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PATTERNS OF SNAKE ROAD MORTALITY ON AN ISOLATED BARRIER ISLAND

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***Abstract*.—Road mortality can have severe impacts on wildlife populations. However, the degree of impact is not uniform across all taxa as some possess life-history strategies that render them especially vulnerable to vehicle collisions. As a group, snakes are greatly impacted by road mortality. However, susceptibility to vehicular mortality on roads can vary with species, age, and/or reproductive class. We present data on 186 snakes of five species (*Coluber constrictor, Opheodrys aestivus, Pantherophis alleghaniensis, Cemophora coccinea,* and *Nerodia fasciata*) killed on roads on Bald Head Island, an isolated barrier island with traffic consisting primarily of slow-moving electric golf carts. *Coluber constrictor* was the snake we most frequently found dead on the road. Neonate snakes of all species comprised the majority (59%) of our collected specimens. We observed male-biased sex ratios in collected specimens for three of the species (*C. constrictor*, *C. coccinea*, and *N. fasciata*). Mortality varied significantly across the study period, with the greatest number of kills recorded in early- to mid-August. Mortality was not strongly correlated with the number of visitors on the island. Instead, we suggest that susceptibility to road mortality is likely related to life-history characteristics (including activity patterns). We recommend attempting to reduce mortality of snakes during their peak activity periods with a combination of public education, heightened awareness via snake crossing signs, and reduced speed limits.**

Key Words.—activity patterns; barrier island; *Coluber constrictor*; golf carts; road mortality; species-specific mortality; traffic

INTRODUCTION

The United States currently contains more than 6.4 million km of roads with 84% of land being located within 1 km of a road (Forman et al. 2003). Roads can have severe indirect impacts on wildlife populations by fragmenting and isolating habitat (Ashley and Robinson 1996), creating barriers to dispersal (Aresco 2005), and degrading habitat quality (Andrews 1990; Reijnen et al. 1995; Forman and Alexander 1998). However, direct mortality is often the result when animals encounter roads (Bernardino and Dalrymple 1992; Gibbs and Shriver 2002; Puky 2006) and may be the single greatest source of non-natural mortality within natural areas (Andrews et al. 2008). Yet, not all taxa of wildlife nor age and reproductive classes of those taxa are equally susceptible to direct road mortality.

Annually, tens to hundreds of millions of snakes are killed by vehicles on roads in the United States (Rosen and Lowe 1994). Snakes are often highly vulnerable to road mortality due to their morphology, behavior (Rosen and Lowe 1994; Andrews and Gibbons 2005), and movement patterns (Caldwell et al. 1956; Seigel and Pilgrim 2002). Furthermore, snakes may be intentionally targeted by motorists (Langley et al. 1989; Ashley et al. 2007), thus increasing the number of snakes killed on roads relative to other wildlife. Road mortality of snakes is well-documented (Klauber 1939; Bernardino and Dalrymple 1992; Smith and Dodd 2003; Jochimsen 2006) and in some cases temporal, spatial, and demographic patterns in mortality have emerged (Bonnet et al. 1999; Enge and Wood 2002; Ciesiolkiwicz et al. 2006; Andrews and Gibbons 2008). More specifically, patterns in snake road mortality can vary spatially and are dependent upon community composition (Andrews et al. 2008). A better understanding of the processes determining susceptibility across a wide geographic range is necessary before impacts of roads on snake populations or communities can be effectively elucidated. Thus, we must quantify the degree of risk experienced by individual species and by different reproductive and age classes among species in different ecosystems. Only with this understanding can we begin to extrapolate results to other systems (Bonnet et al. 1999), and begin to formulate effective management plans to ameliorate road effects.

To our knowledge, no published studies have examined snake road mortality on a barrier island. Barrier islands can support dense populations of snakes with restricted immigration and emigration, and typically harbor a limited number of species (Lewis 1946; Tuberville et al. 2005). Therefore, the objective of our study was to elucidate patterns in species, size, and

TABLE 1. Life-history characteristics of five species of snakes encountered dead on the road (DOR) on Bald Head Island, North Carolina, USA, from 25 April to 1 October 2009. Values (means) were derived from the geographically closest reported studies: Nelson and Gibbons 1972; Gregory et al. 1987; Macartney et al. 1988; Gibbons and Dorcas 2005.

Trait	*Coluber constrictor*	*Pantherophis alleghaniensis*	*Opheodrys aestivus*	*Cemophora coccinea*	*Nerodia fasciata*
Reproductive mode	Oviparous	Oviparous	Oviparous	Oviparous	Viviparous
Clutch size	4–36 (12)	4–44 (15)	3–12	2–19 (5)	6–80 (22)
Foraging mode	Active	Active	Active	Active	Active
Home range size (ha)	9-11	10-15	< 1	Unknown	5
Activity season	Mar - Nov	Mar - Nov	Mar - Nov	May - Aug	Mar - Nov
Activity period	Diurnal	Nocturnal (summer)	Diurnal	Nocturnal	Nocturnal (summer)

reproductive class-specific susceptibility of snakes to road mortality on an isolated barrier island in North Carolina, USA. We also explored seasonal changes in mortality patterns and examined possible correlations between mortality rates and trends in tourist visitation.

METHODS

Study site.—Bald Head Island (BHI), is an 800 ha barrier island located in southeastern North Carolina. The majority of the island was forested and contained large tracts of intact maritime forest including the Bald Head Island Maritime Reserve, a 75 ha forest preserve free of development. The island was bordered to the north by 4,000 ha of protected salt marsh habitat with the Atlantic Ocean to the east and south and the Cape Fear River to the west. Much of the western portion of BHI had been converted to a golf course with 15 freshwater lagoons and large expanses of managed lawn. The southern portion of the island was largely sand dune with sparse low-growing vegetation and little to no tree canopy. There were 1000 homes on the island when we conducted our study; however, a town ordinance required that the natural habitat around each house must not be cleared and there were < 200 year-round residents.

Approximately 35 km of paved road existed on the island. Roads had two lanes, which were often separated by a median of dune or maritime forest vegetation. BHI is separated from mainland North Carolina by a 5-km wide section of the Cape Fear River and could only be accessed via passenger ferry departing Southport, North Carolina. Vehicular traffic on island was restricted to electric golf carts and the rare gas-powered vehicle used by public emergency personnel and private contractors. Posted speed limits on island did not exceed 31 km/hr.

Sampling methods.—From 25 April to 1 October 2009, all snakes encountered by investigators or volunteers while driving golf carts on BHI roads were collected. We surveyed a 4.59 km section of the main island road slowly by golf cart at least once per day. During each trip, we collected all snakes, live or dead. We staggered the timing of the survey throughout a 24 hour period, with transects being conducted based upon vehicle and staff availability. We also collected all snakes encountered opportunistically when driving outside of established surveys. We concentrated surveys on the main island road, which traverses mature maritime forest. However, we frequently drove on all of the islands roads throughout the study period. We attempted to keep the frequency of surveys, timing of surveys, and number of workers participating in surveys as constant as possible throughout the survey period.

We recorded the location and time of observation and brought the snake back to the lab for processing. All snakes were identified to species, weighed, measured, and sexed by probing. We assessed the reproductive status of each snake via palpation (live) or dissection (dead). We determined age class of each snake as adult or neonate based on its snout to vent length, with young of the year snakes being <300 mm for *Coluber constrictor* (Black Racer) and *Pantherophis alleghaniensis* (Yellow Rat Snake) and <200 mm for *Opheodrys aestivus* (Rough Green Snake), *Cemophora coccinea* (Scarlet Snake) and *Nerodia fasciata* (Banded Water Snake; Gibbons and Dorcas 2005). Live snakes were given unique identification brands (Winne et al. 2006) and were subsequently released at their capture location. We released all snakes within 24 hours and released many within an hour following capture. We derived clutch-size and home range data from the available literature (Table 1) and used these parameters to examine patterns in species-specific susceptibility to road mortality using linear regression. We used chi square tests to compare proportions of dead versus live snakes observed. We used a Kruskal-Wallis test to examine differences in mortality occurences throughout the study period looking at the total number of dead snakes collected in two week intervals.

TABLE 2. Number of snakes of five species encountered dead or alive on roads on Bald Head Island, North Carolina, USA, between 25 April and 1 October 2009.

Species	Total dead on road	Adults dead on road	Neonates dead on road	Total alive on road
Coluber constrictor	101	22	79	8
Pantherophis alleghaniensis	17	8	9	26
Opheodrys aestivus	46	32	14	10
Cemophora coccinea	11	11	0	3
Nerodia fasciata	11	3	8	3
Total	186	76	110	50

Traffic volume may be directly related to road mortality (Bernardino and Dalrymple 1992); however traffic data were not available for BHI. Therefore, we used information provided by the passenger ferry operators regarding the number of people visiting the island on a daily basis throughout the study period as an index of traffic volume. We used a Pearson's rank correlation to explore relationships between road mortality and this index of traffic volume. All tests were performed using SPSS 15.0 (SPSS Inc. Chicago, Illinois, USA) and alpha levels were set at 0.05.

RESULTS

From 25 April to 1 October 2009, we collected 186 dead on road (DOR) snakes of five species from the roads of BHI (Table 2). We captured and marked an additional 50 snakes of the same five species alive on road (AOR). We never subsequently encountered marked snakes as DOR, although we could have missed marks on severely mutiliated specimens. Seventy-nine percent of snakes we encountered were DOR and 21% were AOR. Encounters of both live and dead snakes differed significantly by species from expected if all encounter probabilities were considered to be equal (χ^2 = 13.25, df = 4, P <0.001). The snake we most often encountered DOR was *C. constrictor* (Table 1), and the snake we most often encountered AOR was *P. alleghaniensis*. Proportions of dead snakes differed significantly from proportions of live snakes we encountered (χ^2 = 13.87, df = 4, P <0.001).

Visitation to the island, which was used as an index of traffic volume, increased from under 200 to over 2000 visitors during summer weekends and holidays; but, was not significantly correlated with snake road mortality (r^2 = 0.013, P = 0.19). The total number of DOR snakes we encountered varied significantly across the study period (Fig. 2: χ^2 = 52.03, P <0.001). The greatest number of DOR snakes we encountered was found in early- to mid-August. The majority of DOR snakes we collected (79%) were the diurnal species: *C. constrictor* and *O. aestivus*. Adult *C. constrictor* road mortality was male-biased (Fig. 1: 70%); 67% of female *C. constrictor* encountered on roads were gravid (Fig. 1). Overall, 34% of female snakes we found on roads were gravid. Neonates accounted for 59% of all DOR snakes, with 78% of DOR *C. constrictor* and 73% of DOR *N. fasciata* being neonates. The only species for which we did not encounter neonates either DOR or AOR was *C. coccinea*. Encounter rates of snakes were positively related to reported home range sizes (r^2 = 0.47, P = 0.02), however, our encounters with neonates were not related to reported clutch sizes (r^2 = 0.04, P = 0.12).

DISCUSSION

Despite the limited duration of the study (five months), the small size of the study site, and the fact that the majority of the traffic consisted of slow-moving golf carts, we documented 186 DOR snakes. Paved roads and vehicles clearly can have a negative impact upon snake populations and communities (Klauber 1939; Bernardino and Dalrymple 1992; Andrews et al. 2008). However, quantifying the degree of the impact can be difficult (Dodd et al. 1989). In a study similar to ours, Rosen and Lowe (1994) projected that observed snake road mortality amounted to the removal of five km^2 of snake population over the duration of the study. Although the snake population levels on BHI are unknown, the large number of DOR snakes documented during this limited time period warrant conservation concern.

Assessment of the degree of impact is dependent upon not only the numbers of dead snakes but also on the sex, reproductive condition, and life stage of the individuals killed. This study, in addition to others (e.g., Bonnet et al. 1999; Ciesiolkiwicz et al. 2006; Row et al. 2007; Andrews and Gibbons 2008), suggests that not all species, ages, or reproductive classes are equally susceptible to direct road mortality and that these patterns may change seasonally. In an expansive 54-year road survey of snakes in South Carolina, Andrews and Gibbons (2008) reported a male bias for nearly half of the species encountered on roads. We report a male bias for three of the five species (*C. coccinea*, *N. fasciata*, and *C. constrictor*) found on roads on BHI. While Andrews and Gibbons (2008) also reported a tendency for snakes encountered on roads to be larger than snakes found off-road, we observed that over half of the snakes found DOR on BHI were neonates. While we do not have data on the average size of off-road snakes on BHI, this suggests the possibility of a different

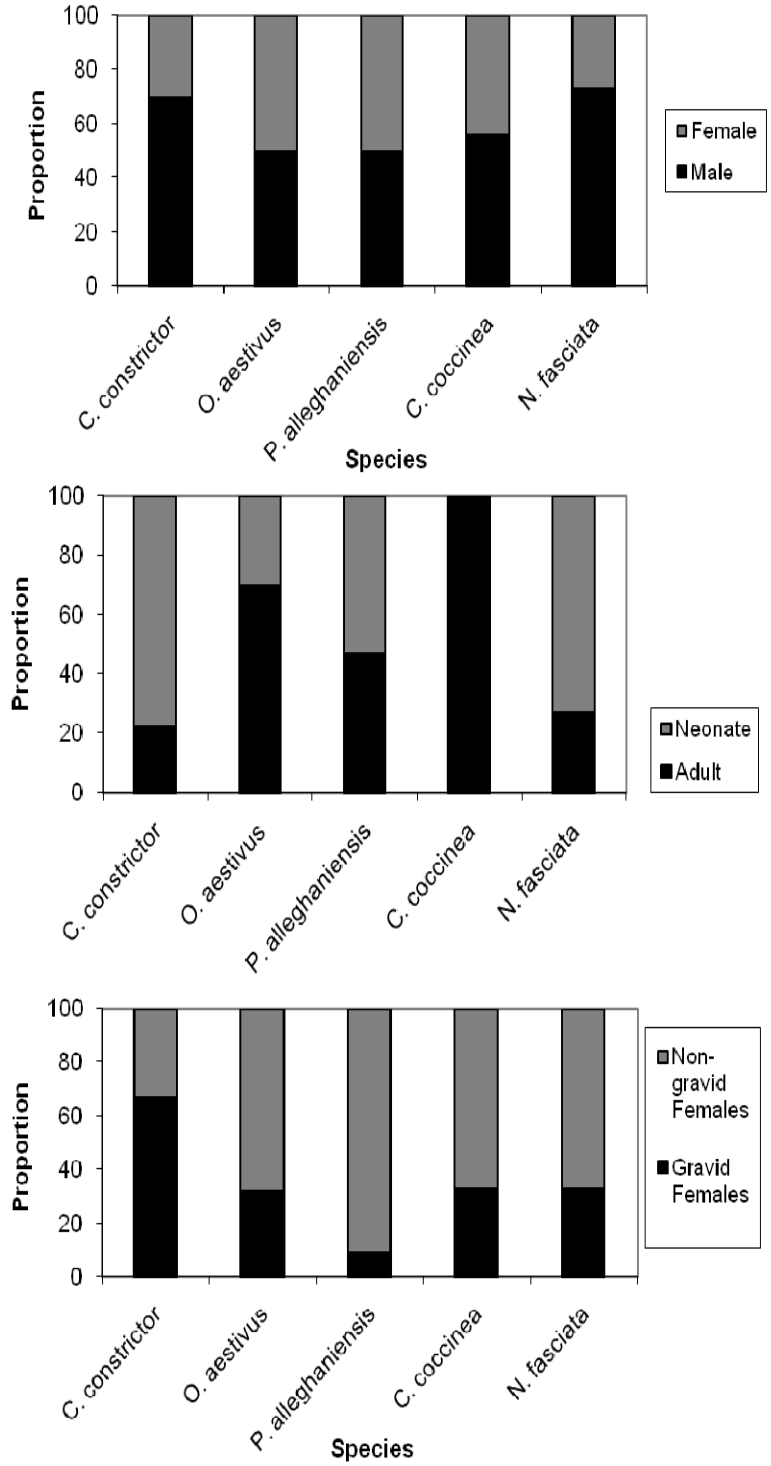

FIGURE 1. Relative proportions of male and female (top), neonate and adult (center), and gravid and non-gravid female (bottom) snakes encountered dead on the road on Bald Head Island, North Carolina, USA between 25 April and 1 October 2009.

pattern. Roads with high traffic volume and speed limits, like many of the roads surveyed in Andrews and Gibbon (2008), likely reduces the number of small snakes observed due to lowered obervability and rapid carcass degradation from repeated collisions. Conditions on BHI, low traffic volume, and surveying via slow-moving golf carts are ideally suited for detection of small-bodied snakes.

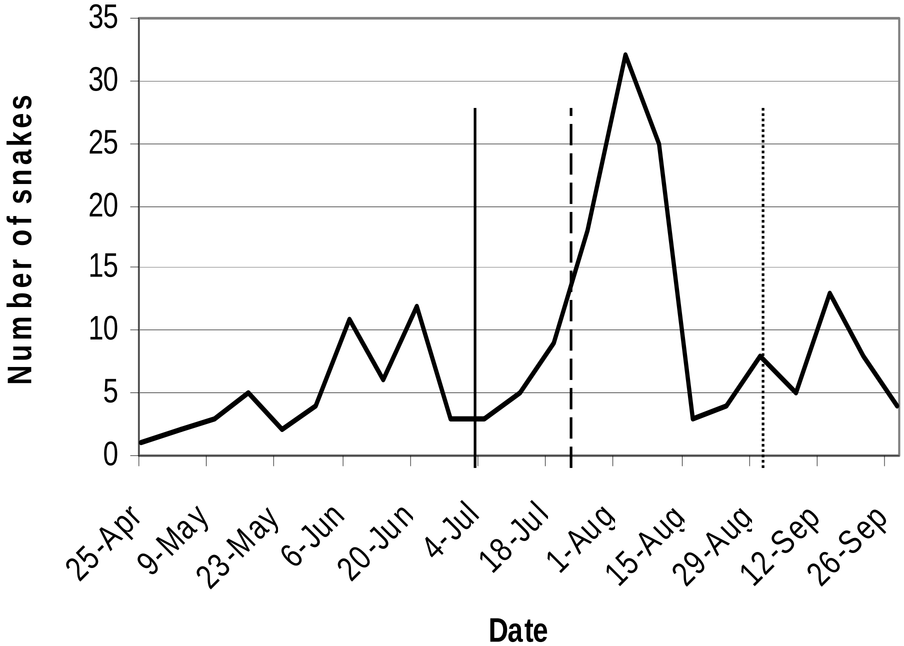

FIGURE 2. Number of dead on road snakes encountered on Bald Head Island, North Carolina, USA from 25 April to 1 October 2009. Vertical lines indicate first encounters with neonates of *Coluber constrictor* (solid), *Opheodrys aestivus* (dashed), and *Pantherophis alleghaniensis* (dotted).

The majority of DOR snakes found in this study were neonates of three species: *C. constrictor, N. fasciata,* and *P. alleghaniensis*. Neonate snakes may have been represented in large numbers due to the propensity of this life stage for long distance and erratic dispersal movements often characterized by a single large burst of travel (Gregory et al. 1987; Blouin-Demers et al. 2007). Snakes making longer movements are more likely to encounter roads so are more prone to being killed by a vehicle (Bonnet et al. 1999). Furthermore, the small size and cryptic coloration of many young snakes likely reduces their detectability, potentially increasing their probability of being struck. The large number of neonates recorded in this study may also be a reflection of higher detection probabilities from surveying via a slow-moving open-sided golf cart, whereas studies employing standard vehicles are prone to overlook the small bodies of DOR neonate snakes (Enge and Wood 2002). Demographically, the preponderance of DOR neonate snakes in our study may be less of a concern for the persistence of snake populations on BHI than other age and reproductive life stages because neonates naturally experience high mortality rates and may be less important from a population standpoint than certain other age and reproductive classes (Parker and Plummer 1987). However, a reduction or elimination of juvenile recuitment into the population can have serious demographic impacts for snake populations (Kingsbury and Attum 2009; Shine and Bonnet 2009).

Despite our limited knowledge of population demographics for many snake species, mortality of gravid females may have serious ecological impacts for a population (Parker and Plummer 1987; Bonnet et al. 1999; Row et al. 2007). Mortality of gravid females results in a reduction of the reproductive output for the entire population (Shine and Bonnet 2009). Equal levels of mortality of neonates or adult males will likely have a less significant effect in most situations (Bonnet et al. 1999). We observed that a large proportion of *C. constrictor* (67%) found DOR during our study were gravid. Gravid *C. constrictor* may be more likely to encounter roads as a result of this species' large home range size and propensity for gravid females to make long movements prior to nesting (Gregory et al. 1987; Macartney et al. 1988). Despite the importance of gravid females on a population level, mortality to other segments of snake population should not be overlooked. In some snake species, large, physically fit males make long mate-searching movements during the reproductive season increasing their risk of encountering roads (Madsen et al. 1993). High mortality rates to adult males can limit population growth by hindering genetic diversification (Shine and Bonnet 2009).

The majority (79%) of snakes we found DOR on BHI were the two diurnal species, *C. constrictor* and *O. aestivus*. This high proportion of diurnal species may be a reflection of relative abundance or the overlap of snake activity with the periods of the greatest golf cart activity on BHI. Most golf cart traffic on BHI is beach-related and thus, confined to daylight hours. *Pantherophis alleghaniensis* was the species most often found AOR. When approached by vehicles, *P. alleghaniensis* tend to freeze for long periods of time (Andrews and Gibbons 2005) leaving them vulnerable to being struck. Although not all drivers may actively avoid striking snakes (Langley et al. 1989), *P. alleghaniensis* may be more easily detected than other species due to their large size and immobility, thus allowing some drivers to avoid them. Furthermore, some drivers that may intentionally strike snakes when driving in cars or trucks may be hesitant to do so when in open-sided, slow-moving golf carts.

The number of daily visitors to BHI increases from less than 200 during April and early-May to over 2000 during summer weekends and holidays. Most visitors rent golf carts presumably leading to an increase in traffic volume as visitation increases. Road mortality rates on BHI were not correlated with visitor numbers, which was used as an index of traffic volume. Although not the case on BHI, increased traffic volume has been correlated with increased snake road mortality in another study (Bernardino and Dalrymple 1992). We suggest that patterns in snake road mortality may be driven more by snake activity patterns than traffic volume (Jochimsen 2006). For instance, *C. coccinea* is only active above ground during the hottest months of the summer (Nelson and Gibbons 1972), thus *C. coccinea* was only found DOR during those active months. The most dramatic increase in mortality occurred following the emergence of neonate *C. constrictor*, presumably making large dispersal movements. *Opheodrys aestivus* and *P. alleghaniensis* neonates emerged shortly afterward, contributing significantly to the number of DOR snakes. Interestingly, road mortality surveys may provide unique insight into reproductive timing for certain snake species (e.g. Klauber 1939), especially in understudied ecosystems such as barrier islands.

Our data must be interpreted in light of the fact that we were not able to quantify survey effort throughout the season because we relied heavily upon opportunistic encounters with DOR snakes. We typically conducted surveys once daily, with effort applied towards staggering surveys at all times of the day and night. This was supplemented by opportunistic encounters with DOR snakes from the authors, co-workers, and volunteers. We were not able to quantify volunteer effort throughout the study; however, because volunteers contributed less than 5% of the DOR snakes analyzed in this study, we do not believe that changes in volunteer effort obscured our ability to make accurate inferences about trends in snake mortality. Despite our inability to quantify effort, we attempted to keep the number of surveys per day, number of surveys conducted at different times of the day and night, and number of observers as constant as possible. We believe that the timing and number of surveys conducted were arrayed in such a way as to accurately describe seasonal patterns in road mortality and not simply increases in survey effort.

This study provided preliminary evidence that many snakes are being killed by slow-moving golf carts on a small, isolated barrier island. Patterns in mortality rates varied seasonally and by species. Within a species, susceptibility to road mortality varied by both reproductive class and age. Although a myriad of threats face species inhabiting rapidly developing coastal habitats, road mortality may constitute the greatest direct threat to snake communities on developed barrier islands such as BHI. Managers must take into account variation in species, reproductive class, and age-specific susceptibility to road mortality when designing management plans for snakes. Fortunately, during our study, snake movments were temporally constrained and predictable allowing for effective planning to minimize road mortality. Suggested mitigation measures include snake crossing signs, temporary road closures, and speed limit reductions coupled with public education and outreach.

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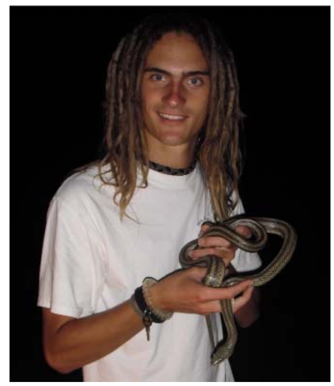

ERIC J. NORDBERG is a recent graduate from Penn State University with a B.S. in Wildlife and Fisheries Science. His passion for reptiles has led him to jobs working with sea turtles in North Carolina and along the gulf coast of the Florida. More recently he has started working where his passion lies; conducting timber rattlesnake surveys across Pennsylvania. Eric hopes to attend graduate school to pursue a Master's degree in the ecology of rattlesnakes. (Photographed by Daniel Myers)

KATHERINE E. STEPANOFF graduated from Penn State University with a B.S. in Wildlife and Fisheries Sciences. Her interest in reptiles has allowed her to work with snakes, alligators, and sea turtles in North Carolina and with that knowledge better create reptile educational programs for the public. Although her ultimate goal is to attend graduate school, she is currently looking for local environmental education work to accommodate her Olympic rugby training schedule. (Photographed by Daniel Myers)

JACOB E. HILL recently earned his B.A. in Biology from the University of North Carolina at Chapel Hill. He has worked with many species of snakes, semi-aquatic turtles, and marine turtles. His research interests include the nesting ecology of turtles and anthropogenic impacts on barrier island herpetofauna. (Photographed by Brett DeGregorio)