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Recovery of a Blanding's Turtle Population Through Nest Protection and Headstarting

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Abstract - A regionally significant population of the rare *Emydoidea blandingii* (Blanding's Turtle) at Great Meadows National Wildlife Refuge (GM) in Massachusetts declined in numbers of individuals of >110 mm SCL from an estimated 135 in 1973 to ~54 in 2004, when we began a long-term conservation management program for this population. In the early years of our efforts, the majority of females in the population were older individuals, mostly marked as adults in the 1970s (and thus >50 years old), and juveniles appeared scarce. In response, we began protecting Blanding's Turtle nests at GM in 2003 and began headstarting hatchlings and releasing them back into the population regularly in 2007. By the end of 2023, we had released 683 headstarted juveniles into the GM wetlands. Using data from nearly 20 years of population monitoring, including 430 turtle-years of radio-telemetry, we estimate that the number of Blanding's Turtles >110 mm SCL at GM has increased significantly during that period. Our 2023 population estimates, derived from an integrated capture–recapture model (using trapping and telemetry data) and a known-fate model (telemetry only) suggest that the population has nearly quadrupled (204 individuals, 95% CI = 176–240) or sextupled (316 individuals, 95% CI = 185–442), respectively, when compared to the 2003 estimate (54 individuals). Trapping data also support the conclusion that headstarting has greatly augmented the GM Blanding's Turtle population, with the population skewing younger and catch-per-unit-effort climbing throughout this effort.

Introduction

Emydoidea blandingii (Holbrook) (Blanding's Turtle) populations are in decline throughout their range, and the species is currently under review for Federal listing under the Endangered Species Act (Compton 2007, Congdon and Keinath 2006, USFWS 2023, King et al. 2021). Blanding's Turtles are characterized by high adult survivorship (Congdon et al. 1993), and declining populations are often a result of low levels of juvenile recruitment (Congdon et al. 1983, Engeman et al. 2010, Standing et al. 1999). One potential conservation intervention, therefore, is "headstarting", wherein turtle hatchlings are temporarily captive-reared and returned to their natal population (Tetzlaff et al. 2019, Thompson et al. 2020) as individuals that are larger, older, and theoretically more capable of surviving to maturity (Bennett et al. 2017, Spinks et al. 2003). Some believe headstarting is a "halfway technology" (Frazer 1992) that does not address the reasons behind population decline, or believe that adult-focused interventions are more efficacious (Heppell et al. 1996, Seigel and Dodd 2000). Despite these reservations, headstarting is an

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increasingly accepted chelonian conservation intervention strategy (Burke 2015, Spencer et al. 2017, Thompson et al. 2020).

Blanding's Turtles and other species within the subfamily Emydinae have been frequent subjects of headstarting efforts in the past 20 years. Many of these headstarting projects have achieved at least provisional success, including for Blanding's Turtles (Arsenault 2011, Carstairs et al. 2019, Golba et al. 2022, Starking-Szymanski et al. 2018, Wijewardena et al. 2023), *Glyptemys insculpta* (Le Conte) (Wood Turtle; Mullin et al. 2020, 2023), *Emys orbicularis* (L.) (European Pond Turtle; Bona et al. 2012, Canessa et al. 2016, Mitrus 2005), and *Actinemys marmorata* (Baird and Girard) (Western Pond Turtle; Spinks et al. 2003, Vander Haegen et al. 2009). However, many of these interventions have not yet spanned a generation of their target species' lives, and evaluating the effects of interventions on long-lived species requires similarly long-term monitoring (Bennett et al. 2017, Magurran et al. 2010). We report here on a 20-year effort to restore a suburban population of Blanding's Turtles in Eastern Massachusetts, primarily through nest protection and headstarting. In the early 1970s, this population supported an estimated 135 adults and large juveniles of >110 mm straight-line carapace length (SCL; estimated from mark–recapture data using the Lincoln–Petersen index; Graham and Doyle 1977). The 110-mm SCL size minimum for this population estimate was due to sampling bias that favored turtles >110 mm SCL, which the authors attributed to behavioral differences in the smallest size classes. To maintain comparability, and because we see similar biases in our sampling efforts, we will use the same size minimum for the population estimates throughout this report. In 2004–2005, population monitoring and an associated population estimate (also derived using the Lincoln–Peterson method) revealed that the Blanding's Turtle population at this site had dwindled from 135 to 54 individuals, and most of the extant individuals were older adults (Windmiller 2006), indicative of a lack of recruitment and an unhealthy population structure (Browne and Hecnar 2007).

Faced with this evidence of population decline, we began a multi-faceted conservation-management project for the population. Our conservation-management efforts have included trapping and visual surveys, telemetry, nest protection, habitat management and enhancement, and headstarting. Our primary goal is to help restore the GM Blanding's Turtle population to a number of adults that is greater than the estimated population size in the 1970s and in a manner that would allow the maintenance of this elevated population size without further headstarting.

Field Site Description

We conducted all studies described here within or near Great Meadows National Wildlife Refuge (GM) in eastern Massachusetts. The GM site lies adjacent to the Concord River and contains a diversity of seasonal and permanently flooded wetlands dominated by 2 large (~35 ha [87 ac] each), man-made, shallow (generally <1.5 m [5 ft] in depth), semi-permanently flooded, impounded ponds. Open water typically prevails in the central areas of the impoundments in the early spring, but the same areas are usually densely covered with non-native *Nelumbo lutea*

Willd. (Yellow Lotus) by later summer. The impoundments are fringed with tall, herbaceous marsh vegetation dominated by *Typha* spp. (cattails), with scattered patches of dense aquatic shrubs, particularly *Cephalanthus occidentalis* L. (Buttonbush) and *Myrica gale* L. (Sweetgale). Other wetlands used by Blanding's Turtles in the area include seasonal vernal pools, floodplain marshes, and a large shrub-swamp that had recently been impounded by *Castor canadensis* Kuhl (American Beaver). The protected national wildlife refuge at the heart of the field site is located within an area of relatively dense, suburban, residential development and lies <30 km (19 mi) from downtown Boston, MA.

Methods

Field methods

Intermittently between 2004 and 2022, we trapped for Blanding's Turtles using sardine-baited hoop traps (Memphis Net and Twine 76–93 cm diameter, 0.6-cm mesh [Memphis, TN] or similar) and sardine-baited collapsible traps (Promar 30–40 cm by 60–80 cm, 0.6-cm mesh [Gardena, CA] or similar) during the turtles' active pre-nesting season (April–June), before water levels dropped too far to trap effectively. Our effort varied through the years, with the bulk of our trapping effort conducted in 2004–2005, 2012–2013, 2017–2019, and 2021–2022. We non-randomly located the traps in areas that appeared to offer the most suitable habitat for Blanding's Turtles, and the specific wetlands and areas within the larger impoundments in which we trapped varied from year to year.

Upon first capture, we marked all individual Blanding's Turtles using a triangular metal file to notch the marginal scutes with a unique pattern using a system modified from Cagle (1939). We measured all captured turtles (straight line carapace length [SCL; measured from nuchal/cervical scute to between the rearmost marginal scutes], straight line plastron length, and maximum carapace width and depth) using vernier calipers and weighed them using small digital scales. We estimated the ages of individuals by counting annuli on their plastral scutes (e.g., Graham and Doyle 1977) and considered the individuals as adults if they had an SCL >185 mm, a mass >1000 g, or an annulus count >17. For adult Blanding's Turtles, we determined sex using secondary sex characteristics, primarily the concavity of the plastron (Graham and Doyle 1977). We fitted a subset of non-headstarted and captive-reared Blanding's Turtles with radiotransmitters (generally 6 g R1-2B for subadults and 33 g AI-2 for adults; Holohil Systems Ltd, Carp, ON, Canada), bonded to the rear of the carapace via epoxy (Steelstik; J-B Weld, Sulphur Springs, TX) and weighing <5% of the turtle's total mass. We tracked these turtles a minimum of 3 times per year but often more frequently.

During the nesting season, from 1 June to 3 July, we sought nesting females by radiotracking individuals and soliciting members of the community to text our "turtle hotline" when they saw adult Blanding's Turtles on land. Although we rarely discover novel nesting females from these texts, community participation is vital, as nearly all Blanding's Turtles in this population nest on private property. We conducted surveys daily starting at 6 PM and generally ending at midnight, following

Linck et al. (1989). When we located nests, we deployed predator-exclusion structures (metal or plastic screening), secured with landscape staples, over each cavity. We report on the statistics for nests recorded between 2007 and 2022. For most nests (n = 108; 85.7%), we replaced the flat screening with a hardware-cloth cage in late July or early August to capture emerging hatchlings. If the nest location precluded the installation of a cage, we removed the eggs after 50–60 days in situ and then incubated the eggs until they either hatched or were deemed not viable (n = 18 nests; 14.3%). We captive-reared most hatchlings from these nests (n = 710; 87.9%), as we direct-released some hatchlings to comply with permit limits.

Headstarting methods

Our goal in headstarting hatchling Blanding's Turtles was to increase the likelihood that the turtles would survive until adulthood. We hypothesized that headstarting juvenile Blanding's turtles aids this goal by keeping them in protective captivity during their vulnerable first year while increasing the turtles' growth rate relative to non-headstarted individuals of similar age. Specifically, we hypothesized that headstarting would allow us to release 9-month old Blanding's turtles at sizes typical of much older non-headstarted juveniles and thus reduce their mortality rate, primarily from predation, during the turtles' early juvenile years.

We trained individual headstarting supervisors to raise the hatchling Blanding's turtles under close supervision by Zoo New England. Our partners raised the hatchlings in pairs, typically in 20-gallon (75.7-l) long-style glass aquariums. Under our supervision, they outfitted each turtle habitat with a submersible heater, water filter, UV light bulb on a timer, and a floating dock or other basking area. Supervisors set the submersible heaters at 26.5 °C (80 °F) and set the light to 12 hours on/12 hours off. The supervisors fed the turtles commercial turtle pellets. We asked all supervisors to weigh and measure the turtles at least once monthly. When individual turtles did not grow at a steady rate, we adjusted feeding techniques or food types until the turtles regained an acceptable growth rate. In some instances, we brought individual turtles with injuries, potential illness, or slow growth rates into our veterinary facility for medical evaluation or treatment (see Wilder et al. 2024 [this issue] for more details.)

We generally headstarted hatchlings for ~9 months (September to June), although turtles were headstarted an additional year (n = 17; 2.4%) if they did not reach 75 g (our self-imposed minimum release weight starting in 2017). Each year, we released these headstarted juvenile Blanding's Turtles into the GM wetland complex between mid-May and July. We released turtles in pairs into areas of suitable habitat within the GM impoundments and other nearby wetlands known to be inhabited by Blanding's Turtles. We radio-tagged a subset of these headstarted juveniles upon release (n = 105).

Data analysis

We conducted 3 parallel analyses to assess the changing demography of Blanding's Turtles at GM. The first and second analyses derive survival and demography estimates via radiotelemetry data (known-fate model) and a combination of radiotelemetry and other encounters (trapping, incidental capture; integrated capture–recapture model), respectively. The third assesses the changing demography of the population via differences in catch-per-unit-effort during trapping surveys over time. Data processing was largely conducted in R v. 4.3.1 (R Core Team 2022), with most figures created using the R package 'ggplot2' (Wickham 2016). We treated Blanding's Turtles at GM as a closed population for modeling purposes, including all turtles captured at the impoundments and in satellite wetlands within 3 km (1.9 mi) of the refuge. Although Blanding's Turtles are known to be capable of longer-distance movements (e.g., Herman et. al 1994), we have yet to record the movement of any individual in the GM population beyond this 3 km (1.9 mi) zone despite many turtle-years of radiotracking.

Known-fate survival estimates and survival-derived population estimates. We calculated finite annual survival rates (1 - [deaths/turtle-years tracked]) (Robertson and Westbrooke 2005) for our telemetered adult Blanding's Turtles. For headstarted juveniles, we used a Kaplan–Meier survival analysis (Kaplan and Meier 1958) to estimate the post-release annual survival rates for headstarted turtles for their first year post-release and thereafter (2–5 years post release). For turtles that died during radiotracking, we assumed that their dates of death were the midpoints between the dates on which they were last observed alive and the dates on which they were found dead. If we lost the signal of a turtle and could not relocate it, we censored that individual at the midpoint of the last successful observation and the unsuccessful relocation. We trained this known-fate model using data from the inception of this project through October 2022.

We estimated the number of headstarted juveniles by extrapolating our derived survival rates over the time the cohorts had been in GM (# turtles * year 1 survival * post-year 1 survival$^{[t-1]}$). To determine how many of these individuals fit the definition of "adults and large juveniles" according to Graham and Doyle (1977), we calculated what percentage of the formerly captive-reared turtles we recaptured were larger than 110 mm within each subsequent year post-release. We applied these percentages to the estimates derived via known-fate modeling.

For non-headstarted adults and large juveniles, we also used known fates to estimate the extant population. Turtles known to be dead were removed from the population (value 0), and turtles recaptured in 2023 counted as a whole individual (1). For those turtles who were not captured in 2023 but had been captured between 2010 and 2022, we calculated their impact on population size as ($0.966^{[2023\text{ - last year seen}]}$), where 0.966 is our estimate of annual adult survival generated with the previously described method. The sum of these values is the expected adult and large juvenile population in GM as of 2023 via known-fate modeling.

Integrated capture–recapture analysis. We integrated all Blanding's Turtle encounters at the study site (trapping, incidental capture, telemetry) into a single parameter-estimation framework using a modified Cormack–Jolly–Seber (CJS) approach (Schofield et al. 2009). We modeled apparent survival and detection probability on an annual time-step and assigned radio-tracked turtles a 100% detection probability in this model (equivalent to an annualized known-fate model). We estimated mean detection probability (for non-radio-tracked turtles) as a function of stage class (first-year after headstarting, small juvenile, large juvenile, and adult), sex, and size-at-release, with a logit-normal random effect to represent among-year variation:

$$\text{logit}(p_{i,t}) = mean.p(stage_{i,t}) + fem.eff * is.af_{i,t} + sar.eff.p * sar_i + \gamma_t,$$

Where $p_{i,t}$ represents the detection probability for individual i at year t, $mean.p(stage_{i,t})$ represents mean stage-specific detection probability (logit scale), *fem.eff* is a coefficient enabling separate detection probability estimates for adult males vs. females, $is.af_{i,t}$ is an indicator variable reflecting whether an individual is an adult female, *sar.eff.p* is a regression coefficient representing the effect of size-at-release on detection probability of headstarted individuals up to and including the "small juvenile" stage, sar_i is the size at release (weight in grams, centered and scaled prior to analysis) and γ_t is a random effect drawn from a normal distribution with mean 0 and standard deviation σ representing annual differences in detection probability.

Similarly, we modeled apparent survival ϕ as a logit-linear function of stage, size-at-release, and head-start status:

$$\text{Logit}(\phi_{,t}) = mean.phi(stage_{i,t}) + sar.eff.phi * sar_i + hs.eff * is.sj.js_{it},$$

Where $\phi_{i,t}$ represents annual apparent survival, $mean.phi(stage_{i,t})$ represents mean stage-specific apparent survival (logit scale), *hs.eff* is a coefficient enabling survival of headstarted individuals in the small juvenile class to differ from the survival of non-headstarted juveniles, *sar.eff.phi* is a regression coefficient representing the effect of size-at-release on the survival of headstarted individuals up to and including the "small juvenile" stage, and $is.sj.hs_{i,t}$ is a binary indicator of whether individual i is a headstarted juvenile at time *t*. We computed the total number of living headstarted individuals in the population as a derived parameter by computing the sum of the latent binary indicator variable $z_{i,t}$ (0 if dead, 1 if alive) for all individuals released as headstarts. We estimated the abundance of non-headstarted individuals each year as a function of estimated detection probabilities using a Horvitz–Thompson estimator (Bjorndal et al. 2005).

We fitted the integrated capture–recapture model in a Bayesian framework using Markov Chain Monte Carlo (MCMC) in JAGS (Plummer 2022), which was called from R using the 'jagsUI' package (Kellner 2021). We assessed convergence of the MCMC chains by visual inspection of traceplots and by ensuring that potential scale-reduction factors were below 1.1 for all parameters (Brooks and Gelman 1998). R and JAGS code for these analyses are available at https://github.com/kevintshoemaker/GM_EMBL_Headstart2023.

Demographic and population change over tme via trapping. To calculate trapping efficiency, we considered every night that traps were set a "trap night," and considered all captures of Blanding's Turtles (whether novel or a recapture) a capture. We included only traps set during April, May, and June (the turtles' active but pre-nesting season) in this analysis to make the trapping events comparable, although we have trapped in the latter half of the active season when water levels allowed. We also excluded trapping sessions that occurred outside the impoundments and/or the primary auxiliary swamp, again for comparability. We calculated catch-per-unit-effort (CPUE) as captures / 100 trap nights.

For four 2-year time periods (2004–2005, 2012–2013, 2017–2018, and 2021–2022) in which we conducted significant trapping, we classified unique Blanding's Turtle individuals captured as small juveniles (SCL ≤ 110 mm), large juveniles (110 mm < SCL ≤ 185 mm), and adults (SCL >185 mm). For each time period, we calculated the proportion of these individuals that belonged to each age class.

Results

We captive-reared 710 headstarts between 2003 and 2023. Of these, 27 (3.8%) died in captivity, and 683 were released into the GM population. The average weight of these turtles at release, excluding those headstarted longer than 1 year, was 149.5 g (min–max = 34–460 g; first quartile: 103.8, third quartile:190.1) and their mean carapace length at release was 88.8 mm (first quartile: 79.1, third quartile: 100.0). A subset of these (n = 105) were tracked via radiotelemetry post-release. From June 2003 to October 2023, we recorded >3000 encounters with 778 unique Blanding's Turtles in the GM metapopulation. Of these, 95 were non-headstarted individuals, and the remainder were captive-reared headstarted turtles. We recaptured radiotelemetered adults a median of 4.4 times per year (first quartile: 3.3, third quartile:6.0) and headstarted juveniles a median of 5.7 times per year (first quartile: 3.3, third quartile: 13.0).

Survival and abundance estimates

We placed radiotransmitters on 61 unique wild adult Blanding's Turtles (41F, 20M) that we tracked from 0.01 to 17.38 years for a sum of 319.5 turtle-years and a calculated annual survival rate of 0.966 (95% CI: 0.940, 0.981). Our integrated capture–recapture model (including all captures) indicated a similar estimate of adult (apparent) survival for adult Blanding's Turtles in the GM metapopulation (ϕ_A = 0.962, CI: 0.945, 0.978; Fig. 1). The survival rate of headstarted juveniles in the first year post-release, as calculated via Kaplan–Meier, was 85.7% (95% CI: 0.772, 0.915; Table 1). During their second through fifth year post-release, the survival rates of headstarted Blanding's Turtles climbed to 93.4% annually (95% CI: 0.846, 0.976; annualized estimate for this 4-year period; Table 1). Five headstarted turtles were radiotracked for more than 1 non-consecutive period, as their initial

Table 1. Calculated annualized survival via Kaplan–Meier for headstarted Blanding's Turtle juveniles post-release at GM in Massachusetts, 2003–2022. Survival estimates are given for the first year post-release and then annually thereafter. "At risk" denotes the total number of subjects (here, headstarted Blanding's Turtles) that are at risk of the event of interest (here, mortality events).

	At risk	Died	Censored	Estimated annual survival probability	95% CI
Y1	105	15	69	0.857	0.772–0.915
Annualized, Y2–Y5	76	5	34	0.934	0.846–0.976

radios failed but the individuals were recaptured and the radios replaced. Our integrated capture–recapture model (incorporating data from all released headstarts) generated a similar (but slightly lower) estimate for apparent survival in the first year post-release (ϕ_{hs1} =0.758, 95% CI: 0.624, 0.853), the second year post-release (ϕ_{hs2} =0.766, 95% CI: 0.592 , 0.901), and averaged across the second through fifth year post-release (ϕ_{hs2-5} =0.825, 95% CI: 0.776, 0.872). For small juveniles (SCL < 110 mm, excluding headstarted individuals in their first 2 years post-release) apparent survival differed between headstarted (0.850, 95% CI: 0.788, 0.909) and non-headstarted (0.748, 95% CI: 0.388, 0.937) juveniles, though the estimate for non-headstarted small juveniles is based upon a very low sample size. Based on the integrated model, the release weight of headstarted individuals had a strong effect on apparent survival (Fig. 2a) as well as detection probability (Fig. 3), whereby individuals with higher release weight experienced higher survival rates and greater detection probabilities. As a consequence, head-started individuals large enough to receive radio-transmitters (≥160 g) were expected to have higher annual survival (0.830; CI 0.787, 0.872) than individuals <160 g (0.790; CI 0.742, 0.836) over the first 5 years post-release (Fig 2b).

Using the known-fate estimates of survival for the 683 individuals that have been released into GM for each year post-release, we estimate that 390 headstarted juveniles (95% CI: 231, 534) were extant in the population as of summer 2023. Of these, 241 (95% CI: 110, 368) consisted of headstarted "large juveniles" (>110 mm) as calculated using mean growth rates for headstarted juveniles after release. Our integrated capture–recapture model, with lower survival estimates for headstarted individuals post-release, estimated the number of surviving headstarted juveniles as

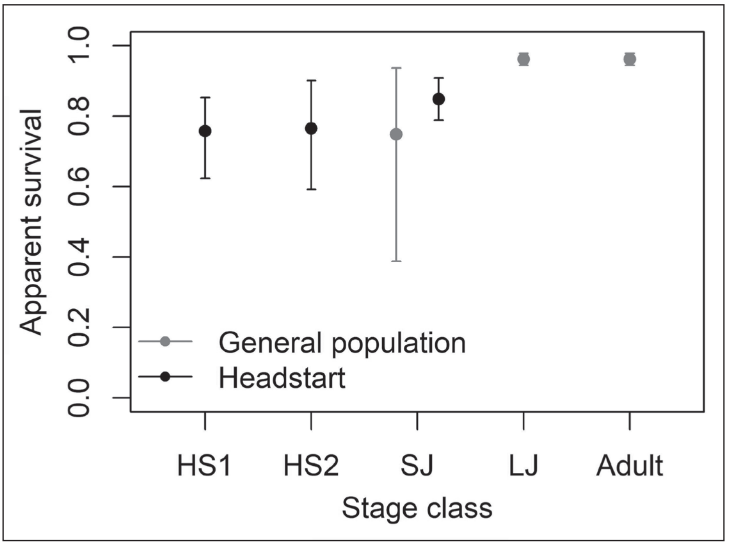

Figure 1. Annual apparent survival estimates (*y* axis) and 95% credible intervals for the first year after release of head-started individuals (HS1), the second year after release (HS2), small juveniles (SJ; CL < 110 mm), large juveniles (LJ; 110 <CL<185 mm), and adult Blanding's Turtles in our focal population (Great Meadows National Wildlife Refuge and surrounding area in Massachusetts), estimated using an integrated Bayesian capture–recapture model that incorporated telemetry and capture-recapture data. Apparent survival for the SJ stage was estimated separately for headstarts (black) versus non-headstarts (gray).

of summer 2023 as 288 (95% CI: 252, 330), with 141 (95% CI: 116, 174) of these in the "large juvenile" class (Fig. 4). When we add the estimated number of non-headstarted adults and older juveniles to the population (74.35 via known-fate and 64.5 via our integrated capture–recapture model) we receive 2 estimates of the current size of the population of Blanding's Turtles in GM: 316 individuals (95% CI: 185, 442) via known-fate modeling, and 204 individuals (95% CI: 176, 240) via the integrated model.

Demographic and population change over time via trapping

From 2004 to 2022, we conducted 4987 trap-nights of trap-based sampling effort in the GM metapopulation during the months of April, May, and June. During these trapping sessions, we recorded 306 captures of Blanding's Turtles, for an average CPUE of 6.14. For four 2-year time periods (2004–2005, 2012–2013, 2017–2018, and 2021–2022), we calculated the percentage of unique captures that were subadults (<185 mm) SCL at capture (see Fig. 5). The CPUE has climbed rapidly over time, from 2.1 captures per 100 trap-nights in 2004/2005 to 16.8 in 2021/2022.

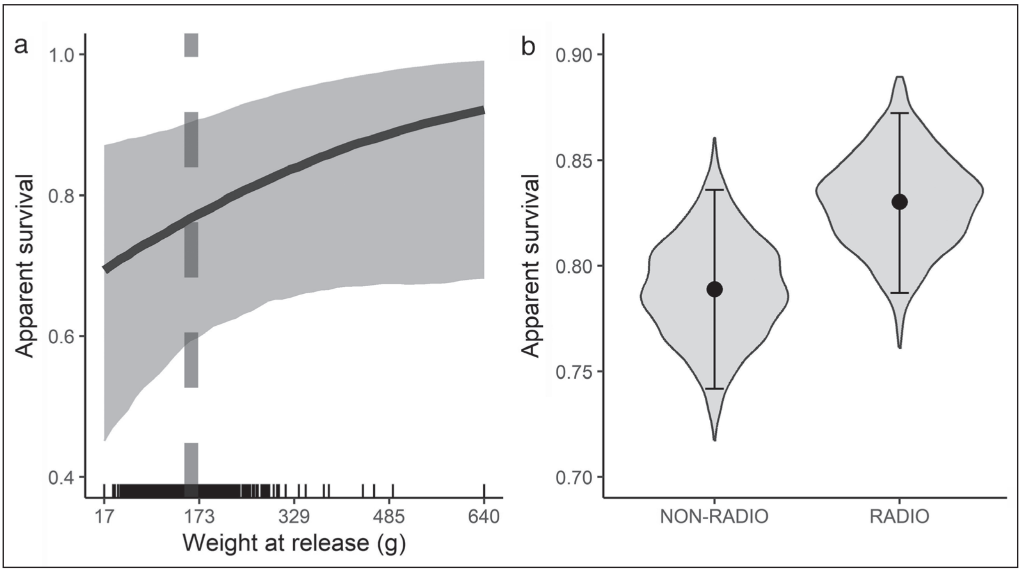

Figure 2. (a) Effects plot illustrating annual apparent survival over their second year post-release (*y* axis) of head-started juvenile Blanding's Turtles as a function of weight at release (g; *x* axis). The solid line indicates the median values predicted using an integrated Bayesian capture–recapture model. The gray ribbon represents a 95% credible interval. The dashed vertical line indicates the weight threshold (160 g) we used as a lower bound for placing radio-transmitters on head-started turtles (only turtles with release weight of ≥160 g could receive a radio-transmitter). The apparent survival estimates presented here were computed for head-started individuals in their second year post-release, although predictions are similar for the first 3–5 years post-release. (b) Apparent survival estimates (averaged for the first 5 years post-release) for head-started individuals that were released below the threshold weight for receiving a radio-transmitter ("NON-RADIO") versus individuals released above the threshold weight ("RADIO").

Discussion

The nest-protection and headstarting efforts conducted over the past 2 decades has resulted in a significant increase in the overall Blanding's Turtle population at GM. Headstarted juveniles survive at high rates with no apparent physiological impairment. Depending on the method used to estimate the current population of individuals of >110 mm SCL in the GM population, the population size has risen from ~54 individuals in 2005 to ~204 (nearly 4-fold increase, integrated model) or to ~316 individuals (nearly 6-fold increase, known-fate model). The population of adults and larger juveniles is also much larger than it was in the early 1970s (estimated 135 individuals of >110 mm SCL; Graham and Doyle 1977). While we have not yet documented reproductive success for any of our captive-reared headstarts, several from the 2007 to 2010 cohorts are reaching reproductive size (185 mm SCL, 1000 g) and will likely nest in the next 1–2 years, especially as some studies show headstarted turtles reproducing at younger ages than non-headstarted individuals (Haskell et al. 1996, Thompson et al. 2020). Continued long-term monitoring of this headstarting program will be vital to fully assess its success (Bennett et al. 2017, Parker et al. 2013, Seddon et al. 2007), and evaluating conservation interventions improperly or ineffectively can be detrimental or misleading (Bertolero et al. 2018, Ewen et al. 2014). Therefore, although we are sharing this as an example of a successful intervention, we will continue to monitor this population until we are confident it is self-sustaining. We plan to taper off headstarting and reduce the

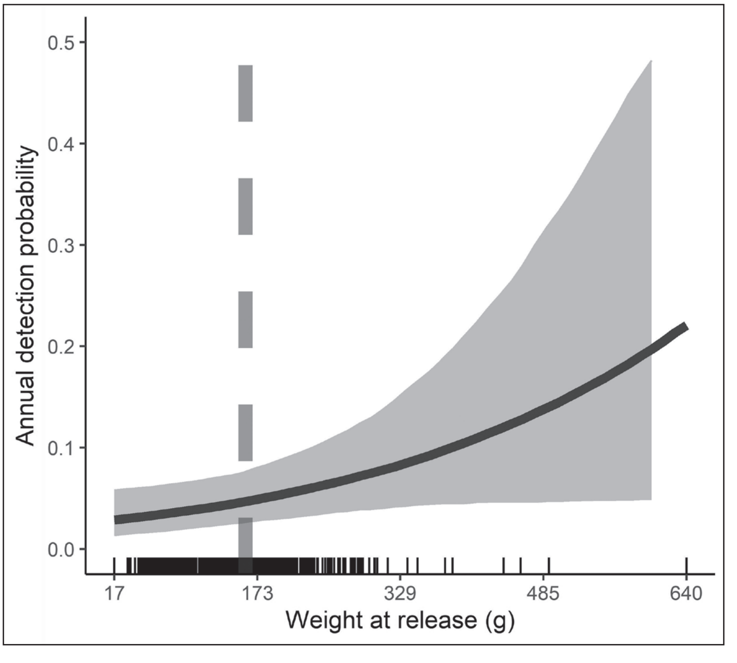

Figure 3. Effects plot illustrating annual detection probability (*y* axis) of head-started juvenile Blanding's turtles as a function of weight at release (*x* axis; in g). The solid line indicates the median values predicted using an integrated Bayesian capture-recapture model. The gray ribbon represents a 95% credible interval. The dashed vertical line indicates the weight threshold (160 g) we used as a lower bound for placing radio-transmitters on head-started turtles (only turtles with release weight ≥ 160 g could receive a radio-transmitter). The detection probability estimates presented here were computed for head-started individuals in their second year post-release.

frequency of our trapping surveys, but to continue annual nest-protection efforts until the number of nesting females increases and contains a significant number of formerly headstarted Blanding's Turtles.

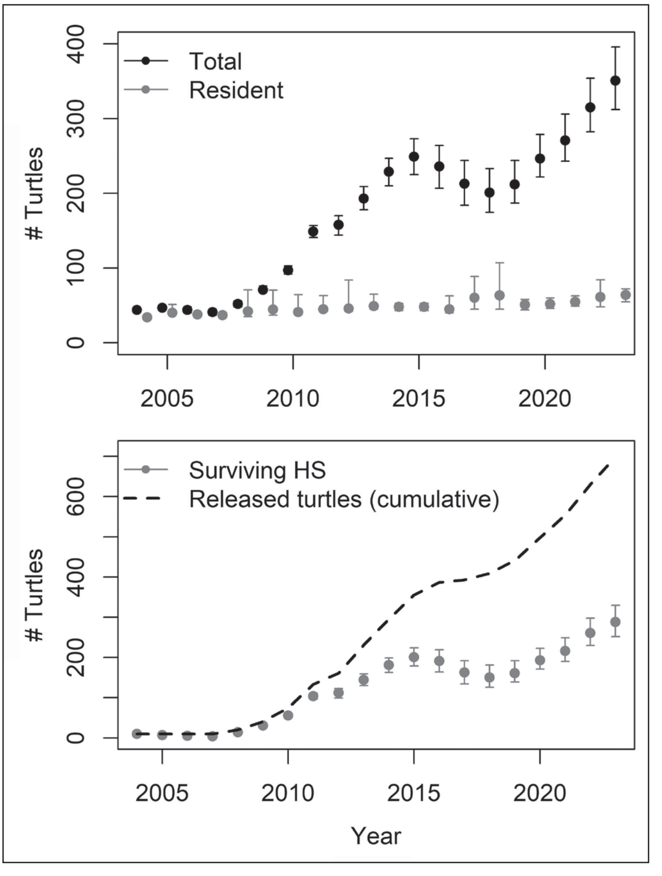

Figure 4. Top: Estimated Blanding's Turtle abundance at Great Meadows National Wildlife Refuge (GM) in Massachusetts from 2003 through 2022, displaying total abundance (black) and abundance excluding headstarted individuals ("resident"; gray). Abundance estimates were derived using a Horvitz–Thompson estimator based on detection probabilities from a Bayesian capture–recapture model integrating telemetry, trapping and visual encounter data. Bottom: Cumulative total headstarted juvenile (HS) releases over time (dashed line) coupled with the estimated total number of surviving headstarts (gray) over time at the GM study site. All estimates were derived from an integrated capture recapture model fitted in a Bayesian framework.

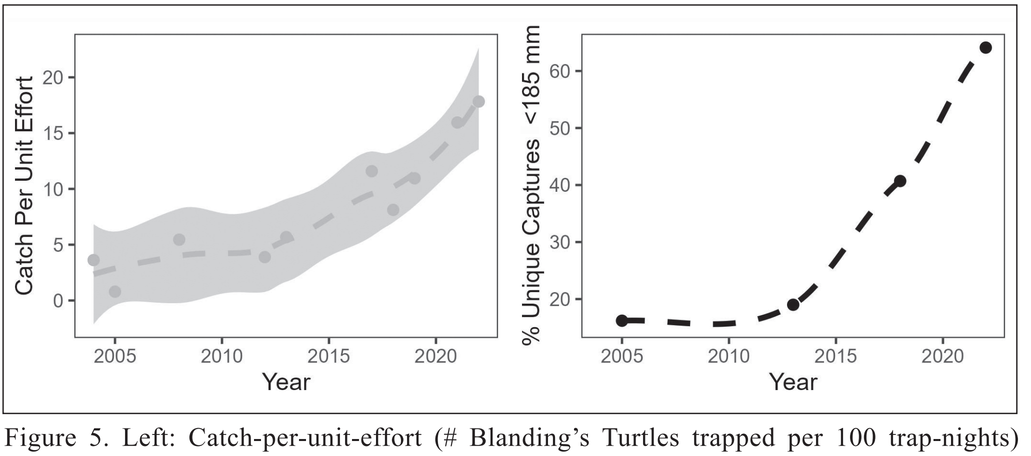

Figure 5. Left: Catch-per-unit-effort (# Blanding's Turtles trapped per 100 trap-nights) is plotted annually, including a Loess curve. Right: Percent of unique Blanding's Turtles captured during 2004–2005, 2012–2013, 2017–2018, and 2021–2022 that were sub-adult (<185 mm).

This change in the population, marked both by more turtles and a healthier demographic balance, is supported by the change in our trapping results over time. Since the inception of our conservation-management efforts in 2004, our catch-per-unit effort has risen significantly (i.e., 2.1 captures per 100 trap-nights in 2004/2005 to 16.8 in 2021/2022), suggestive of a large increase in the number of free-living Blanding's Turtles. Furthermore, the demography of the turtles trapped has changed notably over time, with adults making up nearly 83.9% of unique captures in 2004/2005 trapping efforts and only 35.9% of unique captures in 2021/2022. These data support our conclusions that this population is growing and demonstrating a healthier demography than the senescent, declining population we encountered in 2003. We did not include 2023 trapping data in our analyses, as they were conducted in August due to unusually high water levels in the impoundments and thus are not seasonally equivalent to our other trapping data, but over 200 trap nights in 2023, we recorded 59 Blanding's Turtle captures (44 unique individuals), for a CPUE of 29.5. In addition, we captured 4 headstarted juveniles from the 2010 cohort in this trapping window; 3 of these 4 had not been captured since their release in 2011, and all are either adults or nearly so (SCL min–max: 179–191 mm). As such, while these results are encouraging, they also may be conservative.

One potential contributor to our success in this conservation intervention is the size of our headstarted juveniles at release. Although we usually only headstart our turtles for 8–9 months, they reached an average release weight of 149.5 g (min–max: 43–460, first quartile: 103.8, third quartile: 190.1). This average size is larger than or comparable to weights reported in several projects which headstarted Blanding's Turtles for 18+ months (e.g., 91–150 g [Starking-Szymanski et al. 2018], 123.6 g–180.1 g [Cann et al. 2021]). Comparing our mean release weight to Blanding's Turtle growth data from Congdon and van Loben Sels (1991) and Graham and Doyle (1977) respectively, our average headstarted juvenile is comparable to a non-headstarted 7-year-old turtle in Michigan or 3-year-old juvenile in Massachusetts. On average, our headstarted turtles reach 110 mm SCL at 4 years of age (3 years after release), ~3 years earlier than Congdon and van Loben Sels' (1991) Blanding's Turtles. This size advantage appears to confer a survival advantage to our headstarts, compared to non-headstarted juveniles or turtles released at smaller sizes (see Fig. 2). Although accelerated growth rates may lead to deleterious effects, we have not seen physiological differences between headstarted Blanding's Turtles and their non-headstarted conspecifics, and neither have other experts we consulted.

Our estimates of the survival of post-release headstarted juveniles are high. We estimate that ~75% (or 86% based on known-fate telemetry-observations data) of headstarted juveniles survive their first year post-release, well within the high end of the survival values calculated for wild-hatched, juvenile freshwater turtles in the literature: 50–92%; (Arsovski et al. 2018; Blamires et al. 2005; Cann et al. 2021, 2023; Feng et al. 2019; Folt et al. 2016; Germano 2016; Hanscom et al. 2020; Tutterow et al. 2017). Over the subsequent years, survival rates continue to increase in both models. According to our radiotelemetry-derived model, slightly older headstarted juveniles survive at 93.4% annually between 2 and 5 years post-release (min–max = 84.6–97.6). Telemetry studies of headstarted Blanding's Turtles have yielded similar survival estimates (i.e., 63–96% [Starking-Szymanski et al. 2018], 89–98% [Carstairs et al. 2019], 43–89% [Wijewardena et al. 2023]). These numbers are only slightly lower than the calculated rate of adult survival in this population, 0.966 (95% CI: 0.940–0.981), well within the survival rates reported in the literature for Blanding's Turtle adults (e.g., Congdon et al. 1993, Reid et al. 2016).

It is important to acknowledge that we saw similar trends but different magnitudes in our integrated model versus the known-fate model. We believe that both models are excellent windows into the dynamics of this population, and provide both to provide a more comprehensive picture of the system. One difference between the 2 approaches is that the detection probability, vital for CJS modeling (such as our integrated model), can be challenging to estimate for small juveniles (which are rarely captured). As an example, the smallest non-headstarted juvenile trap-captured at GM was a 280-g, 122-mm SCL individual that appeared to be 6 years old by counting annuli. The distinction between "not there" and "not detected" for this life stage is difficult to distinguish. This is a potential strength of known-fate modeling; radiotelemetry of just-released juveniles allows us to examine differential survival (and habitat use) for younger age-classes. However, these data are also likely to be biased, as we generally only radiotrack turtles large enough (>160 g) to carry 12-month radiotransmitters, meaning all telemetered turtles are larger than the mean release weight (149.5 g). Our integrated model shows that the survival of these larger radiotracked individuals was higher than headstarted individuals with lower weight-at-release (Fig 2b). On the other hand, the integrated model may be biased towards a conservative estimate, as the trapping data derives from traps that were placed non-randomly and in a manner that varied between years thus possibly reducing the actual detection probabilities between subsequent trapping events. We plan to continue to assess potential survival differences between survival and recapture rates of different release sizes as we monitor this population, but we do regularly recapture turtles that were released in the smallest size classes.

Our known-fate derived estimate of the population of Blanding's Turtles at GM as of 2023 is 316 individuals (min–max = 185–442), or more than twice as large as it was in the 1970s and nearly sixfold larger than it was in 2003. The population estimate derived from our integrated capture–recapture model is slightly lower, at 204 (min–max = 176–241). We believe these estimates may be conservative estimates of population size. They assume a static annual survival for our headstarted juveniles within their size classes, while the literature suggests that a turtle's annual survival rate climbs as they age and grow (Arsovski et al. 2018, Enneson and Litzgus 2008, Spencer et al. 2017); also, even our minimal detection probabilities for young turtles may be artificially high, due to their cryptic nature.

Headstarting alone may not be enough to recover rapidly declining populations everywhere (Bubac et al. 2019, Frazer 1992), but our results show that, in at least some circumstances, headstarting can be an effective strategy for population augmentation and restoration. We hope that our experience can assist conservation managers to justify, plan, and evaluate similar headstarting programs, and encourage others to "act quickly" when rapid population declines are reported (Martin et al. 2012). Successful conservation interventions, especially for long-lived species, are generally longitudinal, adaptive, and iterative; we encourage those pursuing such projects to consider the ecological, landscape-level, and biogeographical contexts of their focal population. Populations may respond variably to identical conservation measures, so consistent assessment and adjustments are invaluable in shaping management plans. We have, for example, attempted and abandoned a small reintroduction program of headstarted Blanding's Turtles into wetlands in an area near GM after the initial results indicated that the released juveniles were undergoing unsustainably high levels of mortality from predation. Likewise, we encourage managers to preemptively define quantitative goals for each project. While these goals may be adjusted over time, it is important to know what "success" looks like for your project; otherwise, wildlife managers risk continuing headstarting programs and other conservation interventions that are either ineffective or have already met their conservation goals simply because everyone involved already knows how to conduct that intervention.

The primary goal of this project was to restore this GM population of Blanding's Turtles in a manner that will eventually allow the population to be self-sustaining. Our initial, quantitative goal was 200 or more adults, although this goal is flexible and iterative. We have demonstrated that headstarted Blanding's Turtles at GM are growing and surviving at high rates, and will likely be recruited into the adult population as they attain sexual maturity. All indications are that the adult population will approach or exceed our stated goal of 200 individual Blanding's Turtles within the next 10 years. While we will continue to refine our population estimates and assess demography over time at GM, we plan to phase out our headstarting program in the next 5 years at this location and to shift our efforts to bolster other populations in need. Along with our partners in the US Fish and Wildlife Service, the Massachusetts Division of Fisheries and Wildlife, and the conservation commissions of Concord and Bedford, MA, we will continue to help manage and enhance habitat within and near GM and to protect a portion of each year's Blanding's turtle nests against predation. We hope these habitat-enhancement and ongoing nest-protection efforts will allow this restored population to flourish and sustain the gains attained through headstarting with more limited human intervention in the coming years.

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