						1			
Forest-edge Species														
Baltimore Oriole ( <i>Icterus galbula</i> )	1		1						2					
Blue-gray Gnatcatcher ( <i>Polioptila caerulea</i> )	17	1	12		16	1	8		23		14	2	3	

**Table 1** Continued

Guild/Species	Adjacent Land Use						Forested Corridor Width (m)						REF			
	LDR		HDR		OFC		0-75		76-150		>150					
	Number of Sites		(19)		(12)		(16)		(10)		(23)			(14)		(3)
	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Blackpoll Warbler ( <i>Dendroica striata</i> )	12		5	1	6		4		14	1	5					
Eastern Kingbird ( <i>Tyrannus tyrannus</i> )			1		3				1		3					
Eastern Wood-Pewee ( <i>Contopus virens</i> )	2				2	2			3		1	2	2	1		
Great Crested Flycatcher ( <i>Myiarchus crinitus</i> )	15	1	6		12		5		16	1	12		3			
Gray Catbird ( <i>Dumetella carolinensis</i> )	17	6	11	8	13	8	8	6	20	6	13	10				
Magnolia Warbler ( <i>Dendroica magnolia</i> )	1	1		1				1	1			1			1	
Orchard Oriole ( <i>Icterus spurius</i> )			1		2				2		1					
Rose-breasted Grosbeak ( <i>Pheucticus ludovicianus</i> )	1		1		1				2		1					
Red-eyed Vireo ( <i>Vireo olivaceus</i> )	15		8		12	2	6		16		13	2	3	1		
Ruby-throated Hummingbird ( <i>Archilochus colubris</i> )	9	5	12	3	12	8	7	1	12	7	14	8	3			
Summer Tanager ( <i>Piranga rubra</i> )	2				7				5		4		2			
White-eyed Vireo ( <i>Vireo griseus</i> )	3		5		9	1	1		8	1	8					
Palm Warbler ( <i>Dendroica palmarum</i> )			1						1							
Yellow Warbler ( <i>Dendroica petechia</i> )	2		2		3		1		4		2					
Forest-interior Species																
Acadian Flycatcher ( <i>Epidomax virscens</i> )	7	1	5		3		1		7	1	7		3			

**Table 1** Continued

Guild/Species	Adjacent Land Use						Forested Corridor Width (m)						REF (3)	
	LDR (19)		HDR (12)		OFC (16)		0-75 (10)		76-150 (23)		>150 (14)			
	S	F	S	F	S	F	S	F	S	F	S	F		
American Redstart ( <i>Setophaga ruticilla</i> )	11	3	6	1	6	1	5	1	12	3	6	1	1	3
Black-and-white Warbler ( <i>Mniotilta varia</i> )	10		6		5	1	1		12		8	1	3	2
Blue-headed Vireo ( <i>Vireo solitarius</i> )	3	1	1	1	2	1		1	3	1	3	1	1	
Black-throated Blue Warbler ( <i>Dendroica caerulescens</i> )	13		5		6	1	5		10		9	1	1	2
Black-throated Green Warbler ( <i>Dendroica virens</i> )	1	1			1				1	1	1		1	1
Canada Warbler ( <i>Wilsonia mericana</i> )			1						1					
Hooded Warbler ( <i>Wilsonia merica</i> )	7	1	2		3		2		6	1	4		1	
Kentucky Warbler ( <i>Oporornis formosus</i> )					1						1			
Louisiana Waterthrush ( <i>Seiurus motacilla</i> )	3		3		2				4		4		1	
Northern Parula ( <i>Parula mericana</i> )	15		10		11		7		17		12		3	
Northern Waterthrush ( <i>Seiurus noveboracensis</i> )	3						1				2			
Ovenbird ( <i>Seiurus aurocapillus</i> )	7		3		7		1		7		9		2	
Prothonotary Warbler ( <i>Protonotaria citrea</i> )					1		1							
Scarlet Tanager ( <i>Piranga olivacea</i> )	7		1		3		2		6		3			
Swainson's Thrush ( <i>Catharus ustulatus</i> )	1		1		1		2		1					
Veery ( <i>Catharus fuscescens</i> )	2								1		1			

**Table 1** Continued

Guild/Species	Adjacent Land Use						Forested Corridor Width (m)							
	LDR		HDR		OFC		0-75		76-150		>150		REF	
	Number of Sites		(12)		(16)		(10)		(23)		(14)		(3)	
	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Worm-eating Warbler ( <i>Helmitheros vermivorus</i> )			2		1						3		1	1
Wood Thrush ( <i>Hylocichla mustelina</i> )	10	2	8	3	4	1	2		12	4	8	2	1	
Yellow-throated Warbler ( <i>Dendroica dominica</i> )					1						1		3	

**Table 2** Final regression models for spring migration (2004-5). Reported with coefficients and partial F-statistic significance levels for included variables for greenways in Raleigh and Cary, NC. Significance levels set at  $\alpha = 0.05$  for variable inclusion in models

Dependent Variable*	Model $R^2$	Model $P$	Intercept	Forested Width	Greenway Composition and Structure				Adjacent Land Use		
					Canopy Cover	Canopy Height	Hard-woods	Shrub Density	Building Cover	Pavement Cover	Bare Earth
Migrant Richness	0.583	$P<0.001$	-0.5165	0.0019 $P<0.001$		0.0064 $P=0.008$	0.0105 $P<0.001$		0.0152 $P=0.029$		
Migrant Abundance	0.362	$P<0.001$	-0.1234				0.0151 $P<0.001$	0.1639 $P=0.010$			
Field-edge Richness	0.221	$P=0.004$	0.0890					0.1019 $P=0.005$	0.0128 $P=0.020$		
Field-edge Abundance	0.323	$P<0.001$	0.4298		-0.0067 $P=0.029$			0.1839 $P<0.001$	0.0185 $P=0.013$		
Forest-edge Richness	0.641	$P<0.001$	-0.4613	0.0013 $P<0.001$		0.0040 $P=0.033$	0.0108 $P<0.001$				
Forest-edge Abundance	0.596	$P<0.001$	-0.7895	0.0017 $P<0.001$		0.0058 $P=0.035$	0.0143 $P<0.001$				
Forest-interior Richness	0.512	$P<0.001$	-0.5153			0.0097 $P<0.001$	0.0074 $P=0.006$			-0.0129 $P=0.008$	-0.0267 $P=0.015$
Forest-interior Abundance	0.464	$P<0.001$	-0.7104			0.0120 $P=0.001$	0.0089 $P=0.013$			-0.0147 $P=0.022$	-0.0334 $P=0.022$

\* All dependent variables were square-root transformed in regression analyses.

**Table 3** Final regression models for fall migration (2004). Reported with coefficients and partial F-statistic significance levels for included variables for greenways in Raleigh and Cary, NC. Significance levels set at  $\alpha = 0.05$  for variable inclusion in models

Dependent Variable*	Model $R^2$	Model $P$	Intercept	Forested Width	Greenway Composition and Structure			Adjacent Land Use
					Canopy Cover	Canopy Height	Shrub Density	Building Cover
Migrant Richness	0.363	$P < 0.001$	0.7667	0.0018 $P = 0.001$	-0.0095 $P = 0.003$		0.1038 $P = 0.046$	
Migrant Abundance	0.305	$P < 0.001$	1.2735	0.0024 $P < 0.001$	-0.0111 $P = 0.004$			
Field-edge Richness	0.324	$P < 0.001$	0.8274	0.0018 $P < 0.001$	-0.0088 $P = 0.002$			
Field-edge Abundance	0.354	$P < 0.001$	1.1245	0.0022 $P < 0.001$	-0.0122 $P < 0.001$			
Forest-edge Richness	0.134	$P = 0.011$	0.4326				-0.0168 $P = 0.011$	
Forest-edge Abundance	0.129	$P = 0.013$	0.4539				-0.0174 $P = 0.013$	
Forest-interior Richness	0.211	$P = 0.006$	-0.5106			0.0041 $P = 0.048$	0.0690 $P = 0.039$	
Forest-interior Abundance	0.125	$P = 0.015$	-0.4246			0.0059 $P = 0.015$		

\* All dependent variables were square-root transformed in regression analyses.

Figure

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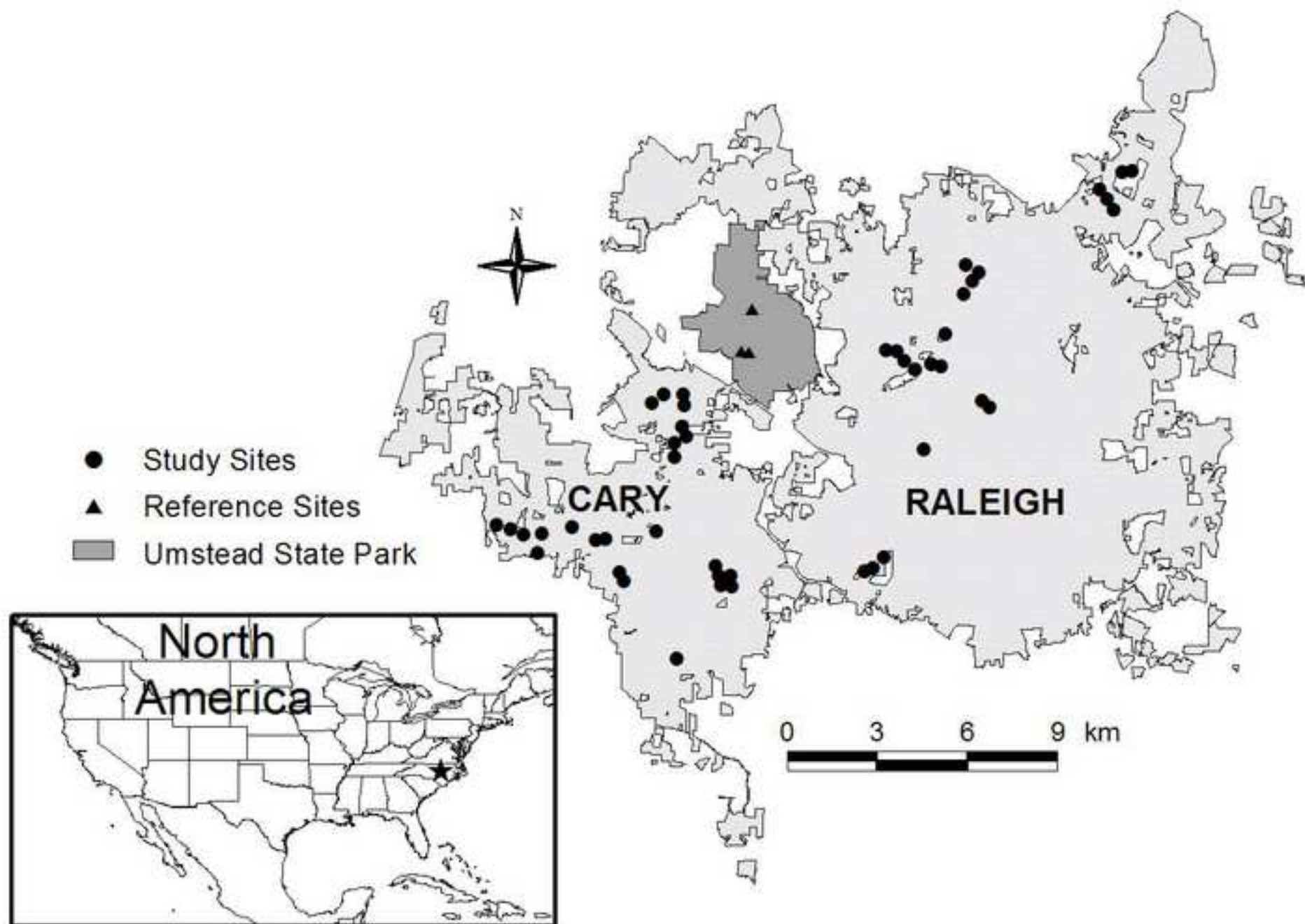
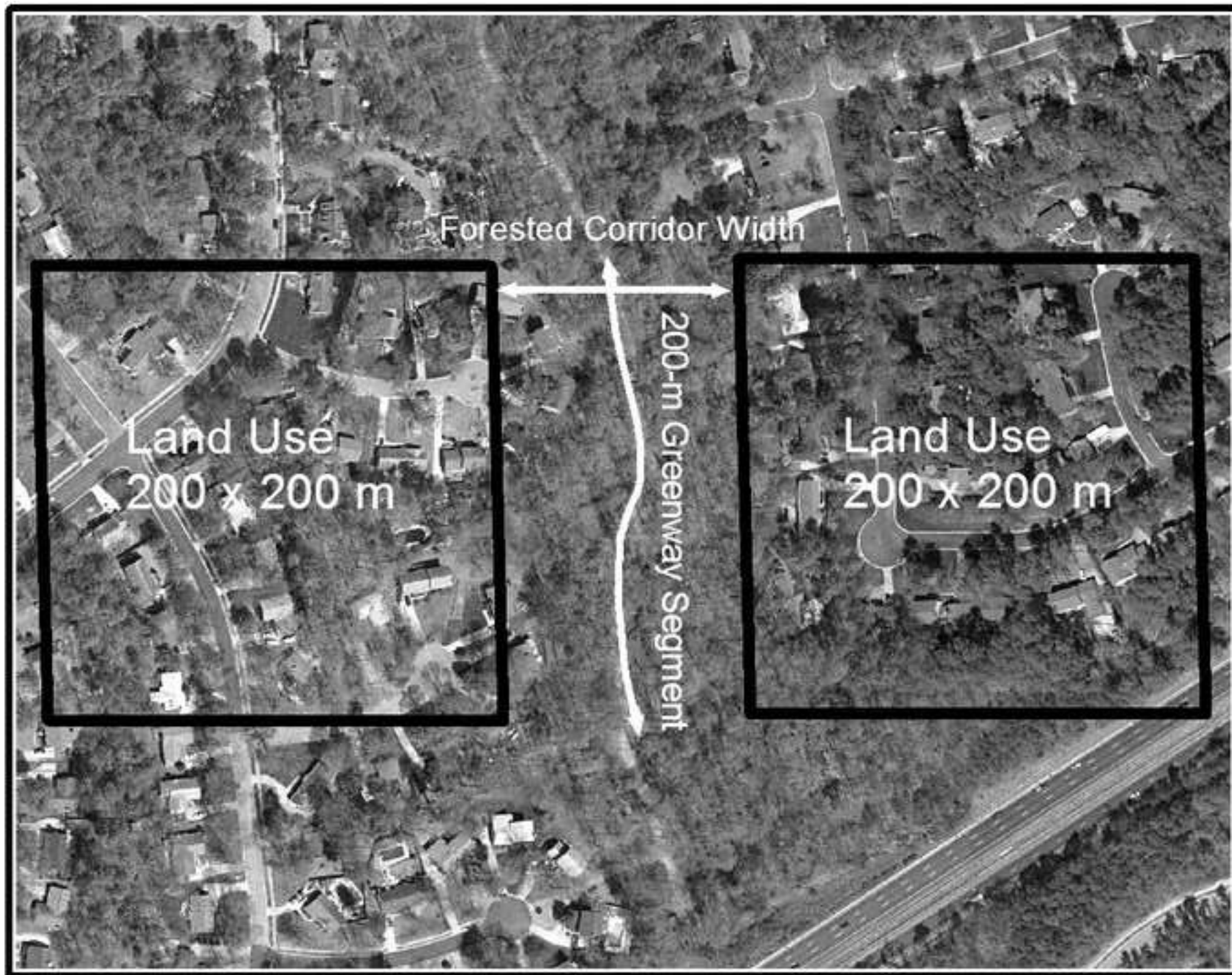


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Figure

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