Terrestrial Activity and Habitat Selection of Eastern Mud Turtles (*Kinosternon subrubrum*) in a Fragmented Landscape: Implications for Habitat Management of Golf Courses and Other Suburban Environments

Leigh Anne Harden[1,2], Steven J. Price[1,3], and Michael E. Dorcas[1]

In urbanized landscapes, golf course ponds may provide the only remaining habitat for semi-aquatic animals. Eastern Mud Turtles (*Kinosternon subrubrum*), which rely heavily on both aquatic and terrestrial habitats, may face challenges on golf courses, which typically have significantly modified and fragmented landscapes. We conducted a radio-telemetric study of 11 mud turtles inhabiting a golf course pond in the western Piedmont of North Carolina to investigate their terrestrial activity and habitat selection in a fragmented landscape. Most turtles moved to terrestrial habitats in late summer and emigrated a mean distance (± SE) of 187.2 ± 67.4 m and moved a mean straight line distance (± SE) of 119.3 ± 47.4 m from the pond. We determined habitat selection using logistic regression to compare turtle locations with random locations and found that mud turtles selected forested habitats with moderate canopy cover and no grass. Mud turtles also selected habitat containing herbaceous vegetation and woody debris as overwintering locations. Mud turtles did not select heavily disturbed habitats with limited canopy cover and pavement or cut grass associated with fairways, roughs, and residential lawns. Overall, our study suggests that maintaining relatively undisturbed forested habitat within fragmented urban landscapes, such as those found on golf courses, may allow for the persistence of these semi-aquatic turtles. Information from this study can be used to better understand critical upland habitat requirements of other semi-aquatic species inhabiting fragmented landscapes and aid in the implementation of habitat management plans.

IN urbanized landscapes, ponds and wetlands on golf courses may represent the only remaining habitat for semi-aquatic and wetland-dependent species (Scott et al., 2002; Montieth and Paton, 2006; Failey et al., 2007). Because many semi-aquatic species extensively use terrestrial habitats, land use surrounding aquatic habitats can greatly affect the persistence of species. Golf course development often involves forest clearing, land leveling, and residential construction, which can drastically alter and fragment the landscape both physically and biologically (Forman and Godron, 1986; Love, 1999). In addition, subsequent urbanization associated with golf course developments introduces threats to wildlife including roads, pollution (McKinney, 2002), and human-subsidized predators (Riley et al., 1998).

Semi-aquatic turtles can be found inhabiting urban ponds, such as those found on golf courses (Failey et al., 2007), yet turtle life history characteristics, such as delayed sexual maturity (Bennett et al., 1970; Gibbons, 1983; Ernst et al., 1994), suggest sensitivity to anthropogenic habitat fragmentation and destruction (Baldwin et al., 2004; Marchand and Litvaitis, 2004). Road density increases with urbanization, leading to adult mortality (Steen and Gibbs, 2004) and decreased interpopulation movements (Ernst et al., 1994). This may result in smaller, less viable populations (McKinney, 2002). Urbanization may also increase the abundance of human-subsidized predators, such as raccoons (*Procyon lotor*; Riley et al., 1998; Smith and Engeman, 2002; Larivière, 2004) and cats. Modifications to upland habitats also likely reduce nesting and overwintering locations for turtles (Wilson, 1998).

The semi-aquatic Eastern Mud Turtle (*Kinosternon subrubrum*) is a bottom-dweller of shallow, slow-moving water bodies and isolated wetlands (Ernst et al., 1994), but during the late summer and fall, individuals leave their aquatic habitat for extended periods to overwinter on land. While on land, mud turtles may move around above and below ground before settling in a burrow in which they remain relatively inactive for winter (Bennett, 1972; Gibbons, 1983; Buhlmann and Gibbons, 2001). Based on previous studies in natural, non-fragmented terrestrial landscapes, mud turtles typically overwinter in forested habitats with leaf and/or pine litter and shrubs (Skorepa and Ozment, 1968; Scott, 1976; Buhlmann and Gibbons, 2001; Steen et al., 2007). Although several studies have documented habitat use and seasonal activity of mud turtles (Buhlmann and Gibbons, 2001; Tuma, 2006), no studies have investigated the terrestrial habitat selection of mud turtles in anthropogenically-modified environments, such as the heterogeneous landscapes of golf courses. Golf courses offer an ideal landscape to study the impacts of habitat alteration (Montieth and Paton, 2006) on the terrestrial habitat selection of semi-aquatic animals because golf course landscapes usually consist of a mosaic of habitats such as fairways, forests, streams, shrubs, and residential yards.

Given that many semi-aquatic animals inhabit water bodies in anthropogenically-altered landscapes, it is important to understand how they select habitats associated with fragmented landscapes. The focus of our study was to investigate terrestrial activity and habitat selection of mud turtles inhabiting a golf course. Because mud turtles use both aquatic and terrestrial habitats, this species can serve as a model for other semi-aquatic turtles thus facilitating recommendations regarding terrestrial habitat preservation in anthropogenically modified environments.

[1] Department of Biology, Davidson College, Davidson, North Carolina 28035-7118; E-mail: (MED) midorcas@davidson.edu. Send reprint requests to MED.
[2] Department of Biology and Marine Biology, The University of North Carolina at Wilmington, 601 S. College Road, Wilmington, North Carolina 28403; E-mail: lah4492@uncw.edu.
[3] Department of Biology, Wake Forest University, Winston-Salem, North Carolina 27109; E-mail: sjprice@davidson.edu.
Submitted: 3 March 2008. Accepted: 6 August 2008. Associate Editor: M. J. Lannoo.
 DOI: 10.1643/CH-08-037

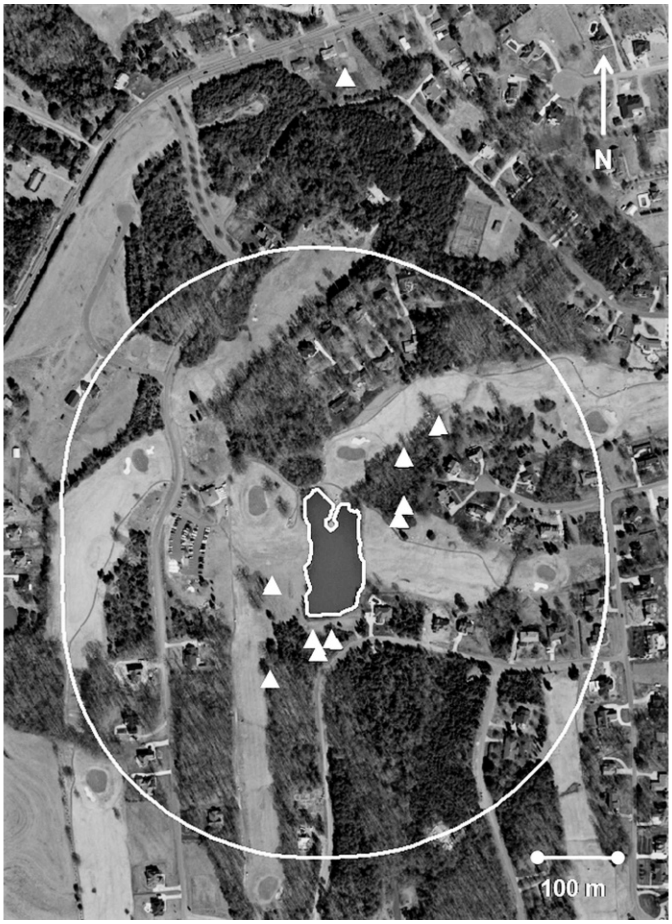

Fig. 1. Aerial view of Mallard Head Golf Course study site. The pond (0.87 ha) is located in the center of the photo outlined in white. The larger oval-shaped outline is a 28.3 ha area 300-m buffer zone that includes all random locations generated by ArcGIS. The closed white triangles represent the overwintering locations of ten mud turtles.

MATERIALS AND METHODS

Study site.—This study was conducted at a golf course pond on Mallard Head Country Club in Mooresville, located in Iredell County, North Carolina (UTM E: 509745, UTM N: 3935998, Zone 17). The pond has a surface area of 0.87 ha with creeks at both the north and south ends. The pond consists of both deep water and shallow muddy regions with limited emergent vegetation. Numerous species of fishes and turtle species such as Eastern Painted Turtles (*Chrysemys picta*), Common Snapping Turtles (*Chelydra serpentina*), Yellowbelly Sliders (*Trachemys scripta*), and River Cooters (*Pseudemys concinna*; Failey et al., 2007) inhabit the pond. Adjacent upland habitat consists of fairway, residential homes, a paved road, shrubs, and patches of mixed pine and hardwood forest. Within a 28.3 ha area (300-m buffer zone, explained below) surrounding the pond, approximately 35.3% was urban, 35.3% was in-play zone (i.e., fairways, greens, rough, tee box), and 28.4% was forested land (Fig. 1).

Capture and radio-telemetry.—We captured 11 mud turtles from 15 June to 26 July 2006 using aquatic hoop-net traps (model MHNIA, 2.54 cm mesh, Memphis Net and Twine, TN) baited with sardines. Upon capture, individuals were returned to the laboratory and were marked and measured following processing techniques of McCoy et al. (2007). Radio-transmitters (SB-2; Holohil Systems Ltd., Carp, Ontario; 4 g) coated in plastic tool dip were secured to the posterior carapace of each mud turtle with epoxy putty (Loctite® Five Minute Marine Grade Epoxy). Following processing and preparation, mud turtles were returned to their exact pond location within three days of capture. Nine out of 11 mud turtles were males and all turtles were adults, based on documented carapace length at maturity (Gibbons, 1983; Ernst et al., 1994), with carapace lengths of 80–181 mm (mean = 102 mm).

Turtles were located using radio-telemetry three times per week beginning 25 June 2006 through November 2006, when mud turtles ceased regular movement. During the colder months (November 2006 to February 2007), we radio-tracked turtles once per week. When turtles began moving again in early March 2007, we located individuals three times per week until they moved back to the pond, when we concluded the study. Radio-transmitters were replaced in the field every five months. During the replacement process, mud turtles were handled as little as possible; the entire replacement process took approximately three to five minutes.

Habitat measurements.—For each turtle location, we recorded various habitat measurements at macro- and microhabitat scales and Universal Transverse Mercator (UTM) coordinates using a hand-held global positioning system (GPS, approx. 5 m accuracy). Macrohabitat was determined by the presence/absence of the six land cover types in which the turtle was found, which included pond, forest, partial forest, grass, shrub, and urban (Table 1). We also recorded more detailed microhabitat variables, which were measured by characterizing the percentage of each cover type (e.g., % ground cover, % herbaceous vegetation) within a 3-m radius circular plot surrounding each turtle location (Table 1). We used a geographic information system (GIS; ArcGIS ver. 9.1, ESRI, Redlands, CA) to measure the total distance moved between locations and the straight-line distance between the two farthest points.

In addition to analyzing habitat for each turtle location, we analyzed habitat for corresponding random locations within a 300-m buffer surrounding the pond. The 300-m study area was based upon Burke and Gibbons (1995), who found that a 275-m buffer zone surrounding the pond protected 100% of terrestrial mud turtle locations. The random locations were generated as a numbered list in ArcGIS ver. 9.1 (Hawth's Analysis Tools). Each time a turtle moved to a new location, we used a GPS to navigate to the next random location on the list and then collected the same microhabitat and macrohabitat information as above. The random locations served as a control (representation of the available habitats) and were completed soon after each turtle movement to ensure that the habitat availability had not changed (Compton et al., 2002).

Habitat selection analysis.—Previous mud turtle habitat studies (Wetmore and Harper, 1917; Skorepa and Ozment, 1968; Scott, 1976; Buhlmann and Gibbons, 2001; Steen et al., 2007) have documented the use and importance of litter (leaf, pine, and grass), closed canopy, mixed forests, shrubs, and dense vegetation. Therefore, we chose these habitat variables and also included others that were present in the landscape such as grass cover and grass type, fallen woody debris, pavement, and soil for our golf course habitat

Table 1. Macro- and Microhabitat Variables Recorded at Each Turtle and Random Location.

Macrohabitat variable	Microhabitat variables in 3-m radius plot
Categorical variable:	Categorical variables:
Land cover types	Grass type (cut or uncut)
Pond	Canopy cover
Forest	none = <2%
Shrub (herbaceous vegetation, low-lying plants)	low = 2–20%
Urban structure (parking lot, driveway, cart path)	moderate = 20–80%
Partial forest (isolated, small cluster of <10 trees)	high = >80%
Grass	Continuous variables:
	% Grass
	% Litter (pine needles, leaves)
	% Bare soil
	% Pavement
	% Herbaceous vegetation
	% Fallen woody debris <10 cm diameter (e.g., twigs)

selection analysis (Table 1). For our habitat analysis, we included all 72 terrestrial turtle locations and the 72 corresponding random locations. We did not record random location data for each time we located a turtle but instead, each time the turtle moved to a new location. We used paired logistic regression to analyze terrestrial habitat selection by comparing habitat use (i.e., turtle locations) with habitat availability (i.e., random locations) within a 300-m buffered area surrounding the pond (Millspaugh and Marzluff, 2001). Using an information-theoretic approach, we assessed paired logistic regression models via AIC (Akaike Information Criterion; Akaike, 1973) after correcting for small sample size by using AIC_c (Burnham and Anderson, 1998). Following initial global model analyses, 17 candidate models were selected. Candidate models with the greatest Akaike weight (w), which determines the probability of that model being the best among the candidate models, were considered supported (Mazerolle, 2006).

We used one-tailed Wilcoxon signed rank test to analyze habitat selection of overwintering locations, which we defined as the terrestrial locations where mud turtles spent the most time underground or under ground cover without moving. We compared the ten mud turtle overwintering locations with the ten corresponding random locations (collected right after each turtle selected their overwintering location) using the same nine habitat variables (Table 1). One mud turtle (ID code CHO; Table 2) was not included in this analysis because it died before selecting an overwintering location.

RESULTS

Terrestrial activity.—Mud turtles with transmitters emerged from the pond during the summer and fall months; emergence dates ranged from 15 July to 24 November 2006. Because we only located turtles every other day, all data are based on movements between observations. Mud turtles moved a mean straight line distance of 119.2 ± 47.4 m and a mean distance of 187.2 ± 67.4 m before selecting an overwintering location (Table 2). Mud turtles crossed an average of four distinct habitats (pavement/gravel, fairways, and yards of cut grass) and moved an average of 5.2 times on land before overwintering (Table 2). Overwintering locations averaged a distance of 112.4 ± 46.7 m from the pond. Mud turtles spent an average of 132.9 ± 13.6 days in their below-ground overwintering location (Table 2). Most mud turtles were found buried 3 to 5 cm below the soil surface so that the top of the carapace was level with the ground but generally covered with leaf litter. Occasionally, turtles were found as deep as 10 cm underneath the soil surface. Two mud turtles (CHO and CIN; Table 2) died while in the terrestrial environment, likely from predation (Harden and Dorcas, 2008).

Mud turtles returned to the pond during the late winter and early spring months; return dates ranged from 11 March (approximately) to 21 April 2007. Mud turtles moved an average of three times from the time they emerged from their overwintering location to the time they returned to the pond. The average total distance traveled on land by mud turtles was 297.3 ± 118.0 m, and the average total number of land movements made by mud turtles was eight. Mud turtles spent an overall average of 178.2 ± 21.7 days on land.

Habitat selection.—Within the candidate model set (Table 3), the model that garnered the majority of the weight included forested macrohabitat, moderate canopy cover, and no grass (w = 0.74). The other model, which included forested macrohabitat, moderate canopy cover, leaf/pine litter, and no grass, had some support (w = 0.25). Both supported models suggested that when selecting for terrestrial habitat, mud turtles were most likely to choose forested macrohabitat with moderate canopy and no grass and also preferred more leaf/pine litter than random locations. Furthermore, the models suggested that human-associated variables (e.g., fairways, lawns, pavement) were never selected.

Habitat variables of the ten overwintering locations were significantly different from the habitat variables of the ten corresponding random locations (Table 4). The difference in habitat variables among locations suggested that when selecting for an overwintering location, mud turtles preferred forested macrohabitat with minimal, uncut grass, and more leaf/pine litter, soil, herbaceous vegetation, fallen woody debris, and canopy cover than random locations (Fig. 1).

DISCUSSION

It is well established that conserving forested uplands surrounding wetlands is critical for semi-aquatic species

Table 2. Mud Turtle Terrestrial Activity from Pond Emergence to Pond Return. Straight line distance is farthest distance a mud turtle moved from the nearest edge of the pond. Total distance traveled was calculated by adding all of the straight line distances between each turtle location for each mud turtle.

Turtle code	Sex	Pond emergence date	Straight line distance (m)	Distance moved before overwintering (m)	# of movements before overwintering	Mean # days spent at temporary locations	Approx. overwintering date*	Total habitats crossed	Approx. # days spent on land*	Total # terrestrial movements	Approx. pond return date*	Total distance traveled (m)
BMX	F	15 Jul 06	84.6	133.1	4	28.7	13 Oct 06	5	239	5	11 Mar 07	174.6
CIN[a]	M	4 Aug 06	57.5	93.3	5	5.3	28 Aug 06	1	60	5	na	106.1
CIX	F	5 Aug 06	81.2	163.6	5	7.0	4 Sep 06	2	230	7	22 Mar 07	233.8
BKO	M	5 Aug 06	107.0	399.4	8	7.3	30 Sep 06	9	231	12	23 Mar 07	488.9
CHJ	M	5 Aug 07	157.1	181.9	8	10.3	18 Oct 06	2	231	10	23 Mar 07	338.0
CHO[b]	M	13 Aug 06	56.3	87.6	na	na	na	2	60	6	na	87.6
CHN	M	22 Aug 06	40.9	44.7	4	7.7	14 Sep 06	2	213	8	23 Mar 07	109.5
BMO	M	22 Aug 06	581.3	787.9	11	5.9	21 Oct 06	10	242	18	21 Apr 07	1414.6
CHW	M	22 Aug 06	58.9	62.2	3	24.5	17 Jan 07	4	195	6	5 Mar 07	125.8
BLN	M	6 Oct 06	50.5	50.5	1	na	6 Oct 06	2	158	2	13 Mar 07	94.9
BKW	M	24 Nov 06	36.3	54.9	3	17.0	2 Jan 07	3	101	4	5 Mar 07	96.8
mean	**na**	**na**	**119.2**	**187.2**	**5.2**	**10.1**	**na**	**4**	**178.2**	**7.5**	**na**	**297.3**
± SE	**na**	**na**	**47.4**	**67.4**	**0.9**	**2.0**	**na**	**0.9**	**21.7**	**1.3**	**na**	**118.0**

[a] Turtle CIN selected an overwintering location but then died in late September before returning to the pond.
[b] Turtle CHO died mid-October before selecting an overwintering location so associated measurements were not recorded.
* Indicates these values and dates are an approximation or the median of the range because we did not radio track on a daily basis.

Table 3. Mud Turtle Terrestrial Habitat Selection Assessed Using Paired Logistic Regression and AIC_c. Seventeen candidate models, consisting of macro- and microhabitat variables, were selected from the initial global model analyses. Models in bold gained the most support with the lowest ΔAIC_c values and the greatest Akaike weight.

Model*	# of parameters	AIC_c	Δ AIC_c	Akaike Weight (*w*)
Macro canopy grass	**4**	**105.60**	**0.00**	**0.74**
Macro canopy grass litter	**5**	**107.80**	**2.19**	**0.25**
Macro grass	**3**	**115.19**	**9.59**	**0.01**
Macro canopy litter	4	117.03	11.42	0.00
Macro canopy	3	118.19	12.59	0.00
Macro canopy fallen-woody litter	5	119.18	13.58	0.00
Macro canopy fallen-woody	4	120.08	14.48	0.00
Macro	2	130.11	24.51	0.00
Canopy grass	3	130.59	24.99	0.00
Canopy fallen-woody	3	131.33	25.72	0.00
Macro fallen-woody	3	131.43	25.82	0.00
Macro litter	3	131.60	25.99	0.00
Canopy	2	132.25	26.65	0.00
Canopy litter	3	133.55	27.95	0.00
Fallen-woody	2	175.15	69.55	0.00
Litter	2	180.65	75.04	0.00
Grass	2	182.06	76.46	0.00

* Macro = categorical variable (e.g., forest, pond, shrub, grass etc.), litter = continuous variable (leaf and pine litter), grass = categorical variable (uncut, cut, no grass), canopy = categorical variable (none, low, medium, and high), debris = continuous variable (fallen woody debris < 10 cm).

(Burke and Gibbons, 1995; Buhlmann and Gibbons, 2001; Semlitsch and Bodie, 2003). Our results highlight the importance of forested, terrestrial habitat for mud turtles in anthropogenically-modified habitats and suggest that golf courses with forested lands can provide such habitat for mud turtles. Turtles selected terrestrial forested habitat with moderate canopy cover, leaf/pine litter, and no grass. We found that turtles did not select any human-modified habitats, including fairways or residential yards, for overwintering or terrestrial use. Yet, turtles were able to traverse apparently unsuitable habitats (i.e., fairway, golf cart path, driveway, roads) to get to preferred terrestrial habitats.

Mud turtles in our study traveled a mean straight line distance of 119.2 m (36.3–581.3 m) and exhibited a wide range of terrestrial movements before settling in an overwintering location. Other investigations have found that mud turtles did not move as far as the turtles in our study (range = −4–134.5 m, mean = 44.6 m, Buhlmann and Gibbons, 2001; range = 1–79 m, mean = 19 m, Ligon and Stone, 2003; range = 35–90 m, Tuma, 2006; and range = 24–108 m, mean = 72 m, Steen et al., 2007). The turtles in our study may have moved greater distances and moved more frequently because forested, terrestrial habitat adjacent to the golf course pond was limited. Movements similar to those we documented were observed by Buhlmann and Gibbons (2001), who found that mud turtles in open canopy pine plantation moved more before selecting winter refugia than mud turtles in closed canopy mixed forest, perhaps because of unfavorable temperatures and limited suitable habitat.

Table 4. Mud Turtle Habitat Selection of Overwintering Location Assessed Using a One-Tailed Wilcoxon Signed Rank Test. These nine habitat variables were compared between ten overwintering locations and ten random locations. One mud turtle (ID code CHO) died before selecting an overwintering location and was omitted from this analysis.

Variables	Z-values	*P*-values (one-tailed)
Macro	2.78	0.003
Grass	−2.46	0.007
Grass type	−1.91	0.028
Litter	1.89	0.029
Soil	3.07	0.001
Pavement	−0.66	0.252
Vegetation	3.12	0.001
Debris	3.23	0.001
Canopy	3.04	0.001

Responses of turtles to human-induced habitat fragmentation are poorly understood (Rizkalla and Swihart, 2006). Based on our findings, mud turtles were able to cross a variety of habitats, similar to other semi-aquatic species (i.e., painted turtles, *Chrysemys picta*; Bowne and White, 2004). The ability to traverse a variety of habitats may allow mud turtles to persist, but only if forested uplands exist in close proximity to aquatic environments to provide refugia. Wygoda (1979) and Stone et al. (1993) found that in continuous and homogenous landscapes, movements between water bodies are somewhat common in mud turtles, whereas Buhlmann and Gibbons (2001) found limited mud turtle emigration and immigration from their wetland study site. In our study, most likely as a result of the fragmented landscape and the substantial distance of our pond from other water bodies, inter-pond movements did not occur. Therefore, as suggested by Buhlmann and Gibbons (2001) and Iverson (1991), the use of nearby terrestrial refugia may be more important for population persistence of semi-aquatic turtles than immigration and emigration, especially in our heavily disturbed landscape where threats associated with urbanization (e.g., habitat fragmentation, human-subsidized predators, and road mortality) may be substantial.

We found that urbanized landscapes can expose semi-aquatic species to anthropogenic threats and obstacles. For example, human-subsidized predators (e.g., raccoons, cats, opossums, skunks) may be more abundant (Riley et al., 1998; Smith and Engeman, 2002; Larivière, 2004) and can greatly reduce turtle populations. Mammals were likely the predators of two of our turtles that died during our study, one prior to overwintering and one while overwintering (Harden and Dorcas, 2008). The mortality of these two individuals represented an 81.8% annual survivorship rate of the 11 adult mud turtles in our study. Such an estimate is lower than the 100% mean annual survivorship for 51 adult mud turtles in a three-year study (Buhlmann and Gibbons, 2001) and lower than the 89.0% (male) and 87.6% (female) mean annual survivorship for 1589 adult mud turtles in a 20-year study (Frazer et al., 1991). Our lower annual adult survivorship rate may ultimately impact the stability of our mud turtle population because, based on long-term studies by Congdon et al. (1993, 1994), populations of long-lived species with delayed adult maturity are highly sensitive to decreases in juvenile and adult survival. Therefore, consistently high adult survival is critical for maintenance of a stable population. Unlike our study, previous mud turtle studies (Frazer et al., 1991; Buhlmann and Gibbons, 2001) were conducted in non-urbanized wetland landscapes with forested uplands and thus, annual adult survivorship rates were likely higher because the threats associated with urbanization, habitat fragmentation, and habitat alteration were limited or non-existent.

Previous studies estimating critical upland habitat for mud turtles included 100% of turtle locations; these studies recommended critical upland habitat of 135 m and 90 m surrounding wetlands (Buhlmann and Gibbons, 2001; Tuma, 2006). Semlitsch and Bodie (2003) included 95% of animal locations when suggesting a critical terrestrial habitat for protecting semi-aquatic reptiles and amphibians. As defined by Buhlmann and Gibbons (2001) and redefined by Semlitsch and Bodie (2003), critical upland habitat should not be viewed as a buffer zone, but instead as associated upland habitat adjacent to the wetland (water body) necessary for the protection of semi-aquatic species. In our study, including 100% of mud turtle locations would have required critical upland habitat to extend 581 m from the pond's edge. Alternatively, if we included 90% of our turtle locations similar to Burke and Gibbons (1995), who used 90% of turtle and nest locations to recommend their 73-m buffer zone, our estimate of critical terrestrial habitat surrounding the golf course pond would be 157 m.

Upland habitats are critical for many semi-aquatic turtles. They provide habitat for nesting, overwintering, and aestivating (Wilson, 1998; Wilson et al., 1999). If managed appropriately, fragmented landscapes, such as golf courses, with forested upland habitats surrounding ponds also have the potential to provide habitat for semi-aquatic wildlife (Green and Marshall, 1987). Clearly, if anthropogenically-altered landscapes are to be managed for both humans and wildlife, land managers should consider the behavior and spatial ecology of target wildlife species (Bowne et al., 2006). Preserving or restoring forested upland habitat in close proximity to ponds would benefit numerous wildlife animals such as amphibians (Semlitsch, 1998; Semlitsch and Bodie, 2003; McDonough and Paton, 2006) and semi-aquatic turtles (Bennett et al., 1970; Buhlmann and Gibbons, 2001; Bowne et al., 2006; Scott et al., 2008) and may ultimately help to conserve semi-aquatic wildlife on fragmented landscapes.

ACKNOWLEDGMENTS

We thank S. Linker and E. Campbell of Mallard Head Country Club for support and permission to conduct research on the golf course. We thank N. DiLuzio and K. Cecala for assistance with fieldwork and J. Gibbons for providing some reference materials. Finally, we thank D. Steen for providing comments that improved this manuscript. All procedures were approved by the Davidson College Animal Care and Use Committee (protocol # 3-06-11; 2006). Manuscript preparation was aided by the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, U.S. Department of Energy, through Financial Assistance Award number DE-FC09-96SR18546 to the University of Georgia Research Foundation. Funding provided by Davidson College Biology Department, North Carolina Herpetology Society, Duke Power, and by National Science Foundation Grants (DBI-0139153 and DEB-0347326) to MED.

LITERATURE CITED

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle, p. 267–281. *In*: Second International Symposium on Information Theory. B. N. Petrov and F. Cazakil (eds.). Akademiai Kidao, Budapest, Hungary.

Baldwin, E. A., M. N. Marchand, and J. A. Litvaitis. 2004. Terrestrial habitat use by nesting painted turtles in landscapes with different levels of fragmentation. Northeastern Naturalist 11:41–48.

Bennett, D. H. 1972. Notes on the terrestrial wintering of mud turtles (*Kinosternon subrubrum*). Herpetologica 28:245–247.

Bennett, D. H., J. W. Gibbons, and J. C. Franson. 1970. Terrestrial activity in aquatic turtles. Ecology 51:738–740.

Bowne, D. R., M. A. Bowers, and J. E. Hines. 2006. Connectivity in an agricultural landscape as reflected by interpond movements of a freshwater turtle. Conservation Biology 20:780–791.

Bowne, D. R., and H. White. 2004. Searching strategy of the painted turtle *Chrysemys picta* across spatial scales. Animal Behaviour 68:1401–1409.

Buhlmann, K., and J. W. Gibbons. 2001. Terrestrial habitat use by aquatic turtles from a seasonally fluctuating wetland: implications for wetland conservation boundaries. Chelonian Conservation and Biology 4:115–127.

Burke, V. J., and J. W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: a case study on freshwater turtles in a Carolina bay. Conservation Biology 9:1365–1369.

Burnham, K., and D. Anderson. 1998. Model Selection and Inference: A Practical Information-Theoretic Approach. Springer-Verlag, New York.

Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. Ecology 83:833–843.

Congdon, J. D., A. E. Dunham, and R. C. Van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. Conservation Biology 7:826–833.

Congdon, J. D., A. E. Dunham, and R. C. Van Loben Sels. 1994. Demographics of common snapping turtles (*Chelydra* *serpentina*): implications for conservation and management of long-lived organisms. American Zoologist 34:397–408.

Ernst, C. H., J. E. Lovich, and R. W. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington, D.C.

Failey, E. L., J. C. McCoy, S. J. Price, and M. E. Dorcas. 2007. Ecology of turtles inhabiting golf course and farm ponds in the western Piedmont of North Carolina. Journal of North Carolina Academy of Science 123:221–232.

Forman, R. T. T., and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, Inc., New York.

Frazer, N. B., J. W. Gibbons, and J. L. Greene. 1991. Life history and demography of the common mud turtle *Kinosternon subrubrum* in South Carolina, USA. Ecology 72:2218–2231.

Gibbons, J. W. 1983. Reproductive characteristics and ecology of the mud turtle, *Kinosternon subrubrum* (Lacepede). Herpetologica 39:254–271.

Green, B. H., and I. C. Marshall. 1987. An assessment of the role of golf courses in Kent, England, in protecting wildlife and landscapes. Landscape and Urban Planning 14:143–154.

Harden, L. A., and M. E. Dorcas. 2008. Using thermal biology to investigate habitat use and activity of mud turtles (*Kinosternon subrubrum*) on a golf course, p. 321–323. *In*: Urban Herpetology: Herpetological Conservation Vol. 3. R. E. Jung and J. C. Mitchell (eds.). Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah.

Iverson, J. B. 1991. Life history and demography of the yellow mud turtle, *Kinosternon flavescens*. Herpetologica 47:373–395.

Larivière, S. 2004. Range expansion of raccoons in the Canadian prairies: review of hypotheses. Wildlife Society Bulletin 32:955–963.

Ligon, D. B., and P. A. Stone. 2003. Radiotelemetry reveals terrestrial estivation in Sonoran mud turtles (*Kinosternon sonoriense*). Journal of Herpetology 37:750–754.

Love, W. R. 1999. An Environmental Approach to Golf Course Development. American Society of Golf Course Architects, Chicago.

Marchand, M. N., and J. A. Litvaitis. 2004. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. Conservation Biology 18:758–767.

Mazerolle, M. J. 2006. Improving data analysis in herpetology: using Akaike's Information Criterion (AIC) to assess the strength of biological hypotheses. Amphibia–Reptilia 27:169–180.

McCoy, J. C., E. L. Failey, S. J. Price, and M. E. Dorcas. 2007. An assessment of leech parasitism on semi-aquatic turtles in the western Piedmont of North Carolina. Southeastern Naturalist 6:191–202.

McDonough, C., and P. W. C. Paton. 2006. Salamander dispersal across a forested landscape fragmented by a golf course. The Journal of Wildlife Management 71:1163–1169.

McKinney, M. L. 2002. Urbanization, biodiversity and conservation. BioScience 52:883–890.

Millspaugh, J. J., and J. M. Marzluff. 2001. Radio Tracking and Animal Populations. Academic Press, San Diego, California.

Montieth, K. E., and P. W. C. Paton. 2006. Emigration behavior of spotted salamanders on golf courses in Southern Rhode Island. Journal of Herpetology 40:195–205.

Riley, S. P. D., J. Hadidian, and D. A. Manski. 1998. Population density, survival, and rabies in raccoons in an urban national area. Canadian Journal of Zoology 76:1153–1164.

Rizkalla, C. E., and R. K. Swihart. 2006. Community structure and differential responses of aquatic turtles to agriculturally induced habitat fragmentation. Landscape Ecology 21:1361–1375.

Scott, A. F. 1976. Aquatic and terrestrial movements of farm pond populations of the eastern mud turtle (*Kinosternon subrubrum subrubrum*) in east-central Alabama. Unpubl. Ph.D. diss., Auburn University, Auburn, Alabama.

Scott, D. E., B. S. Metts, and J. W. Gibbons. 2002. Seasonal wetlands and golf courses. United States Golf Association Turfgrass and Environmental Research Online 4:1–7.

Scott, D. E., B. S. Metts, and J. W. Gibbons. 2008. Enhancing amphibian biodiversity on golf courses with seasonal wetlands, p. 285–292. *In*: Urban Herpetology: Herpetological Conservation Vol 3. R. E. Jung and J. C. Mitchell (eds.). Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding amphibians. Conservation Biology 12:1113–1119.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17:1219–1228.

Skorepa, A. C., and J. E. Ozment. 1968. Habitat, habits, and variation of *Kinosternon subrubrum* in southern Illinois. Transactions of Illinois State Academy of Science 61:247–251.

Smith, T. H., and R. M. Engeman. 2002. An extraordinary raccoon, *Procyon lotor*, density at an urban park. Canadian Field-Naturalist 116:636–639.

Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology 18:1143–1148.

Steen, D. A., S. C. Sterrett, S. A. Miller, and L. L. Smith. 2007. Terrestrial movements and microhabitat selection of overwintering subadult eastern mud turtles (*Kinosternon subrubrum*) in Southwest Georgia. Journal of Herpetology 33:532–535.

Stone, P. A., J. B. Hauge, A. F. Scott, C. Guyer, and J. L. Dobie. 1993. Temporal changes in two turtle assemblages. Journal of Herpetology 27:13–23.

Tuma, M. W. 2006. Range, habitat use, and seasonal activity of the yellow mud turtle (*Kinosternon flavescens*) in Northwestern Illinois: implications for site-specific conservation and management. Chelonian Conservation and Biology 5:108–120.

Wetmore, A., and F. Harper. 1917. A note on the hibernation of *Kinosternon pennsylvanicum*. Copeia 1917:56–59.

Wilson, D. S. 1998. Nest-site selection: microhabitat variation and its effects on the survival of turtle embryos. Ecology 79:1884–1892.

Wilson, D. S., H. R. Mushinsky, and E. D. McCoy. 1999. Nesting behavior of the striped mud turtle, *Kinosternon baurii* (Testudines: Kinosternonidae). Copeia 1999:958–968.

Wygoda, M. L. 1979. Terrestrial activity of striped mud turtles, *Kinosternon baurii* (Reptilia, Testudines, Kinosternidae) in west-central Florida. Journal of Herpetology 13:469–480.