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Urban development alters landscapes and changes ecosystems. One of these changes is the homogenization of species, as specialist species are no longer able to survive. Wetlands are vulnerable to alteration and serve as habitat for specialized bird species. To investigate which human disturbances were related to differences in species composition and wetland specialization, I conducted species surveys at five wetland sites in Greensboro, North Carolina. I examined the relationship between avian community composition and disturbance variables using a partial least squares regression. I found that indirect disturbances such as impervious surfaces and commercial land use were negatively associated with wetland specialization. I suggest that effective wetland conservation in urbanizing areas must consider landscape context.

EFFECTS OF HUMAN DISTURBANCES ON AVIAN SPECIES COMPOSITION IN URBANIZED WETLANDS IN THE NORTH CAROLINA PIEDMONT

by

Amelia B. Kane

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Dr. Sarah Praskievicz
Committee Chair

APPROVAL PAGE

This thesis written by Amelia B. Kane has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair	Dr. Praskievicz
Committee Members	Dr. Knapp
	Dr. Li

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CHAPTER I: INTRODUCTION

The 2020 census showed that the American South, including North Carolina, is undergoing a large increase in population, which has in turn led to more construction.[1] Because of this, previously undeveloped habitat is likely to become urbanized or suburbanized. Urbanization is considered to be one of the most significant threats to biodiversity in North America.[2] When a landscape is urbanized, it is altered drastically. Native vegetation may be removed and replaced with non-native ornamentals, noise levels increase, previously permeable surfaces are paved, and humans are continuously present in spaces in which they may previously have been a rarity. Urbanization can be understood to create a novel habitat, one that is homogeneous across the continent.[3]

Over the past five decades, the North American continent has seen a dramatic decline in bird population abundance across nearly all biomes [4]. A survey of urban-rural gradients in three distinct ecoregions—Ohio, California, and Minnesota—demonstrated that as an area becomes more urbanized, the bird species composition becomes more similar to the species compositions of other urban locations, rather than the species composition in less-disturbed parts of that ecoregion.[5] This phenomenon is called biotic homogenization.[6] Biotic homogenization occurs

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[1] US Census Bureau, "Southern and Western Regions Experienced Rapid Growth This Decade," accessed January 5, 2022, https://www.census.gov/newsroom/press-releases/2020/south-west-fastest-growing.html.

[2] Michael L. McKinney, "Urbanization as a Major Cause of Biotic Homogenization," *Biological Conservation*, Urbanization, 127, no. 3 (January 1, 2006): 247–60, https://doi.org/10.1016/j.biocon.2005.09.005.

[3] McKinney.

[4] Kenneth V. Rosenberg et al., "Decline of the North American Avifauna," *Science* 366, no. 6461 (October 4, 2019): 120–24, https://doi.org/10.1126/science.aaw1313.

[5] Robert B. Blair and Elizabeth M. Johnson, "Suburban Habitats and Their Role for Birds in the Urban–Rural Habitat Network: Points of Local Invasion and Extinction?," *Landscape Ecology* 23, no. 10 (December 2008): 1157–69, https://doi.org/10.1007/s10980-008-9267-y.

[6] Kevin R Crooks, Andrew V Suarez, and Douglas T Bolger, "Avian Assemblages along a Gradient of Urbanization in a Highly Fragmented Landscape," *Biological Conservation* 115, no. 3 (February 2004): 451–62, https://doi.org/10.1016/S0006-3207(03)00162-9.

because an urbanized habitat favors some life history traits such as diet, migration pattern, and nesting strategy. For example, bird species that are insectivores, shrub-nesters, long-distance migrants, or territorial species tend to decline in urbanized areas, while granivores, building nesters, year-round residents, and non-territorial species tend to increase.[7] Wetland-dependent species are thought to be particularly vulnerable to the effects of urbanization.[8] Mitigation of the impacts of urbanization on wetland birds requires knowledge of which factors of the altered environment most affect these species.

No clear consensus exists regarding whether factors at the landscape level (surrounding the habitat) or the local level (within the habitat) are more influential for bird species in urbanized areas. A study conducted in Northern California found that local vegetation variables had a more significant impact than land use on bird abundance and species richness.[9] By contrast, development at the landscape level was found to be the strongest driver of bird species composition in the North Carolina Triangle region.[10] Similarly, a study of bird community composition in Mexico City parks found that while local factors had an effect, it was not as pronounced as landscape factors.[11] Bird community composition in isolated marshes in Ontario

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[7] Blair and Johnson, "Suburban Habitats and Their Role for Birds in the Urban–Rural Habitat Network."

[8] Richard A. McKinney, Kenneth B. Raposa, and Rose M. Cournoyer, "Wetlands as Habitat in Urbanizing Landscapes: Patterns of Bird Abundance and Occupancy," *Landscape and Urban Planning* 100, no. 1 (March 30, 2011): 144–52, https://doi.org/10.1016/j.landurbplan.2010.11.015; Michael P. Ward, Brad Semel, and James R. Herkert, "Identifying the Ecological Causes of Long-Term Declines of Wetland-Dependent Birds in an Urbanizing Landscape," *Biodiversity and Conservation* 19, no. 11 (October 2010): 3287–3300, https://doi.org/10.1007/s10531-010-9893-y.

[9] David Luther et al., "Assessing the Impact of Local Habitat Variables and Landscape Context on Riparian Birds in Agricultural, Urbanized, and Native Landscapes," *Biodiversity and Conservation* 17, no. 8 (July 2008): 1923–35, https://doi.org/10.1007/s10531-008-9332-5.

[10] Emily Minor and Dean Urban, "Forest Bird Communities across a Gradient of Urban Development," *Urban Ecosystems* 13, no. 1 (March 1, 2010): 51–71, https://doi.org/10.1007/s11252-009-0103-1.

[11] Ian MacGregor-Fors and Rubén Ortega-Álvarez, "Fading from the Forest: Bird Community Shifts Related to Urban Park Site-Specific and Landscape Traits," *Urban Forestry & Urban Greening* 10, no. 3 (January 1, 2011): 239–46, https://doi.org/10.1016/j.ufug.2011.03.004.

was found to be impacted by human disturbance around the sites, even though the marshes themselves lacked any significant disturbance by humans.[12] Similarly, a twenty-six-year study near Chicago, Illinois, found that wetland-dependent bird species declined in abundance even though there was no net loss of wetlands.[13] As urban sprawl surrounded the study sites, the hydrology, vegetation, and structure of the wetlands changed, and the wetlands became either more densely vegetated or more pond-like.[14] Local-level factors such as vegetation may be influenced by changes at the landscape scale, meaning that the scale at which a study is conducted may influence results.[15] As such, landscape-level factors may be more important for management decisions.[16]

Habitat size has historically been assumed to be the most important determinant of species diversity; however, a study in Ohio examining the effects of forest width in comparison to the effects of surrounding urban development on riparian forest bird species concluded that the landscape matrix was a more important factor than habitat size.[17] Other studies differed and concluded that area size was related to species richness or the strongest predictor of species richness.[18]

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[12] Lyndsay A. Smith and Patricia Chow-Fraser, "Impacts of Adjacent Land Use and Isolation on Marsh Bird Communities," *Environmental Management* 45, no. 5 (May 2010): 1040–51, https://doi.org/10.1007/s00267-010-9475-5.

[13] Ward, Semel, and Herkert, "Identifying the Ecological Causes of Long-Term Declines of Wetland-Dependent Birds in an Urbanizing Landscape."

[14] Ward, Semel, and Herkert.

[15] Robert J. Fletcher and Richard L. Hutto, "Partitioning the Multi-Scale Effects of Human Activity on the Occurrence of Riparian Forest Birds," *Landscape Ecology* 23, no. 6 (July 1, 2008): 727–39, https://doi.org/10.1007/s10980-008-9233-8.

[16] Fletcher and Hutto.

[17] Amanda D. Rodewald and Marja H. Bakermans, "What Is the Appropriate Paradigm for Riparian Forest Conservation?," *Biological Conservation* 128, no. 2 (March 1, 2006): 193–200, https://doi.org/10.1016/j.biocon.2005.09.041.

[18] MacGregor-Fors and Ortega-Álvarez, "Fading from the Forest"; Jukka Jokimäki, "Occurrence of Breeding Bird Species in Urban Parks: Effects of Park Structure and Broad-Scale Variables," *Urban Ecosystems* 3 (1999): 21–34.

Whether the presence of humans within a site has an effect is not clear. A study conducted in parks in Oulu, Finland, concluded that the presence of humans within study sites was not an important factor for species richness or occurrence.[19] A study of the behavior of House Sparrows *(Passer domesticus)* in parks in Madrid, Spain, suggested that responses to the presence of humans are likely species-specific.[20] While bird species composition as a whole does not seem to be significantly affected by the presence of humans within a habitat, responses may be dependent on individual species traits.

In considering alterations to the landscape context as a factor, the question is which changes are most important for which bird species. Different studies have quantified urban or suburban development in different ways, which may influence the difference in results between studies. Several studies have expressed urban development of an area in terms of the amount of pavement or impervious surfaces present; research conducted using this definition of urban development has documented a relationship between higher levels of pavement or impervious surfaces and a measurable decline in species richness or in usable habitat.[21] Other studies use other measures, such as building density, land use, or land cover.[22] However, these approaches have a downside: frequently, ecological studies of urbanization will group all urban land uses

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[19] Jokimäki, "Occurrence of Breeding Bird Species in Urban Parks: Effects of Park Structure and Broad-Scale Variables."

[20] Esteban Fernandez-Juricic et al., "Testing the Risk-Disturbance Hypothesis in a Fragmented Landscape: Nonlinear Responses of House Sparrows to Humans," *The Condor* 105, no. 2 (May 2003): 316.

[21] Christopher J. W. McClure et al., "Pavement and Riparian Forest Shape the Bird Community along an Urban River Corridor," *Global Ecology and Conservation* 4 (July 1, 2015): 291–310, https://doi.org/10.1016/j.gecco.2015.07.004; Timothy Randhir and Paul Ekness, "Urbanization Effects on Watershed Habitat Potential: A Multivariate Assessment of Thresholds and Interactions," *Ecohydrology* 2, no. 1 (2009): 88–101, https://doi.org/10.1002/eco.43.

[22] Jokimäki, "Occurrence of Breeding Bird Species in Urban Parks: Effects of Park Structure and Broad-Scale Variables"; Ward, Semel, and Herkert, "Identifying the Ecological Causes of Long-Term Declines of Wetland-Dependent Birds in an Urbanizing Landscape"; Blair and Johnson, "Suburban Habitats and Their Role for Birds in the Urban–Rural Habitat Network."

together, or only differentiate them in terms of intensity. The assumption that all urban land uses have the same environmental effects has been criticized for not accurately reflecting the ways that social and economic forces shape urban habitats.[23] If insufficient attention is given to the differences between the ways specific kinds of urban land use shape urban habitats, there is a risk of overlooking the underlying causes of patterns of species presence and absence.

Certain landscape alterations favor certain species due to the assortment of traits present in those species. For example, Neotropical migrants were found to be negatively associated with increasing proportion of building area in the landscape, while introduced bird species such as European Starlings *(Sturnus vulgaris)* were positively correlated with proportion of building area.[24] In contrast, year-round residents and short-distance migrants were most affected by the percentage of tree cover.[25] The abundance of some species has also been found to decline with higher proportions of built structures.[26] In multiple ecoregions, differences in land cover between rural, suburban, and urban sites were predictive of a pattern of change from species with more specialized traits, such as insectivorous diet, territorial behavior, and long-distance migration, to less specialized traits, such as granivorous diet, non-territoriality, and year-round residence.[27]

When an area is developed, the alterations are not only physical. Anthropogenic noise pollution may be particularly problematic for birds as they are dependent on acoustic

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[23] Kirstin S. Bourne and Tenley M. Conway, "The Influence of Land Use Type and Municipal Context on Urban Tree Species Diversity," *Urban Ecosystems* 17, no. 1 (March 1, 2014): 329–48, https://doi.org/10.1007/s11252-013-0317-0; E. Jamie Trammell and Scott Bassett, "Impact of Urban Structure on Avian Diversity along the Truckee River, USA," *Urban Ecosystems* 15, no. 4 (December 1, 2012): 993–1013, https://doi.org/10.1007/s11252-012-0251-6.

[24] Derric N. Pennington, James Hansel, and Robert B. Blair, "The Conservation Value of Urban Riparian Areas for Landbirds during Spring Migration: Land Cover, Scale, and Vegetation Effects," *Biological Conservation* 141, no. 5 (May 2008): 1235–48, https://doi.org/10.1016/j.biocon.2008.02.021.

[25] Pennington, Hansel, and Blair.

[26] Jokimäki, "Occurrence of Breeding Bird Species in Urban Parks: Effects of Park Structure and Broad-Scale Variables."

[27] Blair and Johnson, "Suburban Habitats and Their Role for Birds in the Urban–Rural Habitat Network."

communication.[28] A study of the impact of natural gas extraction infrastructure on nesting bird species found that higher noise levels were correlated with a decline in species richness, and that noise pollution by itself altered community composition by disrupting interspecies interactions.[29] An experiment using an array of speakers playing road noise in the absence of physical vehicles (a "phantom road") demonstrated that migratory bird species will preferentially avoid areas with traffic noise.[30] Traffic noise has been found to have a stronger effect than traffic volume on decreasing the probability of detection for two Australian bird species.[31]

In contrast, a study conducted in Boise, Idaho found a lack of association between species richness and noise pollution in an urban-rural gradient.[32] Another study concluded that the distance of a site from the nearest road had a stronger effect on bird species richness than road noise level or traffic volume, suggesting that while noise pollution was a contributing factor, it was not the most important one.[33] Instead, the authors suggest that another aspect of roads is to blame, such as vehicle lights and motion, direct mortality from collisions, habitat fragmentation, the loss of insect prey species, or effects of car exhaust.[34] Traffic noise was also not found to be a strong predictor of bird species community composition in forest fragments in the North

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[28] Clinton D. Francis, Catherine P. Ortega, and Alexander Cruz, "Noise Pollution Changes Avian Communities and Species Interactions," *Current Biology* 19, no. 16 (August 25, 2009): 1415–19, https://doi.org/10.1016/j.cub.2009.06.052.

[29] Francis, Ortega, and Cruz.

[30] Christopher J. W. McClure et al., "An Experimental Investigation into the Effects of Traffic Noise on Distributions of Birds: Avoiding the Phantom Road," *Proceedings of the Royal Society B: Biological Sciences* 280, no. 1773 (December 22, 2013): 20132290, https://doi.org/10.1098/rspb.2013.2290.

[31] Kirsten M. Parris and Angela Schneider, "Impacts of Traffic Noise and Traffic Volume on Birds of Roadside Habitats," *Ecology and Society* 14, no. 1 (2009), http://www.jstor.org/stable/26268029.

[32] McClure et al., "Pavement and Riparian Forest Shape the Bird Community along an Urban River Corridor."

[33] Patricia D. Summers, Glenn M. Cunnington, and Lenore Fahrig, "Are the Negative Effects of Roads on Breeding Birds Caused by Traffic Noise?," *Journal of Applied Ecology* 48, no. 6 (2011): 1527–34, https://doi.org/10.1111/j.1365-2664.2011.02041.x.

[34] Summers, Cunnington, and Fahrig.

Carolina Piedmont; instead, road density was more important than either traffic volume or road width.[35] With noise pollution affecting some sites across an urban-rural gradient more strongly than others, there is the concern that bird calls may be masked not only from conspecifics, but from human observers as well. Research into the effects of road noise on detectability during the Breeding Bird Survey in Great Britain suggested that some species may be less detectable by observers near roads.[36] In contrast, however, another study into the effects of traffic noise concluded that noise pollution did not significantly affect the ability of observers to detect bird species.[37]

While the literature overall supports the idea that increased urbanization causes an altered bird species composition, there is not general agreement on whether direct or indirect impacts have a stronger effect. In this paper, I seek to contribute to the understanding of what factors affect birds in urbanized areas. I am specifically focusing on birds in urban wetlands for two reasons: (1) birds are particularly vulnerable to the effects of urbanization and (2) the ecology of urban wetlands is understudied. I aim to answer the following questions: (1) How do direct and indirect human disturbances affect avian community composition in Piedmont North Carolina wetlands with varying degrees of urbanization? (2) Are species compositions in more-disturbed sites less distinct? I hypothesize that (1) species compositions of more-disturbed wetlands will differ from less-disturbed wetlands, (2) more disturbed sites will have species compositions that are less specialized than less-disturbed sites and (3) species composition will be more affected by indirect disturbances than by direct disturbances.

[35] Minor and Urban, "Forest Bird Communities across a Gradient of Urban Development."

[36] Sophia C. Cooke et al., "Road Exposure and the Detectability of Birds in Field Surveys," *Ibis* 162, no. 3 (2020): 885–901, https://doi.org/10.1111/ibi.12787.

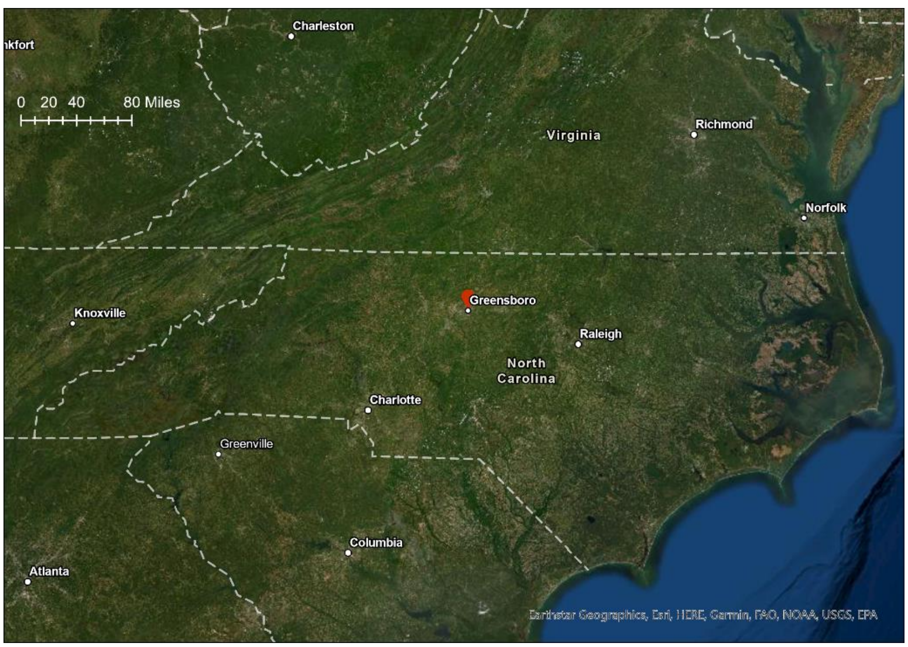
[37] Summers, Cunnington, and Fahrig, "Are the Negative Effects of Roads on Breeding Birds Caused by Traffic Noise?"

CHAPTER II: METHODS

Study Area

I conducted my study in the Greensboro metropolitan area. Greensboro (Figure 1), situated in the Cape Fear River basin, is North Carolina's third-largest city. Greensboro, a suburbanized city with a long history as a major transportation hub and manufacturing center, is located in the North Carolina Piedmont region and has a humid subtropical climate. Like many areas in the Piedmont region of the Southeast, it has undergone intense landscape changes after European colonization, first from deforestation and conversion of land for agricultural use, and subsequently from expanding urban development.[38]

Figure 1. Location of Greensboro, North Carolina



My five study sites were the University of North Carolina at Greensboro (UNCG) wetland, the Bog Garden, Price Park, Moores Creek, and Haw River State Park (Figure 2, Table

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[38] Darrell E. Napton et al., "Land Changes and Their Driving Forces in the Southeastern United States," *Regional Environmental Change* 10, no. 1 (March 1, 2010): 37–53, https://doi.org/10.1007/s10113-009-0084-x.

1). The UNCG wetland (Figure 3) was constructed on the university campus starting in 2017 and is used for research by several university departments.[39] UNCG is located near Greensboro's downtown and residential neighborhoods. The Bog Garden (Figure 4) is a city park with a restored wetland, which is situated near shopping centers and residential neighborhoods, as well as other city parks.[40] The wetland at Price Park (Figure 5) is natural; the site is managed by the city of Greensboro and several local community organizations.[41] Price Park is located on the grounds of a branch of Greensboro's public library, near schools and shopping centers. Moores Creek (Figure 6) is a natural wetland running through a city-owned parcel of land.[42] It is surrounded by suburban residential development. Haw River State Park (Figure 7) is a natural wetland. The park, which is located in Guilford and Rockingham counties, was established in 2005, and includes the headwaters of the Haw River.[43] Haw River State Park is in an agricultural area, with several nearby residential neighborhoods as well.

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[39] "About | Wetlands," accessed March 11, 2022, https://wetlands.uncg.edu/about/.

[40] "Bog Garden at Benjamin Park History," Greensboro Beautiful, accessed March 11, 2022, https://greensborobeautiful.org/gardens/bog-garden/bog-garden-at-benjamin-park-history/.

[41] "IV-A10-Price-Park - Piedmont Bird Club," accessed March 11, 2022, http://www.piedmontbirdclub.org/iv-a10-price-park.html.

[42] "- Gis Data Download," accessed March 11, 2022, http://gis.guilfordcountync.gov/datadownload/DataDownload.aspx.

[43] "History | NC State Parks," accessed March 11, 2022, https://www.ncparks.gov/haw-river-state-park/history.

Figure 2. Map of Study Site Locations within Greensboro Area

Figure 3. Aerial View of UNCG Wetland and Nearby Landscape

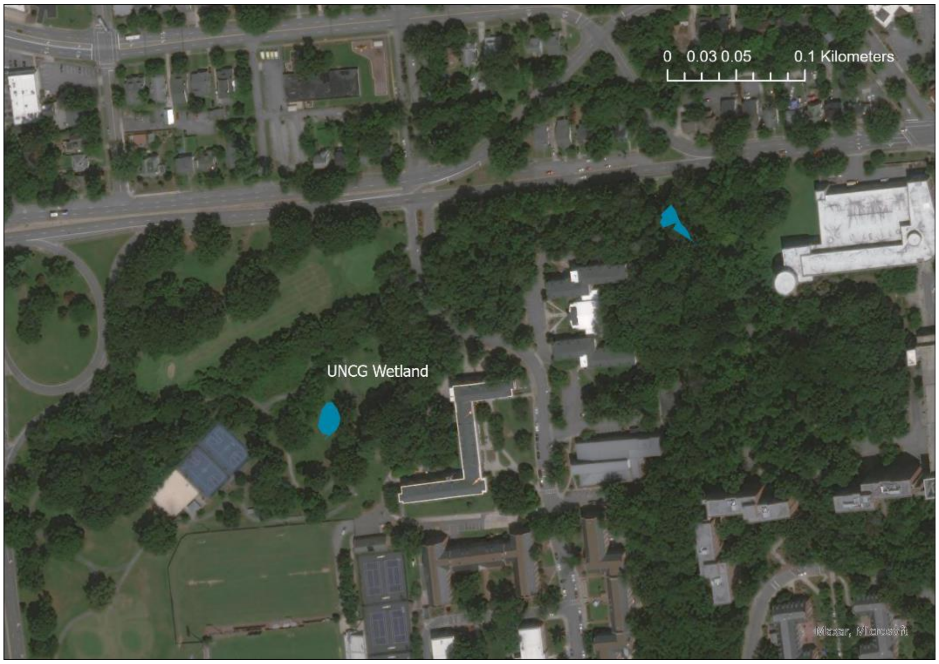


Figure 4. Aerial View of the Bog Garden and Nearby Landscape

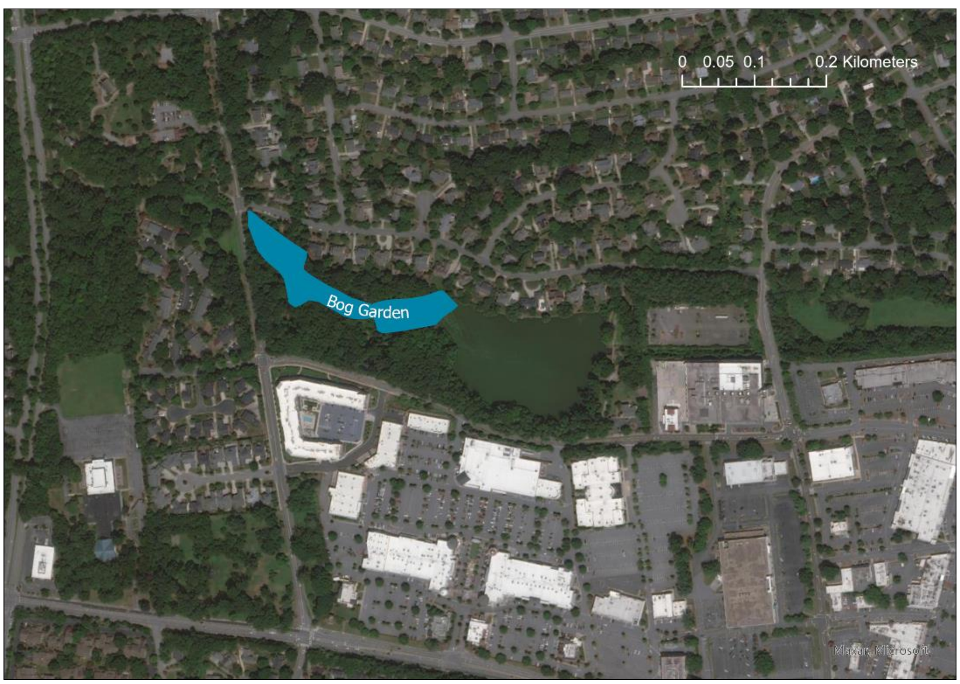


Figure 5. Aerial View of Price Park and Nearby Landscape

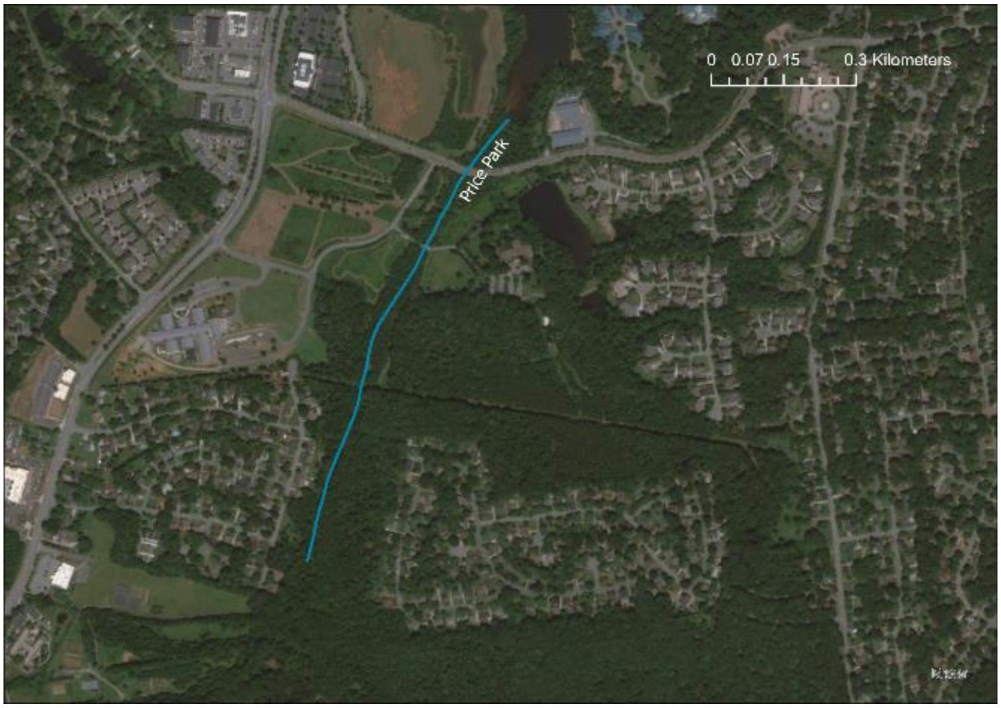


Figure 6. Aerial View of Moores Creek and Nearby Landscape

Figure 7. Aerial View of Haw River State Park and Nearby Landscape

Table 1. Study Sites

Site	Coordinates	Area in hectares	Constructed or natural?	Land ownership or management	Surrounding land use	Site usage
UNCG Wetland	79.809W 36.073N	0.05	Constructed	UNCG	University campus	University campus
Bog Garden	79.838W 36.090N	1.22	Constructed	Greensboro Parks and Recreation Department	City parks, shopping centers, residential development	City park
Price Park	79.881W 36.104N	0.62	Natural with management	Greensboro Parks and Recreation Department & Piedmont Land Conservancy	Public schools; shopping centers	Public library
Moores Creek	79.924W 36.164N	34.67	Natural	City of Greensboro	Suburban residential development	Watershed area
Haw River State Park	79.760W 36.254N	156.44	Natural	North Carolina State Parks	Agriculture; residential development	State park

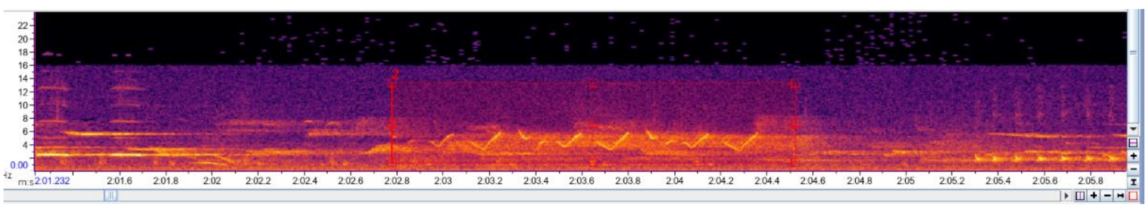
Bird Species Composition

I collected bird species data during a six-week period in May and June 2021, as early summer is the season when Neotropical migrant songbirds have arrived in North Carolina. Observations were done during the dawn chorus, at approximately sunrise. To rule out the possibility of weather or weekly human behavior influencing results, I visited sites only on weekdays and only on days when it was not raining.[44] I visited each site once per week and randomized the day of the week to control for the possibility of weekly disruptive events. I

[44] Jokimäki, "Occurrence of Breeding Bird Species in Urban Parks: Effects of Park Structure and Broad-Scale Variables."

collected species data using an unlimited-radius single-observer survey approach, taking observations from the same location at each site on each visit. I recorded every species of bird identifiable (by visual or audio identification) over a period of 20 minutes (a length of time chosen to allow birds to acclimate to human presence). To verify identifications, I made recordings for later examination using two four-channel digital audio recorders: a Zoom H2n and a Tascam DR-60DMKII. I used Raven Lite to play back the sound recordings and I identified all bird species audible in the recordings (Figure 8). If a bird call was not readily identifiable, I compared the spectrogram in Raven Lite to spectrograms of calls on eBird (Cornell Lab of Ornithology) and verified that it was a species reported at that location.

Figure 8. Spectrogram of a Vocalization of a Common Yellowthroat (Geothlypis trichas), Recorded June 17, 2021 at Haw River State Park and Displayed using Raven Lite.



Direct Human Impacts (Human Presence and Anthropogenic Noise)

I measured human presence at the study wetlands by counting the number of humans present along a consistent route at each site for ten minutes during midday.[45] I visited each site to collect data on human presence three times per site, over the same months as bird observations. As with bird species data, observations were only collected on weekdays and on days when it was not raining.

[45] Jokimäki.

I obtained anthropogenic noise levels from the recordings made at each site with the Zoom H2n. I calibrated Raven Pro with the technical specifications of the recorder and extracted decibel readings from recordings filtered to contain sounds between 0 and 2 kHz. This is the frequency band which contains most traffic noise without including insect or bird sounds.[46] Research conducted by the National Park Service Natural Sounds and Night Skies Division indicates that commercial sound recorders can be an appropriate instrument for evaluating noise pollution.[47]

Site Data

I obtained wetland polygons from the Fish and Wildlife Service National Wetlands Inventory, except for the UNCG wetland, which was not included in the National Wetlands Inventory.[48] A survey-grade real-time kinematic global positioning system (RTK-GPS) (Leica GS14) was used to survey the UNCG wetland. Wetland polygons for all sites were analyzed using ArcGIS Pro (ESRI). To calculate the distance from the city center, I used ArcGIS to measure the distance from each site polygon to an approximately centrally located point in Greensboro. I used ArcGIS to measure the area of each site. I used the area data and the perimeter for each site (also measured with ArcGIS) to calculate the shape complexity for each study wetland:[49]

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[46] Summers, Cunnington, and Fahrig, "Are the Negative Effects of Roads on Breeding Birds Caused by Traffic Noise?"

[47] D. J. Mennitt and K. M. Fristrup, "Obtaining Calibrated Sound Pressure Levels from Consumer Digital Audio Recorders," *Applied Acoustics* 73, no. 11 (November 1, 2012): 1138–45, https://doi.org/10.1016/j.apacoust.2012.05.006.

[48] "Wetlands Data | U.S. Fish & Wildlife Service," accessed March 19, 2022, https://www.fws.gov/program/national-wetlands-inventory/wetlands-data.

[49] Corey S. Shake et al., "Influence of Patch Size and Shape on Occupancy by Shrubland Birds," *The Condor* 114, no. 2 (May 1, 2012): 268–78, https://doi.org/10.1525/cond.2012.110107.

Equation 1

shape index = $\frac{perimeter}{2\sqrt{\pi \times area}}$

Indirect Human Impacts (Land Use, Land Cover, Impervious Surfaces, & Traffic Volume)

I measured land cover and impervious surfaces using the United States Geological Survey's National Land Cover Database for 2019.[50] The land use data were from Rockingham County and Guilford County tax parcels.[51] Traffic volume data were from the North Carolina Department of Transportation's 2019 traffic survey.[52] I created five-hundred-meter and one-kilometer buffers around wetland polygons in ArcGIS, as these are distances at which landscape factors have been found to affect wetland avian community composition.[53] I used these buffers to extract the tax parcels, land cover, impervious surfaces, and traffic volume within the buffer zones.

Data Analysis

I chose to use the Index of Marsh Bird Community Integrity (IMBCI) as my response variable.[54] Measures of species richness alone can be misleading, particularly in urbanized environments. An influx of urban-adapted generalist species into urbanized areas can result in increased species richness metrics[55]. I calculated an IMBCI score for each site using the formula:

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[50] "Data | Multi-Resolution Land Characteristics (MRLC) Consortium," accessed March 11, 2022, https://www.mrlc.gov/data?f%5B0%5D=category%3ALand%20Cover.

[51] "- Gis Data Download"; "Rockingham County GIS," accessed March 11, 2022, https://data-hub-rock-co-gis.hub.arcgis.com/.

[52] "Traffic Survey GIS Data Products & Documents," accessed March 11, 2022, https://connect.ncdot.gov/resources/State-Mapping/Pages/Traffic-Survey-GIS-Data.aspx.

[53] William V. DeLuca et al., "Influence of Land Use on the Integrity of Marsh Bird Communities of Chesapeake Bay, USA," *Wetlands* 24, no. 4 (December 1, 2004): 837–47, https://doi.org/10.1672/0277-5212(2004)024[0837:IOLUOT]2.0.CO;2.

[54] DeLuca et al.

[55] McKinney, Raposa, and Cournoyer, "Wetlands as Habitat in Urbanizing Landscapes"; Blair and Johnson, "Suburban Habitats and Their Role for Birds in the Urban–Rural Habitat Network."

Equation 2

$$W_{IMBCI} = \left[\left(\sum \frac{S_{IMBCI}}{S_N} \right) + MO_N \right] - 4$$

In this formula, W_{IMBCI} is the index value for the site, S_{IMBCI} is an individual species score, S_N is the total number of species found at the site, and MO_N is the number of marsh-obligate species present.[56] To calculate individual species scores, I ranked the life history traits of each species from 1-4, with 1 as the least specialized and 4 as the most specialized and summed the values for each life history category (Table 2). I obtained life history trait data for each species from Birds of the World (Macaulay Library, Cornell University). IMBCI scores were calculated in Excel.

Table 2. IMBCI Species Attribute Score Table (after DeLuca et al. 2004)

	Generalist traits				Specialist traits
Species attribute	1	2	2.5	3	4
Foraging habitat	Habitat generalist		Wetland facultative		Wetland obligate
Nesting substrate	Non-wetland nesters		Wetland vegetation		Wetland ground nester
Migratory status	Year-round resident		Short distance or temperate migrant		Neotropical migrant
Breeding range	North America	North America east of Rocky Mountains			

To measure variation in species composition between sites, I calculated Sørensen similarity coefficients for each pair of sites using Excel. In addition, I calculated the multi-site

[56] DeLuca et al., "Influence of Land Use on the Integrity of Marsh Bird Communities of Chesapeake Bay, USA."

Sørensen similarity coefficient to measure the overall similarity in species composition using the formula:

Equation 3

$$C_S^T = \frac{T}{T-1}\left(1 - \frac{S_T}{\sum_i a_i}\right)$$

where *T* is the number of sites, a_i is the number of species in site A_i (iterated through all sites), and S_T is the total number of species.[57]

Because there were many land cover or land use categories that were not found in site buffers, I reclassified land cover and tax parcel records into broader categories, such as combining mixed, evergreen, and deciduous forests into one forest category. Land cover and tax parcel variables that were not present at any site or had very few records were removed. I divided impervious surface data into quintiles. I performed a chi square test of independence to test if land cover, land use, and impervious surfaces were different between study sites.

Land cover, land use, and impervious surface data were expressed as proportions. To estimate traffic volume per site, I multiplied the average annual daily traffic for a road segment by the length of the segment in the buffer, divided by the total length of the road segment, and took the average in the buffer zone. I logit-transformed all proportional data,[58] setting zero equal to 0.000001 as zero becomes negative infinity using the logit transformation. I normalized all predictor variables to a mean of 0 and a standard deviation of 1. I used SPSS to perform a partial least squares regression (PLS) to measure the effect of predictor variables on IMBCI scores. Partial least squares regression is considered to be effective for studies with a small sample size

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[57] Ola H Diserud and Frode Ødegaard, “A Multiple-Site Similarity Measure,” *Biology Letters* 3, no. 1 (February 22, 2007): 20–22, https://doi.org/10.1098/rsbl.2006.0553.

[58] David I. Warton and Francis K. C. Hui, “The Arcsine Is Asinine: The Analysis of Proportions in Ecology,” *Ecology* 92, no. 1 (2011): 3–10, https://doi.org/10.1890/10-0340.1.

and a larger number of predictor variables, and with predictor variables that are likely to be correlated; for this reason, it is considered to be a good option for ecological studies.[59] I considered a predictor variable to be significant if the variable importance in the projection (VIP) > 1.0, and iterated successive partial least squares regressions with all predictor variables with VIP > 1.0 until reaching the maximum R^2 .

[59] Luis M. Carrascal, Ismael Galván, and Oscar Gordo, "Partial Least Squares Regression as an Alternative to Current Regression Methods Used in Ecology," *Oikos* 118, no. 5 (2009): 681–90, https://doi.org/10.1111/j.1600-0706.2008.16881.x.

CHAPTER III: RESULTS

Species Survey

I identified a total of 42 species across all sites (APPENDIX A: SPECIES PRESENCE-ABSENCE MATRIX), with species per site ranging from 14 at the UNCG wetland to 28 at Haw River State Park. Bird species found at all sites were common birds of the region, including the Carolina Wren (*Thryothorus ludovicianus*), Carolina Chickadee (*Poecile carolinensis*), Tufted Titmouse (*Baeolophus bicolor*), Northern Cardinal (*Cardinalis cardinalis*), American Crow (*Corvus brachyrhynchos*) and Red-eyed Vireo (*Vireo olivaceus*). With the notable exception of the Red-eyed Vireo, which is a Neotropical migrant, the species present at all five sites were year-round residents. The least-observed species included specialized insectivores such as the Blue-gray Gnatcatcher (*Polioptila caerulea*) and Great Crested Flycatcher (*Myiarchus crinitus*), multiple warbler species, and birds typical of larger forest patches such as the Wood Thrush (*Hylocichla mustelina*), Yellow-billed Cuckoo (*Coccyzus americanus*), and Pileated Woodpecker (*Dryocopus pileatus*). IMBCI scores ranged from 1 to 5.571 (Table 3). IMBCI score values are between 0 and 12 and measure how many species present at a wetland exhibit specialized traits.[60] A score of zero indicates that all species detected are generalists, while a score of twelve would indicate that all species were highly specialized.[61]

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[60] DeLuca et al., "Influence of Land Use on the Integrity of Marsh Bird Communities of Chesapeake Bay, USA."

[61] DeLuca et al.

Table 3. Index of Marsh Bird Community Integrity Scores for Each Study Site

Study site	IMBCI score
UNCG Wetland	1
Bog Garden	1.071
Price Park	1.567
Moores Creek	2.8
Haw River State Park	5.571

Species Composition

The Sørensen multisite similarity coefficient was 0.714, indicating that species composition when considered across all sites is relatively similar. When coefficients for pairs of sites are considered, the UNCG wetland and Haw River State Park have the least similar species compositions (Sørensen coefficient = 0.33), and the UNCG wetland and the Bog Garden have the most similar species compositions (Sørensen coefficient = 0.743) (Table 4). Pairwise from closest to furthest from the city center, the pattern of Sørensen coefficients is nonlinear (Figure 9). As sites get closer to the city center, they have species compositions that are increasingly unlike that of Haw River State Park (Figure 10), and as sites get farther out, they have species compositions that are increasingly unlike the species composition at the UNCG wetland (Figure 11).

Figure 9. Pairwise Sørensen Coefficients, from the Pair Closest to City Center to the Pair Farthest from the City Center. UW – UNCG Wetland; BG – Bog Garden; PP – Price Park; MC – Moores Creek; HR – Haw River State Park

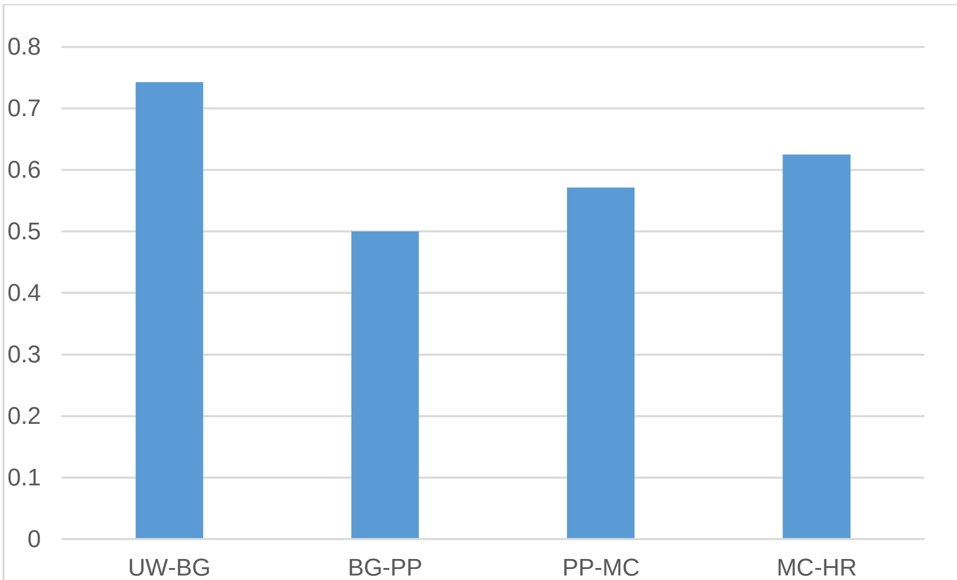


Figure 10. Pairwise Sørensen Coefficients, Each Study Site Compared to Haw River State Park

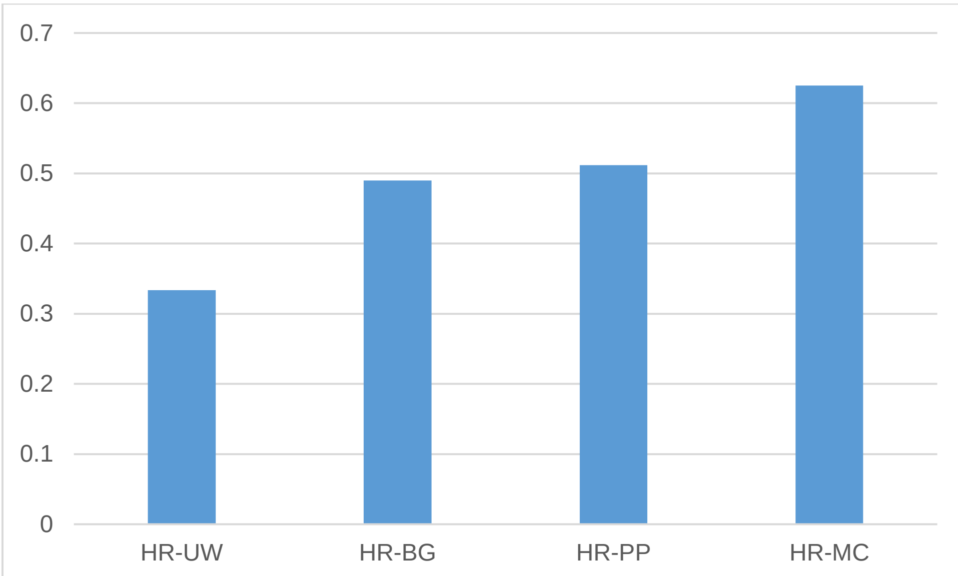


Figure 11. Pairwise Sørensen Coefficients, Each Study Site Compared to the UNCG Wetland

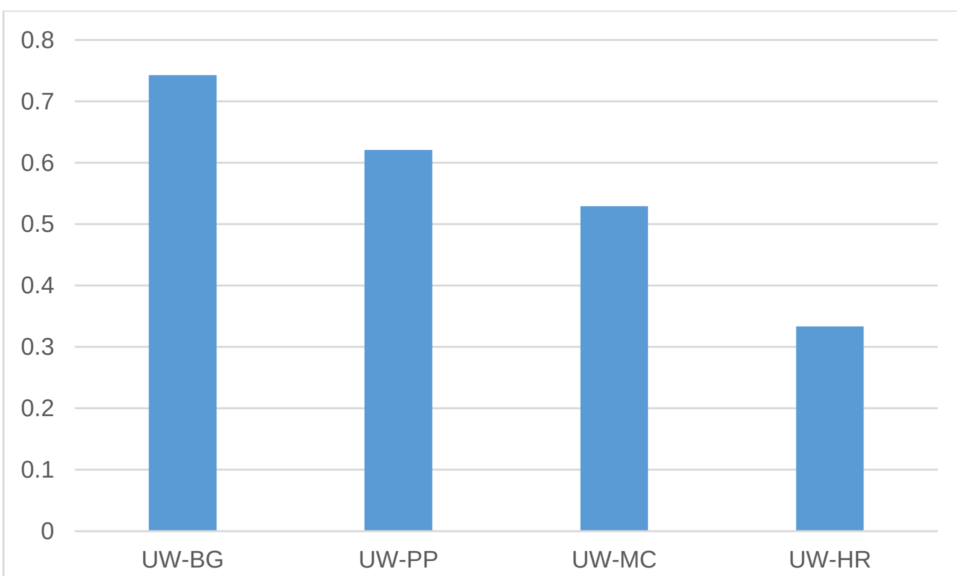


Table 4. Pairwise Sørensen Coefficients for All Sites

Site pair	Similarity coefficient
UW-BG	0.743
UW-PP	0.621
UW-MC	0.529
UW-HR	0.33
BG-PP	0.5
BG-MC	0.488
BG-HR	0.49
PP-MC	0.571
PP-HR	0.511
MC-HR	0.625

Direct and Indirect Disturbances

Residential land use was the highest proportion of land use at all sites for both scales; the least common land use varied by site (APPENDIX B: PREDICTOR VARIABLES USED IN PARTIAL LEAST SQUARES REGRESSION, Figure 12). The UNCG wetland lacked natural land cover based on NLCD classification within 1 kilometer **(**Figure 13). This site also had the lowest level of low-impervious surfaces, while Haw River State Park lacked 81-100% imperviousness within 1 kilometer (Figure 14). Average traffic volume depended on scale, as Price Park had the highest average at the 500-meter buffer, while UNCG had the highest average at the 1-kilometer buffer (Figure 15). Most sites had averages of few or no humans present. The average level of anthropogenic noise was high at all sites. The lowest average anthropogenic noise level was 55.46 decibels (dB) at Moores Creek, while the loudest site was the UNCG wetland, with an average of 63.16 dB. It should be noted that decibels are on a logarithmic scale and noise volume, as perceived by humans, doubles every 10 dB. Outdoor spaces with an average noise level of 55 dB are considered to be at the upper limit for holding a normal spoken conversation comfortably and intelligibly[62]. Based on chi square tests of independence, study site was related to land cover at 1 kilometer ($p < 0.001$) and 500 meters ($p < 0.001$), land use at 1 kilometer ($p = 0$) and 500 meters ($p = 0$), and impervious surfaces at 1 kilometer ($p = 0$) and 500 meters ($p = 0$).

[62] "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (U.S. Environmental Protection Agency Office of Noise Abatement and Control, 1974).

Figure 12. Land Use within 1 Kilometer of Study Wetlands

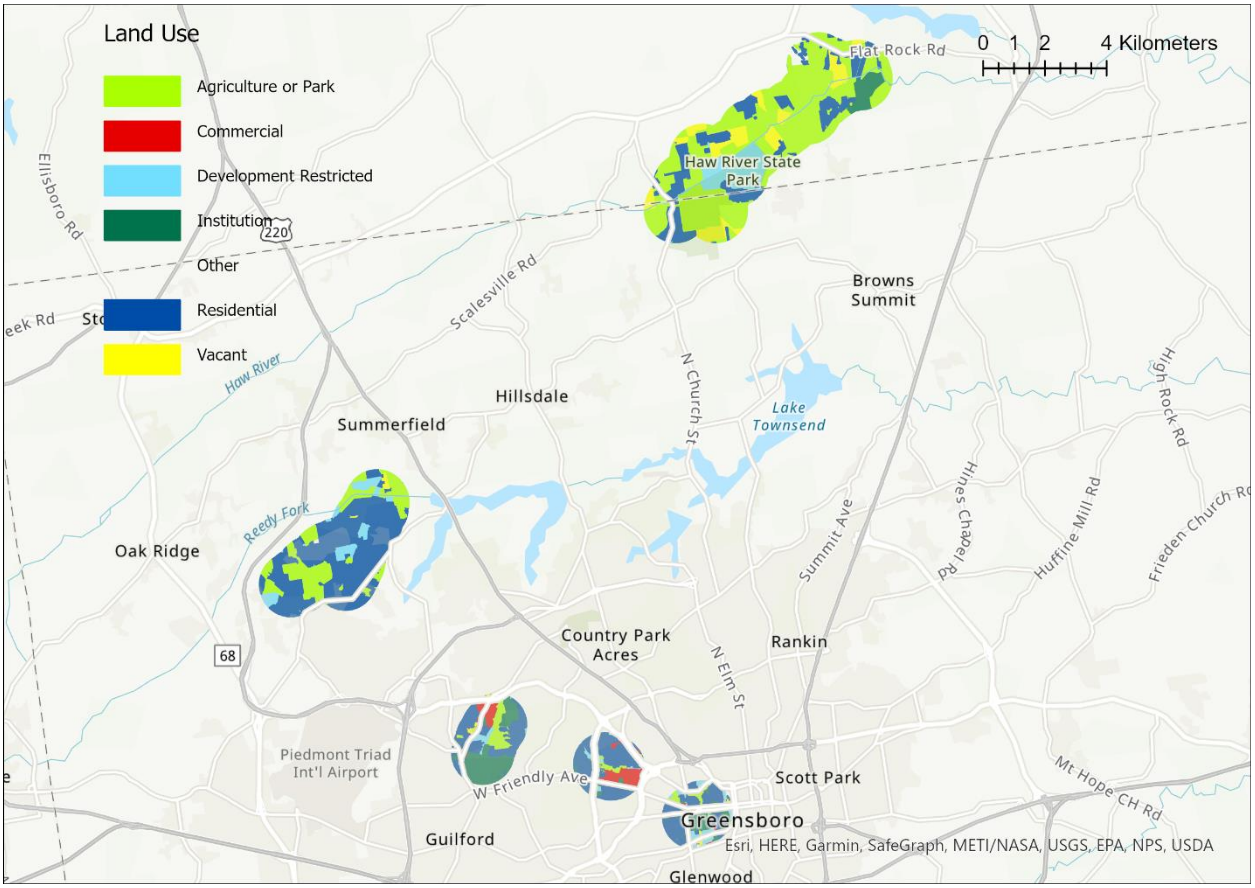


Figure 13. Land Cover within 1 Kilometer of Study Wetlands

Figure 14. Impervious Surfaces within 1 Kilometer of Study Wetlands

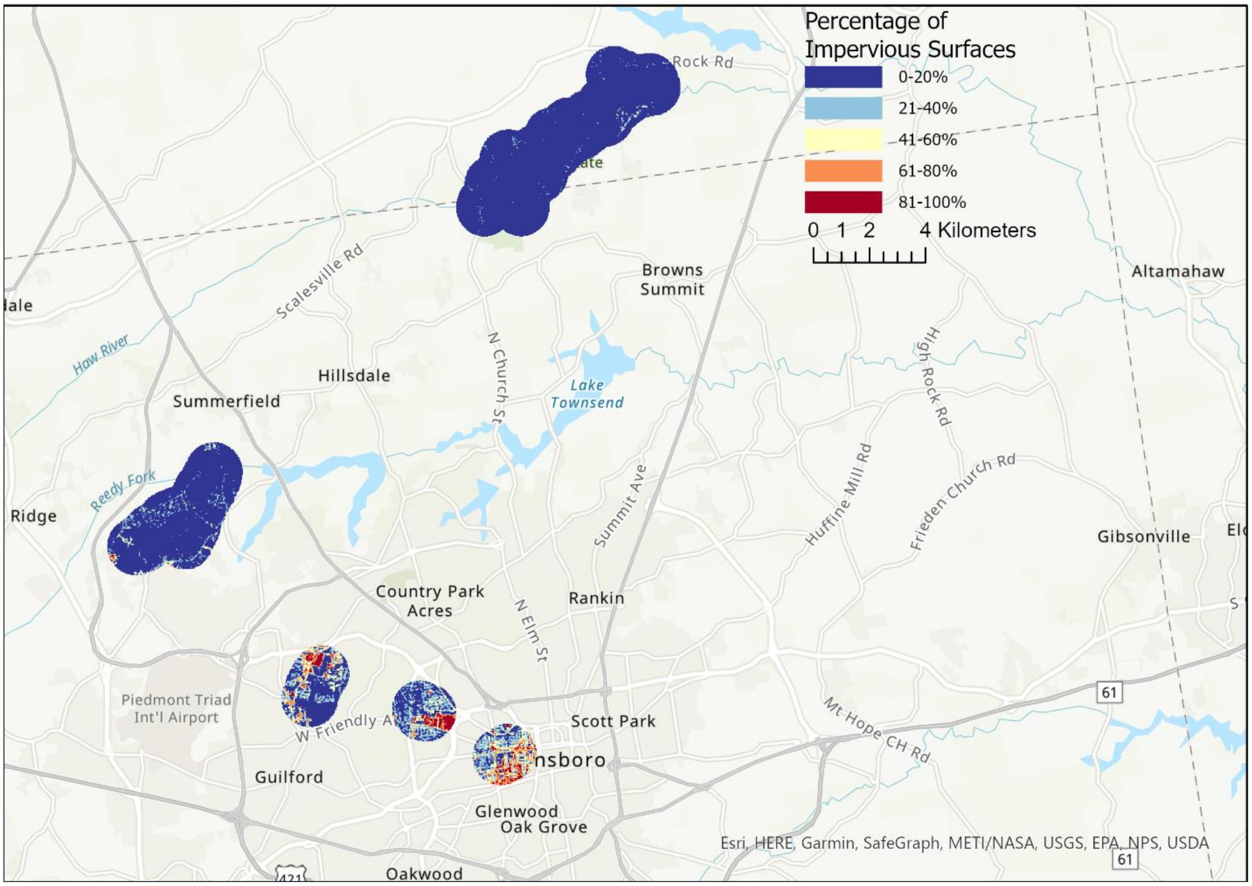
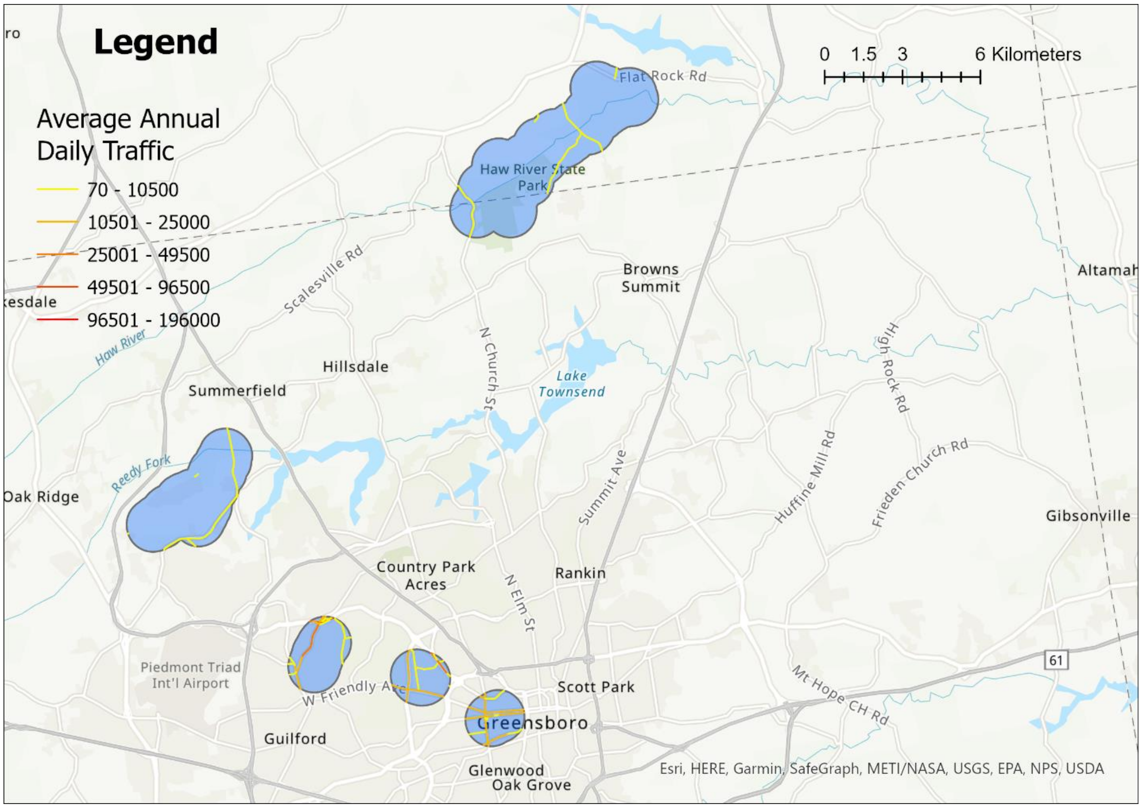


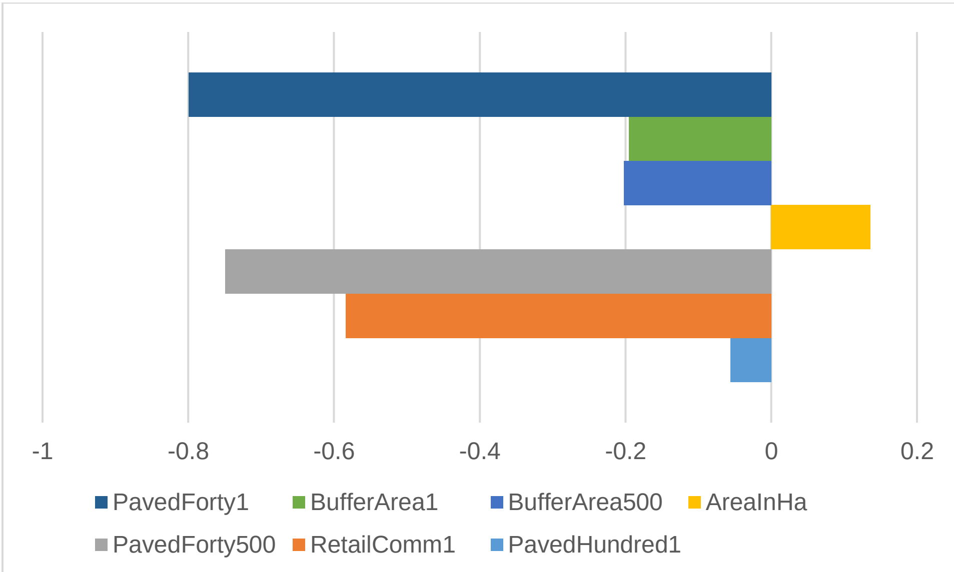
Figure 15. Traffic Volume within 1 Kilometer



Partial Least Squares

The first PLS projection in the fourth iteration was the most explanatory ($R^2 = 0.997$). The VIP for the variables remaining in this model ranged from 0.989 to 1.005. Wetland area in hectares was positively related to IMBCI scores (Figure 16). Other predictor variables had negative correlations with IMBCI scores (Figure 16). Impervious surfaces at 21-40% and 81-100% and retail and commercial tax parcels in a 1-kilometer buffer were predictive of IMBCI score.

Figure 16. Regression Coefficients for Predictor Variables in Fourth Iteration of Partial Least Squares Regression



CHAPTER IV: DISCUSSION

When considered in the aggregate, the study sites had similar species compositions based on the multi-site Sørensen's similarity coefficient. However, individual pairs of sites demonstrated a consistent pattern, where sites with similar levels of disturbance had correspondingly similar species compositions. The high multi-site similarity is likely due to the ubiquitous presence of native generalists such as Carolina Wrens and American Crows, while more specialized species such as Prothonotary Warblers (*Protonotaria citrea*) and Blue-gray Gnatcatchers were only recorded at one site each. However, the species composition was not entirely generalists, as even the most urbanized sites were able to support Neotropical migrants such as Gray Catbirds (*Dumetella carolinensis*) and Red-eyed Vireos. There is the possibility that the similarity of species compositions at the more urbanized sites is due to spatial autocorrelation, as these sites are closer to each other. However, Moores Creek was most similar to Haw River State Park due to the presence of specialist species at both wetlands, despite Haw River State Park being the most distant site from Moores Creek.

The absence of specialized species at more urbanized wetlands changes the way these ecosystems work. Biotic homogenization reduces ecosystem function, rendering homogenized ecosystems less stable over the long term and less resilient to disruptions.[63] The loss of species diversity leads to ecosystems with simplified food-web structures and a higher risk of colonization by invasive species.[64] As such, once biotic homogenization has occurred, the new

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[63] Julian D. Olden et al., "Ecological and Evolutionary Consequences of Biotic Homogenization," *Trends in Ecology & Evolution* 19, no. 1 (January 1, 2004): 18–24, https://doi.org/10.1016/j.tree.2003.09.010; Shaopeng Wang et al., "Biotic Homogenization Destabilizes Ecosystem Functioning by Decreasing Spatial Asynchrony," *Ecology* 102, no. 6 (2021): e03332, https://doi.org/10.1002/ecy.3332.

[64] Olden et al., "Ecological and Evolutionary Consequences of Biotic Homogenization."

species composition may not be in a state of equilibrium, but instead may be vulnerable to further alteration and species loss.

Based on the PLS results, indirect disturbances, rather than direct disturbances, were stronger drivers of wetland bird compositions. This is consistent with some of the existing literature, such as the finding that landscape context had a significant influence on forest bird communities in the Raleigh, North Carolina area.[65] Studies of Midwestern riparian forests also found that development of the surrounding landscape had effects on bird species richness and variation between sites.[66] Wetland-specific studies have found that adjacent urbanization was linked to decreased obligate wetland-nesting birds and to declining abundance of wetland specialists.[67]

None of my direct disturbance predictor variables, including human presence and anthropogenic noise, were significantly predictive of a site's IMBCI score based on the results of the partial least squares regression. Anthropogenic noise not having a major impact on bird species at urban sites is consistent with the conclusions of previous research.[68] While it was not a significant factor, the average anthropogenic noise level was high even at the least-urbanized site. As such, it is possible that any bird species particularly sensitive to anthropogenic noise pollution may already be absent.

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[65] Minor and Urban, "Forest Bird Communities across a Gradient of Urban Development."

[66] Pennington, Hansel, and Blair, "The Conservation Value of Urban Riparian Areas for Landbirds during Spring Migration"; Rodewald and Bakermans, "What Is the Appropriate Paradigm for Riparian Forest Conservation?"

[67] Smith and Chow-Fraser, "Impacts of Adjacent Land Use and Isolation on Marsh Bird Communities"; Ward, Semel, and Herkert, "Identifying the Ecological Causes of Long-Term Declines of Wetland-Dependent Birds in an Urbanizing Landscape."

[68] McClure et al., "Pavement and Riparian Forest Shape the Bird Community along an Urban River Corridor"; Summers, Cunnington, and Fahrig, "Are the Negative Effects of Roads on Breeding Birds Caused by Traffic Noise?"; Minor and Urban, "Forest Bird Communities across a Gradient of Urban Development."

The shape complexity of the wetlands lacked a significant correlation with the IMBCI score. However, based on the PLS model, the size of the wetland itself and of the 500-meter and 1-kilometer buffers was predictive of IMBCI score. Wetland area was the variable most positively associated with the IMBCI score. The species-area relationship is well established.[69] The importance of the buffer area may be a manifestation of the species-area relationship. Wetland area has been found to be a significant factor for IMBCI score.[70]

Indirect disturbance predictors that were significant at one scale were not necessarily significant for both. Previous research has established that the distance at which a landscape variable is measured may determine whether it appears to be significant, as there may be threshold distances beyond which increased development does not have a meaningful effect.[71]

Impervious surfaces were strongly associated with lower IMBCI scores. Degree of impervious surface has been shown in other studies to have a negative effect on various bird metrics. Species richness has been found to be negatively correlated with impervious surfaces, and pavement has been found to decrease usable habitat.[72] Impervious surfaces are more reflective than natural surfaces and can cause distortion of high-frequency birdsong components.[73] In response to this phenomenon many bird species alter the frequency of their songs.[74] A study conducted in Australian towns found that impervious surfaces had negative

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[69] MacGregor-Fors and Ortega-Álvarez, "Fading from the Forest."

[70] DeLuca et al., "Influence of Land Use on the Integrity of Marsh Bird Communities of Chesapeake Bay, USA."

[71] DeLuca et al.; Pennington, Hansel, and Blair, "The Conservation Value of Urban Riparian Areas for Landbirds during Spring Migration."

[72] McClure et al., "Pavement and Riparian Forest Shape the Bird Community along an Urban River Corridor"; Randhir and Ekness, "Urbanization Effects on Watershed Habitat Potential."

[73] J.L. Dowling, D.A. Luther, and P.P. Marra, "Comparative Effects of Urban Development and Anthropogenic Noise on Bird Songs," *Behavioral Ecology* 23, no. 1 (January 1, 2012): 201–9, https://doi.org/10.1093/beheco/arr176.

[74] Dowling, Luther, and Marra.

effects on the density of native bird species but positive effects on exotic species.[75] Similarly, a study in the Cerrado ecoregion of Brazil found that impervious surfaces were the main driver of species richness and had a strong negative effect.[76]

The strong negative correlation between the proportion of specific classifications of percent impervious surfaces and the IMBCI score could be indicative of a threshold effect. If so, it would be similar to the results of a previous modelling experiment that concluded that the threshold for a decline in habitat potential for bird species was 11.35% impervious surfaces in a landscape[77]. The findings of my research are not sufficient to either reject or support the possibility of a threshold of urban development in a landscape, past which specialized species are no longer present.

Nearby retail and commercial land use in the 1-kilometer buffer showed a negative relationship with IMBCI scores and remained in the model after some other metrics of development had been eliminated due to lack of significance. When the effects of human-altered landscapes are studied, urbanization or development are often quantified in ways that do not account for differences in the way urban land is used by humans. Many studies consider "urban" to comprise a single classification of land use. As has been noted by multiple authors, there tends to be a bias towards considering vegetation or "natural" factors, rather than anthropogenic ones.[78] However, an overly narrow focus on natural factors alone fails to consider the ways in

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[75] Gary W. Luck, Andrew Carter, and Lisa Smallbone, "Changes in Bird Functional Diversity across Multiple Land Uses: Interpretations of Functional Redundancy Depend on Functional Group Identity," *PLOS ONE* 8, no. 5 (May 17, 2013): e63671, https://doi.org/10.1371/journal.pone.0063671.

[76] Franco Leandro Souza et al., "Impervious Surface and Heterogeneity Are Opposite Drivers to Maintain Bird Richness in a Cerrado City," *Landscape and Urban Planning* 192 (December 1, 2019): 103643, https://doi.org/10.1016/j.landurbplan.2019.103643.

[77] Randhir and Ekness, "Urbanization Effects on Watershed Habitat Potential."

[78] Bourne and Conway, "The Influence of Land Use Type and Municipal Context on Urban Tree Species Diversity"; Ian MacGregor-Fors and Jorge E. Schondube, "Gray vs. Green Urbanization: Relative Importance of

which the built environment can influence natural factors, and the ways in which the built environment and natural factors can interact. Additionally, the ways bird species respond to the built environment is as varied as the ways they react to natural environments. A study conducted in three cities in Mexico found that even small-scale urban infrastructure (such as ledges, fences, telephone poles, and roof structures) had an effect on which species were present.[79] Nuanced responses to the built environment may be lost by relying on data collected at too broad a scale.

One option for attempting a more accurate measurement of urban land use is to derive data from tax parcel records, as I have done in this study. Tax parcels are at a higher spatial resolution than most prevalent urbanization metrics and are more closely reflective of the actual use of the land by humans.[80] While tax parcel data are not common in ecology and environmental sciences, representing land use with tax parcel data has been found to be meaningful for fields including water quality, ecotoxicology, and urban forestry.[81]

The negative relation between IMBCI scores and commercial land use is likely the result of multiple factors acting together, rather than a single isolated determinant. To start with, it is well established that native plants are vital for maintaining bird species populations in urbanized

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Urban Features for Urban Bird Communities," *Basic and Applied Ecology* 12, no. 4 (June 1, 2011): 372–81, https://doi.org/10.1016/j.baae.2011.04.003; Trammell and Bassett, "Impact of Urban Structure on Avian Diversity along the Truckee River, USA."

[79] MacGregor-Fors and Schondube, "Gray vs. Green Urbanization."

[80] Sarah Praskievicz, "Impacts of Land Use Metrics on Urban Stream Health: Buffalo Creek, North Carolina, USA," *Applied Geography* 139 (February 1, 2022): 102637, https://doi.org/10.1016/j.apgeog.2022.102637.

[81] Bourne and Conway, "The Influence of Land Use Type and Municipal Context on Urban Tree Species Diversity"; Blake E. Feist et al., "Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams," ed. Howard Browman, *PLoS ONE* 6, no. 8 (August 17, 2011): e23424, https://doi.org/10.1371/journal.pone.0023424; Praskievicz, "Impacts of Land Use Metrics on Urban Stream Health"; Long Zhou et al., "Impacts of Land Covers on Stormwater Runoff and Urban Development: A Land Use and Parcel Based Regression Approach," *Land Use Policy* 103 (April 1, 2021): 105280, https://doi.org/10.1016/j.landusepol.2021.105280.

habitats.[82] A study of trees in the greater Toronto, Ontario area found that commercial land use had a pattern of tree distribution that was distinct from residential or vacant lots, as it was dominated by non-native species.[83] The landscaping companies managing the commercial areas were preferentially choosing hardy exotic tree species that could withstand the conditions in which they were being planted.[84]

Commercial land use may also have effects on water quality. An investigation of premature deaths of Coho Salmon (*Oncorhynchus kisutch*) in the Seattle metropolitan area found that one of the strongest associations with salmon mortality was commercial property in a watershed area.[85] While this was a study of fish rather than birds, disruption of one aspect of an ecosystem will have cascading effects on the rest, and disruption to aquatic ecosystems will affect terrestrial ecosystems that intersect with them. The causative agent for the incidents of salmon mortality was most likely runoff contaminated by vehicle-derived pollutants left on impervious surfaces.[86] A similar effect could have repercussions on bird species that depend on water resources. For example, Haw River State Park was the only location at which I recorded a Louisiana Waterthrush (*Parkesia motacilla*), which multiple studies have established to be an indicator species for water quality.[87] Water quality could potentially be an underlying cause for the link between commercial land use and decreased bird specialization; there is, however, a lack

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[82] Pennington, Hansel, and Blair, "The Conservation Value of Urban Riparian Areas for Landbirds during Spring Migration"; Stephen C. Rottenborn, "Predicting the Impacts of Urbanization on Riparian Bird Communities," *Biological Conservation* 88, no. 3 (June 1999): 289–99, https://doi.org/10.1016/S0006-3207(98)00128-1.

[83] Bourne and Conway, "The Influence of Land Use Type and Municipal Context on Urban Tree Species Diversity."

[84] Bourne and Conway.

[85] Feist et al., "Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams."

[86] Feist et al.

[87] Brady J. Mattson et al., "Louisiana Waterthrush: Introduction"," 2020, https://birdsoftheworld.org/bow/species/louwat/cur/introduction.

of existing research on the effects of water quality on urban bird populations. One study conducted in Patagonia did not find evidence for a relationship between bird density or diversity and water quality.[88] In contrast, however, a study in a post-restoration wetland in India found evidence of a negative correlation between decreased water quality and bird diversity.[89]

Many other urban environmental parameters have been established as deleterious for bird species, such as direct mortality from window strikes and from cars, light pollution, higher temperatures, and decreased numbers of insects.[90] Because these are related to impervious surfaces, vehicle presence, and urban infrastructure (such as streetlights and buildings), it is entirely possible that these conditions are more prevalent in retail areas. All of these may be environmental parameters which generalist species are well-equipped to withstand but may represent conditions under which more specialized species will find themselves unable to compete.

This study has implications for urban planning and conservation, as it suggests that wetland species can be affected by surrounding land use. As such, effective conservation management of wetlands must take into account the specific ways land in the urban landscape is used. Additionally, there are likely distance thresholds for the effects of urbanization, so what matters is not merely how a landscape is changed, but where the change occurs in relation to the wetland. Finally, this research has implications for projects intended to create or recreate

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[88] María Laura Miserendino et al., "Assessing Land-Use Effects on Water Quality, in-Stream Habitat, Riparian Ecosystems and Biodiversity in Patagonian Northwest Streams," *Science of The Total Environment* 409, no. 3 (January 1, 2011): 612–24, https://doi.org/10.1016/j.scitotenv.2010.10.034.

[89] Kranti D. Yardi, Erach Bharucha, and Swapnil Girade, "Post-Restoration Monitoring of Water Quality and Avifaunal Diversity of Pashan Lake, Pune, India Using a Citizen Science Approach," *Freshwater Science* 38, no. 2 (June 2019): 332–41, https://doi.org/10.1086/703440.

[90] Michał Ciach and Arkadiusz Fröhlich, "Habitat Type, Food Resources, Noise and Light Pollution Explain the Species Composition, Abundance and Stability of a Winter Bird Assemblage in an Urban Environment," *Urban Ecosystems* 20, no. 3 (June 2017): 547–59, https://doi.org/10.1007/s11252-016-0613-6.

naturalistic habitat within urbanized landscapes, as it suggests that creating a landscape according to the human perception of a wetland may not actually create functioning habitat for specialist species. Based on specific traits, species require certain conditions in their habitat. If a habitat cannot provide them with what they require, the birds will not be there.

CHAPTER V: CONCLUSION

In this study, I sought to answer three questions: (1) whether wetlands with different degrees of disturbance had similar species compositions, (2) whether the avian community composition at less disturbed wetlands was more specialized, and (3) whether indirect disturbance had a stronger effect than direct disturbance. I found that sites with similar levels of urbanization had more similar species compositions, that less-disturbed sites had more specialized species, and that indirect disturbance had a stronger effect on community specialization than direct disturbances. Wetland size had a positive effect on IMBCI scores, and impervious surfaces and retail and commercial land uses had negative effects on IMBCI scores. These findings contribute to existing literature on how urbanization affects bird species, as well as to the utility of tax parcels as a metric of urbanization. These findings suggest that effective conservation management for wetland species requires consideration of landscape context and nearby land use, particularly with regard to how landscape alterations may affect specialized species. Further research on the relationships between specific urban land uses and urban ecology could establish the underlying causes of the impacts of urbanization on specialized species.

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APPENDIX A: SPECIES PRESENCE-ABSENCE MATRIX

	UNCG Wetland	Bog Garden	Price Park	Moores Creek	Haw River State Park
Canada Goose (*Branta canadensis*)		x			
Mallard (*Anas platyrhynchos*)		x			
Wood Duck (*Aix sponsa)*					x
Mourning Dove (*Zenaida macroura)*		x		x	
Yellow-billed Cuckoo (*Coccyzus americanus)*				x	x
Chimney Swift (*Chaetura pelagica*)		x			x
Ruby-throated Hummingbird (*Archilochus colubris)*			x		x
Great Blue Heron (*Ardea herodias)*		x			x
Red-shouldered Hawk (*Buteo lineatus)*				x	x
Eastern Wood-Pewee (*Contopus virens)*				x	
Red-bellied Woodpecker (*Melanerpes carolinus)*	X	x		x	x
Downy Woodpecker (*Dryobates pubescens)*		x	x	x	x
Pileated Woodpecker (*Dryocopus pileatus)*				x	x
Northern Flicker (*Colaptes auratus)*				x	x
Great Crested Flycatcher (*Myiarchus crinitus)*					x
White-eyed Vireo (*Vireo griseus)*					x
Red-eyed Vireo (*Vireo olivaceus)*	x	x	x	x	x
Blue Jay (*Cyanocitta cristata)*	x		x	x	

American Crow (*Corvus brachyrhynchos)*	x	x	x	x	x
Carolina Chickadee (*Poecile carolinensis)*	x	x	x	x	x
Tufted Titmouse (*Baeolophus bicolor)*	x	x	x	x	x
White-breasted Nuthatch (*Sitta carolinensis)*	x	x		x	
Blue-gray Gnatcatcher (*Polioptila caerulea*)					x
House Wren (*Troglodytes aedon)*			x		
Carolina Wren (*Thryothorus ludovicianus)*	x	x	x	x	x
Gray Catbird (*Dumetella carolinensis)*	x	x			
Northern Mockingbird (*Mimus polyglottos)*	x	x			
Eastern Bluebird (*Sialia sialis)*		x			x
Wood Thrush (*Hylocichla mustelina)*				x	
American Robin (*Turdus migratorius)*	X	x	x		
American Goldfinch (*Spinus tristis)*	X	x			
Field Sparrow (*Spizella pusilla)*			x		
Song Sparrow (*Melospiza melodia)*		x			
Eastern Towhee (*Pipilo erythrophthalmus)*	X	x	x		x
Yellow-breasted Chat (*Icteria virens*)					x
Common Grackle (*Quiscalus quiscula)*					x
Louisiana Waterthrush (*Parkesia motacilla)*					x
Prothonotary Warbler (*Protonotaria citrea)*					x
Common Yellowthroat (*Geothlypis trichas)*			x	x	x
Northern Parula (*Setophaga americana)*				x	x
Northern Cardinal (*Cardinalis cardinalis)*	x	x	x	x	x

Indigo Bunting (*Passerina cyanea)*	x	x	x

APPENDIX B: PREDICTOR VARIABLES USED IN PARTIAL LEAST SQUARES REGRESSION

	Mean	Range	Minimum	Maximum
Land cover (500 m)				
CropsPasture500 Proportion of cultivated crops and hay/pasture	0.0653	0.1654	0	0.1654
Forest500 Proportion of evergreen, deciduous, and mixed forest	0.2735	0.6218	0	0.6218
HighMedDev500 Proportion of high and medium development	0.1721	0.4238	0.0007	0.4245
OpenLowDev500 Proportion of low development and open space	0.4266	0.6861	0.0392	0.7253
WetlandsWater500 Proportion of open water, emergent wetlands, and woody wetlands	0.0524	0.1455	0	0.1455
HerbShrub500 Proportion of herbaceous and shrub land cover	0.0100	0.0274	0	0.0274
Land cover (1 km)				
CropsPasture1 Proportion of cultivated crops and hay/pasture	0.0725	0.1942	0	0.1942
Forest1 Proportion of evergreen, deciduous, and mixed forest	0.2460	0.6112	0	0.6112
HighMedDev1 Proportion of high and medium development	0.1644	0.4051	0.0009	0.4061
OpenLowDev1 Proportion of low development and open space	0.4681	0.7275	0.0694	0.7969
WetlandsWater1 Proportion of open water, emergent	0.0388	0.0997	0	0.0997

wetlands, and woody wetlands				
HerbShrub1 Proportion of herbaceous and shrub land cover	0.0101	0.0248	0	0.0248
Land use (1 km)				
AllResidential1 Proportion of all residential tax parcels	0.8959	0.1359	0.8274	0.9633
AgPark1 Proportion of agricultural, park, and common area tax parcels	0.0433	0.1241	0.0024	0.1265
SchoolOfficeChurch1 Proportion of institutional, office, and church tax parcels	0.0151	0.0392	0.0027	0.0419
RetailComm1 Proportion of retail and commercial tax parcel s	0.0146	0.0385	0	0.0385
DevRestricted1 Proportion of development-restricted and government-owned tax parcels	0.0217	0.0417	0.0084	0.0501
Vacant1 Proportion of vacant tax parcels	0.0093	0.0209	0.0013	0.0222
Land use (500 m)				
AllResidential500 Proportion of all residential tax parcels	0.8758	0.1498	0.7863	0.9361
AgPark500 Proportion of agricultural, park, and common area tax parcels	0.0445	0.1292	0.0038	0.1331
SchoolOfficeChurch500 Proportion of institutional, office, and church parcels	0.0149	0.0498	0	0.0498
RetailComm500 Proportion of retail and commercial parcels	0.0217	0.0421	0	0.0421
DevRestricted500	0.0319	0.0438	0.0137	0.0575

Proportion of development-restricted and government-owned tax parcels				
Vacant500	0.0113	0.0323	0	0.0323
Proportion of vacant tax parcels				
Impervious surfaces (1 km)				
PavedTwenty1	0.6152	0.7934	0.1949	0.9883
Proportion of 0-20% impervious surfaces				
PavedForty1	0.1702	0.2961	0.0088	0.3049
Proportion of 21-40% impervious surfaces				
PavedSixty1	0.1061	0.2497	0.0028	0.2526
Proportion of 41-60% impervious surfaces				
PavedEighty1	0.06278	0.1723	0.0001	0.1724
Proportion of 61-80% impervious surfaces				
PavedHundred1	0.0458	0.0907	0	0.0907
Proportion of 81-100% impervious surfaces				
Impervious surfaces (500 m)				
PavedTwenty500	0.629757	0.7967	0.1983	0.9950
Proportion of 0-20% impervious surfaces				
PavedForty500	0.1484	0.2769	0.0032	0.2801
Proportion of 21-40% impervious surfaces				
PavedSixty500	0.1051	0.2578	0.0017	0.2595
Proportion of 41-60% impervious surfaces				
PavedEighty500	0.0658	0.1927	0.0001	0.1929
Proportion of 61-80% impervious surfaces				
PavedHundred500	0.0508	0.1080	0	0.1080
Proportion of 81-100% impervious surfaces				
Traffic volume				
Traffic500	6290.62	11342.44	852.23	12194.67
Average traffic volume in 500-m buffer				
Traffic1	6397.26	9800.41	1045.26	10845.67

Average traffic volume in 1-km buffer				
Direct disturbance				
AvgHumans	3.27	15.33	0	15.33
Average number of people				
AvgNoise	59.78	7.70	55.46	63.16
Average noise in decibels				
Site parameters				
AreaInHa	38.60	156.39	0.05	156.44
Site area in hectares				
BufferArea500	469.11	1189.34	112.02	1301.36
500-meter buffer area in hectares				
BufferArea1	1006.91	2039.95	380.93	2420.88
1-kilometer buffer area in hectares				
ShapeIndex	4.69	5.9	1.55	7.44
Measure of shape complexity				
CityCenterDistance	9805.84	1558.21	19264.50	17706.3
Distance to Greensboro city center in meters				