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Survivorship and Population Densities of Painted Turtles (*Chrysemys picta*) in Recently Modified Suburban Landscapes

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ABSTRACT. – **Populations of long-lived animals, such as semi-aquatic turtles, that depend on high survivorship of reproductive adults, are particularly susceptible to the negative effects associated with habitat modification in suburban areas. Survivorship of semi-aquatic turtles in suburban landscapes may be reduced as a result of a number of factors, including the elimination of appropriate nesting habitat and the introduction of human-subsidized predators. Unfortunately, few studies on turtle populations in anthropogenically modified habitats estimate vital rates, and researchers are rarely able to study populations both before and after development. We studied painted turtle (*Chrysemys picta*) vital rates at 5 ponds in the Charlotte Metropolitan area of North Carolina; 2 ponds and their surrounding habitat underwent development after the first year of study, 1 pond was on a golf course, and 2 were farm ponds. We used Program MARK to generate open population models examining the effects of location and sex on turtle survivorship. Our results showed relatively stable population densities over 4 years across all ponds, with the largest density (approximately 100 turtles/ha) occurring at a recently developed site. Among ponds, turtles had variable annual adult survivorship (ca. 60%–95%), and males generally had lower survivorship than females. Our results emphasize the importance of site-specific habitat factors that influence turtle population demography and indicate that for long-lived species, whose population densities may not respond immediately to habitat change, long-term monitoring efforts examining population vital rates are needed to more fully evaluate the effects of anthropogenic modification.**

KEY WORDS. – **Reptilia; Testudines; Emydidae; *Chrysemys picta*; painted turtle; demography; land-use change; Piedmont; semi-aquatic turtles; urbanization; USA; North Carolina**

Urbanization and other forms of anthropogenic land-use change can pose a serious threat to many populations of semi-aquatic turtles (Mitchell and Klemens 2000). Studies have highlighted the impacts on turtles of road mortality (Haxton 2000; Gibbs and Shriver 2002), land-use composition (Marchand and Litvaitis 2004; Failey et al. 2007), habitat fragmentation (Rizkalla and Swihart 2006), and connectivity among populations within heterogeneous landscapes (Bayless 1975). Additionally, anthropogenic alteration of habitat (e.g., urbanization, introduction of exotic vegetative cover) can influence the temperatures of nest sites, which may lead to biased sex ratios in species that have temperature-dependent sex determination (Kolbe and Janzen 2002).

Most studies concerning the effects of anthropogenic activities on turtle populations use relative abundance as the metric for analysis (Marchand and Litvaitis 2004; Steen and Gibbs 2004; Rizkalla and Swihart 2006), which can be a misleading indicator of population status (Todd and Rothermel 2006). Estimating survivorship may allow for clearer assessments of the effects of habitat change on a population (Todd and Rothermel 2006), especially in regions undergoing rapid land-use changes where time lags in a population's response to habitat conditions may occur (Brooks et al. 1999). Survivorship is an important part of fitness and can be influenced by local and landscape-scale resource heterogeneity (Doherty and Grubb 2002). Maintaining high adult survivorship is vital for populations of long-lived vertebrates, such as semi-aquatic turtles, because these animals have evolved life-history strategies wherein long life spans are needed to offset the cost of delayed reproduction and low nest survival (Congdon et al. 1993). Understanding factors affecting a population's vital rates (e.g., survivorship) is especially critical for conserving and managing populations in urbanized environments (Mitchell 1988; Marchand and Litvaitis 2004; Rizkalla and Swihart 2006; Todd and Rothermel 2006).

Painted turtles (*Chrysemys picta*) are among the best-studied species of North American turtles (Moll 1979) in part due to their wide distribution over much of the United States (Conant and Collins 1998). Annual estimates of adult survivorship for painted turtles are variable, ranging from 76% to 96% (Wilbur 1975; Mitchell 1988). Wilbur (1975) suggested that variation in survivorship may be the result of variation in land uses surrounding wetlands. However, most studies of painted turtle demography have been conducted in relatively undisturbed habitats (Gibbons

1968; Bayless 1975; Frazer et al. 1991). Studies that have been conducted in anthropogenically modified habitats (i.e., urbanized areas) have focused on sites that were developed for a number of years prior to study (Mitchell 1988; Conner et al. 2005; Rees et al. 2009). Thus, studies in suburban and urban environments that have recently undergone habitat modification are needed in order to fully understand the effects of anthropogenic activity on demographic parameters of semi-aquatic turtles.

To investigate the effects of urbanization on painted turtle demography, we conducted a 4-year mark–recapture study of painted turtles inhabiting ponds in the Charlotte Metropolitan area of North Carolina, one of the fastest developing regions in the United States (Ewing et al. 2005). Our main objectives were to estimate adult survival rates and population densities and to examine the relationship between these parameters and broadly defined land-use types surrounding the ponds. Based on the range of survivorship estimates from previous studies (Wilbur 1975; Mitchell 1988), we predicted that survival rates would show site-specific variability that would correlate with land-use type. Specifically, we expected that populations inhabiting ponds surrounded by urbanized landscapes would have reduced survivorship in comparison with populations surrounded by agricultural land uses. We also hypothesized that female turtles would have lower survival as a result of nesting forays in suburban environments where traffic deaths and other factors could increase their risk of mortality.

Our second goal was to examine the immediate effects of land-use change on semi-aquatic turtles using the demographic parameters mentioned above. Habitat modification had not begun at the 2 suburban ponds during our first year of study, allowing the unique opportunity to monitor the effects of land-use changes on turtle populations before and during development. We intuitively hypothesized that in recently developed ponds we would observe decreasing population densities along with decreased survival estimates as a result of the potential negative impacts of habitat modification.

METHODS

Study Area. — We conducted a mark–recapture study of painted turtles at 5 ponds in the Charlotte Metropolitan area of North Carolina. Two of our study sites were farm ponds located on an old farmstead (Robbins 1 [0.52 ha] and 2 [0.32 ha]). Robbins 1 had relatively open water (i.e., free of floating vegetation) and surrounding terrestrial habitat consisted of grasses, shrubs, and old field, while Robbins 2 was almost completely covered by duckweed (*Lemna minor* and *Wolffia* sp.) and had densely forested surroundings. The third pond we studied was located on a golf course that was constructed in 1979 (Mallard Head [0.87 ha]). This pond was bordered on 2 sides by the fairway of the golf course and on a third side by a cart path; the pond was relatively shallow compared to the other ponds (Harden et al. 2009). Finally, we sampled 2 ponds (Christenbury [0.39 ha] and Glen Grove [1.02 ha]) that experienced suburban development after the first year of sampling (i.e., 2005) but were previously surrounded by agricultural landscapes. Both ponds are currently part of residential areas and are approximately 50 m from houses or roads. Christenbury was completely dredged to remove silt during development; surrounding habitat at Christenbury currently consists of single family housing, forest, and old field. Glen Grove was modified through the installation of a fountain and the construction of a mulch footpath along the entire perimeter of the pond. Old field habitat borders the south and western shores of the pond, while single family housing currently borders the northern and eastern shoreline. All ponds were $>$ 10 km apart except for Robbins 1 and 2 (275 m apart).

Collection and Processing Methods. — Sampling was conducted each year from April to July from 2005 to 2008. We sampled each pond using 10 hoop-net traps (model MHNIA, 1-inch mesh, Memphis Net and Twine, Memphis, TN) baited with sardines (process described in detail in Failey et al. 2007). We set traps in shallow water around the edge of the ponds and checked them every other day for 20 days. All turtles captured were returned to the lab for processing before being released the next day that traps were checked.

We permanently marked all new turtles by filing a 3-letter code in the marginal scutes (Sexton 1959). We determined the sex of each turtle by examining foreclaw length, shell shape, and tail length (Ernst et al. 1994). We also took digital photographs of the carapace and plastron of each animal to aid in future identification.

Data Analysis. — For capture–recapture analyses, we combined capture data from each trapping session to generate turtle encounter histories with 4 capture events (1 per year). Using this approach we modeled our data using open population models and anticipated high capture probabilities.

To test hypotheses that survivorship would differ among ponds and, perhaps, over time as a result of land-use changes and that females would have lower survivorship than males, we used open population Cormack–Jolly–Seber (CJS) models (Lebreton et al. 1992) in Program MARK (White and Burnham 1999) to generate estimates of apparent survival (Φ) and recapture rates (p). We generated a CJS model set based on location (i.e., the pond the turtle occupied) and the sex of the turtle; data were organized into 10 attribute groups, one for each sex at each of the 5 study sites. We assumed that recapture rates (p) were likely to depend on the location of the turtle (i.e., the pond it was captured in), its sex, and the effect of time (notated Pond and Sex * t) or only its location and the effect of time (notated Pond * t). We used these recapture rate structures and generated models where apparent survivorship (Φ) depended on different parameter combinations of pond, sex, and time. In this model set we excluded juvenile turtles whose sex could

Table 1. Cormack–Jolly–Seber model set analyzing the effects of location and sex on survivorship and recapture rate of the painted turtle (*Chrysemys picta*).[a]

Model	$QAIC_c$	$\Delta QAIC_c$	w_i	np
Φ(Pond and Sex) p(Pond * t)	641.34	0.00	0.61	25
Φ(Pond) p(Pond * t)	642.82	1.49	0.29	20
Φ(Sex) p(Pond * t)	645.88	4.54	0.06	17
Φ(Pond * t) p(Pond * t)	647.98	6.64	0.02	25
Φ(Pond) p(Pond and Sex * t)	650.32	8.98	0.01	35
Φ(Pond and Sex) p(Pond and Sex * t)	653.69	12.35	0.00	40
Φ(Pond * t) p(Pond and Sex * t)	655.36	14.02	0.00	40
Φ(Sex) p(Pond and Sex * t)	655.59	14.25	0.00	32
Φ(Sex * t) p(Pond and Sex * t)	655.68	14.34	0.00	34
Φ(Sex * t) p(Pond * t)	657.34	16.00	0.00	24
Φ(Pond and Sex * t) p(Pond * t)	660.65	19.31	0.00	40
Φ(Pond and Sex * t) p(Pond and Sex * t)	666.54	25.20	0.00	50

[a] $QAIC_c$ = Akaike Information Criterion values adjusted for small sample sizes and overdispersion; w_i = Akaike weight; np = number of parameters in model; Φ = survivorship; p = recapture rate; t = time.

not be determined accurately (8 from Glen Grove, 2 from Christenbury, 1 from Robbins 1, none from Mallard Head or Robbins 2).

Goodness-of-fit was evaluated for CJS models using a parametric bootstrapping method with 1000 iterations (described in Cooch and White's ''Introduction to Program MARK'' available at http://www.phidot.org/software/mark/docs/book/). The overdispersion factor, $\hat{c}$, was calculated as the observed global model deviance divided by the mean expected model deviance from the bootstrapping results. Model selection was based on Akaike Information Criterion values adjusted for small sample sizes (AIC_c) with lower values identifying greater parsimony. AIC_c evaluates model parsimony based on a combination of both fit and precision (Burnham and Anderson 2002). Akaike weights (w_i) represent the weight of evidence that a given model is the best in the model set (Burnham and Anderson 2002). If overdispersion (greater variability in data than would be expected given the CJS model assumptions) was evident from goodness-of-fit testing (e.g., $\hat{c} > 1$) then AIC_c values adjusted for overdispersion ($QAIC_c$) were used (Burnham and Anderson 2002).

To test the hypothesis that land development would negatively impact population densities, we generated population size estimates for each year (incorporating all turtles captured) using the POPAN formulation of the Jolly–Seber model in Program MARK (Pollock et al. 1990). Separate model sets were generated for each pond, each with 4 candidate models (time dependent survivorship [Φ] and recapture rate [p], constant Φ and time dependent p, time dependent Φ and constant p, and constant Φ and p). Population estimates for each year were taken from the best supported candidate model in each model set. These estimates were then divided by the pond areas previously listed in order to generate population densities.

RESULTS

During the course of the study, we captured 265 individual painted turtles a total of 606 times: 20 individuals from Christenbury, 138 from Glen Grove, 38 from Mallard Head, 57 from Robbins 1, and 14 from Robbins 2 (2 individuals were captured at both Robbins 1 and 2).

Location and Sex Models. — Goodness-of-fit testing for location and sex-based encounter histories suggested slight overdispersion of the data, and, accordingly, a $\hat{c}$ correction of 1.21 was used in the $QAIC_c$ formula for model selection. The best model to explain encounter histories based on location and sex was the model, Φ(Pond and Sex) p(Pond * t), indicating that survivorship depended on the location (pond) and sex of the turtle but was constant over time, while also indicating that recapture rate depended on location of the turtle and varied over time. This model received 61.3% of the support out of the 12 candidate model set (Table 1). The next best model (approximately 29.2% of the model support) included only a location effect on survivorship. Because models with time-varying survivorship had very little support, we used model averaging procedures to generate only 1 survivorship estimate for each sex at each of the study sites (Fig. 1). Survivorship estimates varied

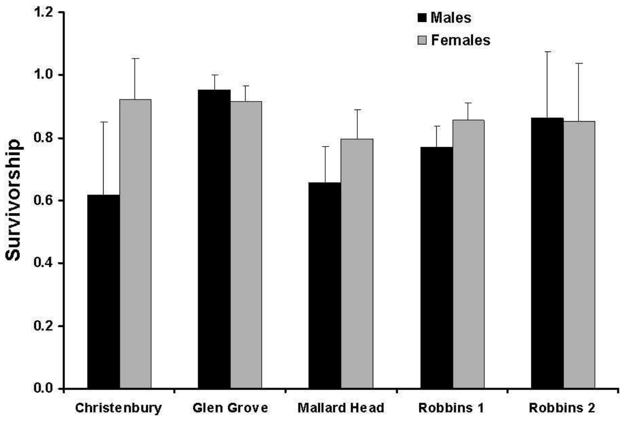

Figure 1. Model averaged survivorship (Φ) estimates for painted turtles (*Chrysemys picta*). Bars represent the estimated survival rates for each sex at each of the 5 study sites. Estimates were generated using Cormack–Jolly–Seber models in Program MARK, and the error bars represent 1 standard error above the estimate.

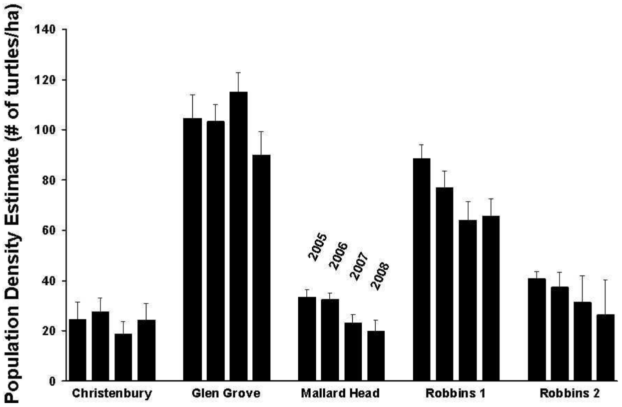

Figure 2. Population density estimates of painted turtles (*Chrysemys picta*) in 5 ponds. Bars represent the estimated population density of painted turtles at each study site from 2005 to 2008 (each bar represents a year). Estimates of population size (later converted to densities) were generated using the POPAN formulation of the Jolly–Seber model in Program MARK and the error bars represent 1 standard error above the estimate. See text for detailed descriptions of the study sites.

from 95.4% (Glen Grove males; Fig. 1) to 62.0% (Christenbury males; Fig. 1). In 3 of 5 ponds (Christenbury, Mallard Head, Robbins 1), females showed higher survivorship rates than males, and in the remaining 2 ponds (Glen Grove, Robbins 2) males had only slightly higher survivorship than females.

Population Density Estimates. — In general, population density estimates were quite variable among study sites (Fig. 2). Glen Grove had the highest population density of any pond, with estimates of just over 100 turtles/ha for the first 3 years of study, while the next highest was at Robbins 1 which had estimates of approximately 64–88 turtles/ha. Estimates for the other 3 ponds were all lower than 50 individuals/ha each year. Most of the populations showed slight density decreases over the course of the study.

DISCUSSION

Our location and sex models showed that survivorship of painted turtles was dependent on the location (i.e., the pond and/or its surrounding land-use type) and the sex of the individual. Additionally, the high variability in our site-specific survivorship estimates suggests that population demographics were likely correlated with habitat variation among ponds. Overall, our survivorship estimates are in agreement with previously published estimates of between 70% and 90%, although one pond had survivorship estimates over 90% for both sexes. The highest estimates of survivorship came from Glen Grove, where survival was estimated to be approximately 95% for males, indicating that the painted turtle population was healthy despite recent land-use conversion. In contrast, Mallard Head, a golf course pond that has been developed for a longer time (the course was built in 1979), had among the lowest survivorship estimates (approximately 66% for males and 80% for females), suggesting that effects of development on turtles may be difficult to detect in the years immediately following modification but may become more pronounced over time (as in Reese and Welsh 1998; Findlay and Bourdages 2000; Marchand and Litvaitis 2004).

Analysis with respect to sex indicated that males generally had lower survivorship than females. Although our results disagree with some previous studies (Frazer et al. 1991), in most freshwater turtles, males are thought to emigrate overland more readily than females (Morreale et al. 1984; Gibbons et al. 1990), and adult male painted turtles are known to use upland habitat for both dispersal and aestivation (Bowne 2008). Such movements away from ponds are indistinguishable from death in our models and may be responsible for the lower observed survivorship estimates for males. Similarly, if males are more prone to overland movement they may be more susceptible to predation or death from motor vehicles when crossing roads, although females may also be exposed to both during nesting forays.

Although differences in population densities among locations indicated potential differences in habitat quality among sites, Christenbury and Glen Grove, the recently developed ponds, did not show sharp declines in population densities as we hypothesized would occur during the years immediately following initiation of development. Thus, our data suggest that there may be a considerable lag time between the modification of habitat and its effect on turtle populations. Several studies have also suggested that semi-aquatic turtle populations may not respond immediately to anthropogenic disturbance (Reese and Welsh 1998; Findlay and Bourdages 2000; Marchand and Litvaitis 2004). Although these studies did not find rapid declines in abundances of turtles in response to habitat alterations, they pointed to population metrics like skewed age ratios (Reese and Welsh 1998) and reduced recruitment rates (Marchand and Litvaitis 2004) as indicators of reduced habitat quality. Findlay and Bourdages (2000) suggested an even more extreme time lag, in which the negative effects of land-use changes on species diversity in wetlands may be undetectable for decades. Alternatively, the level of anthropogenic disturbance in this study may simply have little to no negative impact on turtle populations, and, in fact, a previous study on painted turtle nesting behavior found no negative effects of human activity (Bowen and Janzen 2008).

Contrary to our expectations, we found that a developed pond (Glen Grove) had the largest population densities each year (approximately 100 turtles/ha), even after development occurred. This finding emphasizes the effects of site-specific landscape features on turtle populations and demographics. Although the landscape surrounding Glen Grove had undergone development, the abundance of open habitat along the edge of the pond probably allowed turtles to successfully reproduce and immigrate. Additionally, factors such as road mortality that have been shown to negatively impact turtle populations in developed areas (Steen and Gibbs 2004; Gibbs and Steen 2005) may not present a large threat to populations in our suburban study sites where traffic is slower moving. Furthermore, we found disparate population density estimates between the farm ponds, Robbins 1 and 2, which were only 275 m apart. Robbins 2 consistently had lower population densities than Robbins 1, and we believe this finding may be related to local-scale habitat features. The lower densities at Robbins 2 may be attributed to the dense forest surrounding the pond, which could limit its accessibility to turtles and also reduce availability of nesting sites, while Robbins 1 has a greater proportion of open habitat suitable for nesting or basking.

In conclusion, our results emphasize the effects that site-specific land-uses have on the survival rates and population densities of semi-aquatic turtle populations because we found these metrics to be variable among individual populations. However, the populations in our 2 developed ponds, Christenbury and Glen Grove, did not seem to be severely affected by the land-use changes in their surrounding landscapes based on 3 years of data following the initiation of development. This suggests that some turtle populations may be able to persist in habitats affected by anthropogenic activities for at least a short time period. However, as suburban and urban landscapes become more widely developed, we may expect to find that critical habitat features disappear and thus impact population demographics, as seems to be the case at Mallard Head, a developed golf course pond whose turtles had among the lowest survivorship estimates. We emphasize the need for long-term studies that use mark–recapture techniques to evaluate how population demographics are affected by land-use in animals like turtles where effects may be difficult to discern using only relative abundances.

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