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LANDSCAPE SCALE CORRELATES OF FOX SQUIRREL (Sciurus niger) PRESENCE

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LANDSCAPE SCALE CORRELATES OF FOX SQUIRREL (*Sciurus niger*) PRESENCE ON GOLF COURSES IN COASTAL SOUTH CAROLINA

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Forestry and Natural Resources

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by
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Accepted by:
Dr. Patrick G.R. Jodice, Committee Chair
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ABSTRACT

Although declining throughout the southeast, fox squirrel (*Sciurus niger*) populations are found on some golf courses in rapidly developing coastal South Carolina. This study used 2001 National Landcover Database data to investigate the relationship between fox squirrel presence on golf courses and landscape-scale habitat features. Results indicated that the best predictor of fox squirrel presence on a course was the presence of a fox squirrel population on the nearest neighbor course, regardless of distance. Course age and the total area of undeveloped features on the course were the best predictors of fox squirrel presence on golf courses without a fox squirrel population on their nearest neighbor.. This suggests that regional fox squirrel populations may be stabilized by multi-patch population dynamics. Golf course managers and other large landowners in the region are encouraged to cooperate to preserve movement corridors between habitat patches in order to allow continued fox squirrel dispersal.

ACKNOWLEDGEMENTS

This work would not have come to fruition without the assistance of many parties. Funding for this research was given by the United States Golf Association through their Wildlife Links Program. The U.S. Geological Survey South Carolina Cooperative Fish and Wildlife Research Unit supplied logistical support as well as field vehicles. The staff of the Waddell Mariculture Center in Bluffton and the Bears Bluff National Fish Hatchery on Wadmalaw Island provided field housing. Thanks go to all the golf courses with which I interacted, and especially those that allowed me repeated access to their course for surveys. I would also like to express my appreciation for the assistance of my committee members Jeff Allen, Susan Loeb, and Bo Song. This project benefited greatly from their input. Lastly, I would like to thank my advisor Patrick Jodice for his guidance as well as his patience.

DEDICATION

This work is dedicated to the memory of two people who are not here to see it. My grandmother Dorothy always encouraged me to learn, to enjoy the world around me, and to never tease a weasel. My brother Shawn was my technical advisor and my best friend. You are missed.

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PREFACE

Habitat loss and alteration due to urbanization is a major cause of wildlife endangerment both globally and in the United States. Species vary in their sensitivity to these habitat changes, and some generalist species may persist in fragments of open space within the developed landscape. The coastal region of South Carolina is known internationally as a golf destination, and golf courses represent a major land use in the region. Although rare and declining throughout the southeast, fox squirrel (*Sciurus niger*) populations are found on some of these golf courses. This work uses an intermediate-scale land use/ land cover data set in combination with fox squirrel surveys to determine which landscape- scale habitat features best predict fox squirrel presence. In chapter one I use an information- theoretic approach to test a suite of models which were developed based on fox squirrel biology in the region. Land cover and other habitat characteristics are considered at multiple scales to determine the relative importance of course-level and larger-scale habitat factors. In chapter two I assess the accuracy, error, and usefulness of the 2001 NLCD land use/ land cover raster used for this study by comparing its classifications with those determined visually. This was done using 1999 Landsat imagery and 2005 aerial photos.

UNDERSTANDING THE RELATIONSHIP OF LANDSCAPE SCALE HABITAT FEATURES AND FOX SQUIRREL PRESENCE ON COASTAL SOUTH CAROLINA GOLF COURSES

Introduction

Urbanization is a major cause of species endangerment within the continental U.S. (Czech and Krausman 1997). The landscape conversion that accompanies urbanization occurs over short time intervals and results in relatively permanent changes to native habitats, high-contrast boundaries between patches, and simplification of vegetation communities in the remaining fragments (Miller 2002; Stratford and Robinson 2005). These characteristics of urbanization can amplify the proximate spatial effects of habitat loss and alteration and ultimately result in a mosaic of small patches, often within an unsuitable or actively hostile matrix (Luck 2002; Wiegand et al. 2005; Andersson 2006). Such a rapid and drastic change to the landscape can have both wide-ranging and unpredictable effects on native fauna. Not all wildlife species are, however, equally affected by landscape changes associated with urbanization. While species that require large patches of undisturbed habitat are unlikely to persist in the midst of development (Salsbury 2004), those that are generalists, require smaller patches, or can utilize ecotones or other edge habitat may be able to remain viable (Alderman et al. 2005). Furthermore, regions with clustered patches of partially developed habitat that allow for movements of individuals among patches may further increase the likelihood of species persistence due to the stabilizing effects of multipatch population dynamics (Fahrig 2002; Verbeylen et al. 2003). The dynamics of multipatch populations in fragmented habitats continues to be an important area for research (Davies et al. 2001), especially in partially developed landscapes. The coastal plain of the southeastern US has experienced rapid and intense landscape conversion during the previous 35 years (Allen and Lu 2003). In particular, coastal South Carolina, which was historically characterized by a mix of forest, agricultural land, and mostly rural communities, has in recent years been experiencing a high rate of coastal population growth and development disproportionate to the increase in population. Much of this land conversion has been associated with the building of golf courses and associated resorts and communities. The stat of South Carolina contains over 300 golf courses, of which more than 100 are along the coast. Golf courses are frequently created from large parcels of previously undeveloped, rural land due to the need for large continuous properties and the generally lower land price in rural areas. However, as urban areas have expanded along the coast, many courses have become surrounded by higher-intensity development. In those instances golf courses frequently become the largest parcels of open space in the area.

Traditionally golf courses have been considered to be low-quality habitat for native wildlife, although there is increasing interest in the possible value of these areas for wildlife conservation (e.g. Jodice and Humphrey 1993; Zipperer et al. 2000; Angold et al. 2006; Yasuda and Koike 2006) . For example, although some wildlife populations will inevitably be lost as forested areas are converted to urban areas with golf courses, it is possible that some species will persist and that the functionality of remaining habitat could be improved by considering species requirements when originally planning development (Love 1999; Terman 1997). However, effective planning requires an understanding of the factors which affect species presence in different types of urbanized habitat patches (Mason 2006). For many species and development types these factors are poorly known.

My goal was to investigate the persistence of fox squirrels (*Sciurus niger*), a declining mammal in the southeastern US, on golf courses in the coastal plain of South Carolina. The fox squirrel is listed as a species of special concern in the state largely due to habitat loss, much of which is caused by urbanization (Weigl et al. 1989). Although their relative rarity in wild habitats makes surveys difficult, there is evidence that the coastal plain has traditionally harbored the highest density populations of fox squirrels in South Carolina and that these populations are declining (Harrigal 1993; Loeb and Moncrief 1993). Previous work in Florida indicated that fox squirrels can reach high densities on golf courses, and that although they frequently move between nearby courses, road traffic represents a major cause of mortality (Jodice and Humphrey 1992; Ditgen 1999). Fox squirrels also exhibit a high rate of natal dispersal (Koprowski 1996). Thus, the matrix surrounding the courses may strongly affect population viability.

I sought to assess the relationship between *S. niger* presence on golf courses and landscape-scale habitat features in urban areas of the South Carolina coast. My objectives were to: (1) determine which landscape-scale features best predicted fox squirrel presence on a given golf course, and (2) determine the relative importance of surrounding versus on-course habitat features, including the effect of neighboring golf courses. Previous research suggests that a mosaic of golf courses creates a situation where urban habitat refuges mitigate population decline (Jodice and Humphrey 1993; Ditgen 1999). The data discussed herein will improve our understanding of how fox squirrels react to differing facets of fragmentation and urbanization, and the results can be considered both in new course construction and in further development of extant golf courses in South Carolina and the southeast.

Methods

Study Area

The study area was within the Coastal Plain and Coastal Zone ecoregions of South Carolina (Figure 1.1). The dominant tree species in the coastal plain are pines, generally loblolly (*Pinus taeda*) or more rarely longleaf (*P. palustris*), typically with an understory of turkey oak (*Quercus cerris*). In uplands near river drainages, and where fire is suppressed, hardwoods including white oak (*Q. alba*), pignut hickory (*Carya glabra*), and sweetgum (*Liquidambar styraciflua*) are common. The Coastal Zone ecoregion is a subset of the Coastal Plain and is found seaward of the state inland marine waters boundary. Vegetation for this ecotype is often similar to that in the coastal plain, but the maritime forest community is also common, and includes species such as live oak (*Q. virginiana*), cabbage palmetto (*Sabal palmetto*), southern magnolia (*Magnolia grandiflora*) and southern red cedar (*Juniperus silicicola*). Marsh areas are also frequently present. These are dominated by a variety of sedges and grasses, with the species varying with salinity. Topographic relief is minimal over most of the region.

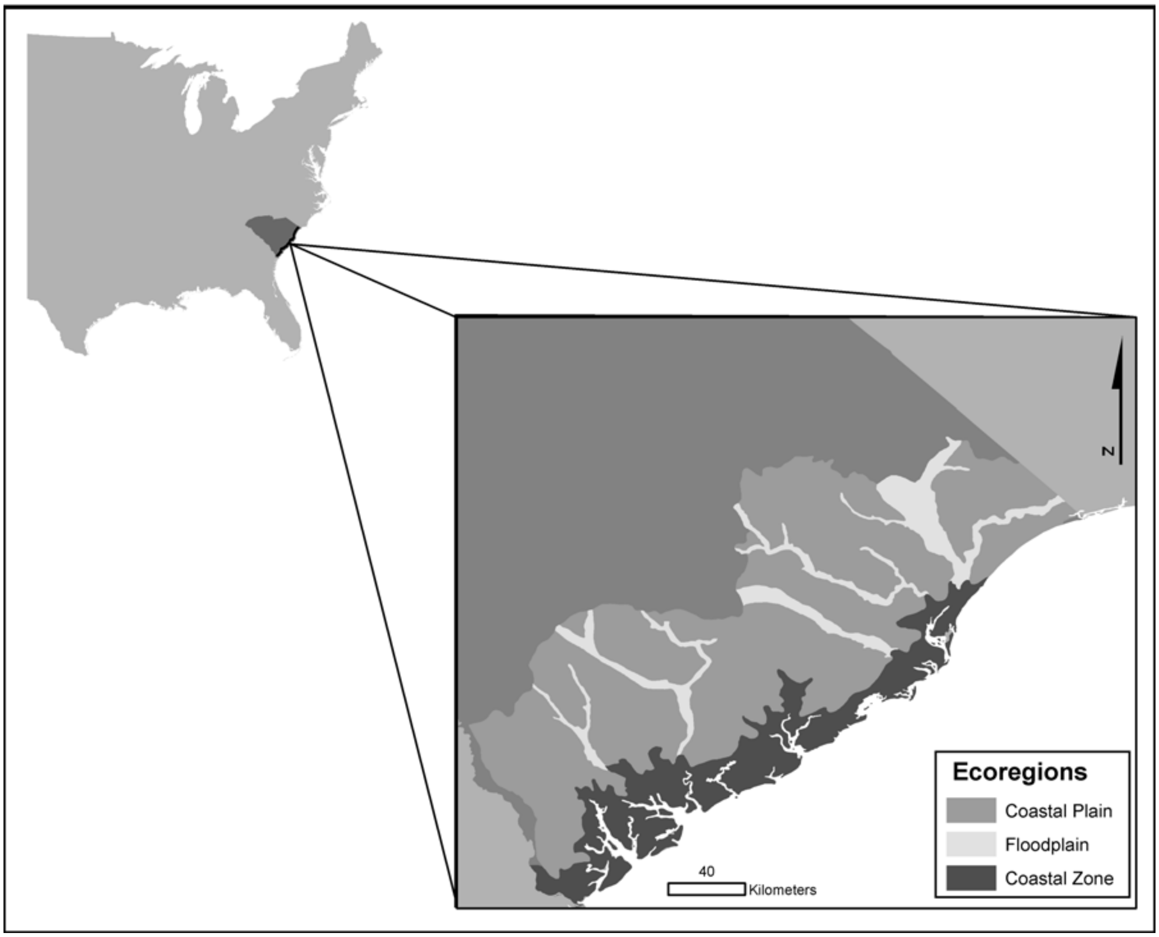

Figure 1.1- Location of study area in coastal South Carolina, showing coastal ecoregions and major cities.

Maintained roughs within golf courses in the Coastal Plain are generally characterized by an overstory consisting of low-density mature pines with minimal understory vegetation. Hardwoods are more common in course areas that are not cleared (e.g. perimeter roughs). Scattered large live oaks are often present along fairways and in other non-play groomed areas. Coastal Zone courses also contain pines, but live oaks and cabbage palms are common, especially in maintained areas. Bottomland tree species such as bald cypress (*Taxodium distichium*) and water tupelo (*Nyssa aquatica*) are present as well, although often in areas that are drier than might be expected due to altered hydrology on courses. Many of the courses have wetland set-aside areas, water features, and sand traps. The climate in most of South Carolina is cool enough to preclude use of non-native tropical plants such as those found commonly on Florida golf courses (Jodice and Humphrey 1992; Ditgen 1999; Lee 1999). Many coastal areas within the state are heavily developed, especially in the vicinities of Myrtle Beach, Charleston, and Hilton Head. Urbanized areas in the coastal zone are frequently dominated by vegetation characteristic of more inland habitats, due to changes in the local hydrology (e.g. filling of wetlands).

Courses included in this study occurred along the entire length of the South Carolina coast (ca. 300 km) but were restricted to within approximately 30 km of the coast. For the purposes of this study, courses were counted as one entity when they adjoined each other, shared the same owner, and were managed as one unit. The number of total holes on the courses ranged from 9 to 72. Courses which were either open or completely landscaped by 1999 and in the appropriate geographic area were selected from those listed in the United States Golf Association member listings. Par 3, executive, and miniature golf courses were not included in the study. Any course located on a sea island where fox squirrels were absent was not included in analyses. Absence of fox squirrels on sea islands is likely due to poor dispersal by this species across water and not necessarily the landscape characteristics of the courses. The primary result of this was that courses on Hilton Head Island were excluded from analysis.

A total of 98 courses were included in this study. Courses that declined to participate in the study and courses that were not adequately represented in the available remote sensing data were excluded. Since much of the landcover data were extracted from a dataset based on 1999 satellite imagery, only courses that were finished (landscaping complete) as of 1999 were used. Courses which substantially differed in appearance between aerial photos and the National Land Cover Database (NLCD) landcover raster also were not included in the study. Data were collected using three methods: telephone interviews with course superintendents/ professionals, fox squirrel surveys conducted on golf courses and remote sensing. Methods particular to each are described below.

Telephone Surveys

Phone surveys were conducted with personnel at each golf course (n=98) to ascertain presence, absence, and perceived abundance of fox squirrels. Respondents were asked to describe the most common color pattern of the fox squirrels on their course. The southeastern fox squirrel differs substantially from the gray squirrel in size, coloration, and behavior. Response to questions based on these factors made me fairly confident in the ability of golf course personnel to distinguish between the species.

Course Surveys

In addition to telephone interviews, I conducted surveys for fox squirrels at 51 of the 98 selected courses. These data were used as a check to determine if the telephone surveys and remotely sensed vegetation data accurately reflected the conditions at the site and to provide estimates of relative fox squirrel abundance on each course. Surveys were conducted twice on each course, once between May and June 2005, and once between November 2005 and February 2006. Spring and summer surveys were conducted between sunrise and 1200 h while fall and winter surveys were conducted between one hour after sunrise and 1400 h. Survey times coincided with higher incidences of foraging activity as reported in other studies (Jodice and Humphrey 1992; Koprowski 2005) and hence provided the highest probability of detection.

I was restricted to conducting surveys from golf cart paths so all survey methods were designed to maximize the quality of the data given this constraint. All surveys were conducted from golf carts driven at 3.5 km/h along cart paths. This restricted the viewing area to those sections of the course visible from the path. Therefore, I was not able to survey heavily forested areas within or adjacent to courses and so all data are specific to the 'active' area of the course. Nonetheless, these areas appear to represent the majority of fox squirrel activity on golf courses in the southeastern US (Jodice and Humphrey 1992; Ditgen 1999; Lee 1999). For each squirrel detected (both gray and fox), I recorded location (using a Garmin GPSMap 76, accurate to approximately 3 meters under ideal conditions), habitat type and behavior (e.g. foraging, social interaction with conspecifics, traveling). I did not generate population estimates because all portions of each golf course were not surveyed (e.g. wetland or dense unmaintained rough). Nonetheless, the high visibility within golf courses allowed for a thorough search of each course and therefore these survey data represent accurate qualitative (i.e., presence/absence, categorical) population assessments.

Remote Sensing/GIS

Initial identification of selected golf courses was done using 1999 aerial photos, mailing addresses from the United States Golf Association member listings and GPS data collected during field visits. GPS points were used to locate golf courses for which they were available. The remaining courses were identified by geocoding their street addresses using ArcGIS 9.1 (ESRI, copyright 1999-2005). Courses were classified as being located in the northern (Horry County) or southern (remaining counties) based on these locations. This north/south split divided the areas such that to in the north the primary ecoregion was Coastal Plain and in the south the Coastal Zone was the primary ecoregion.

The perimeter of each course was delineated using heads-up digitization based on the aerial photographs. The smallest possible polygon that contained all golf course fairways was used to represent the area of the course. Only the active area of the golf course was delineated for two reasons. First, we were not able to define golf courses by property boundaries because cadastral data were not universally available. Second, surveys on each course were restricted to the cart paths, and using course boundaries allowed data from GPS points and aerial photo delineation to be easily comparable in the GIS. GPS tracks from course visits were converted to polygons. For courses where these tracks produced an accurate representation of the course shape, they were used in lieu of the digitized polygon. Manually digitized boundaries were used for unvisited courses and those where the GPS tracks were insufficient (e.g. where the cart path was only in the center of the course).

The primary remote sensing dataset used for analysis was the 2001 NLCD produced by the Multi-Resolution Land Characteristic consortium and available for download at http://www.mrlc.gov/mrlc2k_nlcd.asp (last accessed 12/12/2006). Datasets include landcover classifications as well as tree canopy and impervious cover data at a cell size and ground resolution of 30 meters on a side. The NLCD landcover grid uses a hierarchical classification system similar to that of Anderson (1976). The system consists of nine level 1 classes which represent general landcover types such as forest, development, or wetland. Each level 1 class is comprised of one or more level 2 classes, which provide more detailed land classifications such as deciduous forest, coniferous forest, or estuarine aquatic wetland. Overall accuracy of the dataset in this mapping region is approximately 80% for level 2 classes, although in practice this varies by class (Homer et al. 2004) . Accuracy is presumed to be higher for level 1 classes. Therefore, I collapsed the initial classes into a smaller number of categories (Table 1.1) by combining those classes among which fox squirrels do not distinguish (Weigl et al. 1989; Loeb and Moncrief 1993; Perkins 2004;). This primarily consisted of merging all classes that represented wetlands or other water, since fox squirrels generally do not use wetlands or marshes to a great degree (Kantola and Humphrey 1990; Jodice 1993; Koprowski 1994). Further, classes representing grassy areas, pastures, and agricultural land were combined because fox squirrels use these habitats almost exclusively as movement corridors (Nupp 2000). All development classes were also combined for analyses since accuracy for these classes was low.

Table 1.1- National Landcover Database (2001) habitat classifications and the simplified reclassifications used in logistic regression models for fox squirrel presence on golf courses along the South Carolina coast.

Class	Description	Reclassification for study
11	Open water	1190
12	Perennial ice/snow	1190
21	Developed, open space	20
22	Developed, low intensity	20
23	developed, high intensity	20
31	Barren land	30
32	Unconsolidated shore	30
41	Deciduous forest	41
42	Coniferous forest	42
43	Mixed forest	43
52	Scrub/ shrub	52
71	Grassland/ herbaceous	7080
81	Pasture/ hay	7080
82	Cultivated Crops	7080
90	Woody wetlands	1190
91	Palustrine forested wetland	1190
92	Palustrine shrub wetland	1190
93	Estuarine forested wetland	1190
94	Estuarine shrub wetland	1190
95	Emergent herbaceous wetland	1190
96	Palustrine emergent wetland	1190
97	Estuarine emergent wetland	1190
98	Palustrine aquatic bed	1190
99	Estuarine aquatic bed	1190

Pixel values for the forest cover and impermeability data were converted from continuous to categorical variables representing the percent cover of either paved surfaces or forest to facilitate interpretation and analysis. Although roads can be considered a subset of the development landcover class, we also considered them separately since *S. niger* populations near roads often experience significant mortality rates due to traffic (Ditgen 1999; Lee 1999). Roadlines were based on Census 2000 Tiger/Line files which had previously been edited to increase accuracy (© U.S. Census Bureau, accessed from http://arcdata.esri.com/data/tiger2000/tiger_download.cfm). To create a space-filling raster map from the original data, buffers were applied to the line segments. Seven road types were used, with the classification based on the census feature class codes within the Tiger files. Each type had an associated buffer size, which was chosen to approximate the width of that road type (American Association of State Highway and Transportation Officials 2004). Once all buffers were applied, this information was converted to an ESRI GRID file with a cell size of 3 m^2. Roads data were not resampled to match the 30 m^2 resolution of the NRLC dataset.

The landcover and road grids were clipped to individual courses at three different sizes: the course itself, the course with a 1 km buffer, and the course with a 5 km buffer (Figure 1.2) using Hawth's Analysis Tools (Beyer 2004) and ArcGIS (ESRI, copyright 1999-2005). Fragstats 3.3 (McGarigal et al. 2002) was used to calculate landscape, patch, and class scale metrics for all grids. Metrics used were selected based on biological criteria (e.g. total course area, fractal dimension of course, and areas of landcover/ land use classes). Redundant metrics were avoided (Li and Wu 2004).

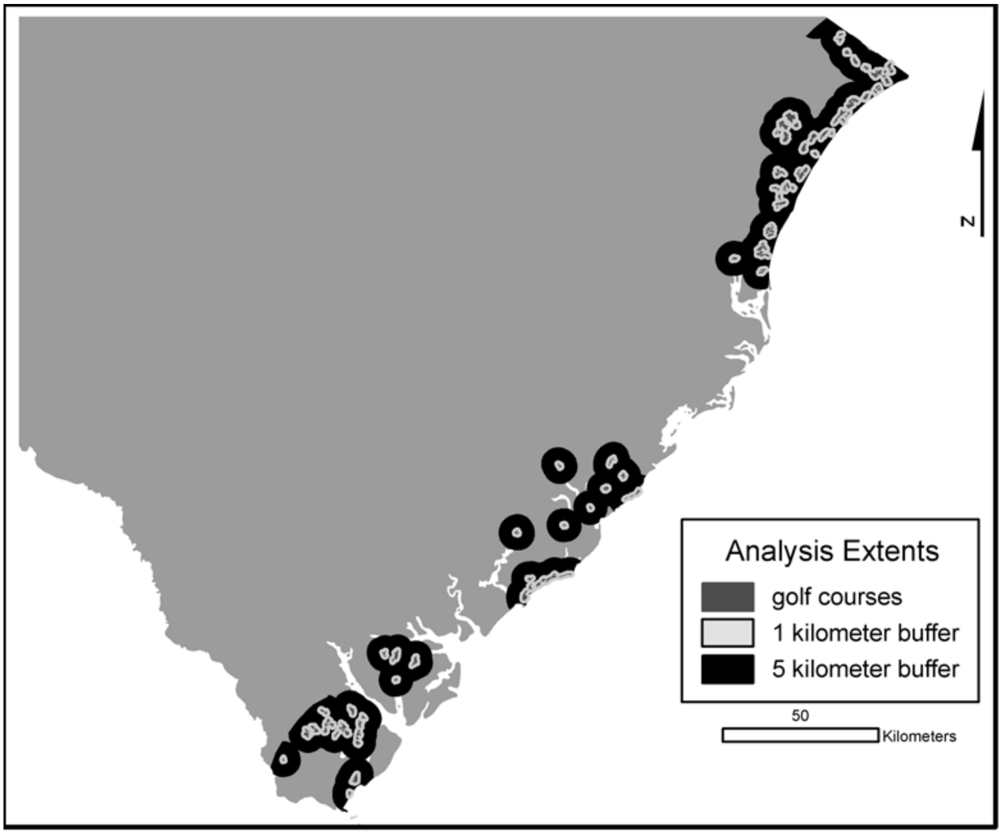

Figure 1.2- Extents for which landcover data were analyzed to determine models of fox squirrel presence on golf courses along the South Carolina coast.

Data Analysis

I used logistic regression models and a model selection approach based on Akaike's Information Criterion (AIC, Burnham and Anderson 2002) to assess the relationship between fox squirrel presence on golf courses and a suite of landscape and habitat variables. The information-theoretic approach allows for the simultaneous consideration of multiple hypotheses and for a ranking of models based on the probability that each is the best given the data and models tested.

We conducted 47 logistic regressions, of which 25 which included all courses ($n = 98$) and 22 which included only courses which did not have fox squirrels on their nearest neighbor course ($n = 35$). Spearman rank correlations were used to assess the relationship between all pairwise combinations of continuous explanatory variables. In cases where models would include correlated variables (Spearman $\varrho>0.50$) the variable with the weaker correlation with fox squirrel presence was dropped. Since landcover data were available at multiple extents, separate models were created for each extent (see Table 1.2 for model descriptions).

Statistical models were created to consider possible hypotheses based on fox squirrel ecology. For example, models 6 through 8 assessed the probability of fox squirrel presence relative to the total area of several landcover types representing relatively natural habitat. Other models consider factors such as the amount of developed area on or surrounding the course (e.g. models 3-5), course age (model 14), and the proximity of other squirrel populations (model 16).

Table 1.2- Parameters used in logistic regression models for analysis of fox squirrels presence on golf courses in coastal South Carolina.

Model	Description	Parameters	Codes
1	proximity	distance to edge of nearest neighbor course with fox squirrels	NNFS
		total area of all golf courses within 5km with fox squirrels	HAF5
2	dispersal	distance to edge of nearest neighbor course with fox squirrels	NNFS
		total road area within 1 km of course	R1KT
3	course development	total developed landcover within course	DECA
4	development 1k	total developed landcover within 1km of course	DE1K
5	development 5k	developed landcover within 5 km of course	DE5K
6	undeveloped course area	coniferous forest landcover within course	41CA
		deciduous forest landcover within course	42CA
		mixed forest landcover within course	43CA
		shrub/scrub landcover within course	52CA
		grassy landcover within course	78CA
		wetland/ open water landcover within course	19CA
7	undeveloped 1k	coniferous landcover within 1km of course	411A
		deciduous landcover within 1km of course	421A
		scrub/ shrub landcover within 1km of course	521A
		grassy landcover within 1km of course	781A
		wetland/ open water landcover within 1km of course	191A
8	undeveloped 5k	coniferous landcover within 5km of course	415A
		deciduous landcover within 5km of course	425A
		scrub/ shrub landcover within 5km of course	525A
		grassy landcover within 5km of course	785A
		wetland/ open water landcover within 5km of course	195A
9	course shape	total course area	TOTA
		patch fractal dimension	PFRC
10	habitat diversity	Simpson's diversity index	SIDI
11	gray squirrel presence	gray squirrel presence or absence	GSPA
12	geographic location	y coordinate of course	YCRD
13	nearest neighbor population	presence of fox squirrels on the nearest neighbor course	NNFP
14	course age	year course was built	YBLT
16	distance to nearest fs pop	distance to nearest golf course w/ fox squirrels	NNFS
17	paved course area	total area on course with >50% impervious cover	I5CA
20	density of populations	total area of all golf courses within 5km with fox squirrels	HAF5
21	roads on course	area of all road types within the course boundary	RCAT
22	roads 1k	area of all roads within 1km of the course	R1KT
23	dispersal w/ nearest neighbor fox squirrel presence	distance to edge of nearest neighbor course with fox squirrels	NNFS
		total road area within 1 km of course	R1KT
		presence of fox squirrels on the nearest neighbor course	NNFP
24	proximity w/ nearest neighbor fox squirrel presence	distance to edge of nearest neighbor course with fox squirrels	NNFS
		total area of courses with fox squirrel populations within 5 km	HAF5
		presence of fox squirrels on the nearest neighbor course	NNFP
25	course proximity	distance to nearest golf course w/ fox squirrels	NNGC

The same analytical process was performed for each model. First I analyzed each logistic regression model in Table 1.2. Logistic regression was the method chosen for this analysis since fox squirrel presence or absence is a binary response variable (PROC LOGISTIC, SAS/STAT system version 9.1, Copyright 1999-2005 SAS Inc., Cary, NC). Models were then ranked using AIC values corrected for small sample size (AICc). When using model selection with AIC, the most plausible and parsimonious model given the data is the one with the lowest AICc. To facilitate comparison of different models, the difference between the AICc of the best ranked model and that of each of the other models in the set (i.e., ΔAICc) was calculated. This value can be used to evaluate the likelihood of a given model being the best tested. Generally, models are considered to be indistinguishable if their ΔAICc values are < 2 and are discarded when ΔAICc values > 10 (Anderson et al. 2001). I also calculated AICc weights (w_i) and used these weights to define a set of models which included the best model in 95% of samples (i.e., 95% confidence set of models, sensu Burnham and Anderson 2002). This group was comprised of all the models which, when ranked, had a cumulative weight of approximately 95%.

I also calculated error estimates for the logistic regression coefficients of each variable for the models in the 95% confidence sets. Estimates for variables appearing in more than one model were assigned an average based on the individual estimates weighted by the AICc weight of the model in which they appear. Estimates from variables which only appeared in one model were not averaged. Linear regression was used to evaluate the relationship of course area to the number of holes on the course. The proportion of northern versus southern courses with fox squirrels was compared using the chi-squared test. Some variables were also compared using t tests. T tests comparing variables between northern and southern courses used a Bonferroni correction to control for type 1 error since multiple tests were performed. All means and coefficient values are reported ± 1 SE unless otherwise noted. All analyses were conducted using SAS/STAT software version 9.1 (© SAS Institute Inc., 1999-2005).

Results

Survey and Landscape Summary Statistics

Fox squirrels were present on 33 of 51 courses surveyed in person, and were reported to be present on 35 of 47 courses that were contacted by telephone only. The proportion of courses with fox squirrels present did not differ between those surveyed in person and those for which presence was determined via telephone interviews (χ^2=1.1, p >0.2). On courses physically surveyed and found to have fox squirrels, the highest count from the two surveys was used as the number observed for that course. The mean number of fox squirrels observed on courses with fox squirrels was 15.3 (± 4.2). A maximum of 59 squirrels was observed on the one 72-hole golf course surveyed. Figure 1.3 shows the frequency distribution of squirrels observed by course. Gray squirrels were present on 79 courses, and only 5 courses had neither fox nor gray squirrels.

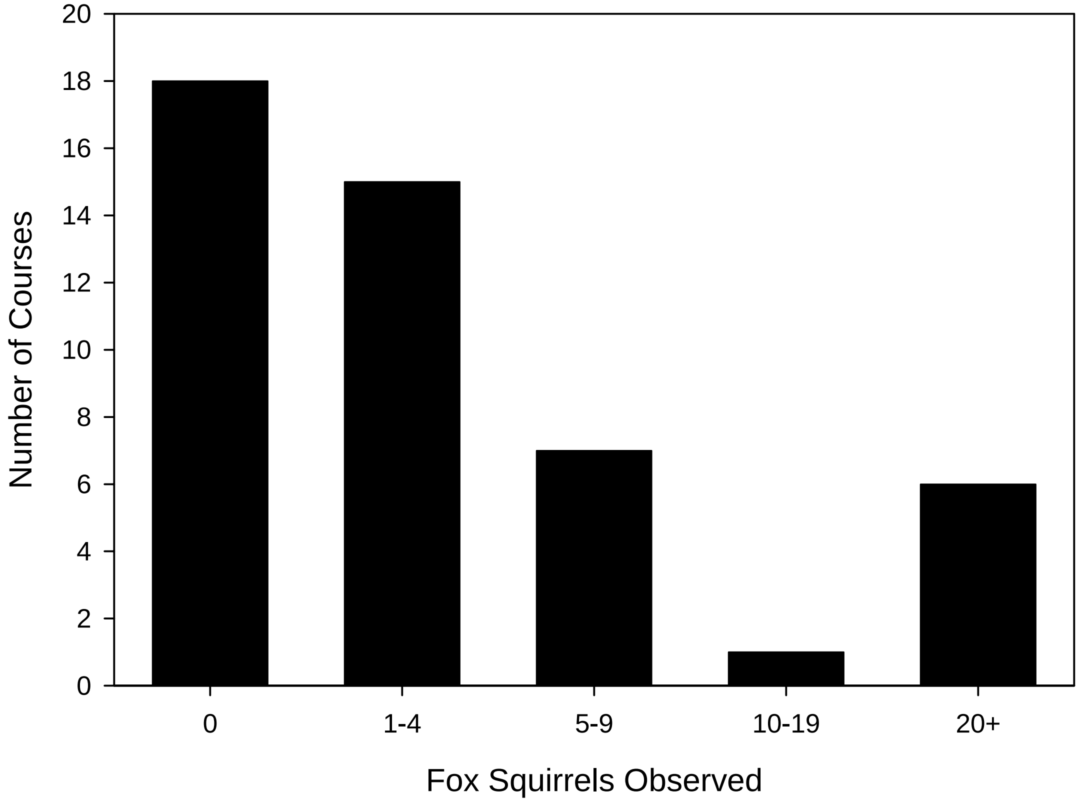

Figure 1.3- Maximum number of fox squirrels observed during population surveys of 51 coastal South Carolina golf courses during 2005 or 2006.

For the 98 golf courses included in the analyses, the mean course area was 126.8 ha (± 7.2). Golf courses ranged in size from 25.5 ha to 400 ha. There were 4 courses with 9 holes, 77 courses with 18 holes, 7 courses with 27 holes, 6 courses with 36 holes, 3 courses with 54 holes, and 1 course with 72 holes. Course area was not related to the number of holes on a course ($F_{1,96} = 0.3$, $P = 0.6$). The mean area per hole was 6.8 ha and did not differ significantly between northern and southern courses ($t_{96} = 0.4$, $P = 0.7$). The majority of golf courses included in this study were less than 25 years old (Table 1.3).

There was a significant difference ($t_{96} = 2.2$, $P = 0.03$) in the mean distance to the nearest neighbor course for golf courses with fox squirrels (1.91± 0.50 km) compared to those without (2.5 ± 0.4 km).The mean distance from a course to the nearest course (i.e., nearest neighbor) was.

Table 1.3- Summary statistics for landscape parameters of coastal South Carolina golf courses ($n = 98$).

Variable	Mean	SE	Minimum	Maximum
Total area (ha)	126.8	7.2	25.5	400.4
Total holes on course	21.1	1.0	9.0	72.0
Total area per hole (ha)	6.8	0.4	1.0	24.3
Nearest course distance (km)	1.4	0.2	0.0	9.7
Nearest course w/ S. niger distance (km)	2.5	0.4	0.0	16.6
Forested area on course (ha)	72.2	4.6	0.4	221.8
Developed area on course (ha)	77.4	5.4	1.9	291.7

Golf courses in the southern part of the coast were significantly more likely to have fox squirrels than those in the northern part of the coast ($\chi^2=16.8$, $p<0.0001$), although there was no significant difference in the numbers of fox squirrels counted on each course ($t_{43}=1.3$, $p = 0.2$). Golf courses from the southern section of the coast also had significant differences in many landscape and habitat features (Table 1.4). Compared to northern courses, southern courses had significantly greater forested area and smaller developed area within 5 km of the course, more extensive areas of wetlands and water both on and within 1 km of the course, and higher habitat diversity. However, despite the greater surrounding forest area, southern courses had significantly less open-canopy forest compared to northern courses.

Table 1.4- Summary statistics for selected landcover features of northern versus southern golf courses in coastal South Carolina (*n* = 98).

Parameter	North mean	North SE	South mean	South SE	Bonferroni-corrected p-value
Simpson's Diversity Index	0.6	0.2	0.7	0.1	0.001
Developed area within 5 km of course (ha)	1975.8	853.6	1260.2	104.8	0.003
Forested area within 5km of course (ha)	1741.3	741.6	2310.5	959.7	0.02
Total road area within 1 km of course (ha)	31.2	15.4	20.6	10.5	0.004
Total wetland/ water area within 1 km of course (ha)	253.1	120.9	436.8	187.3	<0.0001
Area with 25-50% canopy cover within 1 km of course (ha)	96.6	39.5	48.6	26.8	<0.0001
Area with 25-50% canopy cover within 5 km of course (ha)	766.6	214.4	473.7	257.3	<0.0001
Area with 50-75% canopy cover within 1 km of course (ha)	1464.6	401.8	956.9	347.9	<0.0001

Fox Squirrel Presence

Fox squirrel presence on golf courses was best predicted by the logistic regression model that included only a term for the presence or absence of fox squirrels on the nearest neighbor course (i.e., model 13, Table 1.5). Model 13 had a 59% relative likelihood of being the best model for predicting fox squirrel presence on golf courses and was ca. 1.7 x as likely to be the best model as the next highest ranked model (model 24; Table 1.5).

Table 1.5- Model selection statistics from logistic regression modeling of fox squirrel presence on 98 golf courses in coastal South Carolina. Model parameters are defined in Table 2.

Model Number	Name	k [a]	ΔAICc	AICc weight	cumulative sum of AICc weights
13	Nearest Neighbor Fox Squirrel Presence	2	0	0.59	0.59
24	Proximity	4	1.044	0.35	0.939
23	Dispersal	4	4.666	0.057	0.997

a- number of parameters in the model

The odds ratio of fox squirrel presence on courses with fox squirrels also present on the nearest neighbor versus those without was 0.067 (Table 1.6). This corresponds to an 87.3% probability that a course will have fox squirrels if they are also present on the nearest neighbor course and a 31.4% probability that a course will have fox squirrels if they are not found on its nearest neighbor. The coefficient for NNFP had a model-averaged value of -1.27 (± 0.27), i.e., the odds of a course having fox squirrels are ca. 3.5 times greater for courses whose nearest neighbor has fox squirrels.

Table 1.6- Coefficient statistics for all parameters in first, second, and third ranked models of fox squirrel presence on golf courses in coastal South Carolina. All courses were analyzed (*n*=98).

Model	Parameter	Coefficient	SE
13	NNFP	-1.354	0.263
24	NNFP	-1.147	0.285
	NNFS	0.000	0.000
	HAF5	0.002	0.001
23	NNFP	-1.309	0.286
	NNFS	0.000	0.000
	R1KT	-0.007	0.019

The model that ranked as the second best for predicting fox squirrel presence was model 24. However, the coefficient estimates for distance to nearest course with fox squirrels and total area of golf courses with fox squirrels within 5 km were very close to zero and thus it appears they did not contribute strongly to the predictive power of the model. All three models in the 95% confidence set contained the variable NNFP.

Although fox squirrel presence on the nearest neighbor course was by far the best model of those tested, some courses without fox squirrels on their nearest course still had *S. niger* populations. To determine which other factors might predict fox squirrel presence, I removed any models containing NNFP and applied the remaining logistic regression models to courses where there were no fox squirrels on the nearest neighbor course. Fox squirrel presence on this subset of golf courses was best predicted by the logistic regression model that included only a term for the age of the golf course (i.e., model 14, Table 1.7). Model 14 had a 57% relative likelihood of being the best model for predicting fox squirrel presence on this subset of golf courses and was ca. 6.3 times as likely to be the best model than the next highest ranked model (Table 1.7).

Table 1.7- Model selection statistics from logistic regression modeling of fox squirrel presence on golf courses in coastal South Carolina which did not have a fox squirrel population on their nearest neighbor course (*n*=35). Model parameters are described in Table 2.

Model Number	k^a	ΔAICc	AICc weight	cumulative sum of AICc weights
14	2	0	0.571	0.571
6	7	3.672	0.091	0.662
21	2	5.235	0.042	0.703
7	6	5.239	0.042	0.745
25	2	5.649	0.034	0.779
10	2	6.045	0.028	0.806
17	2	6.155	0.026	0.833
12	2	6.526	0.022	0.855
4	2	6.84	0.019	0.873
5	2	6.87	0.018	0.892
3	2	6.886	0.018	0.91
16	2	7.005	0.017	0.927
22	2	7.065	0.017	0.944
20	2	7.069	0.017	0.96

a- number of parameters in the model

The log-likelihood coefficient for course age in this top-ranked model was -0.068 (Table 1.8). Therefore, the likelihood of a course having fox squirrels improves by 1.74% with each 1 year increase in course age.

Table 1.8- Coefficient statistics for all parameters in first and second ranked models of fox squirrel presence on golf courses in coastal South Carolina. Only courses without fox squirrels on their nearest neighbor course were analyzed (*n*=35).

model	parameter	coefficient	SE
14	YBLT	-0.068	0.032
6	41CA	0.011	0.082
	42CA	0.007	0.004
	43CA	0.053	0.068
	52CA	-0.134	0.081
	78CA	-0.007	0.008
	19CA	0.202	0.01

Discussion

Habitat data resolution

Landcover data analyzed in this study were extracted from a raster dataset with $30m^2$ cell size. One of the primary assumptions when using remotely sensed landcover data to assess habitat use in wildlife is that the species in question perceives its environment at a scale equal to or greater than the data resolution. To assess the validity of this assumption we can consider the perceptual range of the species, which is the maximum distance across which an individual can perceive habitat elements. The perceptual range of fox squirrels is estimated to be 400 meters in agricultural landscapes (Zollner 2000; Mech and Zollner 2002). In the context of the NLCD data, this represents 12-15 pixels in any given direction. Additionally, fox squirrels are highly mobile, and have been known to have home ranges >100 hectares (Kantola and Humphrey 1990; Jodice and Humphrey 1993; Ditgen 1999;), although 10-30 hectares are more common (Loeb and Moncrief 1993; Perkins 2004). Although individuals are undoubtedly also affected by microhabitat features, these data suggest that fox squirrels perceive major features of their habitat at a scale at least as great as that of our landcover data.

Both temporal and spatial resolution must be considered when using remote sensing data. My data were extracted from 1999 satellite imagery and it is inevitable that some landscape features are no longer represented accurately. I minimized the impact of temporal variation by only selecting courses which were old enough to be included on the source Landsat imagery. The confusion matrix comparing the classified landcover data to orthorectified aerial photos taken in 2005 indicated that overall accuracy was > 70%, and that the classes with the greatest amount of error (marsh, bare ground, and grass) were those that fox squirrels use primarily as travel corridors, if at all (see chapter 2). These three classes also were primarily confused with each other. Some of the discordance in these classes may also be due to succession of habitat (e.g. grassland to shrub) over the six years separating the sets of imagery. Overall agreement of all forest types between the landcover data and NAIP imagery was 78%. As seen in the results from Chapter 2, accuracies for developed areas were much lower than those for undeveloped landcover classes. Residential areas were most often misclassified as coniferous forest, thereby underestimating the area of development and overestimating forest area. This could result in the models involving forest or development area appearing more predictive than they really were. A similar process may have occurred with road models. However, other work considering the landscape aspects of fox squirrel presence in fragmented woodlots has indicated that landcover aspects such as forest area or area of open ground did not differ with fox squirrel presence. Instead, the primary factor related to fox squirrel presence appeared to be patch isolation (Deuser et al. 1988). These results are very similar to those from this study, and support my assertion that misclassification in the landcover data did not substantially affect the outcome of the analyses.

Nearest neighbor effect and regional population dynamics

The best predictor of fox squirrel presence on a golf course was the existence of a fox squirrel population on the nearest neighbor course. Two explanations for this nearest neighbor effect seem likely. First, single courses in coastal South Carolina may be too small to support a viable population of fox squirrels, although total course area did not appear to be highly predictive based on my statistical models. Although fox squirrels can be very abundant on golf courses in the southeastern U.S. (figure 1.3), many of the courses I surveyed appeared to have small populations. Even densely populated courses may not have a total population size that is great enough to ensure long-term viability. Instead, multiple patches (i.e. courses) may provide a greater habitat area and larger overall population size. Second, fox squirrels exhibit high rates of natal and juvenile dispersal. Given the vagility of this species, courses near each other probably function as local populations within a larger regional metapopulation. Courses that are isolated either by distance or by a relatively impermeable surrounding matrix are more likely to receive a smaller number of immigrants, and so populations on these courses are more likely to be self-contained. Fox squirrels undoubtedly are affected by landcover variables, but it appears from this study that the proximity of populations on adjacent courses may facilitate movement of individuals between courses and hence mask other variations in habitat quality. Results from other studies of fox squirrel populations on golf courses have generally shown that local habitat variables are or appear to be related to fox squirrel abundance (Jodice and Humphrey 1992; Ditgen 1999; Lee 1999). It is possible that regional dispersal characteristics strongly affect fox squirrel presence on a course, while the habitat characteristics of individual patches affect the population size on the course.

Land cover variables and fox squirrel presence

When I examined factors that best predicted fox squirrel presence only on courses without fox squirrels on their nearest neighbor (NNFA), two models with relatively strong support emerged. Both included variables related to the golf course itself. This is not surprising given that NNFA courses are significantly more isolated than those with fox squirrels on their nearest neighbor and that isolated courses with fox squirrels would likely have to be more self-sustaining than those that were less isolated. Golf course age had the strongest relationship to fox squirrel presence for courses whose nearest neighbor did not have a fox squirrel population. The high ranking of this variable may be due to a combination of factors. Older courses may provide a more stable habitat since landscaping is more stable and mature and development less active. Mature trees often produce more mast, snags or trees with cavities allow more opportunities for nesting, and decreased development results in less overall disturbance. Course age also may have acted as a surrogate for course location in this study, and the latter was related to fox squirrel presence. Courses in the southern part of the state were older on average and much more likely to have fox squirrels. The greater prevalence of *S. niger* on southern courses may ultimately reflect historic abundances, however, as the central and southern portions of the South Carolina coast have traditionally had the greatest density of fox squirrels in the state (Harrigal 1993).

The second best model for courses without fox squirrels on their nearest neighbor included the total area of undeveloped landcover types within the course boundary, including water, wetland, forest, grass, and scrub landcovers. Three of these classes had coefficients which differed significantly from zero. Area of coniferous forest and wetland area were positively correlated with fox squirrel presence and scrub/ shrub area was negatively correlated with fox squirrel presence. The positive relationship between coniferous forest and fox squirrel presence is likely due to this species' strong association with mature pine forests in the southeastern U.S. (Koprowski 1994; Perkins 2004) The negative correlation between scrub and fox squirrel presence is likely due to a general avoidance of areas with brushy growth by fox squirrels. This landcover type is also unlikely to provide food or opportunities for nesting. The positive association of wetland area with fox squirrel presence is, however, counter-intuitive. Previous research found fox squirrel usage of wet areas to be low (Jodice 1993). The positive relationship I observed may be due to a third variable that links wetland with the likelihood of fox squirrel presence. For example, courses in the southern part of the study area are both much more likely to have fox squirrel populations and more likely to contain significant areas of wetlands.

Relative importance of course versus landscape-scale factors

Both landscape and course features appeared to impact fox squirrel presence on a course. The presence of fox squirrels on a course's nearest neighbor was the best model given the data and a priori models, which suggests that the system is strongly affected by dispersal between courses. When all courses were considered the presence of fox squirrels on the nearest neighbor course was the only variable with significant predictive power. When only courses without fox squirrels on their nearest neighbor course were considered, the most parsimonious model was course age and the second-best model contained the total area of undeveloped habitat features. Both course age and undeveloped area within a course can be considered local, course-level variables. However, both variables also had a strong relationship with course location (i.e., southern versus northern) along the South Carolina coast as well as the presence of fox squirrels on the course's nearest neighbor. Therefore, regional population dynamics and landscape scale factors appeared to have a much greater ability to predict fox squirrel presence on golf courses in this study compared to course-level variables, or indeed any landcover factor I assessed.

Fox squirrels and urban landscapes

Results from this study are generally consistent with results from other research on southeastern fox squirrels in anthropogenically altered habitats. For example, Ditgen (1999) investigated the relationship between habitat variables and fox squirrel abundance on 60 courses over two counties in southwestern Florida. These courses formed an overall landscape similar to that available in the Myrtle Beach and Hilton Head regions in South Carolina. Significant within-patch factors related to fox squirrel presence included areas of open pine forest, which was positively related to habitat suitability, and areas with dense understory vegetation, which was negatively related to habitat suitability. The number of significant between-patch factors was more numerous compared to the number of within-patch factors. Significant between-patch factors included the land uses adjoining the course and the ease of movement between courses, which was positively related to habitat suitability, and the presence of busy roads near the course, which was negatively related to habitat suitability. Many of the models used for my study were developed based on these factors. This previous work suggests that the opportunity for fox squirrels to move between courses has a positive effect on fox squirrel presence and abundance.

My results did not assign as much weight to within-patch features as results in Ditgen (1999) did. This is largely due to a difference in scope between the studies. Ditgen (1999) conducted an intense investigation of a relatively limited area whereas my study emphasized large-scale features over a much larger area. Conservation management implications resulting from Ditgen’s work are somewhat bleak, as she concluded that automobiles and golf carts were a major cause of mortality for area populations, and that only 7 of 60 courses were likely to provide sufficiently high-quality habitat for long-term population persistence. My work did not focus on individual courses to a degree that would allow me to agree or disagree with these conclusions. However, the strongest model for all courses was related to between-course dispersal which supports Ditgen's assessment that most courses are unable to maintain populations in isolation. The importance of metapopulation dynamics for fox squirrel populations on golf courses in coastal South Carolina also implies that since a hostile matrix effectively makes a course more isolated, roads and other landscape factors which decrease dispersal ability can have a marked effect on populations on individual courses and the metapopulation as a whole.

Research on southeastern fox squirrels in both urban and natural environments demonstrates that roads are a major cause of mortality for this species (Weigl et al. 1989; Loeb and Moncrief 1993; Ditgen 1999). As an extreme example, Lee (1999) found 31 squirrels which had been killed by cars out of an estimated population of ca 760 during a single six month period on a relatively lightly developed sea island in South Carolina.

Lee's study was notable also in that it found that fox squirrel populations had actually increased since the island had been developed, and that the habitat modification resulting from this development were possibly correlated with extremely high-densities of fox squirrels and very small home ranges. An earlier study of big cypress fox squirrels (*S. niger avicennia*) also found population densities to be significantly higher on golf courses than in nearby wild areas (Jodice 1992). High population densities appear to be a common feature of fox squirrel populations on golf courses in the southeastern U.S., and are generally attributed to relatively plentiful and temporally stable food supplies (Jodice and Humphrey

1992; Ditgen 1999; Lee 1999). Population surveys undertaken during my research also suggested that high densities of fox squirrels occurred on some courses.

Conservation implications and management recommendations

A metapopulation is defined as an assemblage of local populations on patches separated from each other, where migration between at least some of the patches is possible (Hanski and Simberloff 1997). This spatial arrangement of patches increases regional population stability and resilience as local populations that would otherwise be extirpated are 'rescued' by immigration of individuals from other populations. Metapopulations are considered to be at equilibrium if the long-term extinction rate is the same as the colonization rate. This does not require, however, that all patches have balanced extinction/colonization rates. Patches of differing habitat quality may result in a source-sink metapopulation when population growth on some patches is positive and on others is negative (Pulliam 1988). For example, an individual golf course may function as a population sink due to a lack of food, high mortality due to predation or traffic, or a lack of available nesting habitat. However, more suitable courses may support viable squirrel populations and thus act as sources. Dispersal from the successful to the unsuitable course may provide enough immigration to create a persistent population. In the normal source-sink model this does not necessarily have a negative impact on the system as a whole, since the sinks are effectively absorbing excess recruitment from the more productive sources. However, traps (unsuitable patches which experience high immigration due to maladaptive habitat selection) may have a destabilizing influence on the metapopulation (Kristan 2003).

Our results suggest that golf courses have a greater opportunity to support or retain fox squirrel populations when the land area surrounding or nearby the course also supports fox squirrels. Presence of fox squirrels on a course's nearest neighbor was by far the strongest predictor of presence on a course. In some cases golf courses may function as ecological traps if dispersing squirrels are attracted to the forested area on the course, but experience high mortality due to the environment they must traverse to reach the course. Because of this, it is important to incorporate areas surrounding and between courses when considering the conservation value of golf courses for fox squirrels in coastal South Carolina. Preservation of movement corridors between nearby golf courses may have a large positive impact on the stability of the metapopulation as a whole. This may be especially important in areas comprised of smaller courses like those found in Myrtle Beach as these are more likely to be unable to support a viable fox squirrel population on their own.

In conclusion, results from this study indicate that the presence or absence of fox squirrels on a given golf course along the South Carolina coast is largely related to fox squirrels being present near that course, and as such is a function of regional population structure. It appears that the levels of dispersal by this species within the system are high enough to largely obscure the effects of landcover type and other habitat variables since even low-quality habitat may contain fox squirrels that have dispersed from more suitable courses. Future research should quantify regional population dynamics and identify courses which are most important to the overall function of the metapopulation. Golf courses with fox squirrels should consider their populations to be part of a larger metapopulation, and we encourage both golf courses and other large landowners in the region to work cooperatively to preserve habitat connectivity as the coastal South Carolina region continues to develop.

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ACCURANCY AND ERROR ASSESSMENT OF THE 2001 NLCD LAND COVER DATASET FOR URBAN HABITAT ASSESSMENT

Introduction

Historically, studies of wildlife habitat assessment have been restricted in scope and spatial extent by the time and expense required to manually collect individual locations and the associated environmental data. Remote sensing data, however, can make large-scale habitat assessments more feasible, especially for organizations with limited personnel and field data collection budgets. Currently these data are increasing in availability as state and federal agencies provide and distribute remote sensing images and derived data at a variety of spatial and temporal scales. The availability, ease of use, and relatively low expense of these data can make them a viable alternative to field collected data for many projects.

One of the newest datasets derived from remote sensing imagery is the National Land Cover Dataset (NLCD). The 2001 version of the NLCD is in the final stages of deployment and data can be freely downloaded from http://www.mrlc.gov/mrlc2k_nlcd.asp. The NLCD is an intermediate scale dataset with a cell size of 30 m^2, leading to a minimum feature resolution of 0.8 ha. One suggested use for this dataset is analysis of wildlife habitat (Cunningham 2006). It is critical, however, to consider the accuracy of source landcover data when undertaking such habitat assessments since misclassification can substantially affect project results. This is especially true for projects which involve a relatively small spatial extent compared to the resolution of the data (for the NLCD data this is considered to be less than state level) or for projects considering difficult to classify features such as wetlands and urbanizing areas. Land cover classifications in general and the NLCD in particular tend to identify some landcover types more accurately than others (Yang et al. 2001). The likelihood of misclassification is higher for classes which are (1) spectrally similar to other land cover classes, (2) rare in the landscape, or (3) found in small or highly heterogenous patches. For example, land cover types composed of grasses, wetlands, or bare ground are typically difficult to separate based on spectral characteristics (Wardlow and Egbert 2003). Urban areas also present a challenge due to the highly dissected nature of many habitats found there and the spectral similarity of developed landcover classes. The rapid rate of habitat change in urban areas also makes it necessary to consider the effects of omission and commission errors due to development in the period between the study and when source imagery was collected for the landcover classification (Loveland et al. 2002).

This study investigates the accuracy of 2001 NLCD data over a sub-state region in relation to two reference data sets. My goal was to quantify classification agreement between the datasets to determine which types of landclasses are most frequently confused. I also considered the strengths and weaknesses of each dataset in the context of urban habitat assessment. This information will be useful in determining the level of confidence that should be given to habitat variables based on NLCD data at this scale, especially when working in urban areas.

Methods

The area of consideration for this study included the coast of South Carolina (ca. 300 km) to ca. 30 kilometers from the coastline. All imagery was clipped to this extent. This landscape includes large areas of coniferous forest as well as wetland. Urbanization of varying intensities also occupies much of the area. A brief description of the study area is provided in Chapter 1.

The 2001 NLCD data were derived from Landsat imagery collected in 1999. I compared the NLCD data to both satellite imagery and aerial photos. I chose a comparison to satellite imagery of the same type and time period to test the effectiveness with which the NLCD processing classified the source imagery. I chose National Aerial Imagery Program (NAIP) aerial photos taken in 2005 as this newer data set allowed me to better quantify the degree of development and habitat change which has occurred over the six years separating the two datasets. The higher-resolution aerial photos (cell size $1m^2$) also allow for a better visual determination of urban landcover classes. All data were orthorectified prior to comparison.

Error matrices were created using cell-by-cell comparisons between the NLCD landcover data and the reference imagery. Initial NLCD classes were combined to yield a smaller number of variables both to ease visual identification of land classes and to more provide more direct applicability to the habitat analysis for which this classification was performed (Nogués-Bravo 2006). The NLCD data were reclassified as defined in Table 2.1 prior to accuracy assessment. Reclassification names do not necessarily describe all the original classes combined. Table 2.1 shows the NLCD land cover classes and the grouping used for comparison with Landsat and NAIP data. Reclass names are symbolized by their first letter in confusion matrices and class error calculation except for class CD, which represents all forest land classes.

Table 2.1. National Landcover Database (2001) habitat classifications and the simplified reclassifications used in accuracy assessments with Landsat 5 and NAIP images.

Class	Description	Landsat Reclass	NAIP Reclass
11	Open water	Open water	Open water
12	Perennial ice/snow	Open water	Open water
21	Developed, open space	Rural development	Rural development
22	Developed, low intensity	Rural development	Rural development
23	developed, high intensity	Intense development	Intense development
L	Barren land	Bare ground	Bare ground
32	Unconsolidated shore	Bare ground	Bare ground
41	Deciduous forest	Deciduous forest	CD (combined forest)
42	Coniferous forest	Coniferous forest	CD (combined forest)
43	Mixed forest	Deciduous forest	CD (combined forest)
52	Scrub/ shrub	Grass and shrubs	Grass and shrubs
71	Grassland/ herbaceous	Grass and shrubs	Grass and shrubs
81	Pasture/ hay	Grass and shrubs	Grass and shrubs
82	Cultivated Crops	Grass and shrubs	Grass and shrubs
90	Woody wetlands	Wetlands	Wetlands
91	Palustrine forested wetland	Wetlands	Wetlands
92	Palustrine shrub wetland	Wetlands	Wetlands
93	Estuarine forested wetland	Wetlands	Wetlands
94	Estuarine shrub wetland	Wetlands	Wetlands
95	Emergent herbaceous wetland	Wetlands	Wetlands
96	Palustrine emergent wetland	Wetlands	Wetlands
97	Estuarine emergent wetland	Wetlands	Wetlands
98	Palustrine aquatic bed	Wetlands	Wetlands
99	Estuarine aquatic bed	Wetlands	Wetlands

Land class types were determined for 1000 randomly selected points in the study area. The landcover class at each point was extracted from the NLCD data using Hawth's Analysis Tools (Beyer 2004) and ArcGIS 9.1 (ESRI, copyright 1999-2005). For Landsat and NAIP imagery, the land class of each point was determined via visual inspection. Since Landsat images included a near-infrared band, it was possible to discriminate between coniferous and deciduous vegetation. NAIP photography is 3-band true color which prevents coniferous and deciduous vegetation from being accurately distinguished visually. The error matrix and error statistics for the NLCD-NAIP comparison were therefore calculated with all forest types collapsed into the level 1 forest class.

For each comparison, a confusion matrix was created, and percentage agreement for all classes was determined. Kappa statistics were also calculated to test overall agreement between maps. Omission and commission errors are reported to yield measures of accuracy for individual classes. For the purposes of this study, omission error refers to the percentage of features that should have been included on the NLCD data, but were not. Commission error refers to features found in the NLCD data that are not found on the reference images (NAIP or NLCD). The former is also referred to as producer's accuracy, while the latter is also known as user's accuracy (Congalton 2001). NAIP imagery was considered to be the most reflective of actual features on the ground. Kappa statistics are given ± 1 ASE.

Results

Agreement of NLCD and Landsat data

Overall accuracy of the NLCD data when compared with reference Landsat data was 61.2%. The simple Kappa statistic value was 0.6 (±0.02) which suggests a moderate level of agreement between the two datasets. However, the level of misclassification varied widely among landcover types (Table 2.2).

Table 2.2. Commission and omission errors resulting from comparison of NLCD classifications with 1999 Landsat images.

Land class	Comission error (% agreement)	Omission error (% agreement)
B	14.29	25.00
C	75.48	74.76
D	42.31	46.81
G	17.22	34.95
I	21.43	69.23
W	63.74	70.45
[illegible]	80.00	60.00
R	32.14	54.55

Two classes (bare ground and grassland) had less than 20% agreement, and high-intensity development had only 21% agreement. These are classes that are known to be difficult to distinguish spectrally (Hollister et al. 2004), and bare ground and high-intensity development are rare landcover types in this study area. Most of the misclassification of developed land types was with other developed land types (Table 2.3). If low-intensity and high-intensity development are combined, accuracy dramatically improves, yielding percentage agreement values of 42.2% and 82.3% for commission and omission error, respectively.

Table 2.3. Confusion matrix resulting from comparison of NLCD classifications with 1999 Landsat 5 images.

Landsat NLCD

	B	**C**	**D**	**G**	**I**	**W**	**O**	**R**	**Total**
B	1	0	0	1	1	0	0	1	4
C	0	237	16	18	3	18	2	23	317
D	1	18	22	3	0	1	0	2	47
G	3	22	6	72	8	47	12	36	206
I	0	0	0	1	9	0	0	3	13
W	0	32	7	19	4	174	1	10	247
O	2	1	0	3	0	33	60	1	100
R	0	4	1	8	17	0	0	36	66
Total	7	314	52	125	42	273	75	112	1000

Concordance of NLCD and NAIP data

Overall concordance of the NLCD data when compared with reference NAIP imagery was 87.4%. The simple Kappa statistic value was 0.53 (±0.02) which suggests a moderate level of agreement between the two datasets. The level of classification disagreement varied widely among landcover types (Table 2.4). Omission error levels were higher for most classes than commission errors, reflecting the development of the South Carolina coast during the 6 years between the NLCD and NAIP data collection dates.

Table 2.4. Commission and omission errors resulting from comparison of NLCD classifications with 2005 NAIP images.

Land class	Commission error (% agreement)	Omission error (% agreement)
B	75.00	16.67
CD	78.24	78.89
G	62.74	85.33
I	7.69	2.63
W	57.82	66.93
O	50.00	50.50
R	35.83	18.04

Landcover classes which represented developed land had particularly low levels of agreement between the NLCD and the aerial photos used, as did the land class representing bare ground. Developed landclasses were commonly confused with several other class types, including forest, grass and shrub, and wetlands (Table 2.5). Both low and high-density development were more likely to be misclassified than correctly identified. Low-density development was nearly twice as likely to be classed as forest or grass as it was to be classed properly. The only classes not heavily confused with low-density development were the rare bare ground and open water.

Table 2.5. Confusion matrix resulting from comparison of 2001 NLCD classifications with 2005 NAIP images.

NAIP/ NLCD	**B**	**CD**	**G**	**I**	**W**	**O**	**R**	**Total**
B	3	1	0	0	0	0	0	4
CD	1	284	11	8	10	8	41	363
G	6	20	192	15	12	20	41	306
I	1	6	2	1	0	1	2	13
W	4	13	6	4	85	14	21	147
O	2	17	7	4	16	50	4	100
R	1	19	7	6	4	6	24	67
Total	18	360	225	38	127	99	133	1000

Discussion

Comparison of NLCD and Landsat data

Comparison of the NLCD landcover layer with contemporaneous Landsat data indicated that the two rasters agreed moderately well. However, several land classes were systematically misclassified. Developed land classes were most frequently confused with each other. Grass and shrubland land classes were confused with most other landclasses, which probably reflects that this land class is frequently in small patches and that these patches are being aggregated with another landclass that is dominant in the pixel. Classes with low accuracies were generally land use/ landcover types that were either rare, spectrally similar to other classes, and found in small patches. This is a common shortcoming of unsupervised classification imagery, although efforts were made by the NCLD development team to mitigate these problems (Homer et al. 2004). Developed landcover types also had unbalanced levels of omission and commission errors. The assumption is often made that, over relatively large areas, omission and commission errors throughout the data compensate for each other. This appears to be a reasonable assumption at the scale we examined with forest and wetland landcovers, but not for developed or early-successional (grasslands and shrubs) land classes.

Comparison of NLCD and NAIP data

NAIP imagery agreed well with NLCD data for wetland, grass, and forest classes. The increased agreement between datasets for forest classes is largely due to the pooling of the individual forest classes. The true-color scheme of the NAIP data also may have allowed a greater opportunity to visually differentiate wetland and grass classes.

Errors for developed landcover classes were much higher compared to those for undeveloped classes. This is likely the result of several factors. First, as previously mentioned, land classification based on spectral signatures is less effective with small or highly heterogeneous patches. Urbanization tends to fragment continuous habitat into a mosaic of smaller and frequently high-contrast land types (Andersson 2006). Second, the smaller pixel size of the NAIP images may allow more successful identification of developed land classes, since the much finer grain can reveal buildings that are not visible on Landsat images. Third, data collection for the NAIP imagery occurred nearly six years after data collection for the landsat images from which NLCD data were extracted. The very low agreement of the NAIP and NLCD data for developed landclasses is largely due to development of the South Carolina coast from 1999 to 2005. This is not really considered to be misclassification by the older data, since landcover was classified based on what was on the 1999 Landsat imagery. The forest land classes are an excellent example of this. Misclassified forest area was primarily confused with other forest landcovers in the NLCD-Landsat comparison (Table 2.3). However, forest areas were confused with several data classes in the NLCD-NAIP comparison, including classes which are easily distinguished spectrally. The most likely reason for this is conversion of other land classes to developed land uses between 1999 and 2005 in the study area.

NLCD data usage recommendations

These accuracy assessments were generated using cell-by-cell comparisons. This is a very strict method of comparing datasets, and as a result percent agreement may be underestimated, especially in areas with highly dissected patch configurations. Overall, these results illustrate the difficulty of finding suitable remote sensing data for characterization of urban habitats. The rapid pace of development in urbanizing areas often means that publicly available data are obsolete by the time it becomes readily available. This is especially true for land use/ land cover due to the time required for data extraction and processing. Unfortunately, urbanizing regions are often those that are most in need of habitat assessment to better conserve wildlife. The best method for resolving conflict between the need for accurate data and need for data based on newer imagery depends on the study scale, the grain required, and the amount of effort that can be dedicated to data processing. One solution would be to collect aerial or satellite imagery of the study area and then perform a classification specific to that region. This should result in a more accurate product since localized classifications are often more accurate than national ones when categories are matched to local conditions. However, the process of classifying imagery can be time-intensive and requires a relatively high level of expertise as well as investment in software, computers, and source data purchasing. For small organizations that lack the finances, time, or infrastructure to perform their own classifications, NLCD landcover data is still a good choice for wildlife habitat assessments, particularly since many of the other free landcover thematic maps are older, less well documented, and may not include urban areas at all (e.g. many state GAP analysis maps). However, it is important to check the accuracy of the data layers in the specific study region, and researchers should be aware that urbanization can cause maps to severely underestimate the extent of developed landcover areas even over relatively short time periods.

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CONCLUSION

The presence of fox squirrels on some golf courses along the South Carolina coast represents an opportunity for conservation of a species that is generally declining in the region. It is important to understand which habitat and landscape characteristics best predict fox squirrel presence in these settings to develop effective conservation efforts.

In the first chapter of this thesis I assessed the relationship between fox squirrel presence on golf courses and landscape and habitat variables derived from federally produced land use/ land cover data. Results demonstrated that the likelihood of fox squirrels being present on a course was much greater when the nearest neighbor course also had fox squirrels. This effect was seen regardless of nearest neighbor distance. On courses without fox squirrel populations on their nearest neighbor, course-scale attributes were the most predictive variable for fox squirrel presence. Course age and the total area of undeveloped habitat features on the course can both be considered to be measures of course habitat stability and suitability. Total area of the course was not a significant predictor of fox squirrel presence, nor was course shape.

In the second chapter of this thesis I tested the accuracy of the 2001 NLCD land use/ land cover map used to provide landcover type and configureation statistics for the models in chapter one. I also compared the NLCD data to newer aerial photos to estimate the degree of error introduced by the age of the landcover data. Results indicated that the NLCD data had a fairly high accuracy, but like most landuse and landcover data it was more successful at distinguishing large patches of habitat that were spectrally unique. Comparison of a 2001 NLCD landcover map with 2005 aerial photos, however, showed extremely high rates of omission error for developed and early successional landclasses. These omissions are primarily due to continuing development of the study area in the time since data were collected for the NLCD project. Because of these omissions, the total area of developed landcover classes was severely underreported. The fact that the NLCD did not accurately represent the features on the ground at the time of fox squirrel population surveys make models containing developed or developing landclasses less useful.

Taken together, these results provide useful insights into the factors related to fox squirrel presence on golf courses in coastal South Carolina. The importance of nearest-neighbor effects suggests that fox squirrels on golf courses constitute a metapopulation, and so dispersal between courses is an important component of habitat suitability in this region. More isolated courses are likely to receive a smaller number of immigrants and so local habitat characteristics are more correlated with fox squirrel presence. Survey data indicated that a majority of the courses visited had very few fox squirrels, suggesting that much of the golf course habitat is not suitable for species persistence. The few courses with very large fox squirrel populations may be acting as sources for other courses in the region. These courses in turn may require immigration to sustain populations. These results are consistent with previous work with fox squirrels on southeastern golf courses which suggest that conservation efforts be directed at habitat improvement or maintenance for source populations and preservation of movement corridors between courses and other large areas of open space in the region.

Although dispersal and immigration from nearby fox squirrel populations appeared to be important to golf course populations, models considering the landcover types and road area between golf courses were not found to be good predictors of fox squirrel presence. This is most likely the result of 1) the high tolerance of fox squirrels for isolated habitats, and their willingness to traverse relatively large regions of unsuitable or hostile habitat, and 2) error in the dataset used to populate the land use/ landcover variables due to age of the source data and continuing area development. Most other research with fox squirrels on golf courses has suggested that development on and around the courses has a negative impact on fox squirrel presence, and that road traffic represents a significant source of mortality. Most other research, however, involved intensive habitat characterization of a relatively small number of courses in a limited geographic region. As such, this current study and previous work by others can be viewed as complimentary, and taken together produce an improved understanding of the factors that best predict fox squirrel presence at multiple spatial scales.