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Survivorship, Home Range, Growth and Reproduction of Eastern Box Turtles (*Terrapene carolina*) Head-Started to Subadult Size on Jekyll Island, Georgia, USA

Joseph E. Colbert[1,2,7], Breanna Ondich[2,3], Richard G. Bauer[2,4], Kimberly M. Andrews[5], Terry M. Norton[2], and Thomas A. Radzio[2,6]

[1]*Conservation Department, Jekyll Island Authority, 214 Stable Road, Jekyll Island, Georgia 31527, USA*
[2]*Georgia Sea Turtle Center, Jekyll Island Authority, 214 Stable Road, Jekyll Island, Georgia 31527, USA*
[3]*Odum School of Ecology, University of Georgia, 140 East Green Street, Athens, Georgia 30602, USA*
[4]*Lee County Parks and Recreation Administration Office, 4310 Palm Beach Boulevard, Fort Myers, Florida 33916, USA*
[5]*University of Georgia, UGA Marine Extension, 715 Bay Street, Brunswick, Georgia 31520, USA*
[6]*San Diego Zoo Wildlife Alliance, 15600 San Pasqual Valley Road, Escondido, California 92027, USA*
[7]*Corresponding author, e-mail: jcolbert@jekyllisland.com*

Abstract.—**Turtle conservation programs should address underlying threats, but population reinforcement measures, such as head-starting, may also play an important role in some situations. Head-starting involves captive-rearing hatchlings to larger body sizes, making them less vulnerable to predators, before release into the wild. Head-starting for a year or less can increase survival, but short head-start durations typically produce small individuals that remain quite vulnerable to predators. We head-started Eastern Box Turtles (*Terrapene carolina*), a declining species of Eastern North America, for 2–3 y until they achieved subadult size in the hope that this would lead to high survival following release. We released nine head-started subadults onto Jekyll Island (Georgia, USA), and assessed survivorship, home range, and growth via radio telemetry. All nine head-started turtles survived from release until radio transmitter removal 4 y later. Home ranges (median minimum convex polygon = 3.1 ha; range, 1.3–28.9 ha) were comparable to those of wild individuals in other studies, and at least eight head-started turtles reached adult size. Radiographs of two females incidentally recaptured 7 y and 10 y after release indicated egg production. Survival of large subadult head-started turtles in this project was greater than that of hatchlings and small juvenile *T. carolina* head-started turtles in other studies, suggesting that head-starting to subadult size may represent an effective population reinforcement option worthy of further study in this and other turtle species.**

Key Words.—conservation; juvenile; reptile; survival

Introduction

Reptiles are in decline worldwide (Gibbons et al. 2000; Cox et al. 2022), and chelonians are no exception with about one-half of turtle species considered threatened or endangered (Bonin et al. 2006; Lovich et al. 2018; Rhodin et al. 2018; Stanford et al. 2020). One reason for this is that life-history traits, such as delayed sexual maturity and low offspring survival, render turtle populations reliant on high adult survival, and, consequently, particularly sensitive to increases in adult mortality (Gibbons 1987; Congdon and Gibbons 1990; Iverson 1991; Congdon et al. 1993). These traits also limit rates at which impacted populations can recover from perturbations, even after threats have been removed (Congdon et al. 1993). This, along with concerns about the viability of small populations, has contributed to interest in the use of population reinforcement measures to accelerate recovery of impacted turtle populations (Spencer et al. 2017; Carstairs et al. 2019).

Head-starting, the process of captive rearing hatchlings to larger sizes at which they are less vulnerable to predators, is a population reinforcement measure that has been applied to terrestrial, freshwater, and marine turtles (e.g., Bell et al. 2005; Fontaine and Shaver 2005; Jensen et al. 2018; Thompson et al. 2020; Tuberville et al. 2021). It is based on the principle that survival is low for turtle eggs and hatchlings but increases as juveniles grow. Although not a substitute for addressing root causes of population decline, such as habitat loss, head-starting may play a complementary, and even central, recovery role in some situations (Jensen et al. 2018; Tuberville et al. 2021). Head-starting for a year or less can increase survival, but such short durations produce small head-start turtles that can remain quite vulnerable to predators (Radzio et al. 2019; Tetzlaff et al. 2019). Head-starting for longer durations can produce larger individuals with potentially higher survival rates but requires more resources, and the effects of prolonged captivity remain unknown for most species.

Occurring throughout much of eastern North America, Eastern Box Turtle (*Terrapene carolina*) populations are declining owing to several factors, including habitat loss and alteration, road mortality, collection, and disease (Stickel 1978; Dodd et al. 1989; Hall et al. 1999; Dodd 2001). Box turtle conservation priorities include protecting natural habitat, reducing existing threats, and understanding population responses to management measures (Dodd 2001; Roe et al. 2019). Eastern Box Turtles often inhabit semi-developed environments, however, where it is likely impossible to eliminate all threats (e.g., road mortality). Successfully translocating turtles to such sites may be particularly challenging if individuals require substantial time to establish site fidelity and exhibit wide-ranging movements that can place them at heightened risk of physiological stress, depredation, and road mortality. Therefore, a need exists to determine whether moderately developed areas can support self-sustaining box turtle populations and whether programs such as head-starting can aid box turtle population recovery once threats have been sufficiently reduced.

In the single study reporting survival rates of head-started Eastern Box Turtles, only about half of small (≤ 70 g) head-started juveniles (9- and 21-mo-old) survived 1 y after release (Tetzlaff et al. 2019). In an attempt to achieve higher survival following release, we head-started Eastern Box Turtles to subadult size. We also wanted to determine the efficacy of head-starting turtles to large body size in general. We reared head-started turtles for 2–3 y and released them as subadults onto Jekyll Island, a barrier island off the Georgia, USA, coast managed for tourism and wildlife. Following release, we used radio telemetry to assess their survival, home range size, and growth over a 4-y period. We also opportunistically collected radiographs to assess reproductive status once individuals reached adult size. Because we released head-started turtles as subadults, our work provides insights into the ecology, including survival rates, of a life stage that is understudied in this and many other turtle species.

Materials and Methods

Study site.—Jekyll Island State Park is a 2,338-ha barrier island off the coast of Georgia, USA, of which approximately two-thirds is protected from development. The island has an estimated 883 residents, receives over one million visitors annually (http://censusreporter.org/profiles/06000US1312791599-jekyll-island-ccd-glynn-county-ga), and supports a resident *T. carolina* population that is the subject of ongoing research (Jeffrey Humphreys et al., unpubl. report). The head-start release site was located within Maritime Forest surrounded by a large freshwater pond, golf course, community garden, largely unused service roads, and other development. Groundcover consisted primarily of herbs, grasses, and dense Saw Palmettos (*Serenoa repens*). Canopy vegetation consisted primarily of Slash Pines (*Pinus elliottii*), Darlington Oaks (*Quercus hemispherica*), and Southern Live Oaks (*Quercus virginiana*).

Study animals.—We head-started Eastern Box Turtles at the Georgia Sea Turtle Center (GSTC), a rehabilitation, education, and research facility located on Jekyll Island. We obtained hatchlings from eggs that came from multiple females. Eggs were subsequently incubated at the GSTC using female producing temperatures (29.4°–30.6° C). After the eggs hatched, we housed the hatchlings in an outdoor educational enclosure year-round for 2–3 y. Head-started turtles received constant access to water and were broadcast-fed peas, carrots, mixed berries, earthworms, and dog food. Head-started turtles reached a mean straight carapace length (CL) of 97.0 ± 6.3 (standard deviation) mm (range, 88–108 mm) and a mean mass of 185.0 ± 44.5 g (range, 132–264 g) in captivity.

Prior to release, we injected Passive Integrated Transponder (PIT) tags subcutaneously in the right inguinal fossa and sealed needle entry points with tissue glue. We also affixed a small radio transmitter (3.6 g and 14 g Advanced Telemetry Systems Inc., Isanti, Minnesota, USA) to the carapace of each turtle using plumber's epoxy (J-B Weld Company, Sulphur Springs, Texas, USA; Fig. 1). We only used larger transmitters later in the study after turtles had increased in size. We inserted transmitter antennas into 3-mm diameter coffee stirrers and epoxied them to individual costal scutes to facilitate unrestricted growth (Fig. 1). We used acrylic paints to camouflage transmitter attachment point materials (Fig. 1).

Releases and monitoring.—We released three head-started turtles in May 2011 and an additional six

Figure 1. Subadult Eastern Box Turtle (*Terrapene carolina*) with radio transmitter head-started and released on Jekyll Island, Georgia, USA. (Photographed by Breanna Ondich).

head-started turtles in September 2011. We tracked head-started turtles released in spring and fall via radio telemetry for 50 and 46 mo, respectively. Once every 10 d, we radio-tracked each head-started turtle for 179.3 ± 13.6 tracking events per turtle (range, 146–191) throughout the 4-y radio-tracking period. We documented turtle locations using a Trimble Juno 3B Handheld GPS (Trimble Inc., Sunnyvale, California, USA). We measured body mass monthly, except during overwintering periods when turtles burrowed belowground. We brought turtles back to the GSTC annually to replace transmitters, collect morphometric measurements, and conduct health assessments.

Home range analysis.—We calculated 100% minimum convex polygon (MCP) and 50% and 95% kernel density estimates (KDE) in ArcGIS Pro 2.6.2 (Esri, Redlands, California, USA). We used a 2-m bandwidth to generate KDEs. We subtracted buildings, gated tennis courts, and ponds from home range estimates because these landscape features are not typically used by box turtles. Some sampling gaps occurred during the 4-y study, resulting in some short (≤ 3-week) gaps in location data (due to hurricane evacuation, equipment malfunction, etc.), including immediately following head-start release. These sampling gaps should have negligible effects on home range estimates, however, because head-started turtles exhibited limited movements following release (pers. obs.).

Results

All nine radio-tracked turtles survived from release in 2011 through transmitter removal in 2015 (Table 1). During the 4-y radio-tracking period, head-started turtles moved up to 400.3 ± 321.2 m (median = 307.6 m; range, 145.5–1,275.6 m) from the release location. Mean 100% MCP and 95% KDE were 6.1 ha (range, 1.3–28.9 ha) and 2.4 ha (range, 0.6–11.9 ha), respectively for the nine turtles (Fig. 2). When we excluded one individual (E) with a particularly large home range (Fig. 2), mean 100% MCP and 95% KDE were 3.2 ± 1.8 ha and 1.2 ± 0.7 ha, respectively. Median 100% MCP and 95% KDE home ranges were 3.1 ha and 1.2 ha, respectively (Fig. 2). Movement activity was minimal during winter. During the 4-y radio-tracking period, head-started turtles grew from subadult to adult size, with the possible exception of one individual whose final CL measurement (118 mm) was just shy of our 120-mm threshold (derived from Dodd 1997); mean CL increased from 97 ± 6.3 mm (range, 88–108 mm) to 126 ± 6.7 mm (range, 118–136 mm; Table 1). Mass increased from 185 ± 44.5 g (range, 132–264 g) to 407 ± 64.0 g (range, 314–513 g; Table 1; Fig. 3).

We removed radio transmitters from head-started turtles in 2015 but incidentally recaptured three of these individuals in 2018–2021. We recaptured the first turtle (F) in May 2018, about 1.5 km from the release site. She had grown 12 mm in CL since 2015 (Table 1). We radio-tracked her for another study and last located her dead in a parking lot a year later. Cause of death was unknown, but a radiograph revealed she was gravid with three eggs. We recaptured a second female turtle (A) in 2020 at the release site. She had grown 13 mm since 2015 (Table 1). Finally, we recaptured a third female head-start (I) in 2021, about 1.5 km from the release site and she had grown 3 mm since 2015 (Table 1) and was gravid with three eggs.

Discussion

We document high post-release survival of Eastern Box Turtles head-started to subadult size. All nine

Table 1. Carapace length (CL) and mass of Eastern Box Turtles (*Terrapene arolina*) head-started on Jekyll Island, Georgia, USA, at release in 2011 and when transmitters were removed in 2015. Individual A was incidentally recaptured in September 2020, at which point CL was 145 mm and mass was 669 g. Individual F was incidentally recaptured in May 2018, at which point CL was 132 mm and mass was 462 g. Individual I was incidentally recaptured twice in June 2021; CL was 134 mm and mass was 474 g on the first encounter.

Individual	Release	Final Tracking	Release CL (mm)	Final CL (mm)	Release Mass (g)	Final Mass (g)
A	18 May 2011	23 July 2015	88	132	143	463
B	21 September 2011	28 July 2015	90	121	132	314
C	21 September 2011	28 July 2015	98	125	201	407
D	18 May 2011	23 July 2015	98	118	167	353
E	21 September 2011	29 July 2015	108	136	264	513
F	21 September 2011	23 July 2015	97	120	183	346
G	21 September 2011	23 July 2015	105	132	245	460
H	21 September 2011	23 July 2015	96	120	173	393
I	18 May 2011	28 July 2015	96	131	159	417

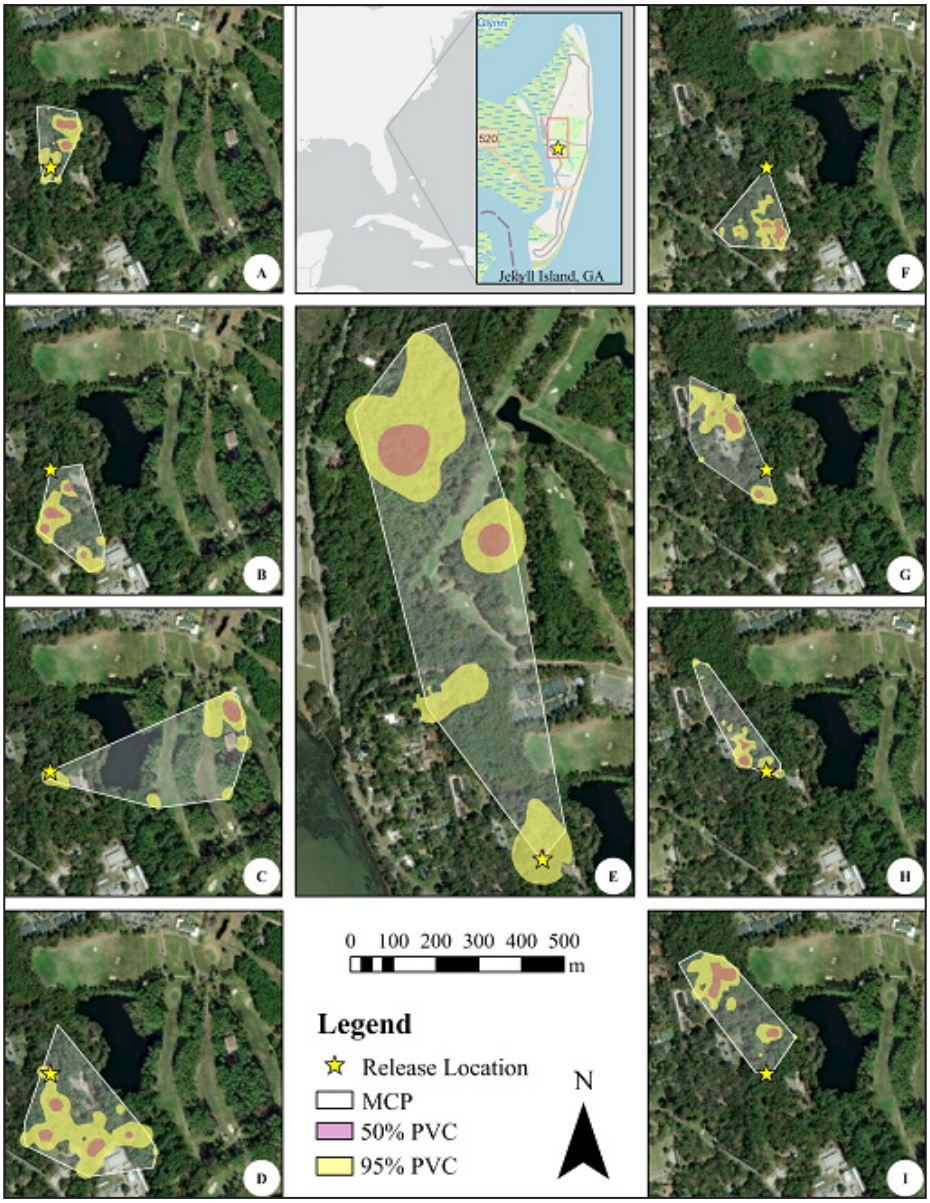

Figure 2. 100% Minimum convex polygon (MCP) and 50 and 95% kernel density home range estimates (KDE) for nine Eastern Box Turtles (*Terrapene carolina*) head-started to subadult size and released onto Jekyll Island, Georgia, USA. Data represent approximately 4 y of radio telemetry observations per individual. The star represents the release site located within a maritime forest patch.

head-started turtles survived the 4-y radio-tracking period, and eight of nine grew from subadult to adult size (≥ 120 mm CL; Dodd 1997). Survival of large head-started turtles was greater than that of hatchling and small (≤ 70 g) head-started *T. carolina* in other studies (Tetzlaff et al. 2019; Altobelli et al. 2021) and is consistent with growing empirical observations and theoretical predictions of high survival of subadult turtles (Congdon et al. 1993; Tuberville et al. 2021). Therefore, despite the sample size limitations of this study, we are encouraged that head-starting to subadult size, which required only about 3 y, may represent an effective population reinforcement tool for Eastern Box Turtles, especially when efforts have been made to address underlying threats.

A primary concern with animal releases is that individuals may require considerable time to establish a fixed home range, which can place them at heightened risk of physiological stress, depredation, and road mortality. Overall, head-started turtles exhibited limited home ranges, similar to those of wild box turtles (7.54 ha; Habeck et al. 2019), which likely contributed to high survivorship by reducing interactions with vehicles and other threats (Dodd 2001; Habeck et al. 2019; Harris et

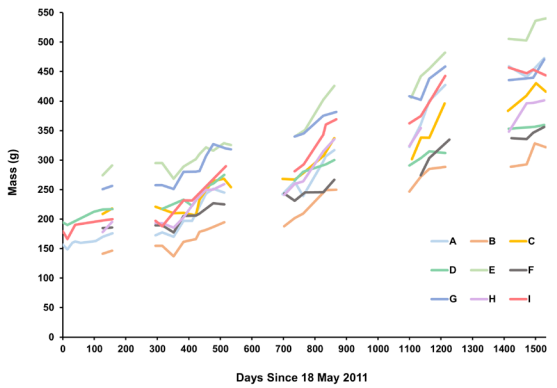

Figure 3. Mass (turtle and radio transmitter combined) for nine (A-F) Eastern Box Turtles (*Terrapene carolina*) head-started onto Jekyll Island, Georgia, USA. Turtles were weighed during the active season only to avoid interrupting brumation.

al. 2020; Roe et al. 2020). One individual, however, used a relatively large area during the 4-y telemetry study. This may have been a consequence of head-starting, but wild box turtles occasionally exhibit comparable home range sizes, and some make long-distance, including so called transient, movements (Kiester et al. 1982; Habeck et al 2019; Harris et al. 2020; Roe et al. 2020). Two other turtles were found about 1.5 km from the release location 7 y and 10 y after release, but notably these turtles remained within 350 m of the release location throughout the initial 4-y radio telemetry period. Home ranges of most head-started turtles overlapped with lightly traveled dirt or paved roads, and although we documented only one mortality event, additional data are needed to generate robust estimates of box turtle survival within semi-developed areas of Jekyll Island.

A central goal of many conservation programs is to improve population viability by increasing numbers of reproductive adults. We released most head-started turtles as subadults and documented their transition to adult size. Although we did not record hatchling production, we documented two gravid head-started turtles, one 8 y after release and one 10 y after release. We also observed some released individuals engaging in reproductive activity with resident adult turtles, and it is possible that more frequent radiograph sampling would have revealed additional evidence of reproduction. Measurements from one female recaptured 9 y after release indicate head-started turtles can reach quite large body sizes (carapace length = 145 mm, mass = 669 g), but the relationship between body size and fecundity remains unclear in this species (Burke and Capitano 2011 and references therein). Additional work is needed into the reproductive success of head-started turtles and their potential impacts on resident conspecifics, particularly when individuals are released as subadults.

Few studies assess head-starting turtles to subadult size, perhaps because rearing individuals in captivity for longer periods requires more resources and concerns that doing so may adversely impact head-start fitness. When compared to previous investigations, our findings suggest head-starting Eastern Box Turtles for longer durations dramatically increases survival rates following release (Tetzlaff et al. 2019; Altobelli et al. 2021). Additionally, limited movements and lack of apparent homing behavior by head-started subadults preclude the need for expensive fences or barriers (e.g., Tuberville et al. 2005) to establish site fidelity. We caution, however, that the small sample size of this study calls for additional work to confirm our findings. We recommend future studies head-start Eastern Box Turtles to ≥ 90 mm CL (≥ 130 g mass) and release individuals into suitable habitat, containing conspecifics, where they are unlikely to come into frequent contact with highly traveled roads. Given occurrence of diseases such as *Ranavirus* that can result in mortality of wild box turtles, head-started turtles should be tested for pathogens prior to release (Johnson et al. 2008).

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Joseph Colbert received his B.S. from the University of South Carolina and his M.S. from the Odum School of Ecology of the University of Georgia, Athens, USA. Joseph is a 2013 Tillman Scholar and was a member of the eighth class of Emerging Wildlife Conservation Leaders. As the Community Wildlife Biologist on Jekyll Island State Park, his work focuses on research and natural resources management strategies that improve wildlife persistence in a sustainably developed community that recieves over three million visitors annually. (Photographed by Brian Lee).

Breanna Ondich currently works at the University of Georgia, Athens, USA, coordinating a mentoring program affiliated with the Society for Freshwater Science and as a Program Manager with The Alongside Wildlife Foundation. She obtained her B.Sc. in Marine Science-Biology from the University of Tampa, Florida, USA, in 2010 and her M.Sc. in Wildlife and Fisheries Biology at Clemson University, South Carolina, USA, in 2021. Bre spent 10 y working on Jekyll Island serving four terms with AmeriCorps, transiting to full time work in the Conservation Department, and later supervising AmeriCorps Members at the Georgia Sea Turtle Center, Jekyll Island, USA. (Photographed by Breanna Ondich).

Richard Bauer is a Conservation Ecologist and Land Manager with the Lee County Board of County Commissioners in Lee County, Florida, USA. He earned a B.S. degree in Biology from Davidson College, Davidson, North Carolina, USA, and a M.S. degree in Conservation Ecology and Sustainable Development from the University of Georgia, Athens, USA. His research interests include spatial ecology, ecotoxicology, and landscape ecology. (Photographed by Jason Boeckman).

Kimberly Andrews is the Coastal Ecology Specialist at the University of Georgia Marine Extension and Georgia Sea Grant in Brunswick, USA, where she leads the Coastal Ecology Lab. She conducts applied research to guide land-use planning and conflict resolution of human infrastructure and activities. Her lab specializes in herpetology and the health and management of coastal and coastal plain ecosystems. Kimberly is active in transportation planning to devise solutions to reduce fragmentation and wildlife mortality and to support our communities that are affected by changing climates and sea-level rise. (Photographer unknown).

Terry Norton earned his D.V.M. at Tufts University, Medford, Massachusetts, USA, and completed a residency in Zoo and Wildlife Medicine at the University of Florida, Gainesville, USA. He is a Diplomate in the American College of Zoological Medicine. He provides veterinary care for the Georgia Sea Turtle Center of the Jekyll Island Authority, The Turtle Hospital in Marathon, and St. Catherines Island Foundation. He has published numerous peer-reviewed manuscripts and book chapters. He was co-editor and author of the book entitled Sea Turtle Health and Rehabilitation. He was the recipient of the Emil Dolensik Award of American Association of Zoo Veterinarians. (Photographed by Chris Hagen).

Tom Radzio is a Researcher with the San Diego Zoo Wildlife Alliance Desert, California, USA. He received a B.S. from Longwood College, Farmville, Virginia, USA, an M.S. from Ohio University, Columbus, USA, and a Ph.D. from Drexel University Philadelphia, Pennsylvania, USA. Much of his current research focuses on juvenile Desert Tortoise (*Gopherus agassizii*) behavior, physiological ecology, and responses to climate change. (Photographed by Martin Radzio).