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Avian Communities and Landscape Characteristics of Golf Courses Within the Beaufort County Sea Island Complex

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AVIAN COMMUNITIES AND LANDSCAPE CHARACTERISTICS OF GOLF COURSES WITHIN THE BEAUFORT COUNTY SEA ISLAND COMPLEX

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ABSTRACT

The native breeding bird community of Beaufort County, South Carolina is experiencing landscape alteration in several forms. A prevalent human land use in the coastal zone is golf course development. This study explored the relationship between golf course land cover (n=23) and avian community metrics. Each study site consisted of the in-play area of the golf course, surrounded by a 400 m zone. Landscape metrics were calculated for each study site, and served as independent variables. The dependent variables were the following avian community metrics: species richness, neotropical migrant richness, abundance, diversity, evenness, and mean Partners in Flight (PIF) score. Stepwise model selection produced multiple linear regression models for each avian community metric. Significant variables in the model were interpreted for ecological meaning. Avian species richness, abundance and diversity increased with the area of the landscape, while the interaction of interspersion/juxtaposition and patch richness had varying but significant effects on diversity, species richness and neotropical migrant richness. Mean patch fractal dimension of residential areas positively affected species richness and evenness, while mean patch fractal dimension of turf was opposite in relation to the mean shape index of turf in the evenness model. Evenness showed unique responses to metrics calculated for forested wetland and mixed upland forest. These results yield insight into avian community response to golf course landscape characteristics, and may aid in future management decisions in the region.

DEDICATION

This work is dedicated to my family and friends, without whom I could not have achieved my goals. Thanks for all the support and love.

"Give liberally and be ungrudging when you do so, for on this account the Lord your God will bless you in all your work and in all that you undertake." Deuteronomy 15:10 NRSV.

ACKNOWLEDGMENTS

This work would not have come to fruition without the assistance of many parties. Funding for this research was provided by the National Fish and Wildlife Foundation Wildlife Links Program. The U.S. Geological Survey South Carolina Cooperative Fish and Wildlife Research Unit and South Carolina Department of Natural Resources provided logistical and financial support. The staff of the Lowcountry Institute on Spring Island arranged field housing, with special thanks to Mark & Ann Hawley for volunteering their guest home for my residence. Thanks go to all the golf courses that participated in the study.

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INTRODUCTION

An estimated 810 bird species can be found in North America, north of Mexico, over the course of a given year (Sibley 2000). Neotropical migratory birds (NTMB) account for 251 of those reported species. Of the total species observed in the U.S., 248 are expected annually in the coastal zone of Beaufort County, South Carolina. The coastal zone eco-region of South Carolina is found seaward of the state inland marine waters boundary, and the portion encompassed by Beaufort County is also known as the sea island complex. Historical breeders in the region included the threatened Swainson's warbler, and the extinct Bachman's warbler, ivory-billed woodpecker, and Carolina parakeet. Currently, there are approximately 119 known species of bird that breed in the region (Appendix A), and several face population-level threats (Table 1). The rest of the annual avian community is comprised of 84 wintering species and 45 species that migrate through the area. The South Carolina coastal zone contains the most diverse suite of habitats of any of the eco-regions of the state (SCDNR 2005). Maritime forest, various pine regimes, estuarine scrub/shrub, early succession, grassland and salt marsh ecosystems naturally characterize the coastal zone of Beaufort County.

I was able to identify approximately fifty 18-hole golf courses in the coastal zone of Beaufort County using Google Maps (2010). Golf courses have previously and continue to have a mixed history of conservation value (Conover and Chasko 1985, Tanner and Gange 2005). Most golf courses require the replacement of natural land cover with turf grass fairways, and in many locations golf courses are part of a larger

TABLE 1. Imperiled breeding birds of the South Carolina coastal zone and their population status. Records in bold are species likely to be found within an area occupied by a golf course. The Audubon Watch List uses the familiar colors of a stoplight to indicate the range-wide level of concern for a species. Red indicates rapid decline, yellow declining, and green least concern. IUCN uses adjectives such as least concern (LC) and near-threatened (NT) to communicate population status. Codes recorded by the Nature Conservancy indicate global (G) and state (S) rank. Rank 1 indicates critically imperiled, 2 imperiled, 3 vulnerable, 4 apparently secure, and 5 secure. Legal abbreviations include federally endangered (FE), federally threatened (FT), of concern in state (SC), state threatened (ST) and state-endangered (SE).

Species	IUCN Status	Audubon	Government Assessment
Bald eagle	**LC**	**green**	**G4, S2, FT/SE**
Swallow-tailed kite	**LC**	**yellow**	**G5**
Red-headed woodpecker	**NT**	**yellow**	**G5**
Red-cockaded woodpecker	**Vulnerable**	**red**	**G3**
Prairie warbler	**LC**	**yellow**	**G5**
Bachman's sparrow	**NT**	**red**	**G3**
Painted bunting	**NT**	**yellow**	**G5**
Northern bobwhite	**NT**	**green**	**G5**
Wood stork	**LC**	**green**	**G4, S1/S2, FE/SE**
Brown pelican	LC	green	G4, S1/S2, SC
Black rail	NT	red	G4
King rail	LC	yellow	G4
Clapper rail	LC	yellow	G5
Wilson's plover	LC	yellow	G5
Least tern	LC	red	G4, S3, ST
Gull-billed tern	LC	yellow	G5
Black skimmer	LC	yellow	G5
Seaside sparrow	LC	yellow	G4

development process that includes residential homes and accompanying infrastructure as well (Mankin 2000). Within the boundary of the golf courses themselves, in-play areas and ornamental vegetation are maintained by supplemental watering and often pesticides. Historically, pesticide use drew attention to avian ecological implications of golf course management through observed mortality of species such as Canada geese (Zinkl et al. 1978, Frank et al. 1991). Subsequent investigations of avian response to pesticide application (Kendall et al. 1992, Kendall et al. 1993) and prey selection (Brewer et al. 1988) resulted in changes in pesticide use (Rainwater et al. 1995) and regulation. The in-play area of the golf course is often surrounded by vegetation and varying intensities of development, categorizing this land use as an intermediate-natural level urbanization (Blair 1996).

Increased urbanization can affect avian species composition (Beissinger and Osborne 1982, Marzluff et al. 2001, Mortberg 2001). Abundance of urban adapters and non-native species may increase with increasing urbanization (Emlen 1974, Hohtola 1978, Green 1984). Gering and Blair (1999) found decreased nest predation pressure with increased urbanization, potentially to the benefit of urban exploiting species. Brown-headed cowbird (*Molothrus ater*) parasitism was shown to increase in fragmented landscapes, causing in some cases a steep decline in host productivity (Robinson et al. 1995). In cases where golf courses provide an otherwise scarce habitat type, such as riparian areas in a dry climate (Merola-Zwartjes and DeLong 2005), species richness and diversity may increase. However, the replacement of vegetation for golf course development can reduce the suitability of the landscape for a species (Dale 2004) and/or result in decreases in abundance or diversity (Sorace and Visentin 2007). Prior modeling research has sought to predict the effects of urbanization on the avian community (Hepinstall et al. 2008).

My goal was to investigate the relationship between golf course landscape characteristics and the breeding bird community of coastal Beaufort County, South Carolina. Golf course development is especially prevalent within the region in Bluffton and Hilton Head (Lewitus et al. 2003). I aimed to characterize and compare landscape features of golf courses to discern how they were related to avian community metrics including species richness, neotropical migrant richness, diversity, abundance, evenness, and mean Partners in Flight (PIF) score. I hypothesized that landscape structure would be related to avian community characteristics and hence show significant correlations with community metrics. I sought to model the relationships between landscape variables and avian community metrics.

METHODS

STUDY AREA

The study area was within the coastal zone eco-region of Beaufort County, South Carolina (Fig. 1). There were 23 study sites, which were all 18-hole golf courses within residential communities (Appendix B). I selected only golf courses that were located within 2 km of the intertidal estuarine marsh or the coastline. I began by contacting the Low Country Golf Course Superintendents Association (LCGCSA) to locate study

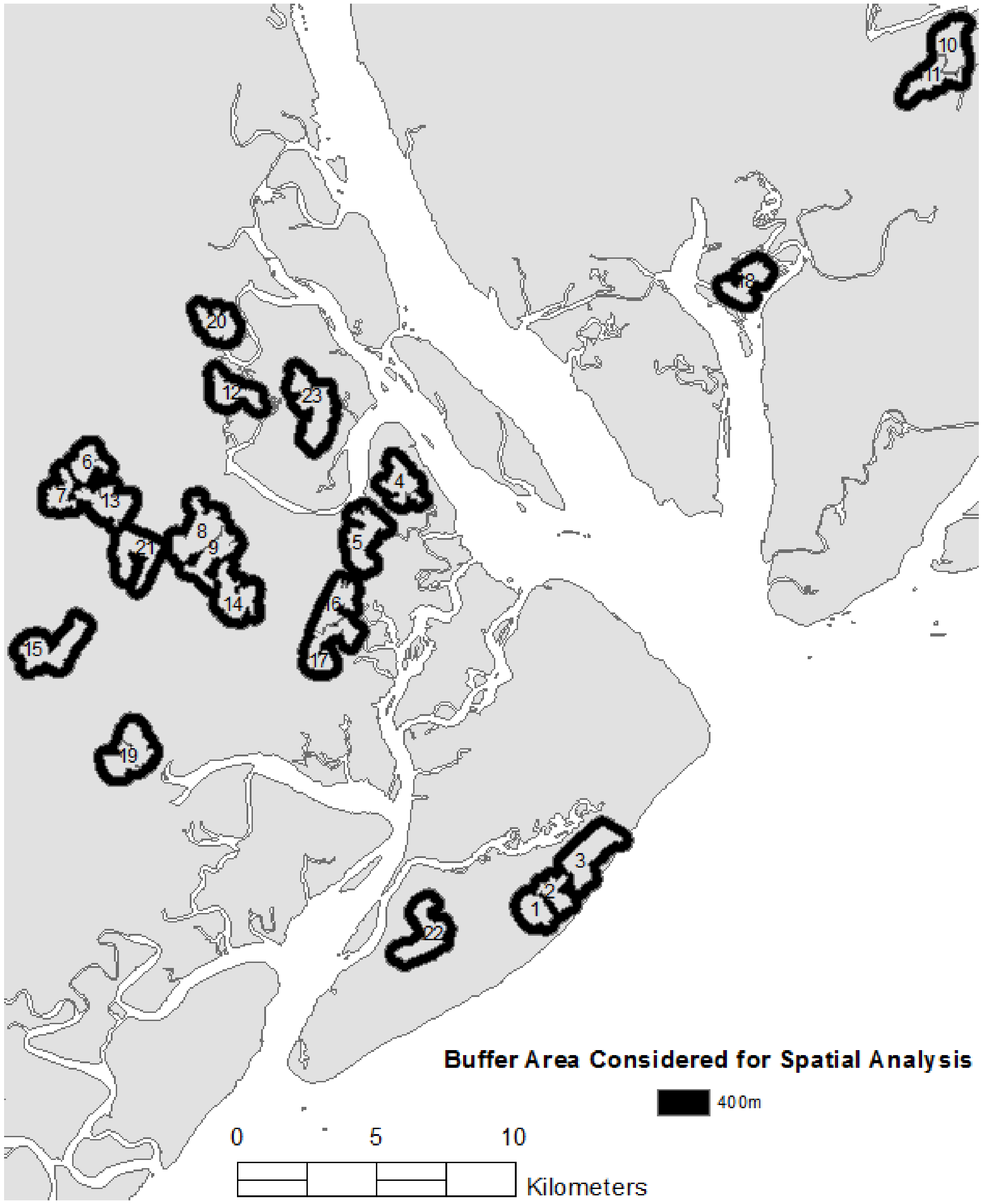

FIGURE 1. The location of 23 golf courses (named in Appendix 1) surveyed for avian community and landscape metrics, May – July 2010, Beaufort County, South Carolina.

participants, and further contacted golf courses in the area based on available contact information online.

Golf courses were concentrated in Bluffton and Hilton Head, leading to an uneven spatial distribution across the county. Sites varied from exclusive, private clubs to joint residential-resort properties. Residential property regulations varied from strict community-enforced property buffer guidelines to minimum county watershed buffer regulations. Thus, the golf courses and surrounding communities varied greatly in housing density, natural vegetation cover, ornamental landscaping, and land use of out-of-play areas.

AVIAN SURVEYS

I surveyed each golf course in 2010 first between May 25 through June 14 (early season), and again from June 17 through July 30 (late season). During each survey, I conducted fixed-radius (200 m) point-counts. I derived this range by listening to a singing male painted bunting in open habitat such as that found on golf courses, and used a range finder to estimate the distance at which vocalizations were no longer audible. Survey stations (n = 253 survey stations across all golf courses) were spaced 440 m apart within a golf course to promote independence of observations while still producing sufficient coverage of the study area. Point count stations were selected by overlaying a 440 m grid on each golf course property using ArcGIS 9.3 and aerial photographs (Fig. 2). A point was used for survey if the detection area included any portion of the in-play area of the golf course.

FIGURE 2. Example of count station and detection area map used for avian point count surveys on 23 golf courses, Beaufort County, South Carolina. May – July 2010. Each station has a radius of 200 m and survey centroids are 440 m apart.

Each point was visited from 0600h – 0900h (early AM) and again from 0910 h - 1200 h (late AM; Hutto 1986). Thus, each survey point was scheduled to be visited four times. A point was visited for 5 minutes, during which time all birds detected visually and aurally were recorded (Hamel et al. 1996). Of the expected 1012 surveys, 239 were not conducted due to access restrictions.

LANDSCAPE CLASSIFICATION

The areal extent of a golf course was defined as the smallest possible polygon containing all fairways and was created by heads-up digitizing the perimeter of the in-play area of each golf course using aerial photographs from 2009. Within 1 km of each course, a land use/land cover layer was created by drawing polygons around habitat patches. The land cover definitions provided by the USGS Land Cover Institute were used, and then regrouped to form coarser categories for ease of land classification (Table 2). This was done to achieve classification accuracy at a finer scale than that provided by the National Land Cover Database (NLCD). The reclassified land cover categories form the coarse scale land classes used in landscape analysis. The vector layer was converted to a raster layer for analysis, with 4.572 m cells (McGarigal 2002).

The coarse land cover classes were then refined to generate a fine scale land cover layer, by adding forest types and development types. The 2002 National Wetlands Inventory was used to classify forest as forested wetland, evergreen upland forest, mixed upland forest, upland planted pine, or unknown type. Developed areas were also classified by aerial photo interpretation as residential or commercial development. Given a 200 m point count radius, birds were detected within but not in excess of 400 m from

TABLE 2. The simplified reclassifications of National Land Cover Database (NLCD 2006) classes used to create a coarse land cover layer for 23 golf courses in Beaufort County, South Carolina. Land area is summed within 400 m of the in-play boundary of all golf courses.

Reclassified Land Cover Categories	NLCD Classes	Land Area (ha)	Proportion of Study Area
Forest	Forest (all types), Forested wetland (all types), Woody wetlands	2324.0	27%
Open	Developed, open space	2206.9	25%
Developed	Developed (all types)	2009.6	23%
Marsh	Estuarine emergent wetland, Estuarine aquatic bed	1687.9	19%
Man-made water feature	Palustrine emergent wetland, Palustrine aquatic bed	423.8	5%
Ocean	Open Water	22.1	<1%
Shrub	Scrub/shrub, Estuarine shrub wetland	14.8	<1%
Crop	Grassland/herbaceous, Pasture/hay, Cultivated Crops	67.8	<1%

the in-play perimeter of the golf course. A study site was thus defined as the golf course itself plus the area within 400 m of the in-play perimeter of the golf course. Landscape variables were generated for coarse and fine scale classification layers using Patch Analyst (Rempel and Carr 2003).

AVIAN COMMUNITY METRICS

Avian survey data were originally collected by JMG and a field technician. However, results were tested for concurrence in avian metric calculations, and bird detection was determined to be disparate by way of a t-test ($p < 0.05$). JMG data were used for all analyses except for golf courses where the only data available for the early season were collected by the second surveyor ($n = 68$ point counts over 36 points). Therefore, some bias may have occurred due to differing bird detection strategies.

Based on the survey data collected I calculated six avian community metrics which served as response variables for subsequent analyses with landscape metrics. Species richness (SR) was defined as the count of species per course. Richness of neotropical migrants (NR) was defined as the number of species per course that were classified as neotropical migrants by the Neoptropical Migratory Birds Conservation Act (NMBCA). Neotropical migrants are species that annually migrate between temperate breeding areas and tropical wintering areas. Therefore, while some species within a family or order may be neotropical migrants (e.g. fulvous whistling-duck, greater white-fronted goose) others might not (e.g. American black duck, mottled duck). The two aforementioned richness metrics were calculated from all survey dates and times. Species abundance (SA) was defined as the number of individuals per species and was calculated by summing all point counts over a course during each of the morning/season time periods. The highest count from these four time periods was used as the abundance measure for a species. The fourth metric I calculated was the mean Partners in Flight score for a golf course (PIF, Carter et al. 2000). I assigned a PIF score to each species by summing indices reflecting the population size, breeding distribution, threats to breeding, and population trend scores assigned by PIF for Bird Conservation Region (BCR) 27. Scores for each parameter ranged from 1-5, with 5 indicating highest conservation concern for that parameter. I ranked percentage of a species' population within BCR 27 from 1-5, by assigning 0-20% =1, 21-40%=2, 41-60% =3, 61-80% = 4, and 81-100% = 5. I added this parameter to the variables mentioned above to calculate a PIF score for each species. For each golf course, species abundance was multiplied by PIF score, and the resulting values were summed and divided by total number of individuals to obtain a mean PIF score. The higher the mean PIF score, the higher the conservation priority for the avian community represented. The fifth and sixth metrics were diversity and evenness, based on a species' frequency of occurrence. First, I calculated frequency as species abundance divided by the total number of birds per course (Shannon and Weaver 1963). Shannon's diversity index (H') was then calculated as frequency multiplied by the natural log of frequency, and an evenness index was then calculated as H'/ln(SR) following Lloyd and Ghelardi (1964).

RELATING LANDSCAPE METRICS TO AVIAN COMMUNITY METRICS

I used multiple linear regression models to assess the relationship between the avian community metrics (dependent variables) and a subset of all possible landscape metrics (independent variables) generated by Patch Analyst (Table 3) . The reduced subset of landscape variables considered for each response variable was based on correlation analyses. I assessed the correlation between each avian community metric and each landscape variable (131 total) available in Patch Analyst for each land class. If the $R^2 > 0.49$ for any single relationship, then that landscape variable was included in subsequent analyses for all avian community metrics (Table 4). Total marsh edge was added for consideration based on hypothesized effect on the avian community composition. For each avian community metric I then applied a stepwise selection process using the set of available independent variables and two-way interaction terms (Table 5). Independent variables were checked for multicollinearity. Independent variables were checked for normality of distribution and outlier observations.

TABLE 3. The subset of landscape variables from Patch Analyst (Rempel and Carr 2003) considered for model selection, based on avian community data collected May – July 2010 in Beaufort County, South Carolina.

Metric	Abbreviation	Description
Number of patches	NUMP	Number of patches of a given land class
Total edge (m)	TE	Total edge of a given land class
Patch richness	PR	Number of land classes
Mean patch fractal dimension	MPFD	Complexity of edge, conceptually defined by Perimeter ≈ $\sqrt{\text{Area}}^{(\text{fractal dimension})}$ (Mandelbrott 1982)
Mean shape index	MSI	Average perimeter-to-area ratio for a class
Area weighted mean shape index	AWMSI	Mean shape index weighted by the size of the patches
Largest patch index (%)	LPI	Percentage of the landscape represented by largest patch
Patch size coefficient of variation	PSCOV	Population coefficient of variation relative to mean patch size for a class
Interspersion & juxtaposition index	IJI	Observed interspersion divided by maximum interspersion
Total land area (ha)	TLA	Total area of the site considered

TABLE 4. Summary of landscape variables considered in modeling avian community on 23 golf courses, May – July 2010, Beaufort County, South Carolina.

Classification Level	Explanatory Variable	Mean	Standard Deviation	Coefficient of Variation
Fine	NUMP Mixed Upland Forest	10.7	11.3	106%
	TE Marsh (m)	9855.0	6832.1	69%
	PSCOV Turf	221.3	99.1	45%
	IJI Turf	63.0	14.8	23%
	TE Forested Wetland (m)	9173.0	10201.2	111%
	MPFD Residential	1.1	0.1	9%
	MPFD Turf	1.1	0.1	9%
	MSI Turf	2.4	0.6	25%
	AWMSI	3.9	0.6	15%
	TLA (ha)	400.8	74.9	19%
	LPI (%)	29.0	11.1	38%
Coarse	PSCOV	362.0	104.1	29%
	PR	7.6	1.4	18%
	IJI	65.5	7.4	11%

TABLE 5. Candidate landscape interaction terms for consideration in avian community models, selected for interpretability and predicted variable relationships.

IJI Coarse*PR Coarse
LPI*PSCOV Coarse
PSCOV Coarse*PSCOV Turf
IJI Turf*IJI Coarse
AWMSI*MSI Turf
AWMSI*MPFD Residential

RESULTS

LANDSCAPE METRICS

For the 23 golf courses in the study, the mean course area was 111.3 ha (± 32.7), and courses ranged from 64 to 173.5 ha. Mixed upland forest was the most common forest type present within the survey area (Table 2), and often comprised the out-of-play areas of the course. The shape metrics of the ubiquitous land cover categories tended to exhibit the lowest variability (Table 4). For example, MPFD measurements were the least variable among landscapes, indicating that these landscapes, whether residential or turf, did not drastically differ in shape complexity among golf courses. In contrast, the number of patches of mixed upland forest and the total edge of forested wetland in and adjacent to golf courses were highly variable, indicating that forest fragmentation occurred at different levels per course. Forested wetland was uncommon on the golf course properties although many golf courses were adjacent to tidal marshes.

AVIAN COMMUNITY

I recorded 84 avian species across all golf courses; surveys did not include flyover observations. Seventeen species listed as breeding in the region that were not detected were also unlikely to be found in areas now occupied by golf courses. Rookeries of wading birds were present on several (39%) courses adjacent to water features and natural marshes and hence wading birds were common. All expected raptors were observed, with the exception of broad-winged hawk and American kestrel. Similarly woodpeckers were commonly detected with the exception of red-cockaded woodpeckers, which were not observed on any golf courses in the study. Other species expected to be breeding in the study area that were not detected included Bachman's sparrow and American woodcock, but surveys did not occur within an optimal time frame to record the latter. The most common warbler detected was pine warbler. Northern bobwhite was found, but only from a stocked population on Spring Island, and purple martin were only located near artificial martin houses. Detected avian species not native to the study region included house finch and brown-headed cowbird. Avian community metrics are summarized in Table 6. Below I describe each in turn.

Species & Neotropical Migrant Richness

Richness of all species and richness of neotropical migrants were both moderately variable (coefficient of variations = 0.23 and 0.36, respectively) across golf courses. There was a range of 32 species recorded across all courses, and a range of nine neotropical migrant species. Chechessee Creek Club likely exhibited artificially low species richness due to availability of only late season data (Table 6). Spring Island exhibited the highest species richness (n=49), and the Dye course at Colleton River Plantation had the highest neotropical migrant richness (n=12) and the second-highest species richness (n=46). The most common birds observed among all courses were Carolina wren, northern cardinal, Carolina chickadee, American crow and tufted titmouse. Neotropical migrants comprised approximately 20% of the species richness across all courses, and most commonly included blue-gray gnatcatcher, northern parula, and yellow-throated warbler. The lowest neotropical migrant richness was observed on

TABLE 6. Summary statistics for avian community response variables, based on data collected from 23 golf courses, May – July 2010 in Beaufort County, South Carolina.

Response Variable	Mean per golf course	Minimum Value	Maximum Value	Standard Deviation	Coefficient of Variation
Species Richness	35.6	17**	49	8.1	0.23
Neotropical Migrant Richness	7.3	3***	12	2.6	0.36
Abundance	144.2	53	422	79.6	0.55
Diversity	2.9	2.4	3.2	0.2	0.08
Evenness	0.82	0.69*	0.89	0.04	0.05
Mean PIF Score	9.7	9.2	10.4	0.3	0.03

*This was an outlier observed on the Dye course at Colleton River, and was removed for analysis.
** Chechessee Creek Club likely exhibited artificially low species richness, due to only late season survey data.
*** One of the two courses with this record likewise suffered potential late season bias.

two courses, one of which may have suffered from bias due to only late season records being included.

Abundance

Abundance of birds on courses was the most variable avian metric (coefficient of variation = 0.55), reflecting in part a difference in the number of avian guilds supported among golf courses. For example, courses featuring rookeries of wading birds tended to exhibit higher abundances overall, and surveys of rookeries provided the highest individual per species counts, particularly with late season counts including young of the year. Spring Island ranked highest in total bird abundance, largely due to the presence of 300 ibises late in the season at one of the large rookeries adjacent to the course. Flocking blackbirds were the second-most numerous birds detected during surveys, followed by edge-exploiting species such as Carolina wren and northern cardinal.

Mean PIF Score

The species recorded with the highest PIF score, and hence the species with the greatest conservation concern, was brown-headed nuthatch (PIF score=18), and this species was found on 19 of the 23 golf courses. Painted bunting (PIF score=17) was found on 15 of 23 courses. The lowest PIF score (=6) birds were urban adapters and/or non-native species: barn swallow, brown-headed cowbird and house finch. Brown-headed cowbird was present on all but three golf courses. Due to the presence of both high and low PIF-priority species on many courses, variability in mean PIF score was low (coefficient of variation = 0.03).

Diversity & Evenness

Species diversity exhibited comparatively lower variability than evenness although the CV for each was quite low. Evenness better reflected the composition of the community compared to diversity by taking species richness into account in the calculation. Highest evenness was observed on Chechessee Creek Club and Palmetto Bluff (evenness = 0.89). While those courses did not rank highest in diversity or richness, the high evenness scores reflect in part that certain species were more common or abundant on the more even courses. For example, Chechessee Creek Club had the highest count of painted buntings. Both courses exhibited the highest numbers of eastern wood-pewee, a forest specialist flycatcher, found throughout the study. Evenness contained an outlier, the Colleton River Dye course observation, which was removed for analysis.

The avian community metrics showed varying correlations with one another (Table 7). Species richness showed the highest correlation with NTMB richness, as these two metrics are not entirely independent. Abundance was strongly correlated with species richness, and moderately correlated with diversity (R^2 =0.53) and NTMB richness (R^2 =0.548).

MODELS

Of the candidate explanatory variables, 11 metrics were significant in the models produced by stepwise selection (Table 8). Below I discuss each dependent variable in turn, and then provide an overview of all models. All plots are simple linear relationships taken from a multiple linear regression.

TABLE 7. Pearson correlation coefficients of avian community variables collected via survey of 23 golf courses in Beaufort County, South Carolina during May-July 2010.

	NTMB richness	Species richness	Abundance	Diversity	Evenness	Mean PIF
NTMB richness	1.000	0.783	0.548	0.424	-0.282	0.116
Species richness	0.783	1.000	0.726	0.659	-0.370	-0.079
Abundance	0.548	0.726	1.000	0.530	-0.119	-0.076
Diversity	0.424	0.659	0.530	1.000	0.407	-0.225
Evenness	-0.282	-0.370	-0.119	0.407	1.000	-0.075
Mean PIF	0.116	-0.079	-0.076	-0.225	-0.075	1.000

Species richness increased as the proportion of large contiguous patches on a golf course increased (Fig. 3) and as the fractal dimension of golf courses increased (Table 8). Similarly, the total land area of a course also had a positive effect on species richness (Fig. 4a). Patch richness and interspersion/juxtaposition had an interactive effect on species richness such that at low values of patch richness, interspersion/juxtaposition was positively related to species richness. Given the area relationship with species richness, species richness was per point was averaged for a golf course. The average species richness per point was not significantly related to area.

The richness of neotropical migratory birds on the golf courses studied was not affected by any single variables but rather by two interaction terms that included variables related to patch characteristics. As with species richness, NTMB richness also was affected by the interaction of patch richness and interspersion/juxtaposition. NTMB richness increased with interspersion/juxtaposition for high values of patch richness. NTMB richness also was affected, however, by the interaction of the mean shape indices for turf and for all classes weighted by area.

Avian abundance on golf courses was affected by an array of factors. Abundance was positively affected by interspersion/juxtaposition (Fig. 5), area-weighted mean shape indexand total land area (Fig. 4b). Avian abundance also varied among golf courses with the interaction of patch size variability and largest patch index.

TABLE 8. Avian metrics modeled in terms of landscape metrics. Independent variables (rows) that appear in the model for a dependent variable (columns) are presented with an estimate (B) and p-value (p). Values appear when the landscape metric was selected for the avian metric model; otherwise blank values indicate that the landscape metric does not appear in the model specified by the column (i.e. P > 0.15). Abbreviations followed by a land class type are metrics calculated for the specified fine classification land class type, and abbreviations with no specification are fine classification landscape level metrics. Abbreviations labeled “coarse” are coarse landscape level metrics (all forest types considered “forest,” all development types considered “developed”).

	Species Richness		NTMB Richness		Abundance		Diversity		Evenness		Mean PIF Score	
	B	p	B	p	B	p	B	p	B	p	B	p
Intercept	-163.607	0.024	-2.439	0.417	-460.141	0.008	1.995	<.0001	-1.205	0.004	10.439	<.0001
NUMP Mixed Upland Forest									-0.002	0.001		
LPI	0.393	0.009										
PSCOV Coarse					-1.13	0.003						
TE Forested Wetland									0.001	0.002		
PR Coarse									-0.007	0.007		
IJI Coarse					4.595	0.02						
MPFD Residential	126.586	0.038							0.777	0.001		
MPFD Turf									1.07	0.001		
MSI Turf									-0.02	0.066		
AWMSI					58.498	0.036			0.017	0.014		
TLA	0.036	0.046			0.66	0.001	0.001	0.052				
PR Coarse *IJI Coarse	0.065	0.001	0.012	0.042			0.001	0.052				
AWMSI *MSI Turf			0.463	0.004								
LPI *PSCOV Coarse					0.02	0.001						
IJI Turf *IJI Coarse											-0.001	0.003

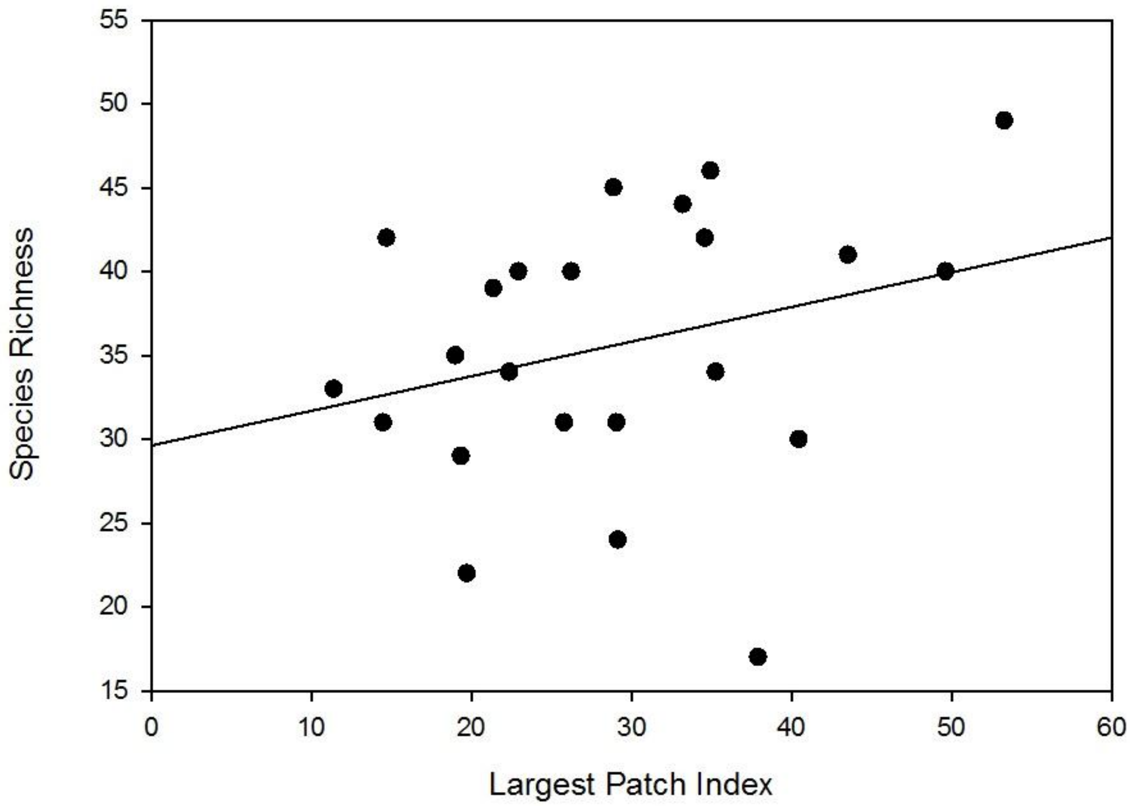

FIGURE 3. The relationship between avian species richness and largest patch index of 23 golf courses in Beaufort County, South Carolina.

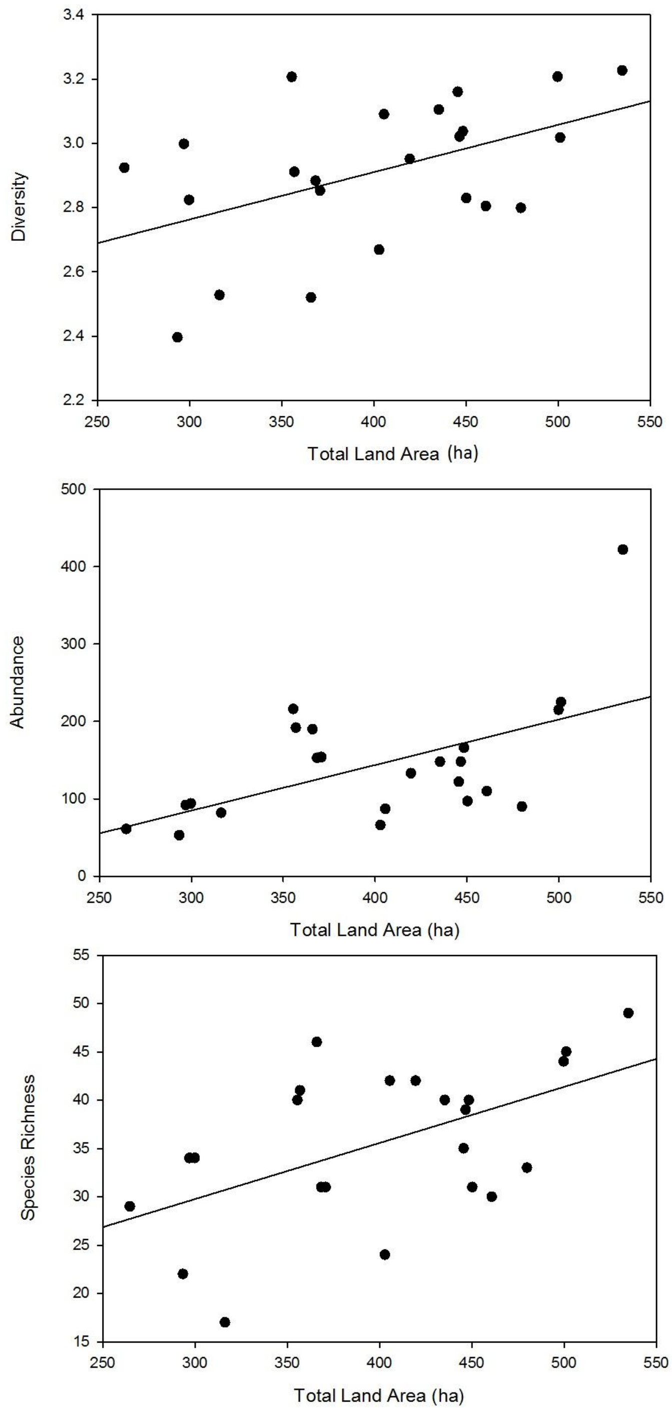

FIGURE 4. The relationship of total land area to avian species richness, avian species diversity and avian abundance of 23 golf courses in Beaufort County, South Carolina. All plots are simple linear relationships taken from a multiple linear regression.

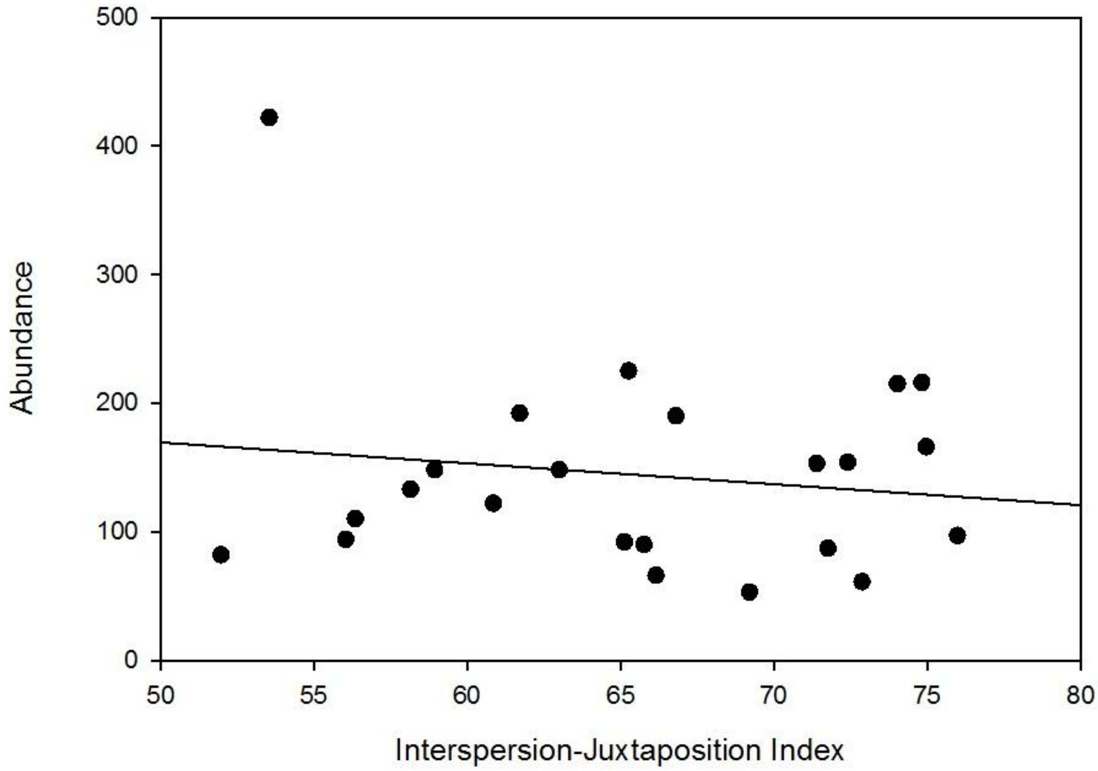

FIGURE 5. The relationship between bird abundance and interspersion-juxtaposition index of 23 golf courses in Beaufort County, South Carolina.

Diversity increased with total land area and with the interaction of patch richness and interspersion/juxtaposition index. The evenness of the avian community among golf courses decreased as patch richness increased (Fig. 6) and as number of patches of mixed upland forest increased. In contrast, evenness increased with an increase in the total edge of forested wetland and with area-weighted mean shape index. Mean shape index of turf was negatively related to evenness, but mean patch fractal dimension of turf was positively related to evenness. Mean PIF was exclusively related to interspersion/juxtaposition index, specifically by the interaction of overall interspersion/juxtaposition index and the specific interspersion/juxtaposition index for turf.

Of the independent variables included in the analyses, total land area of the courses appeared as a significant variable most commonly (n = 3 models). Total land area was positively related to species richness, abundance and diversity (Fig. 4), and these three avian metrics were each positively correlated with each other (Table 7). The interaction of coarse scale IJI and patch richness also was significant in three of the six models (species richness, diversity, and neotropical migrant richness).The only other two variables to appear in more than one model were MPFD residential and AWMSI. MPFD residential positively affected species richness and evenness while AWMSI positively affected abundance and evenness.

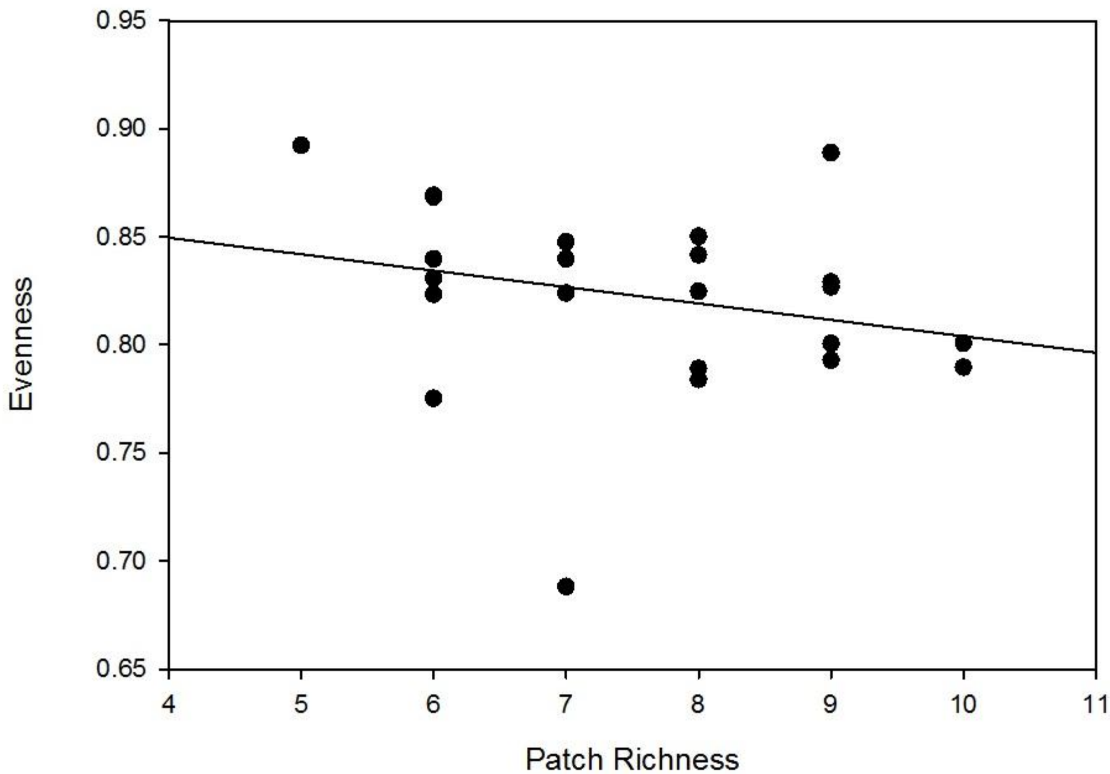

FIGURE 6. The relationship between patch richness and avian community evenness of 23 golf courses in Beaufort County, South Carolina.

DISCUSSION

Species-area curves have been the subject of foundational papers in ecology, describing the relationship between number of species and area (Jaccard 1912, Cain 1938). Several shapes have been proposed as best-fit theoretical models (Tjørve 2003). My results clearly demonstrated that avian species richness, diversity and abundance were all positively related to areal extent of the study area. My results were in agreement with the demonstrated positive relationship between total land area of a site and avian species richness found in a similar study of golf courses in coastal South Carolina (Jones et al. 2005). Positive relationships between areal extent of a site and the abundance (Martin 1980), diversity (Ambuel and Temple 1983) and richness (Helzer 1999) of avian species on a landscape have been reported commonly across multiple habitat types and in many different areas. The increase in species richness with area observed in this study is due to the phenomenon described in which sampling units are distributed over a non-uniform habitat, and are too small to individually capture the full avian community (Gleason 1922). Area metrics simply reflect spatial extent of a study site, no matter what the land cover. There was no comparison between golf courses and natural areas, so the area results are not to suggest preference for golf course development. Neotropical migrant richness did not strongly nor specifically respond to an increase in total area or size of largest patch in my study, though prior literature suggests that a positive relationship exists between neotropical migrant richness and habitat area in riparian zones (Hodges and Krementz 1996).

Landscape heterogeneity can be described by interspersion and patch richness (Reed et al. 1996b). Interspersion has been measured numerous ways through the development of landscape analytical techniques (Roth 1976, Rehm and Baldassarre 2007). IJI is the only metric that takes patch configuration into account by measuring the spatial relationship of different patch types. As IJI increases, patch types become more even and less clumped across the landscape. I found a positive relationship between IJI and avian abundance, implying that as patch types are increasingly interspersed, there are more individual birds. In my study, the Mean PIF score increased with the interaction of IJI and turf-specific IJI. The abundance relationship could partially support the relationship between mean PIF and IJI, as the calculation of mean PIF is based on species abundance. Landscape heterogeneity has been shown to be positively related to bird diversity (Saab 1999). Diversity and species richness have shown positive correlations with patch richness (Titeux et al. 2004) and patch richness density (MacArthur and MacArthur 1961, Johnson 1975, Penhollow and Stauffer 2000). Higher patch richness could reflect more available niches (Johnston and Odum 1956). Thus, the interaction of PR and IJI brings to light a possibly important driver of species richness, NTMB richness, and diversity. Patch richness only occurred, except in one model, in conjunction with IJI.

Evenness decreased with increasing patch richness, and showed opposite responses to metrics describing two different land cover types. Evenness decreased with increasing number of patches of mixed upland forest, which could reflect a negative response to fragmentation (Reed et al. 1996a). Forest specialists are likely to decline with increasing number of forest patches (Pearson et al. 1999). Evenness increased with total edge of forested wetland. Only two survey points were located within a stand of forested wetland, so any other birds detected from the forested wetland would have been on or beyond a forested wetland edge. Thus, it is possible that edge of forested wetland may reflect availability of forested wetland in this study.

Species richness and abundance are not descriptive of the actual species represented in the avian community but rather the numbers of species and individuals. Mean PIF, while more descriptive of the conservation priority of the avian communities surveyed, lends little management insight alone, as scores do not reflect species requirements. The difference in species richness between courses with and without rookeries was up to nine species, reflecting the most common rookery inhabitants. Number of raptor species, and species present, also differed by course depending on available foraging habitat. As mentioned above, the golf courses in this study hosted several non-native species. Brown-headed cowbird is an obligate nest parasite and is not native to the southeastern United States (Mayfield 1965). Decreased productivity in new hosts has been documented (Marvil and Cruz 1989, Trail and Baptista 2002). I observed brown-headed cowbird parasitism of painted bunting and northern parula nests during summers 2008-2009.

The response of avian community metrics to shape metrics has been reported to depend on scale and areal extent of the landscape considered. Haskell et al. (2006) discovered a local (150 m buffer) positive effect of AWMSI and AWMPFD on species richness, but a negative overall effect at 1000 m buffer calculations. The interpretation of fractal dimension comes with a cautionary note, as the calculation of the metric depends on the size of the patch considered and the raster cell size (McGarigal and Marks 1995). The positive relationship between AWMSI of all landscape types within 400 m of the golf course and number of individuals, combined with the negative relationship between MSI turf and evenness, may reflect a local benefit to edge species. As turf is, by definition, the primary or most common land category on all golf courses, the shape of the remainder of the landscape must depend on the shape of the in-play area of the course. The distribution of a higher number of individuals across a specialized suite of edge species would decrease evenness.

Further studies conducted on golf course properties should investigate the effects of microhabitat characteristics on avian communities, and would benefit from additional data collection seasons (MacFaden and Capen 2002). Avian surveys in South Carolina should be completed by June 15 to likely provide the best estimate of neotropical migrant richness. Bird identification error is always possible, and future surveys should include two experienced, simultaneous observers throughout the route. Through consultation during a point count, identification error can be minimized, while bird detection can be increased by more than one observer. Detection varies greatly with land cover, so the effects on detection should be quantified and accounted for. Noise also affected detection, which likewise needed quantification. As mentioned prior, access to survey points was restricted in some cases, which led to unequal coverage of survey areas. Different statistical methodologies, landscape metric calculation methods and variable subsets may yield different results. Evenness, while an important descriptor of the avian community, was described by a complex model. In further studies, a different variable subset may be appropriate.

This study provides yet another example of species/abundance-area relationships, while highlighting a somewhat debated diversity-area relationship (Rohde 1998). The interaction of interspersion/juxtaposition and patch richness provides a novel and variable metric for measuring landscape heterogeneity, though the components have been addressed in prior research. The evenness model hints at a negative response to forest fragmentation and a positive response to forested wetlands, which should be further investigated and considered for management strategies on Beaufort County golf courses. Shape metrics need to be calculated at appropriate scales when considered. With improvement in future study design, different perspectives and replication, these results may be expanded upon to hone an understanding of avian-landscape relationships.

APPENDICES

Appendix A

List of all known breeding bird species of Beaufort County (Sibley 2000).

Observation	Common Name	Scientific Name
Tallied during survey period	Northern Bobwhite	*Colinus virginianus*
	Brown Pelican	*Pelecanus occidentalis*
	Double-crested Cormorant	*Phalacrocorax auritus*
	Anhinga	*Anhinga anhinga*
	Least Bittern	*Ixobrychus exilis*
	Great Blue Heron	*Ardea herodias*
	Great Egret	*Ardea alba*
	Snowy Egret	*Egretta thula*
	Little Blue Heron	*Egretta caerulea*
	Tricolored Heron	*Egretta tricolor*
	Cattle Egret	*Bubulcus ibis*
	Green Heron	*Butorides virescens*
	Black-crowned Night-Heron	*Nycticorax nycticorax*
	Yellow-crowned Night-Heron	*Nyctanassa violacea*
	White Ibis	*Eudocimus albus*
	Wood Stork	*Mycteria americana*
	Black Vulture	*Coragyps atratus*
	Turkey Vulture	*Cathartes aura*
	Osprey	*Pandion haliaetus*
	Swallow-tailed Kite	*Elanoides forficatus*
	Mississippi Kite	*Ictinia mississippiensis*
	Cooper's Hawk	*Accipiter cooperii*
	Red-shouldered Hawk	*Buteo lineatus*
	Red-tailed Hawk	*Buteo jamaicensis*
	Clapper Rail	*Rallus longirostris*
	Common Moorhen	*Gallinula chloropus*
	Killdeer	*Charadrius vociferus*
	Spotted Sandpiper	*Actitis macularius*
	Willet	*Tringa semipalmata*
	Laughing Gull	*Leucophaeus atricilla*
	Ring-billed Gull	*Larus delawarensis*
	Royal Tern	*Thalasseus maximus*
	Mourning Dove	*Zenaida macroura*
	Yellow-billed Cuckoo	*Coccyzus americanus*

Barred Owl	*Strix varia*
Chuck-will's-widow	*Caprimulgus carolinensis*
Chimney Swift	*Chaetura pelagica*
Ruby-throated Hummingbird	*Archilochus colubris*
Red-headed Woodpecker	*Melanerpes erythrocephalus*
Red-bellied Woodpecker	*Melanerpes carolinus*
Downy Woodpecker	*Picoides pubescens*
Northern Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Eastern Wood-Pewee	*Contopus virens*
Acadian Flycatcher	*Empidonax virescens*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Kingbird	*Tyrannus tyrannus*
Loggerhead Shrike	*Lanius ludovicianus*
White-eyed Vireo	*Vireo griseus*
Yellow-throated Vireo	*Vireo flavifrons*
Blue Jay	*Cyanocitta cristata*
American Crow	*Corvus brachyrhynchos*
Fish Crow	*Corvus ossifragus*
Purple Martin	*Progne subis*
Barn Swallow	*Hirundo rustica*
Carolina Chickadee	*Poecile carolinensis*
Tufted Titmouse	*Baeolophus bicolor*
White-breasted Nuthatch	*Sitta carolinensis*
Brown-headed Nuthatch	*Sitta pusilla*
Carolina Wren	*Thryothorus ludovicianus*
Marsh Wren	*Cistothorus palustris*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Eastern Bluebird	*Sialia sialis*
Gray Catbird	*Dumetella carolinensis*
Northern Mockingbird	*Mimus polyglottos*
Brown Thrasher	*Toxostoma rufum*
Northern Parula	*Parula americana*
Yellow-throated Warbler	*Dendroica dominica*
Pine Warbler	*Dendroica pinus*
Prairie Warbler	*Dendroica discolor*
Eastern Towhee	*Pipilo erythrophthalmus*
Chipping Sparrow	*Spizella passerina*
Summer Tanager	*Piranga rubra*
Northern Cardinal	*Cardinalis cardinalis*

	Blue Grosbeak	*Passerina caerulea*
	Painted Bunting	*Passerina ciris*
	Red-winged Blackbird	*Agelaius phoeniceus*
	Common Grackle	*Quiscalus quiscula*
	Boat-tailed Grackle	*Quiscalus major*
	Brown-headed Cowbird	*Molothrus ater*
	Orchard Oriole	*Icterus spurius*
	House Finch	*Carpodacus mexicanus*
Observed outside of survey period	Pied-billed Grebe	*Podilymbus podiceps*
	Bald Eagle	*Haliaeetus leucocephalis*
	Great Horned Owl	*Bubo virginianus*
	Eastern Screech-owl	*Otus asio*
	Yellow-breasted Chat	*Icteria virens*
Not Observed, but Could Occur in Areas Occupied by Golf Course	Broad-winged Hawk	
	American Kestrel	
	Common Ground-dove	
	Field Sparrow	
	Indigo Bunting	
	Bachman's Sparrow	
	Eastern Meadowlark	
	Hairy Woodpecker	
	Red-cockaded Woodpecker	
	Red-eyed Vireo	
	Wood Thrush	
	Common Yellowthroat	
	Hooded Warbler	
Not Observed, Unlikely to Occur in Area Occupied by Golf Course	Glossy Ibis	
	Purple Gallinule	

Wood Duck
King Rail
Black Rail
American Oystercatcher
Black-necked Stilt
Least Tern
Gull-billed Tern
Black Skimmer
Belted Kingfisher
Seaside Sparrow
Northern Rough-winged Swallow
Barn Owl
American Woodcock
Prothonotary Warbler
Wilson's Plover

Appendix B

Beaufort County golf courses surveyed for avian community and landscape characteristics during summer 2010.

Number	Golf Course Name	Location	Rookery?	Earliest Survey Date
1	Arthur Hills	Palmetto Dunes	No	6/9/2010
2	Fazio	Palmetto Dunes	Yes	6/8/2010
3	Rob Trent	Palmetto Dunes	No	6/10/2010
4	Pete Dye	Colleton River	No	6/6/2010
5	Nicklaus	Colleton River	Yes	6/7/2010
6	North Course	Berkeley Hall	No	6/3/2010
7	South Course	Berkeley Hall	No	6/2/2010
8	East Course	Belfair	No	6/1/2010
9	West Course	Belfair	Yes	5/30/2010
10	Cotton Dike	Dataw Island	No	5/26/2010
11	Morgan River	Dataw Island	No	7/8/2010
12	Dogwood & Palmetto	Callawassie Island	Yes	6/13/2010
13	Eagle's Pointe	Bluffton	No	6/4/2010
14	Crescent Pointe	Bluffton	No	5/29/2010
15	Hampton Hall	Hardeeville	No	5/27/2010
16	North Course	Moss Creek	Yes	5/28/2010
17	South Course	Moss Creek	No	5/28/2010
18	Sanctuary	Cat Island	Yes	6/15/2010
19	May River	Palmetto Bluff	Yes	6/14/2010

20	Chechessee	Okatie	No	7/20/2010
21	Rose Hill	Bluffton	No	6/13/2010
22	Country Club	Sea Pines	Yes	6/11/2010
23	Tabby Links	Spring Island	Yes	6/10/2010

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