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A Survival Estimate of Midwestern Adult Eastern Box Turtles Using Radiotelemetry

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ABSTRACT.—Eastern box turtles (*Terrapene carolina carolina*) are widespread in U.S. eastern deciduous forests, yet many populations are experiencing dramatic declines. Herein, we present an assessment of annual survival for adult eastern box turtles that were radio-tracked over a period of 2 y. Using a known fates Kaplan-Meier estimator, the baseline annual survival estimate for adult eastern box turtles in Indiana's south-central region is 96.2%. Annual survival rates varied slightly between the hibernal period (95.6%) and the active period (96.7%). These initial data provide wildlife managers with a baseline from which a recovery period can be calculated. In areas where road mortality and human interface are high, this estimate should be adjusted to ensure the time for recovery is adequate. Further research is recommended over generations and age-classes to better inform management of this protected species.

INTRODUCTION

Turtles are among the longest-lived vertebrates studied in nature (Gibbons, 1987). Many species commonly live for more than 30 y and some greater than 100 (Flower, 1937; Gibbons, 1987). Despite the longevity of Testudine species, this taxon is currently experiencing worldwide declines resulting from the food, medicinal and pet trades, disease and habitat alteration (Garber and Burger, 1995; Gibbons *et al.*, 2000; IUCN, 2009). Declines of reproductive adults reduce recovery rates of populations and can preclude recoveries altogether when coupled with certain life-history traits (Heppell, 1998; Dodd *et al.*, 2006). For example, box turtles are known to persist for decades, but have low annual reproduction and juvenile survivorship (Shine and Iverson, 1995; Dodd, 2001; Steen *et al.*, 2006), making them especially susceptible to local extirpation if adult survivorship decreases. Conservation of the adult age classes in long-lived turtles is critical if populations are to be self-sustaining (Heppell, 1998). Consequently, current and accurate adult annual survival estimates are needed in order for conservation and management strategies to be implemented (Dodd, 1997; Ricklefs, 1998; Congdon *et al.*, 2001).

Eastern box turtles (*Terrapene carolina carolina*) are geographically widespread throughout eastern North American forests, yet many locations are experiencing precipitous population declines (Stickel, 1978; Williams and Parker, 1987; IDNR, 2007). These declines can be attributed to a variety of age- and sex-related factors such as differential survival rates, growth rates and reproductive contribution (Blair, 1976; Frank and Swingland, 1988; St Clair, 1998; Heppell *et al.*, 2000). Although much box turtle biology has been studied, survival estimates

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TABLE 1.—Studies of *Terrapene c. carolina* reporting a survivorship estimate. Many reported estimates were informal or did not provide an annual survival rate. MRR = Mark-release-recapture

Author	Location	Relocation method	Estimator	Survivorship age (years)	Ann. surv. estimate	Standard error
Allen (1868)	Massachusetts	Anecdotal reports	Longevity/ survivorship estimate	60+	N/A	N/A
Flower (1937)	Various	Anecdotal reports	Longevity/ survivorship estimate	20–123	N/A	N/A
Stickel (1978)	Maryland	MRR	Longevity/ survivorship estimate	50–80+	N/A	N/A
Yahner (1974)	Tennessee	MRR	% recovery (informal)	N/A	79.5%	—
Williams & Parker (1987)	Indiana	MRR	Longevity/ survivorship estimate	45–50+	N/A	N/A
Nazdrowicz (2008)	Delaware	Radiotelemetry	Kaplan-Meier data averaged	N/A	81.3–97.7%	0.023–0.069
Current Study	Indiana	Radiotelemetry	Kaplan-Meier known-fates staggered entry	N/A	95.4–97.8%	0.022–0.044

are dominated by survivorship (or longevity) (Allen, 1868; Flower, 1937; Stickel, 1978; Williams and Parker, 1987) as opposed to specific survival rates (annual survival), though some average estimates for annual survival have been made for this species (Yahner, 1974; Nazdrowicz *et al.*, 2008; Table 1). In the Midwest where population declines are of growing concern, no formal survival analyses have been reported. Moreover, no precise estimates have been calculated using a known fates model where the same individuals are tracked over time. Known fates models have the advantage over mark-release-recapture (MRR) estimators in that every animal 'marked' is 'recaptured,' dead or alive, thus eliminating assumptions of the hazard function (*i.e.,* the probability of an animal dying during a short interval) and capitalizing on a recapture probability of ''1'' (White and Garrot, 1990).

Using a modified Kaplan-Meier estimator (Kaplan and Meier, 1958) with 2 y of radiotelemetry data, we present an estimate of the adult annual survival rate of eastern box turtles in Indiana. The results of this research will provide a baseline of adult survivorship and can serve to compare age class survivorship throughout the Midwest. This information can influence management decisions for this legally protected species (Indiana Species of Special Concern) and is important when considering future conservation measures such as reintroduction and head starting (Henry, 2003; IDNR, 2007).

METHODS

STUDY AREA

The study area was located within Morgan, Monroe and Brown counties in south-central Indiana and spans approximately 350 sq km (35,000 ha) in total (Fig. 1). The study area includes sites in Morgan-Monroe State Forest (MMSF) and Yellowwood Sate Forest (YSF).

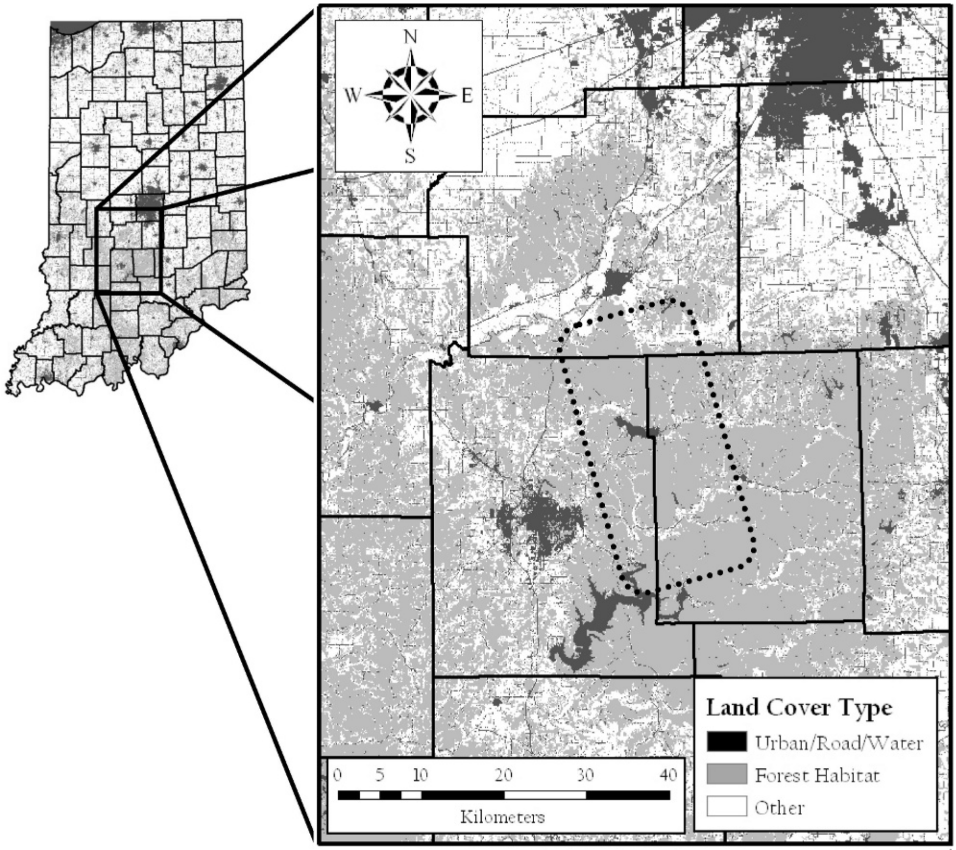

FIG. 1.—Local and regional map of the study area in Indiana, USA. Turtles were radio-tracked in forested habitats of south-central Indiana in Morgan, Monroe and Brown counties (within the approximated dotted rectangle in the center of the local map)

MMSF was established in 1929, comprising nearly 10,000 ha and YSF was created in 1940, comprising nearly 9500 ha. This area was chosen because it was suspected to have a stable population of box turtles based on the relative contiguity of the forest habitat (Fig. 1). The location is characterized by hills and ravines of hardwood, deciduous forests with scattered harvest areas managed for multiple purposes, including research. Dominant canopy species include *Quercus* spp., *Carya* spp., *Fagus grandifolia, Acer saccharum, A. rubrum, Nyssa sylvatica* and *Liriodendron tulipifera.* Herbaceous understory consists of *Smilax* spp., *Parthenocissus quinquefolia, Carex* spp., *Viola* spp. and *Desmodium nudiflorum.*

DATA COLLECTION

Meandering transect, visual encounter surveys were used to find adult turtles between May 2007 and Jul. 2009. Surveys were conducted during the active period of box turtles (daylight hours of Apr. through Oct.) and captured adults were subsequently radio-tagged and tracked. Holohil RI-2B Transmitters (14.5 g each) were epoxied to the carapace of the turtles. Transmitters did not exceed 5% of the animal's total body weight.

Radio-tagged box turtles were monitored from May 2007 to Nov. 2009. Tracking consisted of using a homing technique (White and Garrot, 1990) with portable receivers (Advanced Telemetry Systems, Isanti, MN, USA) to approach and visually locate each turtle. All tracking dates and locations were recorded. Turtles were continually added to the study following a staggered entry design. During the 2007 season, 23 turtles were located and incorporated into the study and by the end of the 2009 season, 45 turtles had been incorporated. All animals were tracked two to three times per week from approximately May to Oct. each year.

SURVIVAL ESTIMATE

We calculated survival of adult box turtles (Nov. 2007 to Nov. 2009) using a modified Kaplan-Meier estimator. Assumptions of survival over specified time intervals and constant survival rates among individuals and are often unrealistic. To account for this, we used the modifications of the Kaplan-Meier procedure outlined by Pollock *et al.* (1989a) that allows for staggered entry and right-censoring. Modeling for staggered entry enables us to continually add individuals, increasing our number tracked and thus, our precision (while decreasing standard error). The estimated survival function ($\hat{S}$) for a given time (t) used in StagEnt program (Pollock *et al.*, 1989a) is calculated as follows:

$$\hat{S}_t = \Pi \left(1 - d_j/r_j\right) \text{ where } j \middle| r_j < t.$$

Active season and hibernal season estimates were calculated separately using the radiotelemetric data across two consecutive years. Active season estimates were grouped by total number of turtles alive (number at risk; r) at the end of each tracking week (sample period; j). The hibernal period data were taken singly, as the animals were not disturbed during this period and any deaths could not be confirmed until the following spring, resulting in sample periods of approximately 6 mo. All censored [deaths or losses (d) and removals] individuals were recorded as censored for the sample period that they were discovered dead, missing or removed from the study.

RESULTS

Over the 2 y period of the study, 48 eastern box turtles were located and subsequently monitored. Approximately 36 locations were collected for each turtle in the 2008 active period and approximately 70 locations per turtle in 2009. Seven turtles were censored over the course of the study (Table 2). Of the three deaths, one was attributed to a known predation attempt, one to severe emaciation, and one to apparent overexposure to freezing temperatures.

The average annual survival estimate was 96.3% with a standard error of 0.04 and a 95% confidence interval of 0.89–1.03. Survival estimates varied little over each of the 6 mo intervals. The average survival rate during the hibernal period is 95.7% (SE = 0.04) whereas that of the active period is 97.0% (SE = 0.03; Table 2). If all estimates are combined, the 2 y survival estimate for adult eastern box turtles in Indiana was 86.4% (SE = 0.05). Due to the small number of total deaths, no individual estimates were made for sexes or for causes of deaths.

DISCUSSION

Previous studies that include a survival estimate for eastern box turtles often lack formal computation due to recapture methods (Table 1). Until recently, estimates were made using long-term MRR where individuals cannot be followed over time. Without following animals to ensure their recapture (and thus, their survival), the resulting estimates are less reliable. It is time-prohibitive to use MRR and exhaustively sample in order to avoid

TABLE 2.—Number of adult eastern box turtles (*Terrapene carolina carolina*) monitored between 2007 and 2009 in south-central Indiana, USA. Standard error = SE and confidence interval = CI

Time period	Total tracked	# Censored	Survival estimate	SE	95% CI
Hibernal 2007	23	1 (♀ lost)	0.954	0.044	0.87–1.04
Active 2008	26	1 (♀ died)	0.963	0.036	0.89–1.03
Hibernal 2008	26	1 (♀ died)	0.960	0.039	0.88–1.04
Active 2009	42	1 (♀ died), 3 (♂ removed)	0.978	0.022	0.93–1.02
				Annual Average	
			0.964	0.035	0.89–1.03
				2-year Total	
			0.864	0.048	0.77–0.96

recapture bias. Radiotelemetry methods and known-fates models have eliminated this problem. By following the same individuals over time to ensure recapture, we are able to calculate more realistic and accurate estimates of annual survival rates. In addition, the estimator (Pollock *et al.*, 1989a) allows for the staggered entry of individuals into the study, increasing precision and reducing standard error (Pollock *et al.*, 1989b).

Individual estimates for sex could not be constructed due to the high survivorship of the study animals. Considering this, longer-term monitoring should be conducted to better assess adult eastern box turtle survivorship over generations. It has been suggested that box turtle populations with estimated adult annual survival rates as high 81.3% may not be viable (Nazdrowicz *et al.*, 2008) due to skewed sex ratios and low juvenile abundance, aspects of the population dynamics that were not studied here.

In eastern box turtles, hatchlings rarely survive to adulthood and decades are necessary to replace adults in a population (Congdon *et al.*, 1994; Belzer, 2002). Even with an apparently high annual survival estimate such as 90%, only one in a population of 100 turtles would be expected to survive after 44 y (Wilbur and Morin, 1988). Moreover, previous studies suggest that there is no guarantee that recovery can be achieved even with population protection or husbandry (Stickel, 1978; Belzer, 2008). In addition, it should be noted that our annual survival estimate was made from data collected on a relatively undisturbed population. Therefore, the estimate presented here is relatively conservative and could be dramatically reduced in areas of increased wildlife-human interface (Budischak *et al.*, 2006) or during widespread stochastic events such as flooding or disease.

This study has shown that relatively undisturbed populations of eastern box turtles in the Midwest have high adult survivorship, a life history trait important for a species with low annual reproductive rates. However, this species continues to decline throughout Indiana (IDNR, 2007). Road mortality, habitat destruction and collection for pets are the purported leading causes (IDNR, 2007; Iglay *et al.*, 2007). Declines of this species within Indiana suggest that further research is necessary at development edges and where the human interface with box turtle habitat is greatest. Information presented herein can aid in management decisions for this protected species and is essential when considering future conservation measures.

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