Reptile Road Mortality around an Oasis in the Illinois Corn Desert with Emphasis on the Endangered Eastern Massasauga

Donald B. Shepard[1], Michael J. Dreslik[2], Benjamin C. Jellen[3], and Christopher A. Phillips[2]

Roads have numerous negative ecological effects on terrestrial fauna, and vehicular mortality can have significant demographic consequences for some species. We studied road mortality of reptiles around Carlyle Lake, Clinton County, Illinois, USA, from April 2000 through November 2002, to assess the impact of vehicular traffic and identify influential factors. Carlyle Lake, a popular tourism/recreation area, is situated in a larger agricultural landscape and is home to the largest Illinois population of the endangered Eastern Massasauga (*Sistrurus catenatus*). We documented 321 cases of reptile road mortality (84 individuals of six turtle species and 237 individuals of nine snake species) while driving our approx. 46 km study route roundtrip daily. Turtle road mortality was highest in May and June, and positively associated with precipitation and minimum daily temperature. Colubrid snake road mortality was highest in April and October, and positively associated with minimum daily temperature. We recorded 42 cases of road mortality of *S. catenatus* with the highest number occurring from mid-August to mid-September. Road mortality in *S. catenatus* was biased toward adult males, which show an increase in movement in August, coinciding with the peak of the mating season and a period of high tourist visitation. The traffic intensity on a road segment did not significantly affect the level of road mortality, but segments through high quality habitats had higher levels of mortality than segments through lower quality habitats. Based on our study on the ecology of *S. catenatus*, we make recommendations to reduce road mortality that should aid in the conservation of the Carlyle Lake population.

ROADS are perhaps the most conspicuous artificial features across most landscapes in the United States and have been shown to have numerous negative ecological effects on both aquatic and terrestrial fauna (Forman and Alexander, 1998; Trombulak and Frissell, 2000; Forman et al., 2003). These negative effects may be direct, such as habitat loss and vehicular mortality, and indirect, such as population isolation and fragmentation (Forman and Alexander, 1998; Spellerberg, 2002; Forman et al., 2003). Documenting indirect effects often requires intensive study and longer time periods whereas direct effects are more apparent and immediate (Forman et al., 2003). Many intrinsic (e.g., sex, reproductive stage and cycle, ecology) and extrinsic factors (e.g., temperature, precipitation, insolation) influence animal movement and can consequently affect road mortality (Gregory et al., 1987; Peterson et al., 1993; Forman et al., 2003). In addition, anthropogenic factors such as traffic volume and patterns may have an effect on road mortality (Fahrig et al., 1995; Hels and Buchwald, 2001; Mazerolle, 2004). Studying road mortality patterns and identifying influential factors can help to generate effective management strategies to reduce the number of animals killed on roads.

Reptiles are reported to be suffering declines worldwide (Gibbons et al., 2000), and road effects are likely contributing to declines in many species. As ectotherms, reptiles are strongly influenced by environmental conditions (Lillywhite, 1987; Peterson et al., 1993; Zug et al., 2001), and the ecology of many species makes them especially susceptible to the negative effects of roads (Forman et al., 2003). For example, in aquatic turtles, adult females are killed on roads as they make terrestrial forays for nesting (Aresco, 2005a; Gibbs and Steen, 2005; Steen et al., 2006). Species with life histories characterized by low reproductive rates and low adult mortality (e.g., most turtles and rattlesnakes) are more vulnerable to demographic consequences of road mortality (Forman et al., 2003). As little as 2–3% additive annual mortality may be more than most turtle species can tolerate and still maintain positive population growth (Brooks et al., 1991; Gibbs and Shriver, 2002). Road mortality has been implicated in changing population sex ratios in turtles (Steen and Gibbs, 2004; Gibbs and Steen, 2005; Steen et al., 2006) and for affecting snake abundances (Rudolph et al., 1999; Kjoss and Litvaitis, 2001). The negative effects of roads are often exacerbated in highly fragmented landscapes (Forman et al., 2003; Marchand and Litvaitis, 2004).

The landscape of the mid-western United States is a matrix of roads, agriculture, urban areas, and degraded natural habitats. In such landscapes, wildlife is often forced into suboptimal habitat patches surrounded by unsuitable habitat and roads that act as dispersal barriers. One example of such a situation is Carlyle Lake, Clinton County, in south-central Illinois. Carlyle Lake, created in 1967, is Illinois'

[1] Sam Noble Oklahoma Museum of Natural History and Department of Zoology, University of Oklahoma, 2401 Chautauqua Avenue, Norman, Oklahoma 73072; E-mail: dshepard@ou.edu. Send reprint requests to this address.
[2] Illinois Natural History Survey, Center for Biodiversity, 1816 South Oak Street, Champaign, Illinois 61820.
[3] Illinois Natural History Survey, Center for Biodiversity, 1816 South Oak Street, Champaign, Illinois 61820; Present Address: Department of Biology, Saint Louis University, 3507 Laclede Avenue, St. Louis, Missouri 63103.
Submitted: 29 November 2006. Accepted: 2 October 2007. Associate Editor: G. Haenel.
 DOI: 10.1643/CE-06-276

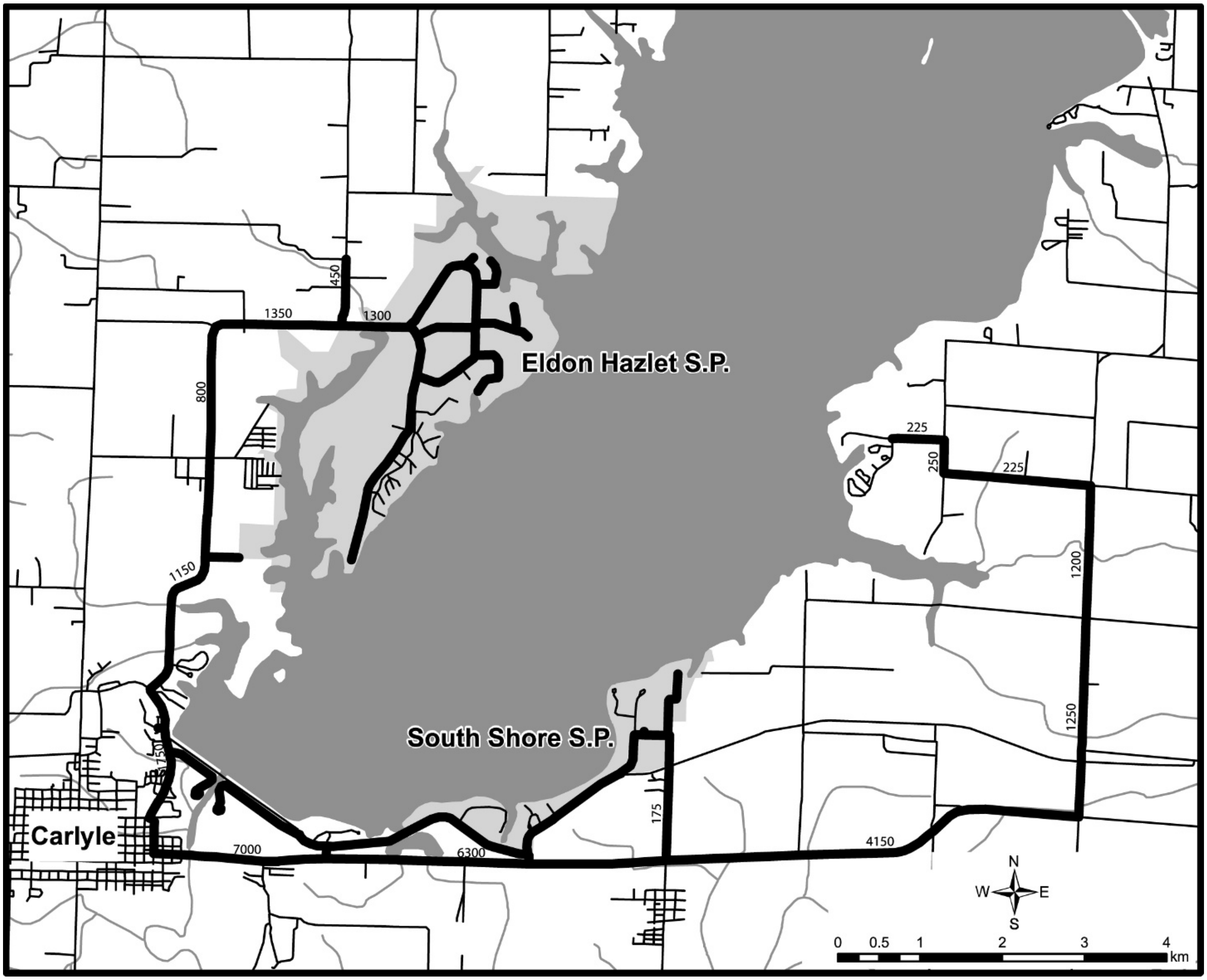

Fig. 1. Map of Carlyle Lake, Illinois, showing the state parks (S.P.) and the study route (bold). Numbers next to roads are annual mean number of vehicles per day for that segment.

largest reservoir at approx. 10,500 ha and is surrounded by a thin band of degraded grasslands, wetlands, and upland and bottomland forest totaling approx. 4,500 ha. The area is situated in a larger agricultural landscape, sometimes referred to as the Illinois Corn Desert because of the vast crop monoculture, and is a popular tourism/recreation area, receiving approximately three million visitors annually. Carlyle Lake is home to the largest known Illinois population of the Eastern Massasauga (*Sistrurus catenatus*), a species which has declined across most of its eastern range and now occurs in a few isolated populations in most states where it persists (Szymanski, 1998). *Sistrurus catenatus* is afforded legal protection at the state/provincial level throughout its eastern range and is currently a candidate for federal listing in the United States (Szymanski, 1998; U.S. Fish and Wildlife Service, 1999).

Here, we examine road mortality of reptiles around Carlyle Lake, Illinois, to assess the impact of vehicular traffic. We look at mortality patterns and attempt to identify the intrinsic (e.g., sex, age class, ecology), extrinsic (e.g., temperature, precipitation) and anthropogenic factors (e.g., traffic volume, pattern) that influence road mortality. Our goal is to generate recommendations for reducing the number of *S. catenatus* killed on roads around Carlyle Lake, which will hopefully benefit other reptile species as well. Carlyle Lake is typical of the situation in many places throughout the developed world and our study will provide important insight into the ecological effects of roads on reptiles and the conservation of wildlife in human-dominated landscapes.

MATERIALS AND METHODS

From April 2000 through November 2002, as part of a larger study on the ecology of *S. catenatus*, we drove an approx. 46 km stretch of road around the southern periphery of Carlyle Lake (38°37′N, 89°21′W; Fig. 1) during the season when snakes were active (approx. 8 months a year from mid-March to mid-November). We drove roads roundtrip at least once daily at varying times between 0700 and 2200 h. Roads were centered on the city of Carlyle, population of approx. 3,400, and included two-lane state highways, paved county and city roads, and paved roads within state parks (Eldon Hazlet and South Shore state parks) and recreation areas.

Although sampling effort varied slightly among road segments on a daily basis because we were conducting other studies, we are confident that effort was roughly equal among segments on a monthly basis and among months, thus we analyze most data at this level.

In 2000, we collected data on all dead-on-road (DOR) *S. catenatus* and all reptiles that were salvageable for collection and deposition in the Illinois Natural History Survey (INHS) amphibian and reptile collection. In 2001 and 2002, we recorded data on every DOR reptile encountered regardless of whether it was salvaged. For each DOR reptile, we recorded the species, date, GPS coordinates, and sex/life stage, if diagnosable. Unsalvaged specimens were removed from the road to avoid recounting them and to prevent scavengers from being hit on the road. We acknowledge that road mortality data for 2000 are incomplete because we only recorded data on salvaged specimens (except for *S. catenatus* for which we documented every case). However, our data set is still large, and numbers and patterns for 2000 are similar to 2001 and 2002. Therefore, we present the 2000 data, but omit it from some analyses where the difference in collecting methods would be important. We also assume that we did not document all instances of road mortality because some animals may have moved off the road or been scavenged prior to our discovery. We are confident, however, that we were able to document the majority of cases and no systematic bias existed that would have impacted our overall results.

We obtained climatic data (minimum, maximum, and mean daily temperature, and daily precipitation) for the study period from the National Climatic Data Center records for the Carlyle Reservoir recording station, Carlyle, Illinois. When data were lacking for the Carlyle Reservoir station, we obtained data from the Nashville, Illinois, recording station (approx. 20 km south). Direct measures of traffic volume for all roads in the study area were not available, but we obtained data on monthly visitation numbers for the study period from the U.S. Army Corps of Engineers, Carlyle Lake Office, Carlyle, Illinois. These numbers are calculated using a formula that includes traffic counts around the lake, collection of use fees, and the average number of people per vehicle, and thus provide an estimate of overall traffic volume around the lake each month. Additionally, we obtained data from the Illinois Department of Transportation on the annual mean number of vehicles per day for some segments of the study route (Fig. 1), which we used as a measure of relative traffic intensity among road segments.

Statistical analysis.—We used chi-square tests to determine if the numbers of DOR reptiles differed among months (April to October), and calculated Pearson correlation coefficients to ascertain if monthly numbers of DOR reptiles were correlated with monthly visitation numbers. We used forward stepwise logistic regression to test if climatic factors (minimum, maximum, and mean daily temperature, and precipitation in the previous 24 h) affected road mortality. For this analysis, the response variable was binary: DOR reptile present or absent on a given day. We analyzed turtles and snakes separately, and treated colubrid snakes separate from the single viperid species (*S. catenatus*) because of differences in their ecology and evolutionary history (e.g., foraging behavior, mating system, reproductive cycle). Further, we used only data from 2001 and 2002 (except for *S. catenatus* for which we had complete data for all years 2000–2002), and restricted our analyses to the months when mortality was highest (May and June for turtles, April and October for colubrid snakes, and August and September for *S. catenatus*).

Variation in traffic intensity among road segments and the quality of the habitat through which different road segments run may affect spatial patterns of road mortality. To test whether these affected the number of DOR reptiles per segment or interact, we categorized habitat and traffic intensity, and conducted a two-way ANOVA with *post hoc* Tukey HSD tests. Because road segments differed in length, we scaled the number of DORs for a segment to the number per km. We then $\log_e$ (x + 1) transformed this number to normalize the data before analysis. Habitat quality was classified as: high, natural or semi-natural habitat occurs on both sides of the road for the majority (>50%) of the segment; moderate, natural or semi-natural habitat occurs on at least one side for the majority (>50%) of the segment or on both sides for a significant portion (25 to 49%); or low, natural or semi-natural habitat is absent from all or most (<24%) of both sides of the segment (e.g., agriculture). Traffic intensity (annual mean number of cars per day) was categorized into three classes based on natural breaks: high, 4,150 to 7,000; moderate, 1,150 to 1,750; or low, 175 to 800 vehicles per day. Analyses were conducted using SPSS 10.0.

RESULTS

Seasonal patterns.—From April 2000 through November 2002, we documented 321 cases of reptile road mortality, which included 84 individuals of six turtle species and 237 individuals of nine snake species (Table 1). The most frequently encountered turtle species were *Trachemys scripta*, *Terrapene carolina*, and *Chrysemys picta*, and the most frequently encountered snake species were *Thamnophis sirtalis*, *S. catenatus*, *Lampropeltis calligaster*, *Coluber constrictor*, and *Nerodia sipedon* (Table 1). No lizards were observed DOR during our study. Overall, the number of DOR reptiles differed among months (April to October: $\chi^2 = 18.41$, df = 6, $P = 0.005$) and the frequency distribution was bimodal with peaks in the spring and early fall (Fig. 2A).

When groups were examined separately, turtle road mortality differed among months ($\chi^2 = 50.0$, df = 6, $P < 0.0001$) and was highest in May and June (Fig. 2A). Sex ratios of DOR turtles were near equal or male-biased (e.g., *C. picta*, 8M:3F, $\chi^2 = 2.27$, $P = 0.13$; *T. carolina*, 15M:3F, $\chi^2 = 8.00$, $P = 0.005$; *T. scripta*, 6M:9F, $\chi^2 = 0.60$, $P = 0.44$). Colubrid snake mortality also differed among months ($\chi^2 = 56.9$, df = 6, $P < 0.0001$) and was bimodal with peaks in April and October (Fig. 2A). Juveniles comprised the majority of colubrid snake road mortality cases in September and October ($\chi^2 = 5.79$, df = 1, $P = 0.02$), whereas adults comprised the majority of cases from April to August ($\chi^2 = 21.5$, df = 1, $P < 0.0001$). We recorded 42 DOR *S. catenatus* during the study period (2000–2002). Road mortality differed among months ($\chi^2 = 34.6$, df = 6, $P < 0.0001$), with the highest number (28) occurring in August and September (Fig. 2B). Of these, 22 (79%) occurred between 15 August and 15 September. Adult road mortality was biased toward males ($\chi^2 = 4.48$, df = 1, $P = 0.03$) and they comprised most of the road mortality cases in August (Fig. 2B). Juvenile/neonate road mortality was most frequent in September (Fig. 2B).

Table 1. Species and Numbers of Reptiles Killed by Vehicles around the Southern Periphery of Carlyle Lake, Illinois, from 2000–2002.

	Year			
	2000	2001	2002	Total
Snakes				
Coluber constrictor	5	14	8	27
Heterodon platirhinos	0	1	2	3
Lampropeltis calligaster	8	12	16	36
Nerodia rhombifer	1	0	1	2
Nerodia sipedon	6	12	8	26
Pantherophis spiloides	2	8	3	13
Sistrurus catenatus	17	14	11	42
Storeria dekayi	2	1	1	4
Thamnophis sirtalis	22	34	28	84
Turtles				
Chelydra serpentina	1	4	4	9
Chrysemys picta	0	3	13	16
Sternotherus odoratus	1	0	0	1
Terrapene carolina	2	9	17	28
Terrapene ornata	0	0	1	1
Trachemys scripta	2	3	24	29

Environmental factors.—During the peak of turtle road mortality, May and June, precipitation in the previous 24 h ($\beta = 1.27$, $\chi^2 = 9.09$, df = 1, $P = 0.003$) and a higher daily minimum temperature ($\beta = 0.06$, $\chi^2 = 4.35$, df = 1, $P = 0.04$) increased the probability of a DOR turtle on a given day. Neither mean daily ($\chi^2 = 0.01$, df = 1, $P = 0.99$) nor maximum daily temperature ($\chi^2 = 0.15$, df = 1, $P = 0.70$) affected turtle road mortality. During April and October, when colubrid snake road mortality was highest, a higher daily minimum temperature ($\beta = 0.06$, $\chi^2 = 9.29$, df = 1, $P = 0.002$) increased the probability of a DOR colubrid snake on a given day, but maximum daily temperature ($\chi^2 = 0.005$, df = 1, $P = 0.94$), mean daily temperature ($\chi^2 = 0.03$, df = 1, $P = 0.87$), and precipitation in the previous 24 h ($\chi^2 = 0.39$, df = 1, $P = 0.53$) had no effect. During August and September, when road mortality of *S. catenatus* was highest, none of the climatic variables significantly affected the probability of a DOR *S. catenatus* on a given day (minimum daily temperature: $\chi^2 = 3.04$, df = 1, $P = 0.08$; maximum daily temperature: $\chi^2 = 3.03$, df = 1, $P = 0.08$; mean daily temperature: $\chi^2 = 3.26$, df = 1, $P = 0.07$; precipitation in previous 24 h: $\chi^2 = 2.08$, df = 1, $P = 0.15$).

Anthropogenic factors.—Visitation at Carlyle Lake was lowest during cold months (November to March) and highest throughout the summer, peaking in July (Fig. 3). Over the course of the entire active season (April to October), mean monthly reptile road mortality was negatively correlated with mean monthly visitation ($r = -0.94$, $n = 7$, $P = 0.002$). Road mortality was lowest during the period with the highest visitation and highest during periods when visitation was increasing (spring) and decreasing (fall; Fig. 3). When examined separately, mean monthly turtle road mortality ($r = 0.13$, $n = 7$, $P = 0.78$) was not correlated with mean monthly visitation, but colubrid snake mortality was negatively correlated ($r = -0.82$, $n = 7$, $P = 0.02$). Considering the entire active season, mean monthly road mortality of *S. catenatus* was not correlated with mean monthly visitation numbers ($r = 0.13$, $n = 7$, $P = 0.79$), but the peak in road mortality did coincide with a period of high visitation (August and September; Fig. 3). Although some days might be expected to have higher visitation levels than others (e.g., weekends), the number of DOR reptiles did not significantly differ among days of the week (April to October in 2001 and 2002: $\chi^2 = 3.93$, df = 6, $P = 0.69$).

Spatial patterns.—Reptile road mortality was most concentrated on roads adjacent to the lake entering and leaving the city of Carlyle, the entrance road to Eldon Hazlet State Park, and roads within both state parks (Fig. 4A). The majority of road mortality of *S. catenatus* occurred within the two state parks (25 of 42 cases or approx. 60%; Fig. 4B). Traffic intensity data (annual mean number of vehicles per day) were available for some road segments (Fig. 1) and 53% of road mortality cases occurred on these segments. Examining these roads, mortality varied considerably among segments over the course of the three-year study (mean = 6.8 DORs per km, SD = 8.2, $n = 15$, range 0–32.9). When only 2001 and 2002 data were examined and averaged, the annual mean number of DOR reptiles per km on these segments was 2.89, and varied from 0 to 15.25 with the entrance road to Eldon Hazlet State Park having the highest level. Habitat quality and traffic intensity did not significantly interact ($F_{3,7} = 0.09$, $P = 0.96$) to affect the number of DOR reptiles per km. Individually, traffic intensity did not significantly affect the number of DOR reptiles per km ($F_{2,7} = 2.02$, $P = 0.20$), but habitat quality had an effect ($F_{2,7} = 9.57$, $P = 0.01$). Road segments through high quality habitats did not significantly differ in mortality from segments through moderate quality habitats ($P = 0.06$), but both had significantly higher mortality than segments through low quality habitats ($P = 0.002$ and $P = 0.03$, respectively).

DISCUSSION

Seasonal patterns.—Snakes and turtles were commonly found DOR throughout our study and several seasonal patterns in road mortality were evident. Colubrid snake road mortality was bimodal whereas *S. catenatus* and turtle

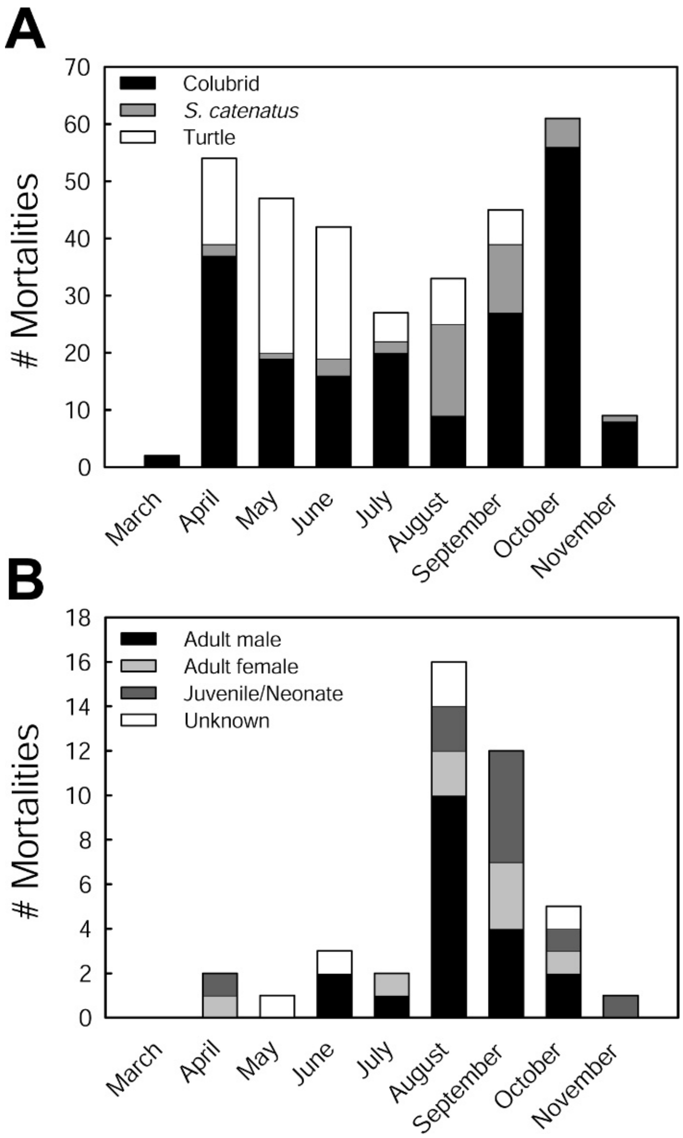

Fig. 2. Monthly frequencies of road mortality of (A) all reptiles and (B) *Sistrurus catenatus* by sex/stage class for 2000–2002.

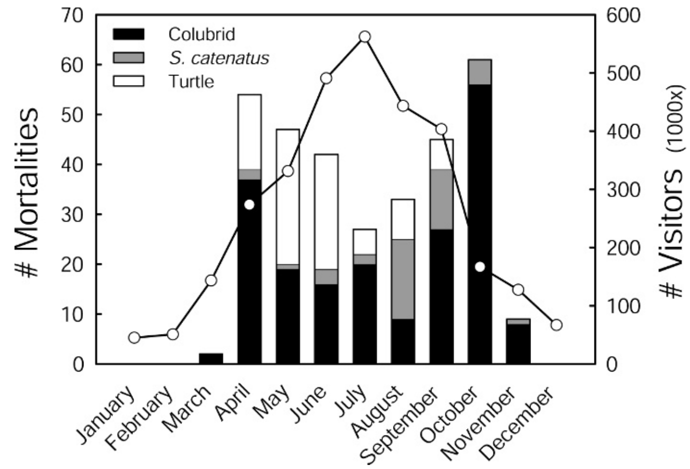

Fig. 3. Monthly frequencies of road mortality (bars) along with mean monthly visitation numbers for 2000–2002 (line) at Carlyle Lake, Illinois.

patterns were unimodal. Previous reptile road mortality studies have found either bimodal or trimodal peaks in annual road mortality (snakes: Campbell, 1953; Enge and Wood, 2002) whereas others have found unimodal (snakes: Rosen and Lowe, 1994; turtles: Ashley and Robinson, 1996) or uniform (Dodd et al., 1989) patterns.

Many factors interact to produce seasonal patterns in road mortality including species ecology, climatic conditions, and traffic patterns. Typically, most DOR adult turtles are females that are killed during nesting forays (Aresco, 2005a; Gibbs and Steen, 2005; Steen et al., 2006). We did not observe such a strong female-biased sex ratio of DOR adult turtles and instead observed near equal or male-biased ratios. Male *T. carolina* move longer distances and have larger home ranges than females at Carlyle Lake (Kuhns, 2004), which may explain the male-biased sex ratio of DOR adults in this terrestrial species. However, reasons for the atypical sex ratio in the two aquatic turtle species may be related to a flood experienced in 2002.

Snakes are at the highest risk of mortality when they move and snakes that move more usually cross roads more frequently (Bonnet et al., 1999; Roe et al., 2006). Road mortality is often high in adult males of species whose mating system involves intense mate searching by males and in species whose ecology involves seasonal habitat shifts (Bonnet et al., 1999). Similar to previous studies, we found that colubrid snakes were primarily killed on roads during the spring and fall, coinciding with movements to and from winter hibernacula (Gibbons and Semlitsch, 1987; Tucker, 1995; Bonnet et al., 1999). Further, most DOR colubrid snakes in the fall were young-of-the-year, which encounter roads during post-natal/hatching dispersal (Campbell, 1953; Bonnet et al., 1999; Enge and Wood, 2002).

Road mortality of *S. catenatus* was highest in August and September, with adult males comprising the majority of cases in August. Male *S. catenatus* movement increases in August, coincident with the peak of the mating season (Dreslik, 2005; Jellen et al., 2007; Aldridge et al., in press). Movement is a major determinant of male mate acquisition success in *S. catenatus* (Jellen et al., 2007) and males would be predicted to encounter roads more frequently during the mating season as they move in search of mates (Bonnet et al., 1999). *Sistrurus catenatus* also often exhibits a seasonal shift in habitat use, especially between hibernation sites and summer home ranges (Seigel, 1986; Johnson, 2000; Harvey and Weatherhead, 2006). If habitats are separated by roads, snakes will be at increased risk of mortality during movement (Bonnet et al., 1999). Seigel (1986) found that road mortality of *S. catenatus* in Missouri was highest from mid-September to mid-October as snakes returned to their hibernacula from their summer home ranges. Adult *S. catenatus* at Carlyle Lake do not exhibit a similar seasonal shift in habitat use (Dreslik, 2005); however, neonate *S. catenatus*, which at Carlyle Lake primarily eat southern short-tailed shrews (*Blarina carolinensis*), exhibit a habitat shift as they move away from their birthing sites to forage before over-wintering (Shepard et al., 2004). Birthing at Carlyle Lake occurs primarily in early-August (Shepard et al., 2004; Aldridge et al., in press) and juvenile/neonate road morality was highest in August and September (Fig. 2B). Thus, the seasonal pattern of road mortality of *S. catenatus* is best explained by the timing of the mating season coupled with the male mating strategy, and neonate dispersal and foraging behavior.

Environmental factors.—Increased road mortality of amphibians is often associated with precipitation (Ashley and

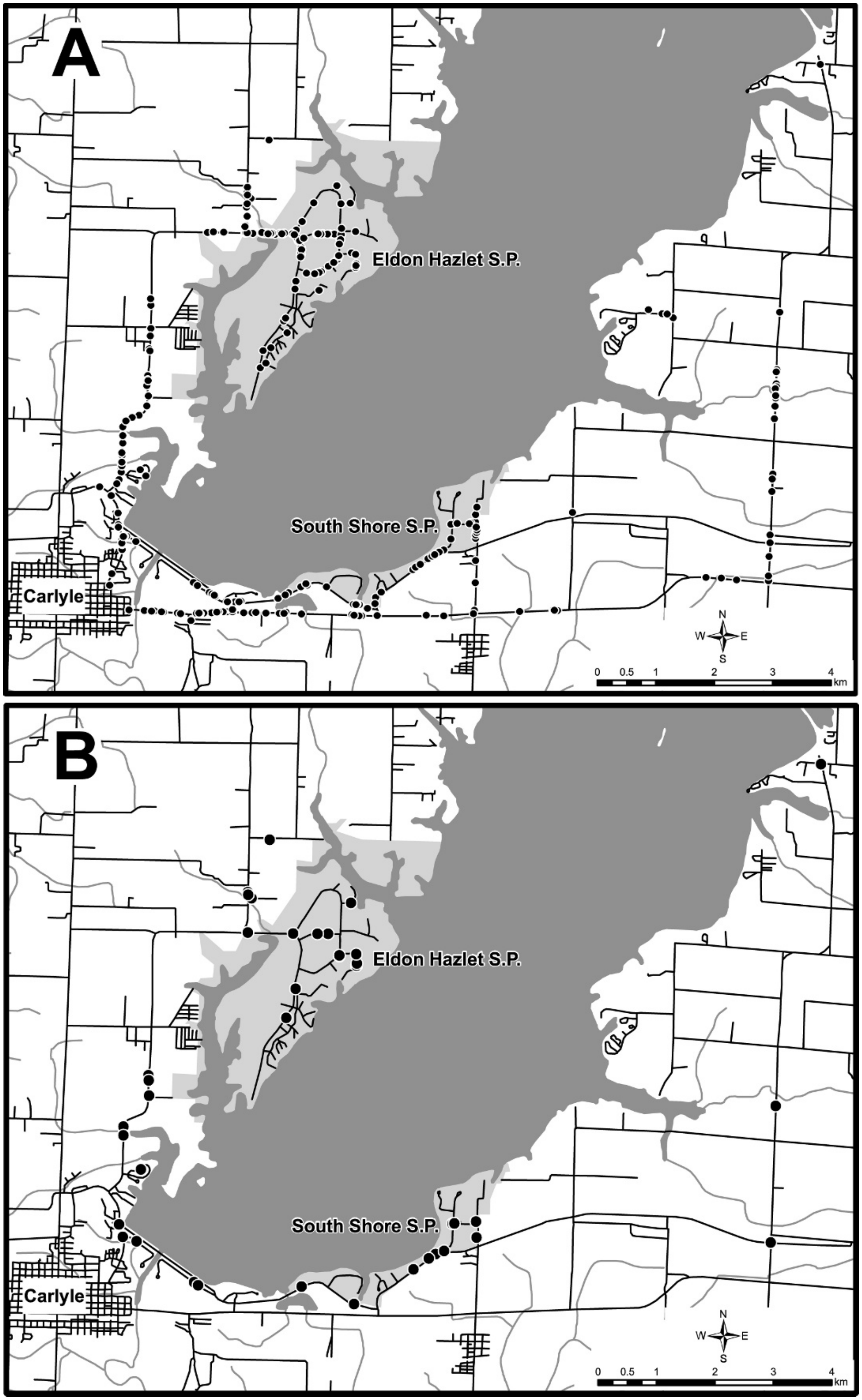

Fig. 4. Map showing locations of road mortality of (A) all reptiles and (B) *Sistrurus catenatus* for 2000–2002.

Robinson, 1996; Hels and Buchwald, 2001; Mazerolle, 2004), but few studies have found a similar association for reptiles. Vijayakumar et al. (2001) found that uropeltid snakes were killed more often on roads during or immediately following rains, but road mortality in all other reptiles was not associated with precipitation. Bernardino and Dalrymple (1992) reported that snake road mortality in south Florida was negatively correlated with monthly rainfall and mean daily minimum temperature, and Dodd et al. (1989) found that climatic variables explained little of the variation in the number of reptiles on roads in Alabama, with the exception of precipitation, which was weakly correlated. In our study, turtle road mortality in May and June was positively associated with precipitation and minimum daily temperature. In aquatic turtles, female nesting forays may be timed with precipitation events because of the water requirements associated with nesting (e.g., sequestration of water and moist soil for digging; Burke et al., 1994; Wilson et al., 1999). Further, precipitation stimulates increased movement and facilitates foraging in terrestrial species like *T. carolina* (Strang, 1983; Donaldson and Echternacht, 2005).

During April and October of our study, road mortality of colubrid snakes was positively associated with minimum daily temperature. Reptile movement is largely influenced by temperature, and a minimum operative temperature is required for normal locomotion (Lillywhite, 1987). Further, snakes may be attracted to roads to thermoregulate, especially in the spring and fall when roads are often warmer than the ambient temperature. Road mortality of *S. catenatus* in August and September showed no significant association with any climatic variable. Thus, road mortality patterns in this species appear to be more influenced by other factors (i.e., male mate-searching and neonate dispersal).

The number of DOR turtles showed a marked increase in 2002 over previous years (Table 1). The reasons for this increase are likely related to the effects of a flood in 2002, which inundated many areas, including parts of both state parks, from mid-May to mid-June. Aquatic turtles track changes in water levels and may cross roads during floods and droughts (Aresco, 2005b). Increased road mortality occurs when waters recede and turtles of both sexes and all age classes are forced to cross roads as they follow the receding water (Aresco, 2005b). This appears to be the case after the 2002 flood and may explain why sex ratios of DOR aquatic turtles were closer to even rather than female-biased as they typically are in other studies (Aresco, 2005a; Gibbs and Steen, 2005; Steen et al., 2006). Snakes also respond to seasonal fluctuations in surface water levels, which may result in increased road crossings (Bernardino and Dalrymple, 1992; Tucker, 1995; Tucker et al., 1995), but we observed no changes in the number of DOR snakes in 2002 compared to the previous two years. Seigel et al. (1998) and Seigel and Pilgrim (2003) observed fewer *S. catenatus* crossing roads in years following a flood similar to the extent of the 2002 Carlyle Lake flood in spite of no apparent change in population size. Unfortunately, we lack detailed data on road mortality at Carlyle Lake for post-flood years for a similar comparison.

Anthropogenic factors.—Several studies have found that traffic volume is positively correlated with road mortality in amphibians (Fahrig et al., 1995; Hels and Buchwald, 2001; Mazerolle, 2004) and reptiles (Szerlag and McRobert, 2006); however, this is not always the case (Dodd et al., 1989; Enge and Wood, 2002). Over the span of the entire active season, reptile road mortality at Carlyle Lake was negatively correlated with monthly visitation numbers. Traffic volume and patterns often influence road mortality through interactions with other factors, which may be species- or site-specific. For example, as air temperature gets warmer in the spring, traffic volume at Carlyle Lake increases as more people use lake facilities. Road mortality is high when daily and seasonal activity patterns coincide with periods of peak traffic volume (Rosen and Lowe, 1994; Hels and Buchwald, 2001). Many snakes are diurnal during the spring and fall, but shift to crepuscular or nocturnal activity during the hot summer months (Gibbons and Semlitsch, 1987; Dodd et al., 1989). Thus, although visitation at Carlyle Lake is highest from June through September, the time of day when most snakes are active during this period does not coincide with the time of day that most visitors use the lake (mid-day). Increases in daytime traffic volume during the spring and fall, or increases in evening and nighttime traffic volume during summer months would likely lead to increased road mortality. It is possible that traffic volume positively correlates with road mortality over shorter time scales than what we examined (e.g., daily within some months or hourly within some days). Although we lack the detailed data on traffic volume needed to test this adequately, we found that the number of DOR reptiles did not significantly differ among days of the week.

Variation in monthly visitation numbers did not significantly explain the seasonal pattern in road mortality of *S. catenatus*; however, the peak of road mortality coincided with a period of high tourist visitation. Male *S. catenatus* movement increases during the mating season as males move in search of mates (Jellen et al., 2007), which results in a higher number of road crossings and increased road mortality. The coincidence of the mating season and high traffic volume during this time of year exacerbates the road mortality problem; however, the effects may be partially alleviated because adult *S. catenatus* shift to a primarily crepuscular/nocturnal activity pattern during summer (Seigel, 1986; Dreslik, 2005). Contrary to our results, Seigel (1986) found that road mortality of *S. catenatus* in Missouri was positively correlated with traffic volume; however, traffic patterns at his site differed from those at Carlyle Lake in that traffic volume was low during the summer and highest in the fall. Other factors such as species vagility (Carr and Fahrig, 2001; Roe et al., 2006) and the speed and angle of crossing (Hels and Buchwald, 2001; Andrews and Gibbons, 2005) also affect the probability of encountering roads and being killed while crossing. Although viperids like *S. catenatus* are more sedentary than most colubrids, and thus would be predicted to encounter roads less frequently, the speed with which they cross roads is considerably slower (Andrews and Gibbons, 2005), which increases the probability of being killed while crossing (Hels and Buchwald, 2001).

Spatial patterns.—Road mortality was high in both state parks, especially the entrance road to Eldon Hazlet State Park and within the park itself. Eldon Hazlet receives considerably more visitors than South Shore State Park because it is larger, has modern campground and RV facilities, cabin rentals, and a yacht club. South Shore State Park has only primitive campsites, picnic areas, and a small boat ramp; although there have been plans to build a resort in the park. Eldon Hazlet State Park is on a peninsula and has only one entrance, a raised road bisecting an inlet of the lake (Fig. 1). Although some research suggests that road mortality is lower on raised sections of roads (birds and small mammals: Clevenger et al., 2003), we found a large number of DOR reptiles on the raised entrance road. Slopes along raised roads are often used by female turtles for

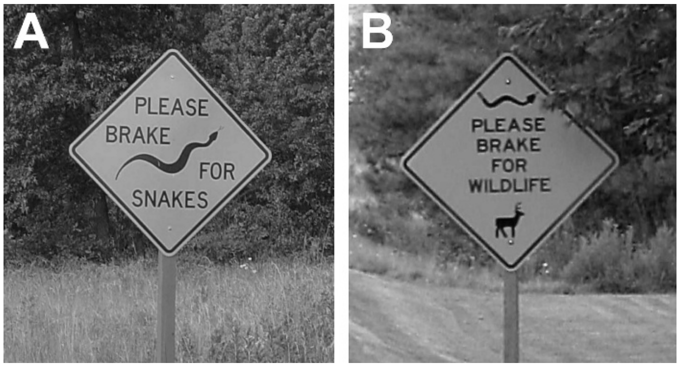

Fig. 5. Signs used at Carlyle Lake, Illinois, in (A) 2001 and (B) 2002, to increase awareness and reduce road mortality of *S. catenatus*.

nesting and may increase their mortality rates (Aresco, 2005a; Steen et al., 2006; Szerlag and McRobert, 2006).

The intensity of traffic on a road segment did not significantly affect the level of road mortality, but the quality of the habitat through which the segment ran was a significant factor. Road segments through high quality habitats had higher levels of mortality than segments through lower quality habitats. In many areas along our study route, suitable habitat existed primarily on the lake side of the road with the opposite side consisting primarily of agriculture or, in one area, a golf course. It is possible that some snakes are attempting to cross over into agricultural fields to forage for small mammals. During our telemetry study on *S. catenatus* at Carlyle Lake, we observed several individuals move across a levee and forage in an agriculture field (Dreslik, 2005). Female turtles, which often make long terrestrial movements during nesting, may be looking for suitable oviposition sites. Likewise, snakes and turtles use golf courses, which often contain abundant prey and include created habitats such as ponds.

Management recommendations.—Road mortality was the largest source of observed mortality for *S. catenatus* at Carlyle Lake (approx. 50%; Dreslik, 2005). In 2001, the USACE and IDNR installed signs (modeled after signs used successfully in Killbear Provincial Park, Ontario, Canada, to reduce road mortality of *S. catenatus*; C. Parent, pers. comm.) along roads where we had documented road mortality of *S. catenatus* in 2000 (Fig. 5A). Some vocal members of the public thought the signs would negatively impact tourism so they were subsequently changed in 2001 (Fig. 5B) on USACE managed properties. These signs were present year-round through 2005, after which their use was discontinued for unknown reasons. These signs appear to have been only minimally successful as road mortality has not significantly decreased (M. Dreslik, unpubl. data), stressing the need for additional measures.

A primary goal of conservation efforts for *S. catenatus* should be to create large areas of habitat that are unfragmented by roads. This would lessen the direct impacts of road mortality and have numerous indirect (e.g., population genetics) benefits as well. Much of the land surrounding Carlyle Lake is agricultural, which makes efforts more feasible than if the land was developed. Land purchase and habitat restoration should be pursued as well as recruiting private land-owners to enroll their lands into reserve programs. In addition, managers must work with local developers and planners to determine where reserves can be created that will not conflict with long-range development plans. For example, the area directly east of South Shore State Park (Fig. 1) is primarily agricultural, contains few roads, is sparsely populated, and is unlikely to interfere with long-range development plans, which appear to be focused on the west side of the lake between the north end of Carlyle and Eldon Hazlet State Park. Because of the cost, politics, and public perception of the snake, such an undertaking is unlikely to happen in the foreseeable future. In the meantime, we suggest a few simple and inexpensive actions that can be taken immediately in an attempt to alleviate road mortality.

Traffic volume and vehicle speed are positively related to road mortality in many animals (Forman and Alexander, 1998; Hels and Buchwald, 2001; Forman et al., 2003). An overall reduction in traffic volume at Carlyle Lake is unlikely and undesirable for local economic interests. However, because of the strong seasonality in road mortality of *S. catenatus*, it may be possible to reduce road mortality significantly by focusing management actions on August and September. Both state parks contain non-essential roads that could be closed seasonally, either completely or at least during the evening and night hours when adult *S. catenatus* are most active. Ten of the 14 DOR adult males in August and September occurred between 1700 h and 0900 h. Most of these snakes were likely killed during the evening and night with some being discovered only the next morning. Conversely, the eight cases of juvenile mortality from late August to early October occurred between 1000 and 1900 h. Seasonal road closure has been used successfully at the LaRue-Pine Hills Research Natural Area in the Shawnee National Forest in southern Illinois to protect snakes against road mortality during migrations to and from hibernacula (Ballard, 1994).

Current speed limits on most state park roads at Carlyle Lake range from 25 to 35 mph. Speed limits inside state parks could be reduced and temporary speed bumps/ramps to create longer gaps between cars could be installed, at least during the peak period of road mortality in August and September. In addition, the signs used previously (Fig. 5) could be reinstalled, at least seasonally, in areas with high road mortality. Decisions to lower speed limits and use signs, however, should be made with caution. Our assumption is that lower speed limits and signs will result in drivers seeing more snakes than they would have seen otherwise and that they will then avoid running them over. However, it is possible that if more snakes are seen, then more snakes will be run over intentionally, as often occurs, thereby increasing road mortality rather than reducing it. This possibility should be considered and roads should be monitored carefully if these actions are implemented.

ACKNOWLEDGMENTS

We thank J. Bunnell, J. Birdsell, G. Tatham, J. Smothers, D. Baum, A. Kuhns, P. Jellen, J. Mui, J. Petzing, S. Ballard, and the various U.S. Army Corps of Engineers and Illinois Department of Natural Resources personnel at Carlyle Lake for field assistance. We also thank A. Kuhns and J. Caldwell for suggestions on improving an earlier version of this manuscript, G. Costa for assistance with making maps, and S. Peltes for providing visitation data. The Illinois Department of Natural Resources, U.S. Fish and Wildlife Service, Illinois Wildlife Preservation Fund, and U.S. Army Corps of Engineers provided financial support.

LITERATURE CITED

Aldridge, R. D., B. C. Jellen, M. Allender, M. J. Dreslik, D. B. Shepard, J. M. Cox, and C. A. Phillips. In press. Reproductive biology of the massasauga (*Sistrurus catenatus*) from south-central Illinois. *In:* Biology of the Rattlesnakes. W. K. Hayes, K. R. Beaman, M. D. Cardwell, and S. P. Bush (eds.). Loma Linda University Press, Loma Linda, California.

Andrews, K. M., and J. W. Gibbons. 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. Copeia 2005:772–782.

Aresco, M. J. 2005a. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. Biological Conservation 123:37–44.

Aresco, M. J. 2005b. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69:549–560.

Ashley, E. P., and J. T. Robinson. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. Canadian Field-Naturalist 110:403–412.

Ballard, S. R. 1994. Status of the herpetofauna in the LaRue-Pine Hills/Otter Pond Research Natural Area in Union County, Illinois. Unpubl. M.S. thesis, Southern Illinois University, Carbondale, Illinois.

Bernardino, F. S., Jr., and G. H. Dalrymple. 1992. Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. Biological Conservation 62:71–75.

Bonnet, X., G. Naulleau, and R. Shine. 1999. The dangers of leaving home: dispersal and mortality in snakes. Biological Conservation 89:39–50.

Brooks, R. J., G. P. Brown, and D. A. Galbraith. 1991. Effects of a sudden increase in natural mortality rates of adults on a population of the common snapping turtle (*Chelydra serpentina*). Canadian Journal of Zoology 69:1314–1320.

Burke, V. J., J. W. Gibbons, and J. L. Greene. 1994. Prolonged nesting forays by common mud turtles (*Kinosternon subrubrum*). American Midland Naturalist 131:190–195.

Campbell, H. 1953. Observations on snakes DOR in New Mexico. Herpetologica 9:157–160.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15:1071–1078.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15–26.

Dodd, C. K., Jr., K. M. Enge, and J. N. Stuart. 1989. Reptiles on highways in north-central Alabama. Journal of Herpetology 23:197–200.

Donaldson, B. M., and A. C. Echternacht. 2005. Aquatic habitat use relative to home range and seasonal movement in Eastern Box Turtles (*Terrapene carolina carolina*: Emydidae) in eastern Tennessee. Journal of Herpetology 39:278–284.

Dreslik, M. J. 2005. Ecology of the eastern massasauga (*Sistrurus catenatus catenatus*) from Carlyle Lake, Clinton County, Illinois. Unpubl. Ph.D. diss., University of Illinois, Urbana-Champaign, Illinois.

Enge, K. M., and K. N. Wood. 2002. A pedestrian road survey of an upland snake community in Florida. Southeastern Naturalist 1:365–380.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wegner. 1995. Effect of road traffic on amphibian density. Biological Conservation 73:177–182.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207–231.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road Ecology. Island Press, Washington, D.C.

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlman, T. D. Tuberville, B. S. Metts, J. Greene, T. Mills, Y. Leiden, S. Poppy, and C. T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50:653–666.

Gibbons, J. W., and R. D. Semlitsch. 1987. Activity patterns, p. 396–421. *In:* Snakes: Ecology and Evolutionary Biology. R. A. Seigel, J. T. Collins, and S. S. Novak (eds.). Macmillan, New York.

Gibbs, J. P., and W. G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16:1647–1652.

Gibbs, J. P., and D. A. Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19:552–556.

Gregory, P. T., J. M. Macartney, and K. W. Larsen. 1987. Spatial patterns and movements, p. 366–395. *In:* Snakes: Ecology and Evolutionary Biology. R. A. Seigel, J. T. Collins, and S. S. Novak (eds.). Macmillan, New York.

Harvey, D. S., and P. J. Weatherhead. 2006. A test of the hierarchical model of habitat selection using eastern massasauga rattlesnakes (*Sistrurus c. catenatus*). Biological Conservation 130:206–216.

Hels, T., and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99:331–340.

Jellen, B. C., D. B. Shepard, M. J. Dreslik, and C. A. Phillips. 2007. Male movement and body size affect mate acquisition in the Eastern Massasauga (*Sistrurus catenatus*). Journal of Herpetology 41:451–457.

Johnson, G. 2000. Spatial ecology of the eastern massasauga (*Sistrurus c. catenatus*) in a New York peatland. Journal of Herpetology 34:186–192.

Kjoss, V. A., and J. A. Litvaitis. 2001. Community structure of snakes in a human-dominated landscape. Biological Conservation 98:285–292.

Kuhns, A. R. 2004. Ecological adaptations of sympatric box turtles (*Terrapene*). Unpubl. M.S. thesis, Illinois State University, Normal, Illinois.

Lillywhite, H. B. 1987. Temperature, energetics, and physiological ecology, p. 422–477. *In:* Snakes: Ecology and Evolutionary Biology. R. A. Seigel, J. T. Collins, and S. S. Novak (eds.). Macmillan, New York.

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. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. Herpetologica 60:45–53.

Peterson, C. H., A. R. Gibson, and M. E. Dorcas. 1993. Snake thermal ecology, p. 241–314. *In:* Snakes: Ecology and Behavior. R. A. Seigel and J. T. Collins (eds.). McGraw-Hill, New York.

Roe, J. H., J. Gibson, and B. A. Kingsbury. 2006. Beyond the wetland border: estimating the impact of roads on two species of water snakes. Biological Conservation 130:161–168.

Rosen, P. C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation 68:143–148.

Rudolph, D. C., S. J. Burgdorf, R. N. Conner, and R. R. Schaefer. 1999. Preliminary evaluation of the impact of roads and associated vehicular traffic on snake populations in eastern Texas, p. 128–135. *In:* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. G. Evink, P. Garrett, and D. Zeigler (eds.). Florida Department of Transportation, Tallahassee, Florida.

Seigel, R. A. 1986. Ecology and conservation of an endangered rattlesnake, *Sistrurus catenatus*, in Missouri, USA. Biological Conservation 35:333–346.

Seigel, R. A., and M. A. Pilgrim. 2003. Long-term changes in movement patterns of massasaugas (*Sistrurus catenatus*), p. 405–412. *In:* Biology of the Vipers. G. W. Schuett, M. Höggren, M. E. Douglas, and H. W. Greene (eds.). Eagle Mountain Publishing, Eagle Mountain, Utah.

Seigel, R. A., C. A. Sheil, and J. S. Doody. 1998. Changes in a population of an endangered rattlesnake *Sistrurus catenatus* following a severe flood. Biological Conservation 83:127–131.

Shepard, D. B., C. A. Phillips, M. J. Dreslik, and B. C. Jellen. 2004. Prey preference and diet of neonate eastern massasaugas (*Sistrurus c. catenatus*). American Midland Naturalist 152:360–368.

Spellerberg, I. F. 2002. Ecological Effects of Roads. Science Publishers, Enfield, New Hampshire.

Steen, D. A., M. J. Aresco, S. G. Beilke, B. W. Compton, E. P. Condon, C. K. Dodd, Jr., H. Forrester, J. W. Gibbons, J. L. Greene, G. Johnson, T. A. Langen, M. J. Oldham, D. N. Oxier, R. A. Saumure, F. W. Schueler, J. M. Sleeman, L. L. Smith, J. K. Tucker, and J. P. Gibbs. 2006. Relative vulnerability of female turtles to road mortality. Animal Conservation 9:269–273.

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

Strang, C. A. 1983. Spatial and temporal activity patterns in two terrestrial turtles. Journal of Herpetology 17:43–47.

Szerlag, S., and S. P. McRobert. 2006. Road occurrence and mortality of the northern diamondback terrapin. Applied Herpetology 3:27–37.

Szymanski, J. 1998. Status assessment for the eastern massasauga (*Sistrurus c. catenatus*). U.S. Fish and Wildlife Service, Endangered Species Division, Fort Snelling, Minnesota.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

Tucker, J. K. 1995. Notes on road-killed snakes and their implications on habitat modification due to summer flooding on the Mississippi River in west central Illinois. Transactions of the Illinois State Academy of Science 88:61–71.

Tucker, J. K., D. W. Soergel, and J. B. Hatcher. 1995. Flood-associated activities of some reptiles and amphibians at Carlyle Lake, Fayette County, Illinois. Transactions of the Illinois State Academy of Science 88:73–81.

U.S. Fish and Wildlife Service. 1999. Endangered and threatened wildlife and plants; review of plant and animal taxa that are candidates or proposed for listing as endangered or threatened; annual notice of findings on recycled petitions; and annual description of progress on listing actions. Federal Register 64:57534–57547.

Vijayakumar, S. P., K. Vasudevan, and N. M. Ishwar. 2001. Herpetofaunal mortality on roads in the Anamalai Hills, southern western Ghats. Hamadryad 26:265–272.

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

Zug, G. R., L. J. Vitt, and J. P. Caldwell. 2001. Herpetology, Second Edition. Academic Press, San Diego.