

Blanding's Turtle Hatchling Survival and Movements following Natural vs. Artificial Incubation

MONIKA KASTLE,^{1,2} JOSHUA KAPPER,³ ANDREW R. KUHN,⁴ WILLIAM GRASER,² GARY GLOWACKI,⁵ ANDREW IBACH,^{3,6} LISA MITCHEM,^{3,7} JOSEPH MOZUCH,^{3,8} NICHOLAS RUDOLPH,³ KARL RUTZEN,^{3,9} AND RICHARD KING^{1,10,11}

¹Department of Biological Sciences, Northern Illinois University, DeKalb, Illinois, 60115, USA

²Forest Preserve District of Kane County, Geneva, Illinois, 60134, USA

³Department of Biological Sciences, University of Wisconsin-Whitewater, Whitewater, Wisconsin, 53190, USA

⁴Illinois Natural History Survey, Prairie Research Institute, University of Illinois, Champaign, Illinois, 61820, USA

⁵Lake County Forest Preserve District, Libertyville, Illinois, 60048, USA

¹⁰Institute for the Study of the Environment, Sustainability, and Energy, Northern Illinois University, DeKalb, Illinois, 60115, USA

ABSTRACT.—To provide estimates of Blanding's Turtle (*Emydoidea blandingii*) hatchling survival and to better understand the utility of alternative management tactics targeting this age class, we monitored survival and movements after natural (caged) and artificial incubation by using radio telemetry. We found that survival was similarly high (ca. 80% over 88 days) across treatments and study locations. Movement distances were similar among treatments but differed among study locations, perhaps because of differences in release site habitat variables. Our results suggest that nest cages and artificial incubation are equally effective methods for increasing survival to hatching. Extrapolating from the 88 days of our study, until resumption of activity following hibernation, we found survival estimates of 40%–78%, depending on the survival function used. When coupled with published rates of nest survival (6%–41%) and hatch success (47%–87%), anticipated age 0 survival, from egg deposition to emergence from hibernation, ranged from 1%–28%. Although our analysis fills a knowledge gap in Blanding's Turtle demography, further study is needed to improve the precision of survival estimates.

Managers of small populations of threatened and endangered species often implement actions to enhance survival during vulnerable life history stages. A frequent concern regarding such actions is that follow-up monitoring is insufficient to meaningfully evaluate alternative tactics (Stem et al., 2005). This is especially true of species with cryptic life stages for which monitoring effort may be prohibitive and technological solutions are lacking (Pike et al. 2008). Hatchling turtles represent one such example. One strategy in turtle conservation is to reduce nest depredation by caging nests in situ or by inducing oviposition in wild-caught females, artificially incubating eggs, and releasing hatchlings (Burke, 2015; O'Connor et al., 2017). These tactics require a significant allocation of resources to track and monitor nesting females and their nests or to track and capture gravid females for induction and egg incubation. In addition, environmental conditions during incubation (temperature, humidity, and their variability) differ between nest-caged and artificially incubated hatchlings, and these differences may influence performance (survival and behavior) posthatching (Usategui-Martin et al., 2019). Consequently, evaluating the outcome of these alternatives is needed to better achieve conservation goals.

The Blanding's Turtle *Emydoidea blandingii* is a long-lived, late-maturing turtle that uses wetland and adjacent upland habitat (Congdon et al., 2008; Congdon et al., 2011; Reid et al., 2016). Threats to this species include habitat loss, road mortality,

and elevated rates of nest predation by subsidized predators, resulting in a lack of recruitment (Congdon et al., 2008). The Blanding's Turtle is ranked as endangered by the International Union for Conservation of Nature (IUCN, 2020), is recognized as being in need of conservation or is listed as threatened or endangered in each U.S. State and Canadian Province in which it occurs (Congdon et al., 2008; COSEWIC, 2016), and is scheduled for candidate status review under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service, 2015).

Posthatch survival of juvenile Blanding's Turtles is poorly known. Nest failure rates, mostly because of nest predators, can be high, ranging from 59%–94% (survival rate = 6%–41%; Butler and Graham, 1995; Congdon et al., 2000; Standing et al., 2000; Reid et al., 2016; Urbanek et al., 2016). Hatching failure, because of infertility or abnormal development, is less frequent, ranging from 13%–53% (survival rate = 47%–87%; Emrich, 1991; Butler and Graham, 1995; Congdon et al., 2000; Joyal et al., 2000; Standing et al., 2000). Posthatch survival estimates from tracking studies using telemetry or fluorescent powder range from 20%–82% (Camaclang, 2007; Arsenault, 2011; Jones and Sievert, 2012; Paterson et al., 2012). Unfortunately, these studies of hatchling survival span variable (and sometimes unreported) time intervals and fail to account for unknown outcomes (e.g., transmitter loss or failure) or removal from study as transmitters reach the anticipated end of battery life or fluorescent powder trails become undetectable.

Management practices aimed at increasing early life stage survival of Blanding's Turtles include nest caging, hatchling releases after artificial incubation, headstarting, and mesopredator control (Standing et al., 2000; Urbanek et al., 2016; Starking-Symanski et al., 2018; Carstairs et al., 2019; Thompson et al., 2020). Here, we compare the effectiveness of nest caging and artificial incubation by examining Blanding's Turtle survival and movement distances after hatchling release. We focus on these two methods because they are relatively simple, requiring only the monitoring of adult females, and thus might be undertaken by individuals or agencies lacking the resources

⁶Present Address: Department of Forestry and Natural Resources, University of Kentucky, Lexington, Kentucky, 40546, USA

⁷Present Address: Mountain Lake Biological Station, Department of Biology, University of Virginia, Charlottesville, Virginia, 22904, USA

⁸Present Address: School of Medicine and Public Health, University of Wisconsin-Madison, Madison, Wisconsin, 53719, USA

⁹Present Address: West Allis Central High School, West Allis, Wisconsin, 53227, USA

¹¹Corresponding Author. E-mail: rbking@niu.edu
DOI: 10.1670/20-084

TABLE 1. Study locations, principle investigator (PI), and sample sizes of telemetered hatchling Blanding's Turtles from caged nests, artificially incubated, or wild caught.^a

Location	PI	Sample size		
		Caged	Incubated	Wild caught
Kane/Lee	MK	19 ^b	27 ^c	1 ^d
Lake/Kenosha	ARK	3 ^e	14 ^f	1 ^g
Rock	JK		17 ^h	

^a Kane/Lee, Kane and Lee County, Illinois; Lake/Kenosha, Lake County, Illinois and Kenosha County, Wisconsin; Rock, Rock County, Wisconsin.

^b Clutches of 10 (2015), 8 (2016), and 1 (2016) released in wetland shallows.

^c Clutches of 10 (2015), 9 (2016), and 8 (2016) released in wetland shallows.

^d Incidental capture (2016) released in wetland shallows.

^e Partial clutch (2008) released at terrestrial nest sites.

^f Two hatchlings from each of 7 clutches (2008) released at terrestrial nest sites.

^g Incidental capture (2008) released at terrestrial nest sites.

^h One clutch of 7 (2015) and 1 clutch of 10 (2016) released at terrestrial nest sites.

for headstarting or mesopredator control. By providing estimates of posthatch survival, we fill a knowledge gap in Blanding's Turtle demography. We make use of formal survival analysis, in which outcomes other than mortality are treated as "censored," to estimate survival and associated confidence limits over the duration of our study and interpolate survival over longer time periods (Collet, 2003), e.g., from hatching through spring emergence after first hibernation. Our analyses, together with recent estimates of survival among older (≥ 1 yr) juveniles (Golba, 2019) and adults (Congdon et al., 1993; Rubin et al., 2004; Ruane et al., 2008; Reid et al., 2016; Golba, 2019), enhance knowledge of Blanding's Turtle survival more generally.

MATERIALS AND METHODS

We combined data from three separate studies spearheaded by authors MK, ARK, and JK and located within 100 km of each other in northern Illinois and southern Wisconsin (Kane and Lee County, Illinois = Kane/Lee; Lake County, Illinois and Kenosha County, Wisconsin = Lake/Kenosha; Rock County, Wisconsin = Rock; Table 1). All locations consisted of shallow wetlands with abundant emergent aquatic vegetation and were the focus of ongoing Blanding's Turtle monitoring and telemetry (exact localities withheld at the request of land managers), providing us with the opportunity to observe nesting females and cage their nests or collect gravid females to obtain eggs for artificial incubation. To cage nests, we checked telemetered animals in late May and early June for afternoon or evening overland movements typical of nesting females. We discretely followed these females to their nesting sites. After a turtle oviposited, we caged nests by using closed cylinders made of 1.27-cm mesh hardware cloth measuring 30 cm in diameter and 25 cm high. Cages were buried to a depth of about 10 cm and held in place with rebar and zip ties or weights placed on flanges at their base. Caged nests were checked daily for hatchlings from late August through mid-September. To obtain artificially incubated hatchlings, we palpated females for shelled eggs, induced oviposition, and incubated eggs as described in Thompson et al. (2020).

Hatchlings from both caged and artificially incubated nests were measured and weighed. Hatchlings greater than 8 g were outfitted with a small radio transmitter (Advanced Telemetry Systems, 0.5–0.6 g) glued to their carapace by using quick-setting epoxy. Hatchlings were released into the shallows of their home preserve wetlands (Kane/Lee) or on land at known

nest sites 20–150 m from wetland margins (Lake/Kenosha, Rock). Telemetered hatchlings were located every 1 to 3 days (using Advanced Communications R-1000, ATS R-2000, or Lotek Biotracker receiver) until the onset of cool weather, after which they were located approximately weekly. Hatchlings were monitored until death, disappearance, or transmitter detachment. Transmitters reaching the end of their expected battery life (30–40 days) were sometimes replaced to extend tracking duration. Remaining transmitters were removed before anticipated battery failure. The distance moved between sequential locations was measured using a flexible tape or from global positioning system (GPS) coordinates.

We used Kaplan-Meier survival analysis 1) to compare survival between incubation methods by using data on 19 hatchlings from caged nests and 27 artificially incubated hatchlings from the Kane/Lee study; 2) to compare survival among study locations by using data on 47 Kane/Lee hatchlings, 18 Lake/Kenosha hatchlings, and 17 Rock hatchlings; and 3) to estimate survival across methods and locations by using data on all 82 hatchlings combined. Wild-caught hatchlings were excluded from comparisons of hatchlings from caged nests to artificially incubated hatchlings ($n = 1$) but were included in comparisons among studies and combined estimates ($n = 2$). Analyses were carried out using SPSS 25.0, IBM. Documented deaths and disappearances occurring within the expected transmitter battery life were scored as mortalities. Disappearances were confirmed by extending the search area and repeating searches on subsequent dates. Transmitter detachments and removals were treated as censored data as was a single mortality attributed to antenna entanglement. For our combined analysis, we fit exponential, Weibull, and Gompertz survival functions to our Kaplan-Meier results by using the curve fitting function of SPSS. These functions differ in whether they treat the risk of mortality as constant (exponential function) or monotonically changing over time (Weibull and Gompertz functions; Collett, 2003). A useful feature of these functions is that they allow extrapolation of survival beyond the end of our telemetry study.

We restricted our analysis of movement distance to movements measured over intervals of 1 to 5 days. Because movement distances were skewed right, we transformed data by using natural logarithms after adding 1 to achieve normality. We computed mean movement distance for each turtle for which five or more distances were recorded. We used a *t*-test to compare mean movement distance between hatchlings from caged nests ($n = 15$) and hatchlings from artificially incubated eggs ($n = 20$) from the Kane/Lee study. We used analysis of variance with Tukey post-hoc tests to compare mean movement distances among hatchlings from the Kane/Lee ($n = 36$), Lake/Kenosha ($n = 15$), and Rock studies ($n = 16$). Equal variances were confirmed using Leven's test before analysis was conducted.

RESULTS

Transmitters were placed on 82 hatchling turtles (Table 1), and survival was monitored for up to 88 days (Appendix 1). Thirteen turtles were confirmed or inferred to have died during our study. Causes of mortality included predation ($n = 5$ carcasses showing evidence of trauma), entanglement ($n = 1$), and unknown causes (2 carcasses without trauma and 5 animals that disappeared within expected battery life). The fates of the remaining 69 turtles were treated as censored because of

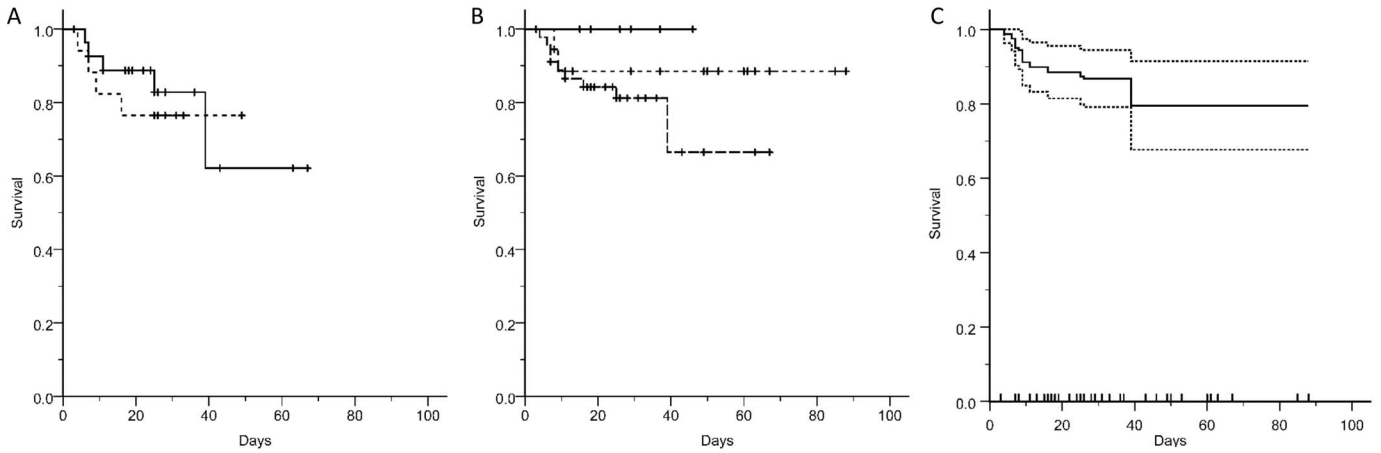


FIG. 1. Hatchling Blanding's Turtle survival functions comparing nest-cage (dashed line) and artificially incubated hatchlings (solid line) (A), comparing Kane/Lee (long dashed line), Lake/Kenosha (short dashed line), and Rock (solid line) studies (B), and for all 82 hatchlings combined (dotted lines represent 95% confidence limits) (C). Censored data are indicated by hash marks on survival lines (A, B) or on the horizontal axis (C).

transmitter loss ($n = 13$), battery failure ($n = 3$), or conclusion of the study ($n = 53$).

Survival did not differ between 19 hatchlings (4 mortalities) from caged nests and 27 artificially incubated hatchlings (6 mortalities) from the Kane/Lee study (Tarone-Ware $\chi^2 = 0.222$, $P = 0.637$; Fig. 1A). Survival also did not differ among 47 Kane/Lee (10 mortalities), 18 Lake/Kenosha (2 mortalities), and 17 Rock hatchlings (0 mortalities; Tarone-Ware $\chi^2 = 4.254$, $P = 0.119$; Fig. 1B). Estimated survival over the entire 88-day study for all 82 hatchlings combined was 79.6% (SE = 0.061, 95% confidence interval = 67.6%–91.6%; Fig. 1C). Results of the Kaplan-Meier survival analysis were well fit by the Gompertz survival function ($r^2 = 0.93$)

$$Survival = e^{\left[\frac{-0.0097}{-0.0397} (1 - e^{-0.0397 Days}) \right]}$$

and the Weibull survival function ($r^2 = 0.86$)

$$Survival = e^{(-0.0224 Days^{0.5484})}$$

and more poorly by the exponential survival function ($r^2 = 0.52$)

$$Survival = e^{0.0038 Days}$$

(Fig. 2).

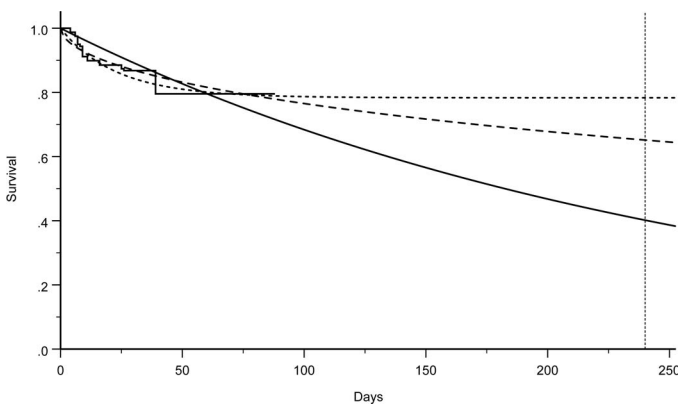


FIG. 2. Observed hatchling Blanding's Turtle survival for 82 hatchlings combined (stepped line) with corresponding exponential (solid line), Weibull (long dashed line), and Gompertz (short dashed line) survival functions. Extrapolated survival to 240 days occurs where these functions cross the dotted vertical line.

We analyzed 1,049 movements by 67 hatchling turtles (5–45 movements per turtle) (Appendix 1). Median distance moved between telemetry locations was 1.5 m (range = 0–294 m). Distance moved was positively correlated with the number of elapsed days between locations but only weakly so ($r^2 = 0.017$, $n = 1,049$, $P < 0.001$), and thus no correction was made for elapsed days. We found no difference in distance moved between hatchlings from nest cages and hatchlings from artificially incubated eggs (back-transformed mean = 2.1 vs. 2.0 m; $t = 3.323$, $df = 33$, $P = 0.749$) in the Kane/Lee study. We found significant differences in movement distance among study locations (back-transformed mean = 2.1 m in Kane/Lee, 2.4 m in Lake/Kenosha, and 8.6 m in Rock; $F_{2,64} = 41.943$, $P < 0.001$). Tukey post-hoc comparisons revealed Kane/Lee = Lake/Kenosha < Rock (Fig. 3).

DISCUSSION

We used radiotelemetry to test for differences in survival and movement distances between Blanding's Turtle incubation

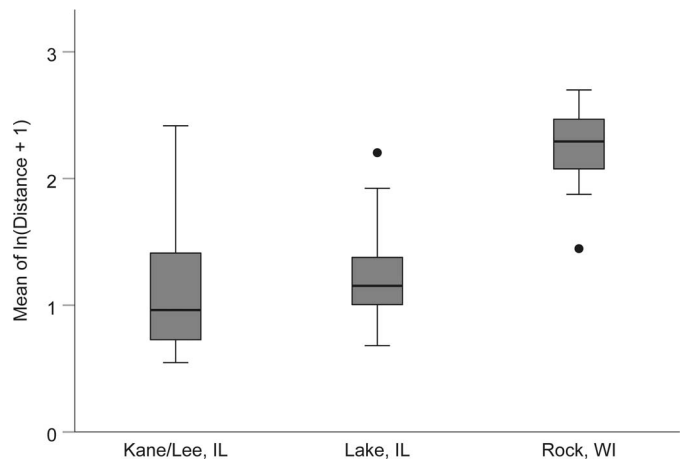


FIG. 3. Box-plot of mean movement distance by Blanding's Turtle hatchlings at three study locations. Horizontal bars represent the median, boxes represent the interquartile range, line and whiskers represent the range, and points represent outliers. Distance (m) was transformed by taking logarithms after adding 1 before computing the mean for each turtle.

methods and among study locations and to estimate survival across methods and locations. We found no significant difference in survival between Blanding's Turtle hatchlings from natural (caged) nests and those produced by artificial incubation. Likewise, we found no significant difference in survival among studies despite the fact that Lake/Kenosha and Rock hatchlings were released at nest sites and had to make overland movements to reach wetlands, whereas Kane/Lee turtles were released in wetland shallows. Admittedly, our ability to detect differences in survival is limited by sample size and study duration. For example, given our sample size and observed survival rates, our power to detect a difference among study locations is approximately 0.66 (https://www.statstodo.com/SSizSurvival_Pgm.php; Machin et al., 2009). We found no difference in movement distance between hatchlings from natural nests and those produced by artificial incubation. The similarity in the survival and movement distance of hatchlings from caged nests and those produced by artificial incubation suggests that both tactics may be effective for reducing mortality caused by nest predators. We recognize that hatchlings from caged nests and those produced by artificial incubation may differ in ways not detected in our study or that differences may not become apparent until later in life (e.g., effect on growth of constant vs. variable incubation temperature; Booth 2006). Thus, further study is warranted. Regardless, both tactics are labor intensive and should be evaluated against other options (no intervention, nest site restoration, headstarting, and mesopredator control) when designing management plans.

We did find differences in movement distance among studies, with Rock hatchlings moving significantly farther than Lake/Kenosha and Kane/Lee hatchlings. Possibly, the shorter movement distances exhibited by Kane/Lee hatchlings were a consequence of being released at wetland margins and not having to make overland movements. However, movement distances also differed between Rock and Lake/Kenosha hatchlings, of which all were released on land at known nest sites, suggesting that local habitat features may also be important.

Overall, during our investigation, we found hatchling Blanding's Turtle survival to be relatively high, ca. 80% over 88 days, exceeding that observed in Nova Scotia (20%–50%; $n = 29, 36, 16,$ and 18 turtles tracked from hatching to hibernation in 2006, 2007, 2008, and 2010; Arsenaault, 2011) and Ontario (42%, $n = 48$ turtles tracked for 53 days posthatching; Paterson et al., 2012). However, in the Nova Scotia and Ontario studies, 31%–75% of hatchlings were lost because of transmitter detachment, transmitter failure, or unknown causes, potentially biasing survival estimates downward. A similar rate of survival to our study was observed in Massachusetts by using fluorescent powder to track 72 turtles, but it occurred over a much shorter time interval (range = 1–48 days, mean = 4.5 days posthatching; Jones and Sievert, 2012). Our estimates also exceed those observed in hatchling wood turtles (11%, $n = 42$ turtles tracked for up to 58 days; Paterson et al. 2012) and hatchling gopher tortoises at 2 of 3 sites (88-day survival = ca. 30%, 50%, and 100%; $n = 45, 20,$ and 20 , estimated from Fig. 2 in Pike and Seigel 2006; gopher tortoise survival decreased to 0% at all 3 sites by 365–765 days).

Survival beyond the 88 days of our study can be extrapolated using survival functions fit to the results of our Kaplan-Meier analysis. Given a typical hatch date for our study locations of 3 September, we computed survival until resumption of activity following hibernation (ca. 1 May), an interval of 240 days. The Gompertz survival function results in inferred survival of 78%

over 240 days, with almost no mortality occurring beyond the end of our study (Fig. 2). The Weibull function results in inferred survival of 65% with modest overwinter mortality, and the exponential function results in inferred survival of 40% (Fig. 2). Statistical fit alone favors the Gompertz function ($r^2 = 0.93$ vs. 0.86 and 0.52 for the Weibull and exponential functions, respectively), but it seems likely that at least modest rates of overwinter mortality occur among young Blanding's Turtles. Regardless, when coupled with published rates of nest survival (6%–41%; Butler and Graham, 1995; Congdon et al., 2000; Standing et al., 2000; Reid et al., 2016; Urbanek et al., 2016) and hatch success (47%–87%; Butler and Graham, 1995; Congdon et al., 2000; Emrich, 1991; Joyal et al., 2000; Standing et al., 1999), extrapolated hatchling survival rates (40%–78%) result in anticipated age 0 survival (defined here as extending from egg deposition to emergence from hibernation) of just 1%–28%.

Although estimates of age class 0 turtle survival are accumulating, most are limited to nest and egg survival and few encompass the entire age class. For example, of 54 estimates of age 0 survival tabulated by Iverson (1991), just 7 included hatchlings. Fifteen such estimates were tabulated by Heppell (1998), but no distinction was made between egg survival and survival over the entire age class. An alternative approach, advocated by Pike et al. (2008), is to infer juvenile survival rates from information on adult survival, age at maturity, and clutch size, assuming constant population size. The result is a mean annual survival rate, averaged over the entire juvenile stage (ca. 14 yr in Blanding's Turtles) that reveals little about survival during specific year classes (e.g., age 0 as in this study). The paucity of data on hatchling and juvenile turtle survival (compared, e.g., to adult survival; Rachmansah et al. 2020) reflects the technical challenges of tracking (e.g., via telemetry) and monitoring (via capture-mark-recapture) young turtles. Filling this knowledge gap for additional species will provide a better understanding of turtle demography and aid conservation planning. Regardless, evidence is growing that increasing the survival of this vulnerable age class (via nest protection, artificial incubation, headstarting, and mesopredator control) increases population persistence both in Blanding's Turtles (Urbanek et al., 2016; Carstairs et al., 2019; Golba 2019; Thompson et al., 2020) and in other turtle species (e.g., Vander Haegen et al. 2009; Munscher et al. 2012; Milinkovitch et al. 2013; Peñaloza et al. 2015; Shaver and Caillouet 2015; Engeman et al. 2016; Quinn et al. 2018).

Acknowledgments.—Funding and logistical support was provided by The Nature Conservancy, Lake County Forest Preserve District, Forest Preserve District of Kane County, Forest Preserve District of DuPage County, Northern Illinois University, University of Illinois Urbana Champaign, U.S. Fish and Wildlife Service, University of Wisconsin–Whitewater, P. and G. Shackelford, S. Foster, R. Hay and Turtles for Tomorrow, C. Vogel, the Shearer Family, Mr. and Mrs. Hodge, C. Sweeney, M. Watrous, R. Conway, B. Parker, E. Sweeney, and J. Van Altena. Work was carried out under permits from the Illinois Department of Natural Resources (05-11s, 07-04s, and 16-045), Wisconsin Department of Natural Resources (SCPSRLN-19-26, 586, and 645), Illinois Nature Preserves Commission, and The Nature Conservancy. Institutional Animal Care and Use Committee approval was provided by Northern Illinois University (LA16-0015), University of Illinois (06129), and University of Wisconsin–Whitewater (K145011020Q). We gratefully acknowledge field assistance provided by J. Atkinson, K. Cassel, D. Fritz, C.

Golba, K. Hausmann, B. House, J. Lorenz, P. Pieper, K. Rebman, K. Schmidt, Z. Welch, and S. Wyrick and the comments of two anonymous reviewers.

LITERATURE CITED

- ARSENAULT, L. M. 2011. Headstarting Blanding's Turtles (*Emydoidea blandingii*) in Nova Scotia: An Investigation of Artificial Incubation, Captive-rearing, and Release to Natural Habitats. M.S. Thesis, Acadia University, Wolfville, Nova Scotia, Canada.
- BOOTH, D. T. 2006. Influence of incubation temperature on hatchling phenotype in reptiles. *Physiological and Biochemical Zoology* 79: 274–281.
- BURKE, R. L. 2015. Head-starting turtles: learning from experience. *Herpetological Conservation and Biology* 10:299–308.
- BUTLER, B. O., AND T. E. GRAHAM. 1995. Early post-emergent behavior and habitat selection in hatchling Blanding's turtles, *Emydoidea blandingii*, in Massachusetts. *Chelonian Conservation and Biology* 1:187–196.
- CAMAACLANG, A. E. 2007. Science, Management, and Policy in Conservation Biology: Protecting Post-emergent Hatchling Blanding's Turtles in Nova Scotia. M.S. Thesis, Dalhousie University, Halifax, Nova Scotia, Canada.
- CARSTAIRS, S., J. E. PATERSON, K. L. JAGER, D. GASBARRINI, A. B. MUI, AND C. M. DAVY. 2019. Population reinforcement accelerates subadult recruitment rates in an endangered freshwater turtle. *Animal Conservation* 22:589–599.
- COLLETT, D. 2003. *Modelling Survival Data in Medical Research*, 2nd ed. Chapman & Hall/CRC, USA.
- COMMITTEE ON THE STATUS OF ENDANGERED WILDLIFE IN CANADA (COSEWIC). 2016. COSEWIC assessment and status report on the Blanding's turtle *Emydoidea blandingii*, Nova Scotia population and Great Lakes/St. Lawrence population, in Canada. Available from: <http://www.cosewic.ca/index.php/en-ca/>.
- CONGDON, J. D., A. E. DUNHAM, AND R. C. VAN LOBEN SELS. 1993. Delayed sexual maturity and demographics of Blanding's Turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. *Conservation Biology* 7:826–833.
- CONGDON, J. D., T. E. GRAHAM, T. B. HERMAN, J. W. LANG, M. J. PAPPAS, AND B. J. BRECKE. 2008. *Emydoidea blandingii* (Holbrook 1838)—Blanding's turtle. Pp. 1–12 in A. G. J. Rhodin, P. C. H. Pritchard, P. P. van Dijk, R. A. Saumure, K. A. Buhlmann, and J. B. Iverson (eds.), *Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group*. Chelonian Research Foundation Monographs No. 5. Chelonian Research Foundation, Lunenburg, Massachusetts. doi:10.3854/crm.5.015.blandingii.v1.2008, Available from: <http://www.iucn-tftsg.org/cbft/>.
- CONGDON, J. D., O. M. KINNEY, AND R. D. NAGLE. 2011. Spatial ecology and core-area protection of Blanding's turtle (*Emydoidea blandingii*). *Canadian Journal of Zoology* 89:1098–1106.
- CONGDON, J. D., R. D. NAGLE, O. M. KINNEY, M. OSENTOSKI, H. AVERY, R. C. VAN LOBEN SELS, AND D. W. TINKLE. 2000. Nesting ecology, and embryo mortality: implications for the demography of Blanding's turtles (*Emydoidea blandingii*). *Chelonian Conservation and Biology* 3:569–579.
- EMRICH, M. E. 1991. Blanding's Turtle (*Emydoidea blandingii*) Nesting Behavior and Response to an Artificial Nest Habitat. M.S. Thesis, Bard College, Annandale-on-Hudson, New York, USA.
- ENGEMAN, R. M., D. ADDISON, AND J. C. GRIFFIN. 2016. Defending against disparate marine turtle nest predators: nesting success benefits from eradicating invasive feral swine and caging nests from raccoons. *Oryx* 50:289–295.
- GOLBA, C. K. 2019. Growth and Survival of Wild and Head-started Blanding's Turtles (*Emydoidea blandingii*). M.S. Thesis, Northern Illinois University, DeKalb, Illinois, USA.
- HEPPELL, S. S. 1998. Application of life-history theory and population model analysis to turtle conservation. *Copeia* 1998:367–375.
- IUCN 2020. The IUCN Red List of Threatened Species. Version 2020–1. Available from: <https://www.iucnredlist.org>.
- IVERSON, J. B. 1991. Patterns of survivorship in turtles (order Testudines). *Canadian Journal of Zoology* 69:385–391.
- JONES, M. T., AND P. R. SIEVERT. 2012. Elevated mortality of hatchling Blanding's turtles (*Emydoidea blandingii*) in residential landscapes. *Herpetological Conservation and Biology* 7:89–94.
- JOYAL, L. A., M. MCCOLLOUGH, AND M. L. HUNTER. 2000. Population structure and reproductive ecology of Blanding's turtle (*Emydoidea blandingii*) in Maine, near the northeastern edge of its range. *Chelonian Conservation and Biology* 3:580–588.
- MACHIN, D., M. J. CAMPBELL, S. B. TAN, AND S. H. TAN. 2009. *Sample Size Tables for Clinical Studies*, 3rd edition. Wiley-Blackwell, United Kingdom.
- MILINKOVITCH, M. C., R. KANITZ, R. TIEDEMANN, W. TAPIA, F. LLERENA, A. CACCONE, J. P. GIBBS, AND J. R. POWELL. 2013. Recovery of a nearly extinct Galápagos tortoise despite minimal genetic variation. *Evolutionary Applications* 6:377–383.
- MUNSCHER, E. C., E. H. KUHNS, C. A. COX, AND J. A. BUTLER. 2012. Decreased nest mortality for the Carolina diamondback terrapin (*Malaclemys terrapin centrata*) following removal of raccoons (*Procyon lotor*) from a nesting beach in northeastern Florida. *Herpetological Conservation and Biology* 7:176–184.
- O'CONNOR, J. M., C. J. LIMPUS, K. M. HOFMEISTER, B. L. ALLEN, AND S. E. BURNETT. 2017. Anti-predator meshing may provide greater protection for sea turtle nests than predator removal. *PLoS One* 12: e0171831. doi:10.1371/journal.pone.0171831.
- PATERSON, J. E., B. D. STEINBERG, AND J. D. LITZGUS. 2012. Revealing a cryptic life-history stage: differences in habitat selection and survivorship between hatchlings of two turtle species at risk (*Glyptemys insculpta* and *Emydoidea blandingii*). *Wildlife Research* 39: 408–418.
- PEÑALOZA, C. L., O. HERNÁNDEZ, AND R. ESPÍN. 2015. Head-starting the giant sideneck river turtle (*Podocnemis expansa*): turtles and people in the Middle Orinoco, Venezuela. *Herpetological Conservation and Biology* 10:472–488.
- PIKE, D. A., AND R. A. SEIGEL. 2006. Variation in hatchling tortoise survivorship at three geographic localities. *Herpetologica* 62:125–131.
- PIKE, D. A., L. PIZZATTO, B. A. PIKE, AND R. SHINE. 2008. Estimating survival rates of uncatchable animals: the myth of high juvenile mortality in reptiles. *Ecology* 89:607–611.
- QUINN, D. P., K. A. BUHLMANN, J. B. JENSEN, T. M. NORTON, AND T. D. TUBERVILLE. 2018. Post-release movement and survivorship of head-started gopher tortoises. *Journal of Wildlife Management* 82:1545–1554.
- RACHMANSAH, A., D. NORRIS, AND J. P. GIBBS. 2020. Population dynamics and biological feasibility of sustainable harvesting as a conservation strategy for tropical and temperate freshwater turtles. *PLoS One* 15: e0229689.
- REID, B. N., R. P. THIEL, AND M. Z. PEERY. 2016. Population dynamics of endangered Blanding's turtles in a restored area. *Journal of Wildlife Management* 80:553–562.
- RUANE, S., S. A. DINKELACKER, AND J. B. IVERSON. 2008. Demographic and reproductive traits of Blanding's turtles, *Emydoidea blandingii*, at the western edge of the species' range. *Copeia* 2008:771–779.
- RUBIN, C. S., R. E. WARNER, D. R. LUDWIG, AND R. THIEL. 2004. Population structure of Blanding's turtles (*Emydoidea blandingii*) in two suburban Chicago forest preserves. *Natural Areas Journal* 24:44–48.
- SHAVER, D. J., AND C. W. CAILLOUET, JR. 2015. Reintroduction of Kemp's Ridley (*Lepidochelys kempii*) sea turtle to Padre Island National Seashore, Texas and its connection to head-starting. *Herpetological Conservation and Biology* 10:378–435.
- STANDING, K. L., T. B. HERMAN, AND I. P. MORRISON. 1999. Nesting ecology of Blanding's turtle (*Emydoidea blandingii*) in Nova Scotia, the northeastern limit of the species' range. *Canadian Journal of Zoology* 77:1609–1614.
- STANDING, K. L., T. B. HERMAN, M. SHALLOW, T. POWER, AND I. P. MORRISON. 2000. Results of the nest protection program for Blanding's Turtle in Kejimikujik National Park, Canada: 1987–1997. *Chelonian Conservation and Biology* 34:637–642.
- STARKING-SZYMANSKI, M., T. YODER-NOWAK, G. RYBARCZYK, AND H. A. DAWSON. 2018. Movement and habitat use of headstarted Blanding's turtles in Michigan. *Journal of Wildlife Management* 82:1516–1527.
- STEM, C., R. MARGOLUIS, N. SALAFSKY, AND M. BROWN. 2005. Monitoring and evaluation in conservation: a review of trends and approaches. *Conservation Biology* 19:295–309.
- THOMPSON, D., G. GLOWACKI, D. LUDWIG, R. REKLAU, A. R. KUHN, C. KLATT GOLBA, R. KING. 2020. Benefits of head-starting for Blanding's turtle size distributions and recruitment. *Wildlife Society Bulletin* 44:57–67.
- URBANER, R. E., G. A. GLOWACKI, AND C. K. NIELSEN. 2016. Effect of raccoon (*Procyon lotor*) reduction on Blanding's turtle (*Emydoidea blandingii*) nest success. *Journal of North American Herpetology* 2016:39–44.

USATEGUI-MARTIN, A., A. LIRIA-LOZA, J. D. MILLER, M. MENDINA-SUÁREZ, S. JIMÉNEZ-BORDÓN, V. PÉREZ-MELLADO, AND D. MONTERO. 2019. Effects of incubation temperature on hatchling performance and phenotype in loggerhead sea turtle *Caretta caretta*. *Endangered Species Research* 38:45–53.

U.S. FISH AND WILDLIFE SERVICE. 2015. Endangered and threatened wildlife and plants; 90-day findings on 31 petitions. *Federal Register* 80: 37568–37579.

VANDER HAEGEN, W. M., S. L. CLARK, K. M. PERILLO, D. P. ANDERSON, AND H. L. ALLEN. 2009. Survival and causes of mortality of head-started western pond turtles on Pierce National Wildlife Refuge, Washington. *Journal of Wildlife Management* 73:1402–1406.

Accepted: 28 February 2021.

Published online: 11 June 2021.

APPENDIX 1. Hatchling Blanding's Turtle fates and distances moved. Each row represents an individual turtle identified by study, treatment, release date, and end date. Duration refers to the number of days over which an individual turtle was tracked. Fate refers to the status of the turtle at the end of the study (0 = turtles that were alive when transmitters were removed, detached, or failed; 1 = turtles that were known or inferred to have died). Distance is the mean distance moved between tracking locations (raw distances in m were transformed by taking logarithms after adding 1 before computing means shown here). *N*, the number of movements recorded; ID, turtle identifier.

ID	Study	Treatment	Release	End date	Duration	Fate	Distance	<i>N</i>
1	Kane/Lee	Caged	9 Sep	13 Sep	4	1	0.55	6
2	Kane/Lee	Caged	9 Sep	5 Oct	26	0	2.42	10
3	Kane/Lee	Caged	7 Sep	8 Sep	1	0		
4	Kane/Lee	Caged	9 Sep	12 Sep	3	0		
5	Kane/Lee	Caged	9 Sep	18 Sep	9	1		
6	Kane/Lee	Caged	9 Sep	28 Oct	49	0	0.73	18
7	Kane/Lee	Caged	9 Sep	5 Oct	26	0	1.05	10
8	Kane/Lee	Caged	9 Sep	28 Oct	49	0	1.35	18
9	Kane/Lee	Caged	9 Sep	28 Oct	49	0	0.89	18
10	Kane/Lee	Incubated	15 Aug	21 Aug	6	1		
11	Kane/Lee	Incubated	15 Aug	12 Sep	28	0	1.70	9
12	Kane/Lee	Incubated	15 Aug	26 Aug	11	1		
13	Kane/Lee	Incubated	15 Aug	22 Aug	7	1		
14	Kane/Lee	Incubated	15 Aug	21 Oct	67	0	1.67	18
15	Kane/Lee	Incubated	15 Aug	22 Aug	7	0		
16	Kane/Lee	Incubated	15 Aug	17 Oct	63	0	1.65	17
17	Kane/Lee	Incubated	15 Aug	26 Aug	11	0		
18	Kane/Lee	Incubated	18 Aug	9 Sep	22	0	0.87	9
19	Kane/Lee	Incubated	18 Aug	9 Sep	22	0	0.70	9
20	Kane/Lee	Incubated	18 Aug	30 Sep	43	0	0.69	16
21	Kane/Lee	Incubated	18 Aug	6 Sep	19	0	0.70	9
22	Kane/Lee	Incubated	18 Aug	13 Sep	26	0	0.95	5
23	Kane/Lee	Incubated	18 Aug	4 Sep	17	0	0.81	7
24	Kane/Lee	Incubated	18 Aug	11 Sep	24	0	1.23	9
25	Kane/Lee	Incubated	18 Aug	11 Sep	24	0	0.72	10
26	Kane/Lee	Incubated	18 Aug	23 Sep	36	0	1.08	13
27	Kane/Lee	Incubated	18 Aug	13 Sep	26	0	0.93	10
28	Kane/Lee	Caged	11 Sep	6 Oct	25	0	1.74	10
29	Kane/Lee	Caged	11 Sep	6 Oct	25	0	0.73	10
30	Kane/Lee	Caged	11 Sep	14 Oct	33	0	0.69	9
31	Kane/Lee	Caged	11 Sep	12 Oct	31	0	0.66	12
32	Kane/Lee	Caged	11 Sep	14 Oct	33	0	0.98	13
33	Kane/Lee	Caged	11 Sep	27 Sep	16	1	1.57	6
34	Kane/Lee	Caged	11 Sep	9 Oct	28	0	0.82	11
35	Kane/Lee	Caged	11 Sep	6 Oct	25	0	1.25	10
36	Kane/Lee	Caged	11 Sep	18 Sep	7	1		
37	Kane/Lee	Caged	11 Sep	12 Oct	31	0	1.01	12
38	Kane/Lee	Incubated	15 Aug	23 Sep	39	1	1.23	10
39	Kane/Lee	Incubated	15 Aug	21 Oct	67	0	1.23	17
40	Kane/Lee	Incubated	15 Aug	21 Oct	67	0	0.65	18
41	Kane/Lee	Incubated	15 Aug	9 Sep	25	0	2.20	6
42	Kane/Lee	Incubated	15 Aug	9 Sep	25	0	1.70	6
43	Kane/Lee	Incubated	15 Aug	23 Sep	39	1		
44	Kane/Lee	Incubated	15 Aug	9 Sep	25	1	1.47	6
45	Kane/Lee	Incubated	15 Aug	2 Sep	18	0		
46	Kane/Lee	Incubated	15 Aug	21 Oct	67	0	0.74	17
47	Kane/Lee	Wild	18 Sep	4 Oct	16	0	0.79	6
48	Lake/Kenosha	Caged	5 Sep	11 Nov	67	0	0.74	45
49	Lake/Kenosha	Incubated	6 Sep	19 Sep	13	0	2.20	6
50	Lake/Kenosha	Incubated	7 Sep	16 Sep	9	1		
51	Lake/Kenosha	Incubated	7 Sep	6 Nov	60	0	1.53	38
52	Lake/Kenosha	Wild	10 Sep	4 Dec	85	0	1.09	37
53	Lake/Kenosha	Incubated	7 Sep	15 Sep	8	0		
54	Lake/Kenosha	Incubated	7 Sep	6 Oct	29	0	1.03	43
55	Lake/Kenosha	Incubated	7 Sep	4 Dec	88	0	0.98	41
56	Lake/Kenosha	Incubated	7 Sep	26 Oct	49	0	1.17	32
57	Lake/Kenosha	Incubated	7 Sep	27 Oct	50	0	1.15	35

APPENDIX 1. Continued.

ID	Study	Treatment	Release	End date	Duration	Fate	Distance	N
58	Lake/Kenosha	Incubated	7 Sep	30 Oct	53	0	1.25	39
59	Lake/Kenosha	Incubated	7 Sep	18 Sep	11	0	1.92	5
60	Lake/Kenosha	Incubated	7 Sep	7 Nov	61	0	0.93	40
61	Lake/Kenosha	Caged	5 Sep	7 Nov	63	0	1.13	44
62	Lake/Kenosha	Incubated	7 Sep	15 Sep	8	1		
63	Lake/Kenosha	Incubated	7 Sep	14 Oct	37	0	0.68	27
64	Lake/Kenosha	Caged	5 Sep	7 Nov	63	0	1.50	43
65	Lake/Kenosha	Incubated	7 Sep	7 Nov	61	0	1.20	42
66	Rock	Incubated	14 Aug	12 Sep	29	0	2.38	6
67	Rock	Incubated	17 Aug	2 Oct	46	0	2.36	13
68	Rock	Incubated	17 Aug	23 Sep	37	0	2.27	11
69	Rock	Incubated	17 Aug	23 Sep	37	0	1.87	11
70	Rock	Incubated	17 Aug	2 Oct	46	0	2.69	13
71	Rock	Incubated	17 Aug	23 Sep	37	0	1.45	13
72	Rock	Incubated	17 Aug	23 Sep	37	0	2.59	11
73	Rock	Incubated	17 Aug	1 Sep	15	0	2.70	6
74	Rock	Incubated	14 Aug	9 Sep	26	0		
75	Rock	Incubated	14 Aug	1 Sep	18	0	2.18	6
76	Rock	Incubated	14 Aug	1 Sep	18	0	2.48	6
77	Rock	Incubated	14 Aug	1 Sep	18	0	1.96	6
78	Rock	Incubated	14 Aug	12 Sep	29	1	2.46	6
79	Rock	Incubated	14 Aug	1 Sep	18	0	1.97	6
80	Rock	Incubated	14 Aug	1 Sep	18	0	2.31	6
81	Rock	Incubated	14 Aug	12 Sep	29	0	2.24	6
82	Rock	Incubated	14 Aug	1 Sep	18	0	2.21	6