The maturation of forested areas on an urban golf course contributes to a shift in songbird community structure over time

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Introduction

Urbanization is considered one of the greatest threats to biodiversity conservation worldwide. Urban expansion shrinks, fragments, and isolates remnant vegetation patches on the landscape, leading to decreases in the abundance and diversity of wildlife and other forms of biodiversity (Ricketts, 2001; Alberti, 2005). Over half of the world's population resides in urban areas and over two-thirds of the world's population is expected to live in urban areas by the year 2050 (United Nations Population Division, 2012). As urban centers expand, it is critical to understand how urban development impacts wildlife on the landscape.

Large-scale changes to the landscape through urban development have prompted many studies of large green spaces in urban areas and the role that these spaces play in conservation of wildlife species (Lin and Fuller, 2013; Aronson et al. 2014). Golf courses represent large areas of green space with a variety of vegetative structures and compositions that can support a wide array of wildlife species. Golf courses are particularly important for wildlife conservation in urban areas (Tanner and Gange, 2005; Hodgkison et. al, 2007; Sorace and Visentin, 2007). Studies of wildlife on golf courses usually attempt to assess the overall "ecological value" of a golf course for promoting the abundance and diversity of wildlife species.

Measures of biological diversity such as richness, species diversity, and evenness are a common metric for investigating how green spaces contribute to conservation of wildlife species. Biological diversity on a landscape is important for multiple reasons, including the provisioning of ecosystem services and the resilience of wildlife populations in the face of disturbance (Chapin et al. 2000). Another commonly used metric for assessing the "ecological value" of a green space is a "conservation value" index (Gotmark et. al, 1986). These indices weight abundance measures for each species in a community to reflect the conservation priority of that species. By summing the weighted abundance measures for each species, an overall conservation value is computed for the study site representing the degree to which that site supports species of higher conservation priorities. Using a combination of general measures like species richness along with conservation value indices can more accurately represent a site's overall conservation value (Nuttle et. al, 2003).

Songbirds are a useful indicator taxa for assessing how land use change affects wildlife because they are easily observable, have specific habitat associations, and are sensitive to disturbance (Nuttle et. al, 2003). Birds often are the focus in studies that assess biodiversity at large green spaces in urban areas (Hodgkison et. al, 2007; Terman, 1997; Tanner and Gange, 2005; Sorace and Visentin, 2007).

The structure and composition of vegetation at a site is one of the most important characteristics that will influence the presence, abundance, and distribution of birds (Patterson and Best, 1996; James and Wamer, 1982). Previous studies of urban bird assemblages have shown that increasing the volume of understory vegetation and increasing the overall density of trees on an urban landscape can increase the abundance and diversity of songbirds (Chace and Walsh, 2006; Shwartz et al., 2013; Stagoll et al., 2013; Threlfall et. al, 2016). Studies of this type often attempt to quantify the relationship between the makeup of vegetation and the structure of the bird community at the site. In doing so, land managers gain insight into how different vegetation management practices such as maintaining remnant forest patches and increasing understory volume affect the bird community found there.

In most studies of urban golf courses and bird community structure, golf courses are compared to other land use types such as residential areas, nearby natural areas, or other urban green spaces such as parks and cemeteries (Threlfall et. al, 2016; Hodgkison et. al, 2007; Tanner and Gange, 2005). However, there are a lack of studies that investigate how bird assemblages compare among different areas across a golf course. Indeed, the few studies that have compared community assemblages among different areas of a golf course have provided evidence that the floral and faunal communities vary greatly (Yasuda and Koike, 2006). Furthermore, some studies have provided evidence that local conditions are more important in determining bird species richness than the landscape condition, particularly in urban areas (Clergeau et. al, 2002). This merits further investigation, and we attempted to fill this knowledge gap by asking the first focal question: *How do songbird assemblages and vegetation structure compare among three distinct areas of a golf course: ≥ 50 meters from play areas, < 50 meters from play areas, and play areas themselves?*

Additionally, studies that investigate how a major change in land use alters the bird community by directly comparing populations at the site before and after the change are extremely rare.

Study designs of this nature are called "before-after control impact studies" (BACI), in which a response variable is measured before and after the impact of some intervention, disturbance, or change to the system (Osenberg et. al, 2006). These studies are rare because they require large inputs of time and resources, and it is difficult to design and implement studies prior to some change in the system. In fact, only about 6 – 29% of studies on how a major intervention (or disturbance) affects measures of biodiversity utilize a BACI design (Papathanasopoulou et. al, 2016).

Most studies of songbird assemblages on golf courses attempt to simulate what the landscape was like prior to construction of the course by comparing songbird numbers between a golf course and a nearby site that looks similar to the landscape prior to development of the course (Tanner and Gange, 2005; Alexander et. al, 2019). Although useful information can still be gained by simulating what a study site was like prior to some change on the landscape, it is better to compare actual numbers at the study site before and after the alteration. We attempted to fill this knowledge gap by asking the second focal question: *How does the structure of the songbird community at an urban golf course in 2020 compare to prior to course construction in 2001?*

We focused on 29 focal species and compared metrics based on these species to data collected by Lineberger et. al (2001) in "Centennial Campus Biological Survey". This study assessed the structure of the songbird community and vegetation at the study site prior to construction of Lonnie Poole Golf Course in 2001. These comparisons allowed us to draw conclusions about how the bird community at Lonnie Poole has changed in response to construction of the course and the intensive vegetation management practices used at the site in golf course maintenance.

Our specific research questions were: (1) How do the songbird community and vegetative structure at the site compare from 1999 (prior to course construction) to now? (2) How are local variables such as noise level and vegetation structure related to the abundance of songbirds at different areas of the course? (3) How do songbird assemblages compare among play areas, areas < 50 meters from play areas, and areas ≥ 50 meters from play areas?

Based on previous studies, we expected the overall abundance of birds at Lonnie Poole to be lower today than it was in 2001, but that the community will be more diverse than it was prior to course construction (Tanner and Gange, 2005). We also predicted that vegetation structure would be an important predictor of the number of songbirds detected at each sampling location (Nooten et. al, 2018). Furthermore, we expected that the level of ambient noise in an area would be negatively correlated with the number of birds detected (Arevalo and Newhard, 2011). Finally, we expected the songbird community to vary with distance to play area, with the largest differences between intensively managed playing areas and areas ≥ 50 meters from play areas with relatively undisturbed remnant vegetation (Nooten et. al, 2018).

Methods

Study Site

Lonnie Poole Golf Course (LPGC) is a 101-hectare naturalistic golf course located in Raleigh, NC. Raleigh is one of the most rapidly urbanizing areas in the country and the green spaces that remain in the metropolitan area represent critical habitat for many wildlife species. LPGC is adjacent to a major highway (I-40) and the surrounding landscape is generally represented by low to moderate intensity urban development. Lonnie Poole likely represents a refuge for many wildlife species because of this developed surrounding landscape. LPGC is a certified Audubon International Signature Sanctuary, a certification recognizing the course's commitment to sustainability. The course has been recognized for its value to Monarch butterflies (*Danaus plexippus*), native pollinators, and songbirds such as the Eastern Bluebird (*Sialia sialis)*. It features about 40-hectares of forested areas on the course and surrounding the course as a buffer, a common characteristic of naturalistic golf courses. These forest patches are dominated by an overstory of loblolly pine (*Pinus taeda*) and mixed hardwoods including white oak (*Quercus alba*). The rest of the course consists of intensively managed grassland, water features, and "edge" areas between play areas and out-of-play areas. The wide range of vegetation types at Lonnie Poole provides the opportunity to support a variety of songbirds, from grassland to shrubland to forest-dwelling species.

Sampling Design

Sampling points for bird surveys and vegetation measurements were selected from the 2001 "Centennial Campus Biological Survey". In that study, 12 points were set up in a 3x4 square grid over the study site with each point about 200 meters apart (Figure 1). For the present study, we added six points in a similar grid fashion to increase spatial replication and capture the forest patches present in those areas of the study site.

Lonnie Poole Golf Course
Sampling Point Layout

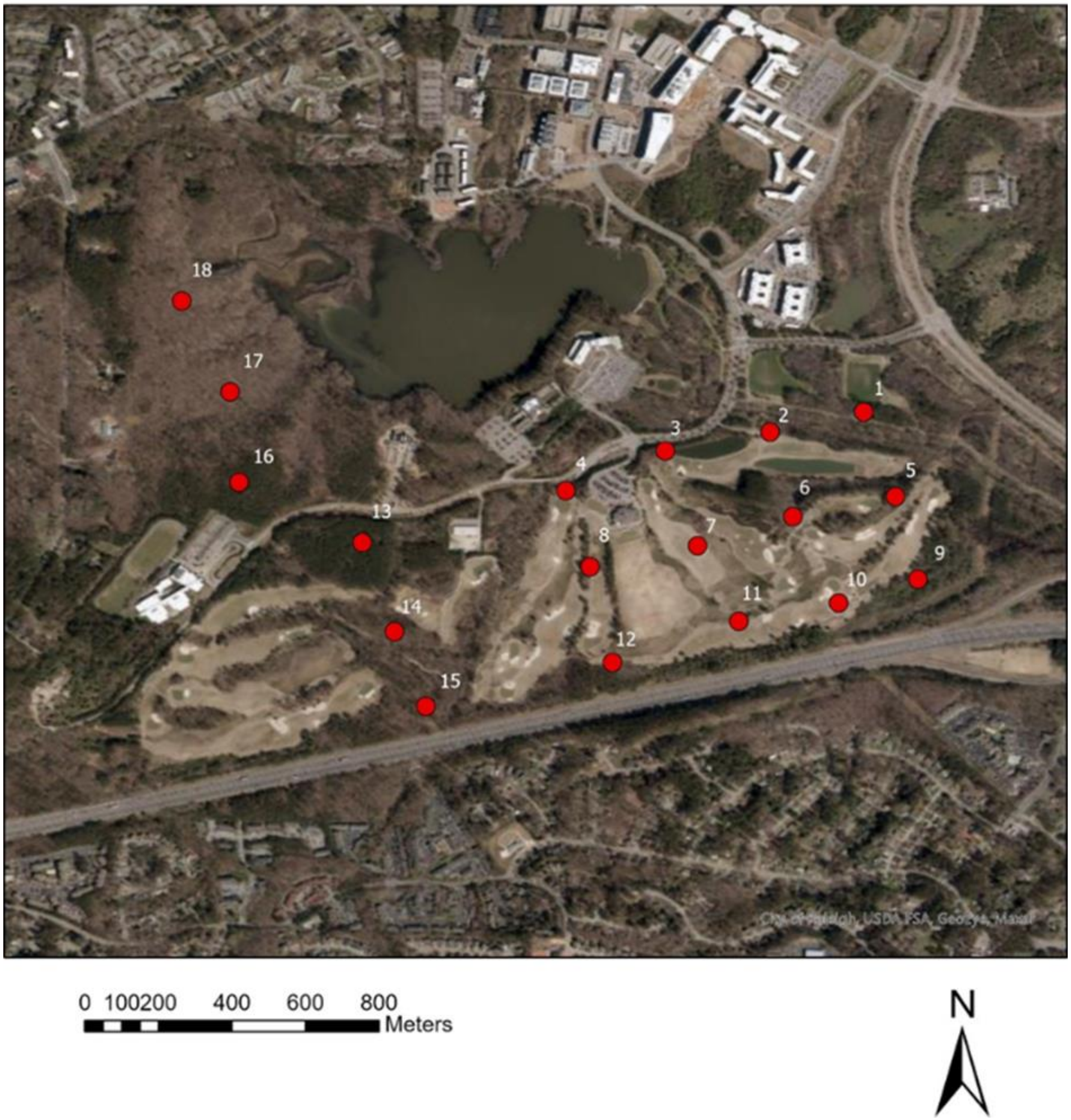

Figure 1: Displays the layout of sampling points for bird surveys and vegetation measurements at Lonnie Poole Golf Course. Points 1-12 were monitored in Lineberger et. al (2001). Points 13-18 were added to the present study to capture parts of the study area represented by closed canopy forest that are furthest from golf course play areas. Due to spatial restrictions, points 16-18 were added in a closed canopy forest stand adjacent to the golf course. Although these points are not located on the golf course "proper", they represent boundary vegetation to the course and therefore measurements conducted there are still useful for analysis. Addition of these points allowed us to capture the diversity of vegetation types that are present on the course and in the immediate area.

Vegetation Surveys

We measured basal area and volume of understory vegetation at each sampling point from July through August 2020. The resulting data was compiled in Microsoft Excel and analyzed using RStudio. We use a 10BAF wedge prism to estimate total basal area (m^2/hectare) at each plot.

We defined "understory" as any vegetation (dead or alive) within 2 meters of the ground. We used a modified version of the point-intercept method used by Rupprecht and Byrne (2014) to estimate the volume of understory vegetation at each sampling point. We established four 25-meter transects in each cardinal direction from each sampling point, with points on each transect designated at 5, 10, 15, 20, and 25 meters. At each point on the transect, we placed a 2 meter pole marked in increments of 0-0.2 meters, 0.2-0.5 meters, 0.5-1 meters, and 1-2 meters vertically on the ground. The nature of the vegetation that intersected any part of the pole was recorded, as well as the height increment on the pole that the vegetation intersected. Classifications of vegetation for this study included leaf litter, forbs, grass/sedge/rush, woody regeneration, downed wood, and shrub.

We computed an index of understory vegetation density for each height interval in a plot by summing the total number of times that vegetation intersected that interval at each transect point and dividing this number by the total number of transect points (21; 5 on each transect and the center point itself) to get a proportion of transect points in the plot at which vegetation is present in that height interval. We then multiplied this proportion by the total volume occupied by that height interval in the plot to get an estimate of the total volume of vegetation occupying that height interval. Finally, we summed each height interval's estimated volume of vegetation to get an overall estimate of understory volume for the plot. The equation for the estimate of understory volume for a given height interval is shown below.

(Equation 1)

$$V_h = (N_h/N_p) * V_{sh}$$

V_h: Estimated understory volume for a given height interval

N_h: Number of times that vegetation intersected the pole at all transect points for a given height interval at each plot

N_p: Total number of transect points sampled at each plot

V_{sh}: Total volume occupied by that height interval in each 25x25m plot (calculated by multiplying plot area by height of the interval)

Finally, the V_h for each height interval is summed to get an overall estimate of understory density for each plot.

Bird Surveys

We selected 29 focal songbird species for investigation (Appendix I). We selected native songbird species with diverse habitat associations and sensitivities to urban development to investigate the influence of sound level, basal area, understory volume, and distance to play areas on songbird abundance.

We conducted songbird surveys from June-July 2020 using fixed-radius circular point counts. We conducted point counts on four separate occasions from June to July starting at 6AM and completing within four hours of sunrise to maximize detections of singing males (Hamel et al. 1996; Petit et al. 1997). Counts lasted 5 minutes, with an initial one minute settling period upon arriving at the point to minimize songbird behavioral response to the observer's presence (Sorace and Visentin, 2007). During this one minute settling time, we recorded the time, temperature, cloud cover, wind speed, and noise decibel level (Hamel et. al, 1996). We also recorded decibel level at the conclusion of each count to get an average decibel level over the count period. We recorded all aural or visual detections of focal species during the 5-minute count period.

Data Analysis

We fit multiple regression models with basal area, understory density, decibel level, and the categorical variable for distance to play areas as predictors of the number of focal species detections.

We summed all detections across the four visits to each point to get the overall number of detections of each focal species at each point. We grouped sampling points into golf play areas (n=5), less than 50 meters from play areas (n=6), and greater than 50 meters from play areas (n=6). We excluded Point 2 from all models because vegetation was so dense it was not possible to measure basal area or understory density at this point.

We grouped sampling points categorically rather than simply adding another numerical variable for the distance of each point to play areas because all points in play areas would have a value of “0” for their distance to play areas. The distribution of the numerical predictor would be unevenly distributed among all values for that predictor and would therefore make model fitting difficult. In this way, we lost some ability to estimate the numerical relationship between distance to play areas and abundance measures for focal species. However, this classification of points was useful for estimating the “effect” that distance to golf course play areas have on each of the response variables.

Studies of this type often divide species into guilds and investigate patterns within these guilds (Nuttle et. al, 2003). We summarized the abundance measures of songbird species by foraging guild, sensitivity to urban development, and vegetation selection schemes and used these values as response variables in separate multiple regression models. Rather than running models with different combinations of predictors and selecting the top models for each response variable, we kept the same covariates in each model and compared the results of the models. In this way, we were able to investigate how predictors were related to each response variable when controlling for all other predictors. This allowed for us to draw conclusions on the relative effects that predictors had on different songbird guilds. Equation 2 shows the general linear formula used for modeling.

(Equation 2)

[response variable] ~ [basal area] + [understory density] + [average decibel level] + [indicator$_{>50m}$] + [indicator$_{<50m}$]

Comparison of Community Structure: 2001 to 2020

Diversity Metrics and Conservation Value Indices

To compare the songbird assemblages at the site to prior to construction of the course in 2001, we utilized data from Lineberger et. al. (2001). The primary objective of the 2001 point counts was to compile an overall presence/absence list of bird species on the course, rather than investigating overall bird community structure and how it was related to vegetation at the site. Because of this, some recommended point count protocols were not followed. Specifically, Lineberger et. al (2001) did not visit each sampling point on each survey day and visited only a few sites at least three times. Most sampling points were only visited once during the study.

These factors limited our ability to conduct robust statistical comparison between the two studies. However, qualitative comparisons of biodiversity metrics and conservation value indices between the two studies was still useful and appropriate.

We compared metrics of the overall songbird community including species richness, species diversity, and evenness between the two studies. Species richness is simply the number of different species that were detected in a survey. Species diversity for each survey was characterized using the Shannon-Weaver Diversity Index. This index is commonly used in wildlife surveys as a measure of the overall species diversity present at a site from a sample of individuals (Spellerberg and Fedor, 2003). It characterizes the species richness of a sample while taking into account the relative abundances of individuals for each species. It is used to calculate an overall measure of “Evenness”, which is a measure of the distribution of the number of individuals detected among all species. The equation for the Shannon-Weaver Diversity Index is displayed below.

(Equation 4)

$$H = -\Sigma(p_i * \ln(p_i))$$

H = Shannon Weaver Diversity Index

p_i = proportion of individuals detected from species ‘i’

The “Evenness” of an observed sample of individuals is then computed with the following equation.

(Equation 5)

$$E_H = H/H_{Max}$$

E_H = Evenness

H = Shannon-Weaver Index

H_{Max} = Maximum diversity value for a sample, computed by taking the ln(number of species observed)

We also computed “conservation value” indices for the present study and the 2001 biological surveys using a system that classifies each songbird species by level of conservation concern developed by the Partners In Flight (PIF) conservation program. This program, managed by the Bird Conservancy of the Rockies, uses input and data from dozens of ornithological experts in over ten countries to assess songbird species’ relative conservation concern (Nuttle et. al, 2003). In this database, bird species are assigned values for breeding distribution, nonbreeding distribution, relative abundance, threats to breeding, threats to nonbreeding, population trend, and area importance on a scale of 1-5, with 1 meaning “low conservation priority” and 5 meaning “high conservation priority”.

We summed the PIF values for each focal species to get an overall composite PIF score for each species. This composite score was then used as the “weighting factor” for the relative abundance of each songbird species in computing the conservation value represented by that species in the study. By multiplying the relative abundance of a species by this weighting factor and summing these values across all species, we computed an overall “conservation value” of the site for each study. The equation for this procedure is displayed below.

(Equation 6)

$$CV_{species} = p_{species} * PIF_{species}$$

$CV_{species}$: the contribution of a certain species to the “conservation value” for an entire study

$p_{species}$: proportion of individuals from a given species for an entire study

$PIF_{species}$: the summed PIF values for a given species

By summing the $CV_{species}$ values for each species in a study, the overall "conservation value" for each study was computed.

Other Metrics

To control for the large difference in sampling effort and spatial variation in point visits between the two studies, we compared the total number of detections for each species on a "per point visit" basis. The number of point visits was simply the total number of point counts that were conducted over the study period: 18 from the 2001 surveys and 72 from the present study.

Finally, we compared the "proportional occurrence" of each focal species between the two surveys to get an idea of how the relative abundances of different species changed between surveys. We calculated proportional occurrence as the number of detections for a given species divided by the total number of detections in that survey. This allowed for comparison of the detection data between the two studies while controlling for the large difference in total number of detections (188 in 2001 and 590 in the present study).

Results

Vegetation Structure Comparison to 2001

Basal Area – 2001 vs. 2020

Point	2001 Basal Area (m^2/hectare)	2020 Basal Area (m^2/hectare)
1	17.9	41.3
2	0	N/A
3	25.0	27.5
4	28.0	11.5
5	120.1	32.1
6	0	23.0
7	3.0	0
8	17.9	11.5
9	5.1	18.4
10	0	0
11	0	0
12	16.1	0

Table 1: Displays estimated basal area at each sampling point for the 2001 and 2020 surveys.

Basal area among all sampling points varied in both studies, reflecting the diversity of vegetation structures present at the site pre- and post-construction of the golf course. Some sampling points had a decrease in basal area since 2001, some had an increase, but overall basal area among all 12 points did not change significantly over time. It is important to note that points 13-18 were added in 2020 to capture the forested areas of the course. These points were not sampled in 2001.

Songbird Community Comparison: 2001 to 2020

Lineberger et. al (2001) Point Count Data Summary

Species	Detections	Detections Per Point Visit	Proportional Occurrence
Carolina Wren	38	2.11	0.20
Northern Cardinal	30	1.67	0.16
Eastern Towhee	19	1.06	0.10
Indigo Bunting	16	0.89	0.09
Mourning Dove	15	0.83	0.08
Carolina Chickadee	12	0.67	0.06
Red-Bellied Woodpecker	9	0.50	0.05
Blue-Gray Gnatcatcher	8	0.44	0.04
Yellow-Breasted Chat	8	0.44	0.04
Common Yellowthroat	7	0.39	0.04
Tufted Titmouse	6	0.33	0.03
Brown-headed Cowbird	4	0.22	0.02
American Robin	4	0.22	0.02
Great-Crested Flycatcher	2	0.11	0.01
Brown Thrasher	2	0.11	0.01
Red-Eyed Vireo	2	0.11	0.01
Pine Warbler	2	0.11	0.01
Downy Woodpecker	2	0.11	0.01
American Goldfinch	1	0.06	0.01
Northern Mockingbird	1	0.06	0.01
Summer Tanager	0	0	0
Eastern Bluebird	0	0	0
Northern Parula	0	0	0
Wood Thrush	0	0	0
Killdeer	0	0	0
Hairy Woodpecker	0	0	0
Brown-Headed Nuthatch	0	0	0
White-Breasted Nuthatch	0	0	0
Eastern Phoebe	0	0	0

Table 2: Displays the point count data from the 2001 biological surveys. Each focal species is summarized by the total number of detections, detections per point visit (18), and proportional occurrence of the species (computed by dividing number of detections for a given species by total number of detections of all species).

There were 188 detections of focal species in 2001 from 18 total point visits. The most common species observed in 2001 were the Carolina Wren, Northern Cardinal, Eastern Towhee, and Indigo Bunting, who made up over half of all detections from the surveys (Table 2). Nine focal species were not detected at all in 2001.

2020 Point Count Data Summary

Species	Detections	Detections Per Point Visit	Proportional Occurrence
Carolina Wren	82	1.14	0.14
Tufted Titmouse	66	0.92	0.11
Northern Cardinal	63	0.88	0.11
Pine Warbler	56	0.78	0.09
Northern Mockingbird	38	0.53	0.06
Eastern Towhee	34	0.47	0.06
Indigo Bunting	24	0.33	0.04
Downy Woodpecker	23	0.32	0.04
American Robin	22	0.31	0.04
Red-Eyed Vireo	20	0.28	0.03
Eastern Bluebird	18	0.25	0.03
Carolina Chickadee	16	0.22	0.03
Brown-headed Cowbird	16	0.22	0.03
Summer Tanager	15	0.21	0.03
Hairy Woodpecker	14	0.19	0.02

American Goldfinch	13	0.18	0.02
Brown-headed Nuthatch	12	0.17	0.02
Northern Parula	10	0.14	0.02
Blue-Gray Gnatcatcher	9	0.13	0.02
Red-Bellied Woodpecker	9	0.13	0.02
Great-Crested Flycatcher	6	0.08	0.01
White-Breasted Nuthatch	5	0.07	0.01
Eastern Phoebe	5	0.07	0.01
Mourning Dove	4	0.06	0.01
Yellow-Breasted Chat	3	0.04	0.01
Brown Thrasher	2	0.03	0.00
Killdeer	2	0.03	0.00
Common Yellowthroat	2	0.03	0.00
Wood Thrush	1	0.01	0.00

Table 3: Displays the point count summaries from 2020. Each focal species is summarized by the total number of detections, detections per point visit (72), and overall percent occurrence of the species (computed by dividing number of detections for a given species by total number of detections of all species).

There were 590 detections of all focal species in 2020 from 72 total point visits. The most commonly observed species in 2020 were the Carolina Wren, Tufted Titmouse, Northern Cardinal, and Pine Warbler (Table 3). Individuals from these four species made up about 40% of all detections.

Nine focal species observed in 2020 were not observed in 2001, including the Summer Tanager, Eastern Bluebird, Northern Parula, Wood Thrush, Killdeer, Hairy Woodpecker, Brown-headed

Nuthatch, White-breasted Nuthatch, and Eastern Phoebe. These species were detected at higher rates in 2020 and made up about 9% of the overall focal species community.

Biodiversity Measures – Community Comparison between 2001 and 2020

Year	Detections	Point Visits	Detections per Point Visit	Species Richness	Diversity Index	Evenness	Conservation Value
2001	188	18	10.44	20	2.542	0.849	10.712
2020	590	72	8.19	29	2.918	0.867	10.461

Table 4: Displays the summary comparison between point count data from the 2001 surveys and the present study. “Species Richness” is defined as the total number of focal species detected from the study. “Diversity Index” values are the computed Shannon-Weaver index for each survey. “Evenness” is a measure of the distribution of individuals detected among each species and is a function of the Shannon-Weaver Index.

Detections per point visit was slightly greater for individuals from all focal species combined in 2001 compared to 2020 (Table 4). However, species richness and diversity were greater in 2020, and species evenness and conservation value indices were similar between the two studies.

The species richness values do not take into account the large difference in sampling effort between the two point count studies. The higher number of species observed in 2020 could simply be a product of the fact that sampling effort was four times higher in 2020 compared to 2001 (18 point visits vs. 72 point visits). However, the Shannon-Weaver indices, Evenness values, and Conservation Value indices control for this difference in sampling effort because they use the proportion of individuals detected in each species to calculate them. Therefore, the large difference in sampling effort and number of detections between the two studies has a smaller effect on these values.

2020 - Comparison of Community Structure and Vegetation Across the Course

Vegetation Characteristics - 2020

Vegetation structure varied among sampling points in 2020. Average basal area across all sampling points was 10.3 square meters per hectare. The minimum basal area was 0, and the maximum was 43 square meters per hectare. The average estimated volume of understory across all sampling points was about 484 cubic meters, with a minimum of 65 cubic meters and a maximum of 879 cubic meters. These values reflect the structural diversity of vegetation present across the course.

Vegetation Summary of All Sampling Points - 2020

Point	Point Category A = Play Areas B = <50m from Play Area C = >50m from Play Area	Basal Area (m^2/hectare)	Volume of Understory Vegetation (m^3)
1	B	41.3	720
2	B	N/A	N/A
3	B	27.5	579
4	B	11.5	617
5	B	32.1	879
6	B	22.9	767
7	A	0	93
8	A	11.5	514
9	B	18.4	626
10	A	0	65
11	A	0	318
12	A	0	729
13	C	25.3	748
14	C	29.8	290
15	C	36.7	168
16	C	43.6	215
17	C	18.4	421
18	C	20.7	486

Table 5: Displays each sampling point with it's point category, basal area estimate, and understory volume estimate. Points in category "A" are in play areas, points in "B" are less than 50 meters from play areas, and points in "C" are greater than 50 meters from play areas. Point 2 was completely dominated by shrub/scrub vegetation structure and was not accessible to be able to conduct these measurements.

Structural diversity was greatest <50m from play areas, with the highest basal area and understory volume estimates (25.5 m^2/ ha mean basal area and 698 m^3 understory volume). Points ≥50m from play areas had the highest basal areas (mean = 28.9 m^2/ha), but low understory volumes (mean = 388 m^3). Play areas had the lowest basal areas (mean = 2.3 m^2/ha) and understory volumes (mean = 344 m^3).

2020 – Diversity Metrics and Conservation Value By Point Category

Category	Detections	Point Visits	Detections Per Visit	Species Richness	Species Diversity	Evenness	Conservation Value
Play Areas	157	20	7.85	24	2.738	0.861	9.9236
<50m From Play Areas	258	28	9.21	26	2.78	0.853	10.7907
≥50m From Play Areas	125	24	7.29	20	2.57	0.861	10.4571

Table 6: Displays the summary of detection data from each category of sampling points with respect to their distance to golf course play areas. Play areas had five sampling points in them, areas less than 50 meters from play areas contained seven sampling points, and areas greater than 50 meters from play areas had six sampling points.

Focal species detection rates, overall species richness and diversity, and PIF conservation value scores were greater at points located <50 meters from play areas than in play areas and at points further from play areas (Table 6). Species richness and diversity were lowest ≥50 meters from play areas compared to the other two categories.

Multiple Regression Models: 2020

Model – Effect of predictor variables on total number of detections of individuals from all focal species

R Output Table

Variable	**Estimate**	**Std. Error**	**t-value**	**p-value**
Intercept	**79.517**	**22.680**	**3.506**	**0.00492***
Basal Area	**-0.0238**	**0.051**	**-0.465**	**0.651**
Understory Volume	**0.004**	**0.010**	**0.461**	**0.654**
Decibel Level	**-0.925**	**0.404**	**-2.289**	**0.043***
≥50m from Play Area	**-4.209**	**7.967**	**-0.528**	**0.608**
<50m from Play Area	**3.091**	**7.909**	**0.391**	**0.703**

Multiple R-squared = 0.4759

Table 7: Displays the R Output Table for the multiple regression model with a residual standard error of 7.403 on 11 degrees of freedom. The significant coefficient estimates (at the $\alpha = 0.10$ level) for each predictor variable are signified with a "*". The significant estimate of an intercept for this model does not have any real meaning, as it

represents the expected total number of detections when all predictor variables = “0”. This number mostly reflects what a point with “0” decibel level would display, and that is not realistic in any setting in nature.

As average decibel level increased, the total number of detections of all focal species decreased. The other covariates in the model were not important predictors of bird detections. The relatively low R^2 value indicated that these covariates poorly predicted the overall abundance of songbirds present at any point on the course.

Model – Effect of predictor variables on the proportion of forest-dwelling individuals detected

R Output Table

Variable	Estimate	Std. Error	t-value	p-value
Intercept	0.335	0.2406	1.394	0.1908
Basal Area	0.000265	0.00054	0.488	0.6354
Understory Density	0.0000985	0.000102	0.957	0.3592
dB Level	-0.0014	0.00428	-0.329	0.7485
≥50m from Play Areas	0.2427	0.0845	2.872	0.0152*
<50m from Play Areas	0.0611	0.0839	0.728	0.4816

Multiple R-Squared = 0.7743

Table 8: Displays the R Output Table for the linear model on 11 degrees of freedom. The significant coefficient estimates (at the $\alpha = 0.10$ level) for each predictor variable are signified with a "*".

Points ≥50m from play areas had significantly higher proportions of forest-dwelling songbirds compared to play areas (0.24 higher). Other covariates in the model were not important predictors for the proportion of forest-dwelling individuals present at any given point. However, the R^2 value indicates that this model predicted the proportion of forest-dwellers detected at any point moderately well.

Model – Effect of predictors on the number of urban avoider individuals detected

R Output Table

Variable	Estimate	Std. Error	t-value	p-value
Intercept	20.084	7.981	2.516	0.029*
Basal Area	-0.0199	0.018	-1.101	0.294
Understory Density	-0.004	0.003	-1.206	0.253
dB Level	-0.278	0.142	-1.957	0.076*
>50m from Play Areas	3.029	2.804	1.081	0.303
<50m from Play Areas	3.189	2.783	1.146	0.276

Multiple R-Squared = 0.4179

Table 9: Displays the R Output Table for the linear model on 11 degrees of freedom. The significant coefficient estimates for each predictor variable (at the $\alpha = 0.10$ level) are signified with a "*".

Decibel level had a significant negative effect on the number of urban avoiders detected. Other covariates in the model were not important predictors, and the R^2 value shows that this model was not effective at predicting the number of urban avoiders detected.

Model – Effect of predictors on the proportion of insectivores detected

R Output Table

Variable	Estimate	Std. Error	t-value	p-value
Intercept	0.806	0.2487	3.239	0.00789*
Basal Area	0.00114	0.000563	2.034	0.06684*
Understory Density	0.0000617	0.000106	-0.58	0.5735
dB Level	-0.00677	0.00443	-1.528	0.1547
≥50m from Play Areas	0.1572	0.08738	1.799	0.0995*
<50m from Play Areas	0.0415	0.0867	0.478	0.6419

Multiple R-Squared = 0.816

Table 10: Displays the R Output Table for the linear model on 11 degrees of freedom. The significant coefficient estimates for each predictor variable (at the $\alpha = 0.10$ level) are signified with a "*".

Basal area had a significant positive effect on the proportion of insectivores detected, but this effect was too small to be biologically significant. There was a 0.15 higher proportion of insectivores detected ≥50m from play areas compared to play areas. The R^2 value indicates that this model was effective at predicting the proportion of insectivores detected.

Model – Effect of predictor variables on the number of omnivores detected

R Output Table

Variable	Estimate	Std. Error	t-value	p-value
Intercept	**13.819**	**8.643**	**1.599**	**0.1382**
Basal Area	**-0.0210**	**0.0196**	**-1.073**	**0.3064**
Understory Density	**0.0026**	**0.0037**	**0.694**	**0.5019**
dB Level	**-0.0017**	**0.1539**	**-0.011**	**0.9913**
>50m from Play Areas	**-6.575**	**3.0362**	**-2.166**	**0.0532***
<50m from Play Areas	**0.151**	**3.0141**	**0.050**	**0.9609**

Multiple R-Squared = 0.7658

Table 11: Displays the R Output Table for the linear model on 11 degrees of freedom. The significant coefficient estimates for each predictor variable (at the $\alpha = 0.10$ level) are signified with a "*".

There were about 6.5 fewer omnivorous individuals detected ≥50m from play areas compared to play areas. No other covariates in this model were important predictors for the number of omnivores detected, but the R^2 value indicates that this model was effective at predicting the number of omnivores detected.

Discussion

Comparison: Pre- and Post-Construction

The focal species community at Lonnie Poole was similar from 2001 to 2020 in a few ways. Two of the most common species in 2001 (Carolina Wren and Northern Cardinal) were also two of the most common species in 2020. Some rare species in 2001 were still rare in 2020, such as the Wood Thrush and Brown Thrasher. It appears that the construction of the course has not changed the overall abundance of focal songbird species, as detections per point visit was similar between the two studies.

The construction of the course also has not significantly impacted the conservation value of the site for songbirds. The overall conservation value of the songbird community did not change much from pre- to post-construction (10.71 in 2001 vs. 10.46 in 2020). Lineberger et. al (2001) characterized the site as a "heterogenous mixture of many different vegetation types", but that much of the study site was characterized by “vast, monotypic fields of kudzu”. The prevalence of invasive plants such as kudzu likely degraded the value of the site for native songbirds in 2001. If the site had been a pristine environment prior to course construction, the conservation value of the site would likely be lower following course construction. It is important to consider the condition of the property prior to construction in assessing how the development of a golf course will affect the songbird community. If a golf course is to provide the greatest benefits to wildlife conservation, it should be constructed on a property that is not already of great conservation value.

There were also some notable differences in the songbird community from 2001 to 2020. Forest-dwelling species were detected at higher rates in 2020 and they made up a larger proportion of the focal community compared to 2001. Nine species detected in 2020 were not detected at all in 2001, and seven of these species are forest-dwellers. Their presence in 2020 is likely a result of the maturation of forested areas on the course since 2001 (Melles et. al, 2003). There was forest cover present at the site in 2001, but it was relatively young and interspersed with substantial areas of kudzu infestation. In developing the course, about 40 hectares of forested areas were retained. In the 20 years since course construction, these areas have grown and matured, leading to this shift in community structure. Hence, retaining forest cover during course construction can increase the abundance and diversity of associated species and increase the overall songbird diversity present at a golf course pre- and post-construction.

All focal species, regardless of habitat associations, were present at the course in 2020. This is likely due to the diversity of vegetation structures that are present throughout the course, which is reflected by the large range of basal areas and understory volumes measured at each sampling point. Our results provide evidence that maintaining a diverse mix of vegetation structures on an urban golf course can support a wide range of species with various habitat associations.

Comparison of Community Structure Across the Course

Songbird community structure varied among different areas of the golf course, supporting similar studies that demonstrated differences in the floral and faunal communities on different areas of a course (Yasuda and Koike, 2006). Measures of biodiversity, abundance, and conservation value were greatest at areas of the course <50 meters from play areas. These "edge" areas provided songbirds access to multiple vegetation types in close proximity, and likely attracted a diversity of bird species associated with different vegetation conditions (ie. structure and composition). Although species diversity and richness were lowest ≥ 50 meters from play areas, the conservation value of the bird community in these areas was greater than in play areas. Furthermore, the greatest proportion of forest-dwelling and insectivorous songbirds was present at points furthest from play areas, most likely because these areas have the greatest amount of contiguous forest. There were fewer omnivores found ≥ 50 meters from play areas, indicating that food resources may have been more abundant for omnivorous species near play areas because of either a greater diversity in vegetation conditions there or because of the foods associated with human activities in play areas.

These results highlight the importance of maintaining a variety of vegetation structures on a golf course to support a wide range of songbird species with different habitat requirements. Golf course developers need to recognize that different areas of a course will harbor markedly different assemblages of songbirds and should carefully consider how to design and manage a course to support a wide variety of species. Specifically, golf course developers should try to retain a large amount of remnant forest on the landscape and increase the structural diversity and area of vegetation to promote the overall abundance and diversity of songbirds at the site.

Local Conditions Influence on Songbird Abundance

Average decibel level proved to be the best predictor for songbird abundance at different areas of Lonnie Poole Golf Course, with an increase in ambient noise correlating to a decrease in songbird detections, regardless of guild. This supports results from other studies that have linked noise levels to a decrease in songbird abundance (Arevalo and Newhard, 2011). Decibel level had a larger effect on insectivores than on granivorous and omnivorous species, suggesting that insectivores may be more sensitive to sound than the other two guilds. Lonnie Poole is directly adjacent to a major interstate (I-40), which is a significant source of noise. Indeed, the sampling point that was closest to I-40 had the greatest average decibel level of all sampling points and also had the fewest detections of all focal species. Golf course developers should recognize the impacts that significant sources of noise can have on the songbird community as they plan for conservation initiatives in the course design.

Implications for Urban Wildlife Management

Our study demonstrates that golf courses can support a diverse array of songbird species with various habitat associations. Greater diversity of vegetation structures present on a golf course provides benefits to a wide range of species, particularly in highly developed landscapes with a lack of green spaces. Retaining large amounts of forested areas when planning development of a golf course can promote the retention of forest-dwelling songbird species and increase the overall richness and diversity of the songbird community present at the course.

The condition of a property prior to golf course construction plays a large role in the degree of change in the bird community from pre- to post-construction. If a property is high intensity development or agriculture pre-construction, the conservation value of the site would likely increase after golf course development. Conversely, golf course development in a more pristine area is likely to reduce the abundance of some songbird species, especially those associated with contiguous forest. The vegetation conditions at Lonnie Poole prior to course development were similar to post-construction, with a high diversity of structures across the entire site. However, the site was in a degraded state pre-construction, with invasive plants such as kudzu dominating many areas of the site. It is likely that development of Lonnie Poole has kept the bird community neutral or improved it in some ways, which is reflected by the similar conservation value indices for the site pre- and post-construction.

Limitations and Future Research

There are a few important things to consider when interpreting the results of our analyses. First, we were not able to incorporate the probability of detecting an individual into the measure of abundance. “Index” counts such as the ones used in this study assume constant probability of detection across species and sites, but detection probability can vary among any number of variables, including vegetation structure, species, and time of year (Toms et. al, 2006). Our level of replication (n=18 sampling points) was too low for us to be able to estimate detection probability usefully. Therefore, our measures of abundance at each sampling point likely do not tell the whole story and lack accuracy.

Furthermore, our study had a small spatial extent. We treated each sampling point as its own “site”, only 200 meters apart from each other. Attempting to link these very localized “abundance” measures to local conditions was not useful. This is likely because the home range of songbirds is much larger than the spacing of our sampling points, and it is therefore questionable to treat the community at each sampling point as separate and independent of one another. If the purpose of our study were to compare the songbird community among different green spaces, we could treat each green space as a “site” and would have the level of replication and spatial extent necessary to model detection probability and link vegetative conditions to estimated abundances at each site on a larger scale.

Again, because we assessed only a single golf course, our study focused only on the influence of local variables on the abundance of songbirds. However, songbird abundance and diversity are determined by a complex interplay of both local and landscape-level variables, including adjacent land uses (Clergeau et. al, 2003). If we had been able to capture landscape level conditions influence on bird abundance and diversity, we would have a more accurate picture of how both local and landscape conditions play a role in songbird conservation at a golf course.

In comparing the songbird community between the 2001 and 2020 surveys, we were limited due to issues with inconsistent sampling design and implementation. The lack of spatial and temporal replication of point counts in the 2001 surveys means that the overall abundance measures for each species may not accurately characterize the entire study site in 2001. The most effective way to assess how the songbird community has changed since construction of the course would have been to use distance sampling to estimate the abundances of our focal species at the time of the surveys in 2001 and 2020. But because of the lack of standardization and replication in the 2001 surveys, we were unable to do so. Our comparisons of diversity and abundance measures between the two studies were limited to qualitative comparisons of a few metrics that control for the differences in sampling effort between the two studies. This case highlights the importance of standardizing point count sampling procedures to be able to make robust comparisons of songbird community structure between studies.

Future studies could apply our sampling design at multiple green spaces or golf courses, model detection probability to get accurate songbird abundance estimates, and investigate the effect of local and landscape-level conditions on songbird abundance and diversity at each site. Results from a study of this nature would provide a deeper understanding of how the development of a golf course in an urban area impacts songbird populations.

Appendix

Songbird Focal Species List

Common Name	Scientific Name
Indigo Bunting	*Passerina cyanea*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Great Crested Flycatcher	*Myiarchus crinitus*
Summer Tanager	*Piranga rubra*
Eastern Towhee	*Pipilo erythrophthalmus*
Eastern Bluebird	*Sialia sialis*
Brown-headed Cowbird	*Molothrus ater*
Brown Thrasher	*Toxostoma rufum*
Red-eyed Vireo	*Vireo olivaceus*
Yellow-breasted Chat	*Icteria virens*
Northern Parula	*Setophaga americana*
Mourning Dove	*Zenaida macroura*
Carolina Chickadee	*Poecile carolinensis*
Wood Thrush	*Hylocichla mustelina*
Carolina Wren	*Thryothorus ludovicianus*
American Goldfinch	*Spinus tristis*
Northern Cardinal	*Cardinalis cardinalis*
Northern Mockingbird	*Mimus polyglottos*
Tufted Titmouse	*Baeolophus bicolor*
Pine Warbler	*Setophaga pinus*
Killdeer	*Charadrius vociferus*
American Robin	*Turdus migratorius*
Red-bellied Woodpecker	*Melanerpes carolinus*
Hairy Woodpecker	*Leuconotopicus villosus*
Downy Woodpecker	*Picoides pubescens*
Brown-headed Nutchatch	*Sitta pusilla*
White-breasted Nuthatch	*Sitta carolinensis*
Eastern Phoebe	*Sayornis phoebe*
Common Yellowthroat	*Geothlypis trichas*

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