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Note

Habitat Alteration and Survival Rates of the Ornate Box Turtle

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ABSTRACT Habitat destruction and modification may be the most prominent anthropogenic forces affecting extant biological systems. Growing evidence suggests that turtles are especially vulnerable to many anthropogenic stressors. We evaluated the effects of habitat modification on survival rates of the threatened ornate box turtle (*Terrapene ornata*) in northwest Illinois, USA, using a 20-year mark-recapture dataset. Longstanding development (i.e., cottages, outbuildings, landscape management) reduced the apparent survival of the ornate box turtle, especially among females. In contrast, smaller, more recent development (i.e., construction and paving of a bike path) did not have demonstrable negative effects on apparent survival. Our results indicate that the scale of development is important to consider in management and that adverse effects of anthropogenic development may require a considerable time frame to manifest in long-lived organisms. © 2016 The Wildlife Society.

KEY WORDS development, habitat alteration, Illinois, management, ornate box turtle, sand prairie, survival, *Terrapene ornata*.

Anthropogenic changes to the environment have produced a diverse array of pressures on natural populations. Habitat modification, fragmentation, and destruction may be the most influential changes contributing to the extirpation of numerous species across a variety of taxa (Burkey 1995, Fahrig 2002, Hokit and Branch 2003, Holland and Bennett 2010) and causing various sublethal responses (McCauley and Bjorndal 1999), including shifts in community composition (Perkin and Gido 2012). Anthropogenic influences, though problematic for many species, have been particularly detrimental for turtles (i.e., Order Testudines), of which 50% are considered endangered and an additional 25% are threatened (International Union for the Conservation of Nature [IUCN] 2015). Turtles may be particularly vulnerable to the effects of habitat alteration and destruction because of their high levels of site fidelity (Avens et al. 2003), high population sensitivity to adult survival (Heppell 1998), and need for a diverse array of terrestrial and aquatic microhabitats (Steen et al. 2012). Thus, understanding the effects of habitat alteration on demographic parameters is important to best inform management practices (Gibbons et al. 2000, Böhm et al. 2013).

In turtles, adult survival rates are essential for population growth rates and stability (Crouse et al. 1987; Brooks et al. 1991; Congdon et al. 1993, 1994; Heppell 1998). However, given the often-cryptic nature and lengthy lifespans of many turtles, the amount of time and effort required to collect adequate mark-recapture data often precludes the estimation of these crucial parameters. Management attempts are frequently hampered by the lack of adult survival rates (Gibbons et al. 2000), and environmental impact assessments require these data for accurate calculation of development risks to natural populations (Treweek 1996).

The effects of habitat alteration and destruction on turtle populations are still being determined. Although most studies report an adverse impact on demographic parameters (e.g., survival rates, population stability; Garber and Burger 1995, Marchand and Litvaitis 2004, Converse et al. 2005, Sirois 2011), the magnitude of these effects vary (Dodd and Dreslik 2008, Rees et al. 2009, Dodd et al. 2016) and are not universal (Bowen et al. 2004, Plummer et al. 2008, Cureton et al. 2014). These diverse results are unsurprising, given the large diversity of habitat preferences and use among turtles. Thus, further studies are necessary to determine the

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intricacies of interactions between altered habitats and turtle survival.

The ornate box turtle (*Terrapene ornata*) is a terrestrial species distributed throughout much of the Great Plains, including portions of the southwest United States and northeast Mexico (Dodd 2001, Lodato and Hulvershorn 2001, Ernst and Lovich 2009). This species is threatened in Illinois (Illinois Endangered Species Protection Board 2015) and near threatened globally (IUCN 2015). Although their yellow-tan mottled coloration and often subterranean behavior renders them challenging to locate in the environment (Refsnider et al. 2011), the growing management need for information on adult survival rates motivates dedicated long-term mark-recapture study (Dodd 2001). We compared apparent survival rates of ornate box turtles between 2 sites with differing levels of long-term, persistent human development (i.e., cottages with maintained yards) in northwest Illinois, USA. In addition, we assessed the demographic impacts of a more recent installation of a gravel, and later paved, bicycle path into and through ornate box turtle habitat previously inaccessible to vehicles. Because of illegal collecting in the area (J. T. Strickland, U.S. Fish and Wildlife Service [USFWS], and F. J. Janzen, Iowa State University [ISU], personal observations), we anticipated that substantial long-term levels of development would reduce survival rates due to altered microhabitat availability and possibly enhanced take. We also predicted that the recent construction and paving of the bike path would yield higher rates of illegal collecting, decreasing apparent survival of adult ornate box turtles.

STUDY AREA

We performed seasonal surveys from 1996–2015 at 3 adjacent relict sand prairie sections in the Upper Mississippi River National Wildlife and Fish Refuge, Carroll and Whiteside counties, northwest Illinois, USA (Kolbe and Janzen 2002, Bowen et al. 2004). The sand prairie habitat throughout the area contains a number of open sandy patches and various vegetated parts, which are largely comprised of needlegrass (*Stipa* spp.) along with large patches of prickly pear cactus (*Opuntia* spp.), skunkbrush (*Rhus* spp.), and spiderwort (*Tradescantia* spp.). The western edge of this sand prairie is bordered by a nearly continuous tree line along the Mississippi River. The study area is also inhabited by notable reptile species that are co-distributed in sand prairie habitat in the Great Plains with ornate box turtles, including the six-lined racerunner lizard (*Aspidoscelis sexlineata*; Warner 1998) and the plains hog-nosed snake (*Heterodon nasicus*; Kolbe 1999). Native predators of ornate box turtles that are common in the study area consist of coyotes (*Canis latrans*), skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), and foxes (*Vulpes vulpes*).

The study sites were separated from each other by cottages or fences, and differed from each other primarily by the amount of human development found on each site. Two adjacent sections (6.57 ha) have been developed since the 1940s, with 18 cottages, yards, and driveways present; we grouped these sections for all analyses and considered them the disturbed site. In contrast, other than introduction of a gravel bike path from 2000–2008, after which the path was paved in fall 2008, the third section was undeveloped and considered the refuge site (11.95 ha). Vegetation management varies between sites; the disturbed site is mowed frequently and has large trees, whereas the refuge site is not mowed and tree removal management is in place. Both sites are accessible to the general public and visited daily, with transitory human presence along the bike path at the refuge site and semi-permanent human presence at the disturbed site. Radio-telemetry data indicate that movement of turtles between the sites is possible but uncommon (4 movements between sites during the course of the study). Ornate box turtles in this population exhibit high site fidelity, with 95% of movement constrained within an area of 2.6 ha (Refsnider et al. 2012). The area is bordered on the north by the city of Thomson, on the south by a forested area, and on the east by 2 sets of railroad tracks, agricultural fields, and a highway; the sand prairie terrain slopes from east to west, where the area meets the shore of the Mississippi River.

METHODS

Field Methods

We conducted linear visual surveys for ornate box turtles via transects in each study site. Surveys occurred periodically from mid-May to early July, during the morning hours (0600–1200) when ornate box turtles are most likely to be active (Legler 1960). The amount of time spent at each site conducting surveys varied annually and we recorded person-hours for each year, but not separately between sites. We hand captured turtles and handled them in accordance with the ISU Institutional Animal Care and Use Committee [IACUC], Illinois Department of Natural Resources (DNR), and USFWS permits (IACUC: 12-03-5566-J; recurring DNR permits, most recent NH15.0073; DNR endangered species permit 04-95; USFWS recurring permits, most recent 32576-2015-025). Upon capture, we identified an individual as an adult or juvenile, depending on the presence or absence of secondary sexual characteristics, and noted sex if we identified it as an adult (i.e., males have red eyes, a specialized hind toe, and a concave hind lobe on the plastron; Ernst and Lovich 2009). We marked each turtle individually by notching the marginal scutes (Cagle 1939); we measured straight carapace length with digital calipers and released the turtle at the capture site. When we found juveniles later as adults, we reclassified them from the juvenile category to the appropriate adult sex.

Statistical Analyses

We calculated apparent survival and recapture rates for the population using live-recapture-only Cormack–Jolly–Seber analyses (Cormack 1964, Jolly 1965, Seber 1965) in Program MARK (White and Burnham 1999), with parameter estimates constrained between 1 and 0 using a logit link function. Model selection was based on corrected Akaike's Information Criterion modified for overdispersion

($QAIC_c$), with lower numbers showing greater support (Burnham et al. 1995, Anderson et al. 1998) and $\Delta AIC < 4$ indicating the top models. We conducted goodness-of-fit tests using Program RELEASE in MARK (White et al. 2001).

We investigated the effect of anthropogenic structure development on survival rates; thus, we included a site effect on survival and recapture rates. Because female turtles may experience increased visibility associated with nesting, making them more vulnerable to predation and location by researchers, we included a sex effect on survival and recapture in the model. To determine if yearly environmental factors affected survival and recapture rates, we included year as an omnibus effect for survival and recapture estimates. Moreover, we theorized that size might affect recaptures if larger turtles are more visible to researchers. For juvenile and adult turtles, size may be linked to predation rate if predators are unable to crush or pry larger shells. For these reasons, we included a linear effect of size at first capture on survival and recapture rates. Additionally, we compared models at the refuge site that estimated apparent survival rates based on the effects of path construction (i.e., years grouped into 3 periods: before path construction [1996–1999], after gravel path construction in fall 1999 [2000–2008], after the path was paved in fall 2008 [2009–2015]). We did not estimate this effect at the disturbed site because no bike path was constructed in the area. Finally, we included search effort as a potential factor affecting overall annual recapture rates. To summarize, we generated biologically relevant models for survival based on effects of site, sex, year, size, and path, and modeled recapture rates based on effects of site, sex, year, size, path, and search effort. We selected variables iteratively, first determining the highest-ranked variables for recapture rates, and then ranking all combinations of effects on survival using the top-ranked variables for estimating recapture rates. We modeled combinations of variables additively and as interactions, if appropriate. For the most competitive model, we used Markov chain Monte Carlo sampling methods to define estimates more precisely (4,000 tuning iterations, 1,000 burn-in iterations, 10,000 recorded iterations), and we report these parameter estimates and 95% credibility intervals.

To more fully examine the potential effect of path construction on survival, we ran additional models excluding the disturbed site data. These refuge site models included effects of path construction (i.e., years grouped into 3 periods: before path construction, after gravel path constructed, after the path was paved) and the effects listed above (other than site).

RESULTS

During the 20-year study, we captured 149 unique ornate box turtles (82 F, 42 M, 25 juveniles of unknown sex), with 159 recaptures. We found 25 females, 17 males, and 5 juveniles at the disturbed site, and the remainder (57 F, 25 M, 20 juveniles) in the refuge area.

Goodness-of-fit tests suggested that the data might be underdispersed ($\hat{c} = 0.56$); however, after adjusting $\hat{c}$ between 0.56 and 1, no alteration of model ranking occurred. For this reason, we held $\hat{c} = 0.56$ for the following analyses. For the model set examining effect of site, 3 similar models contained all the model weight. These models differed only in the inclusion of an additive or interaction effect between sex and site or a path effect on survival. Although the top 2 models had a sex effect and the third-ranked model had a path effect, all models shared effects of site on survival of adult turtles, site and year on recapture, and held juvenile survival constant across sites and years (Table 1). Other combinations of site, sex, year, size, path, and search effort were non-informative (i.e., large $QAIC_c$ values or beta estimates overlapping 0) for survival and recapture estimates.

Estimates from the first- and second-ranked models were similar; estimates from the top model are presented here. Adult annual survival rates for females were 31% higher at the refuge site than at the disturbed location (refuge = 0.97, credibility interval 0.94–0.99; disturbed = 0.66, credibility interval 0.50–0.80); this trend was reflected for adult males yet the difference was not statistically significant (refuge = 0.91, credibility interval 0.85–0.97; disturbed = 0.76, credibility interval 0.63–0.88). Juvenile survival across both sites ($\bar{x} = 0.71$, credibility interval = 0.53–0.86) was within the range for adult survival at the disturbed site, but lower than adult survival at the refuge site. Yearly recapture rates at the disturbed site varied from 0.06 to 0.56, and from 0.03 to 0.83 at the refuge location (Fig. S1, available online in Supporting Information).

Despite the presence of a path effect on survival in the third-ranked model (Table 1), beta estimates suggested that this effect was ultimately uninformative ($\beta_{before} = -0.012$, SE = 1.95, 95% CI = −3.84 to 3.81; $\beta_{gravel} = 1.67$, SE = 2.15, 95% CI = −2.55 to 5.89). In addition, survival estimates at different stages of path construction were similar (before path = 0.90, credibility interval 0.76–0.97; after gravel = 0.98, credibility interval 0.91–1.00; after

Table 1. Model results for apparent survival (phi) of adult ornate box turtles in Thomson, Illinois, USA, 1996–2015. The 3 most competitive models are presented; all modeled juvenile survivorship as constant between sexes and sites (refuge vs. disturbed), and modeled recaptures as an interaction between site and year. Path is a categorical variable representing the effects of a bike path (before path construction, after gravel path construction, after the path was paved). We present Akaike's Information Criterion corrected for small sample size and overdispersion ($QAIC_c$), the difference in $QAIC_c$ from the top model ($\Delta QAIC_c$), and the number of parameters in the model (K).

Adult survival model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weights	Model likelihood	K	QDeviance
Phi(site × sex)	889	0.00	0.51	1.00	43	788
Phi(site + sex)	890	0.44	0.41	0.80	43	789
Phi(site × path)	893	3.77	0.08	0.15	44	790

paving = 0.95, credibility interval 0.20–1.00). Further, in the model set run only for the refuge site, path was not a well-supported parameter (see detailed results in Supporting Information).

DISCUSSION

Anthropogenic influences on habitat alteration and destruction have wide-ranging impacts on natural populations. In organisms such as turtles, where adult survival strongly predicts population persistence, awareness of effects of habitat degradation on survival rates is vital to population management (Crouse et al. 1987). This information is important to estimate for turtle species or populations because growing evidence suggests that certain turtle populations can be resilient to particular anthropogenic impacts (Fordham et al. 2009, Spencer and Janzen 2010, Strickland and Janzen 2010, Wolak et al. 2010, Jergenson et al. 2014). In this population, model selection implied a detrimental effect of extensive human development on survival of female ornate box turtles. Specifically, the heavily disturbed areas yielded a 31% decrease in female apparent survival compared to the refuge site, although this effect was not well estimated (wide 95% credibility intervals). Trends in the data suggest a similar but less striking pattern in males, with more data being required to assess this possibility with statistical confidence (95% credibility intervals overlap). These results add to a growing number of studies suggesting an unsurprising, but alarming, deleterious effect of habitat alteration on survival rates of turtles (Garber and Burger 1995, Marchand and Litvaitis 2004, Converse et al. 2005, Sirois 2011). Although we did not perform a population viability analysis, the deleterious impact on adult female survival suggested by this study may have major implications for population persistence because many turtle populations exhibit a strong sensitivity to decreases in adult survivorship (Heppell 1998). This effect may be amplified when individuals are removed in spring prior to reproduction (Dodd et al. 2016).

Previous research suggests that the decrease in apparent survival of turtles at the disturbed site may be due to alterations to available microhabitats (Refsnider et al. 2012). Ornate box turtles exhibit strong fidelity to overwintering and nesting sites (Bernstein et al. 2007), thus even modest human modifications of their properties can adversely affect these animals during these key life stages. Alternatively, permanent human presence in the area could contribute to the decrease in apparent survival due to illegal harvest of the turtles for the pet trade (Schlaepfer et al. 2005). Because this study began 50 years after construction of the cottages, the effects of disturbance on survival are likely to have been present long enough to manifest in the population.

Apparent survival estimates for adults at the refuge site were comparable to those found for a relatively undisturbed ornate box turtle population in Nebraska (0.93 for females, 0.88 for males; Converse et al. 2005) and were higher than those found in a more human-affected population of ornate box turtles in south-central Wisconsin (0.81 for both sexes combined; Doroff and Keith 1990). Additionally, and unsurprisingly, estimates were similar to those previously calculated for the same Illinois population prior to paving of the bicycle path (0.99 for females, 0.90 for males; Bowen et al. 2004).

Unexpectedly, ornate box turtles in the northwest Illinois population appear to be resilient to small amounts of human development. For example, the construction and paving of a bike path through the refuge site left no detectable impact on survival of the box turtles, despite markedly increasing the amount of humans crossing through the site (F. J. Janzen, personal communication) and, thus, the potential for illegal collecting. However, the current study might not have the power to detect a small deleterious effect on survival; additional years of study may yet uncover new insights into the effects of path construction. Furthermore, any deleterious effects of a genetic bottleneck on population viability would not have been determined by the methods in this study (Kuo and Janzen 2004). Caution should be exercised, therefore, before relying heavily on this apparent lack of anthropogenic impact. Consequently, this population warrants further monitoring to assess the ongoing survival patterns of the ornate box turtle.

MANAGEMENT IMPLICATIONS

Our results suggest that managers seeking to provide recreation opportunities for the public may not be forestalled from non-vehicular trail construction out of concern for ornate box turtle conservation. Nonetheless, it is possible that deleterious effects of trail construction may not have had time to manifest in the study population. Regardless, heavier development (e.g., construction of buildings, mowing vegetation) should be avoided to minimize adverse impacts on ornate box turtles. Actions that result in persistent human presence in the environment substantially reduce survival of adult ornate box turtles.

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