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Reintroduction and Head-starting: Tools for Blanding's Turtle (*Emydoidea blandingii*) Conservation

Kurt A. Buhlmann[1,5], Stephanie L. Koch[2], Brian O. Butler[3], Tracey D. Tuberville[1], Veronica J. Palermo[3], Brian A. Bastarache[4] and Zachary A. Cava[2]

[1]*University of Georgia, Savannah River Ecology Lab, Aiken, South Carolina, USA*
[2]*U.S. Fish and Wildlife Service, Sudbury, Massachusetts, USA*
[3]*Oxbow Associates, Inc., Boxborough, Massachusetts, USA*
[4]*Bristol County Agricultural High School, Dighton, Massachusetts, USA*
[5]*Corresponding author, e-mail: kbuhlmann@earthlink.net*

Abstract.— **We reintroduced Blanding's Turtles (*Emydoidea blandingii*) to Assabet River National Wildlife Refuge, Massachusetts, USA, evaluating the relative benefits and risks of using various life stages of Blanding's Turtles collected from a donor population within the same watershed, including direct-release hatchlings (released in autumn shortly after hatching), head-started hatchlings (raised in captivity for 9 mo), juveniles, and adults. We developed a simple population model to evaluate which of several release strategies was most likely to result in a stable population at the recipient site while minimizing negative impacts to the donor site. Model results suggested that annual releases consisting largely of head-started hatchlings were most likely to achieve our goal. We released 81 direct-release and 161 head-started hatchlings at the refuge in 2007–2011. Head-started hatchlings were larger (mean = 62.7 mm carapace length, 46.6 g) compared to direct-release hatchlings (mean = 36.3 mm carapace length, 8.8 g). Simultaneous radio-tracking of 12 translocated sub-adults has provided useful information on habitat preferences that we used to select two sites within the refuge for future releases. We also released six head-started hatchlings with radio transmitters (one in 2009 and five in 2010): one was found dead a year after release. We plan to continue monitoring efforts to assess survivorship, growth, and site fidelity of all released Blanding's Turtles and to compare results among the head-started and direct-release hatchlings. We will update our models and reintroduction efforts based on monitoring data.**

Key Words.—*Emydoidea blandingii*; adaptive management; conservation; hatchlings; head-starting; reintroduction; translocation

Introduction

The ultimate goal of species conservation efforts should be the persistence of viable, self-sustaining populations in their native landscapes. Thus, identification and preservation of existing populations is the first conservation priority, followed by habitat restoration and management and the establishment of conservation corridors connecting habitat patches. However, in increasingly human-altered landscapes, species of conservation concern often survive as non-viable populations or as a few viable populations with insufficient connections between them. Population manipulations, such as reintroduction, may be appropriate under circumstances when the threats and causes of decline have been removed but the populations are so small that they are likely to disappear without temporary intervention (Frazer 1992; Heppell et al. 1996) or are unlikely or unable to recolonize sites on their own.

Success of population manipulations such as reintroductions and head-starting requires appropriate planning to minimize negative genetic and disease consequences, as well as impacts to other native species. Long-term monitoring is critical to evaluating success, as is application of an adaptive management framework to incorporate new knowledge. For long-lived species such as turtles, the time scale for judging success of population manipulations often exceeds the tenure of the manager or researcher. Thus, these techniques are still largely viewed as experimental (Seigel and Dodd 2000) and methods have not been standardized. In general, lower success rates have been reported with non-game (46%) than with game species (86%; Griffith et al. 1989) but few articles have been published regarding the success of freshwater turtle reintroduction projects, including those with a head-starting component (Haskell et al. 1996; Mitrus 2005; Vander Haegen et al. 2009). Here we summarize the development, implementation, and preliminary monitoring results of a collaborative reintroduction project for Blanding's Turtles (*Emydoidea blandingii*), emphasizing the head-starting component.

The Blanding's Turtle is a medium-sized (to 240 mm carapace length [CL]), semi-aquatic freshwater turtle that inhabits wetlands throughout the upper Midwest and New England states in the USA and southeastern Canada. Blanding's Turtles are the most northern-restricted turtle species in North America with a latitudinal range not exceeding 900 km (Buhlmann et al. 2009).

Blanding's Turtles are long-lived with a long generation time (minimum 37 yr; Congdon et al. 1993) and individuals have been known to survive in the wild > 70 yr (Breck and Moriarty 1989; Congdon and van Loben Sels 1993). Blanding's Turtles require 14–20 yr to reach sexual maturity and minimum size at maturity for females is 163 mm CL (Congdon and van Loben Sels 1993). Congdon and Keinath (2006) suggested through modeling that one breeding female is demographically equivalent to 100 eggs (i.e., 8–12 yr of her reproduction). Nest survivorship is highly variable and can range from 0–100% of all nests in a population in a given year. In a long-term Michigan study, first year survivorship of hatchlings was estimated at 26% (Congdon and van Loben Sels 1993), juvenile survivorship (> age 1 yr to maturity) averaged 72% annually, and high annual adult survivorship (96%) characterized natural populations, as adults have few natural predators.

Blanding's Turtles have been known from New England since the early 1800s (Storer 1839) and those populations are disjunct from the Midwestern portion of the range. The species is of conservation concern in every New England state in which it occurs (Levell 2000). The main threats to Blanding's Turtles are road mortality and loss of wetlands and the upland habitats that connect them (Congdon and Keinath 2006; Compton 2007; Beaudry et al. 2009). Although environmental regulations and local community action have sometimes been successful in protecting wetland habitats, loss of upland habitats and landscape fragmentation continue through development and road construction. Known records for Blanding's Turtles in New England total 180 element occurrences (EOs), although 169 of these are represented by only one or a few animals (Compton 2007). Many of these EOs are observations of turtles crossing roads. Only nine sites in New England have documented 10–50 turtles (Compton 2007) and only two or three sites in New England have more than 50 known animals. Thus, most of these sites do not represent long-term viable populations under current conditions.

We identified a new conservation site that we believe contains the components necessary to support a Blanding's Turtle population. We are interested in reintroduction because simply proposing to protect existing sites may not be enough to maintain this species as a viable component of the New England landscape. Our objectives were to: (1) present the decision-making process we created and implemented to evaluate the appropriateness of reintroducing Blanding's Turtles to a selected site; (2) identify the release scenarios most likely to achieve a self-sustaining population using a simple population model that considers both biological and logistical constraints; (3) highlight the use of head-starting as a critical component of our reintroduction strategy; and (4) summarize the preliminary reintroduction results of releases using different life stages of Blanding's Turtles.

Materials And Methods

Identification of a candidate recipient site.— Assabet River National Wildlife Refuge is an 880 ha protected area in eastern Massachusetts, approximately 40 km west of Boston, within the heart of the Blanding's Turtle range in New England. The refuge was established in 2000 from lands acquired from the U.S. Army-Fort Devens complex. Prior to the 1940s, agriculture and timber activities were conducted and a commercial Cranberry bog was in operation. During a period of extensive use from the 1940s through 1970s, numerous bunkers, buildings, and hand-dug wells were built. These human activities ceased prior to the transfer of the property to the U.S. Fish and Wildlife Service.

The refuge contains a diversity of wetland habitats, including numerous vernal pools, extensive shrub swamps, bogs, and a 24 ha glacial lake (Aneptek Corporation, unpubl. report; Butler, unpubl. report). The terrestrial habitat is primarily forested and is comprised of White Pine (*Pinus strobus*) and mixed hardwoods. The size of the refuge, the diversity of wetland habitats embedded in a forested matrix, and minimal automobile traffic within the refuge suggest that the refuge could support a sizeable Blanding's Turtle population. One road-killed female Blanding's Turtle was found immediately east of the refuge in 2000 (pers. obs.). However, surveys have failed to document extant Blanding's Turtles within the refuge (Aneptek Corporation, unpubl. report; Butler, unpubl. report; Buhlmann and Gibbons, unpubl. report). Given the lack of sizable populations nearby and the fragmented landscape between the refuge and other known populations, natural re-colonization is unlikely.

Evaluating the appropriateness of reintroduction.— We constructed a "decision tree" to evaluate whether reintroduction was an appropriate conservation strategy for Blanding's Turtles at the candidate recipient site. The decision tree consisted of an ordered list of questions (Table 1) to be addressed prior to initiating any reintroduction activities. Major findings resulting from the decision tree process are briefly summarized in this paper. More detailed results were included in an Environmental Assessment (U.S. Fish and Wildlife Service. 2007. Establishing a population of Blanding's Turtles (*Emydoidea blandingii*) on Assabet River National Wildlife Refuge: final environmental assessment. U.S. Fish and Wildlife Service. Sudbury, Massachusetts, USA.).

Population modeling to evaluate alternative release scenarios.— A simple population model was developed using VORTEX 9.7 (Lacy et al. 2005; Miller and Lacy 2005) to: (1) determine the numbers of hatchlings that the donor site could provide without negatively impacting the stability of that resident Blanding's Turtle population; (2) estimate the numbers of hatchlings and the duration of repetitive introductions that would be necessary to establish a stable population of Blanding's Turtles on the recipient site; and (3) predict the relative efficiency of different release strategies, including direct release of hatchlings vs. release of head-started hatchlings.

Life-history parameters were estimated from the literature and from unpublished field data, relying on data specific to Massachusetts populations where available. When long-term data were available (Table 2) to estimate specific life history parameters, we based our models on those data rather than on shorter-term data (even if collected from Massachusetts populations). We developed models for both the source population and the

Table 1. Identification of "decision–tree" criteria (U.S. Fish and Wildlife Service. 2007. Establishing a population of Blanding's Turtles (*Emydoidea blandingii*) on Assabet River National Wildlife Refuge: final environmental assessment. Sudbury, Massachusetts, USA.), which we evaluated prior to implementation of reintroduction efforts of Blanding's Turtles.

Question
Q1: Is the species secure in the region?
Q2: Is the proposed recipient site within natural range?
Q3: Does the proposed recipient site currently have a population?
Q4: Is appropriate habitat present on the recipient site?
Q5: Is the recipient site secure and protected?
Q6: Is the cause of the initial decline known?
Q7: Has a donor site been identified?
Q8: Have population impacts to the donor site been considered?
Q9: Have genetic concerns been addressed?
Q10: Have disease transmission concerns been satisfied?
Q11: Has an appropriate life stage and protocol been selected?
Q12: Has population modeling estimated the numbers of animals needed to achieve population viability?
Q13: Is there a plan for habitat management at the recipient site?
Q14: Is there a plan for habitat management at the donor site?
Q15: Is there a monitoring commitment commensurate with modeling results/habitat management needs?

recipient population.

The source population model was based on long-term data collected from that site. We performed manipulations of the assumed population given by the source model each year for 15 y but we continued simulations for another 85 y. Model scenarios included no nest protection (i.e., nest survivorship = 30%), nest protection of 30 nests per year but no harvest (i.e., nest survivorship for first 30 nests = 85%, 30% for all other nests), and nest protection and harvest of 50, 100, or 150 hatchlings for release at the recipient site. We averaged population growth rates for each scenario over the course of the simulation.

The recipient site model was based on a starting population of zero adults, 10 y of annual hatchling releases, and a simulation duration of 50 y. Model scenarios include release of 25, 50 or 100 direct-release hatchlings, or 25 or 50 head-starts. We limited the number of head-starts in our scenarios to 50 individuals, which we assumed to be the number we could feasibly rear in captivity (based on the resources available at the beginning of the project). The model assumed no mortality during the head-starting (captive) phase and that head-starts survived similarly to wild-recruited turtles. Number of adult turtles (averaged over 100 simulations) at 15, 20, 25, and 50 y were reported for each scenario.

Collection and treatment of hatchlings from donor site.—Blanding's Turtle nests at the donor site have been periodically protected from predators since 1987 using wire cage covers, which artificially boost long-term nest success and hatchling recruitment. The number of nests protected each year varied (range 16–43), with hatching success averaging 85% for protected nests (unpubl. data). During 1987–1990, we direct-released 235 hatchlings from their protected nests into donor site wetlands; in the six nesting seasons (2000–2005) immediately prior to start of this reintroduction project, we similarly released 1083 hatchlings at the donor site. Since the start of our reintroduction project in 2006, donor site nests were protected to produce hatchlings for both the donor and recipient sites. To accomplish

Table 2. Baseline parameters used in development of repatriation models for Blanding's Turtle (*Emydoidea blandingii*).

Demographic parameter	Value
Longevity	70 y
Female age at maturity	17 y
Male age at maturity	14 y
% females breeding	80%
Average clutch size	10 eggs
Hatchling sex ratio	50:50
Hatchling survivorship (age 0-1)	30%
Juvenile annual survivorship (age 1-13)	78%
Adult survivorship (age 14+)	96.5%

this, we visited known nesting areas in evenings late May-June and searched for nesting females. When nesting females finished depositing their eggs, we installed predator excluders, collected GPS locations at nests, and noted the identity of the female (or marked her by notching scutes, if previously unmarked). Beginning in early to mid-August, we returned to nests daily to collect emerging hatchlings.

After emergence, we measured all hatchlings (CL to nearest mm) and weighed them to nearest 0.1 g. We gave each hatchling an individual code by marking marginal scutes with cuticle scissors or nail clippers. Generally, we immediately direct-released half of the hatchlings from each nest (e.g., half of each female's reproductive investment) into the main wetland at the donor site. We designated the other half for the recipient site and further divided this group; half of these we direct-released into either Taylor Brook Wetland (2007, 2008) or Pump Station Wetland (2009; Table 3). The other half of the recipient site hatchlings were retained for head-starting through the winter in captivity. However, in autumn 2010, no hatchlings were directly released at the recipient site; instead all were retained for head-starting (Table 3).

Selection of specific release sites.—Our initial release location at the refuge was Taylor Brook Wetland, an herbaceous emergent marsh with clumped grasses, sedges, water lilies, and duckweed on the eastern side of the glacial lake. This marsh forms the headwaters of Taylor Brook. Water levels in Taylor Brook Wetland vary seasonally but the wetland is often kept flooded by resident North American Beavers (*Castor canadensis*) that maintained a dam downstream; water levels often exceeded 2 m in some areas in the spring. We began releasing hatchlings and head-starts in Pump Station Wetland in 2009, a scrub-shrub and marsh habitat with unconsolidated bottom currently influenced by beaver activity. Pump Station Wetland was dominated by shrubby, woody vegetation, including Leatherleaf (*Chamaedaphne catyculata*), Sweet Gale (*Myrica gale*), Alder (*Alnus rugosa*), Red Maple (*Acer rubrum*), Swamp Rose (*Rosa palustris*), Water Willow (*Decodon verticillata*), Sphagnum with patches of open water, and duckweed-covered pockets. At both release sites in the refuge (Fig. 1), we released hatchlings into areas of vegetative cover typical of Blanding's Turtle habitat that consisted of emergent grasses, sedges and rushes, Leatherleaf, Sphagnum, and duckweed (Butler and Graham 1995).

Head-starting techniques.—During the winters of 2007–2008 and 2008–2009, we maintained head-started turtles in 37.8 L aquariums in groups of three to 10 animals. We fed hatchlings ReptoMin® floating food sticks (TetraFauna

(A) Taylor Brook Wetland . (B) Pump Station Wetland.

Figure 1. Release sites of Blanding's Turtles (*Emydoidea blandingii*) at the Assabet River National Wildlife Refuge, Massachusetts, USA. (Photographed by Kurt A. Buhlmann).

United Pet Group, Blacksburg, VA) and Gammare dried shrimp (Vitakraft Pet Products Co, Inc., Bound Brook, NJ) daily, and occasional live insects and tadpoles (which we collected at the recipient site). A calcium supplement was offered weekly. We included basking lights and structures in each aquarium, and we used water heaters when necessary to maintain water temperatures at 24–29 °C. Air temperatures fluctuated between 18–30 °C depending on the type of basking light we used.

During 2009–2010, we maintained head-started hatchlings in a greenhouse at a local high school. Initially, we maintained hatchlings in 41 L plastic bins Sterilite Corporation, Townsend, Massachusetts, USA; 88.6 cm L x 42.2 cm W x 15.6 cm H) of seven to eight animals (Fig. 2). Each bin was equipped with a basking site and a PowerSun^{TM} lamp (Zoo Med Laboratories, Inc., San Luis Obispo, California, USA), and we provided plastic plants (Exo Terra, Mansfield, Massachusetts, USA) for hiding and ease of cleaning. We cleaned bins each day. We set air temperature in the greenhouse to 26.7 °C. One week prior to release, we set greenhouse air temperatures to a cycle that mimicked day (23.9 °C) and night (18.3 °C) temperatures at the recipient site. We weighed and measured head-started turtles weekly while in captivity. We separated animals by size (weight) as they grew to minimize injuries. We maintained head-started turtles of the three smallest size categories (i.e., < 10 g, 10–14.9 g, 15–24.9 g) in bins. As some turtles started to outgrow the bins (after attaining ≥ 25 g body weight), we moved them to 1,741 L aquaculture tubs, with turtles in each size category (i.e., 25–49.9 g, 50–74.9 g and ≥ 75 g) maintained in different tubs (Fig. 3), with appropriately shallow water levels. We fed head-started turtles a turtle "jello" diet consisting of beef heart cut into cubes, dried krill or large shrimp with shells, commercial turtle pellets, shredded sweet potato, calcium, and multi-vitamin supplements (Exo Terra, Mansfield, Massachusettes, USA) incorporated into a gelatin matrix. Items were mixed in a blender and added to unflavored gelatin (Knox®, Kraft Foods Group, Northfield, Illinois, USA). We fed turtles twice daily on weekdays and once daily on weekends and school vacation. If an individual lost 5–7% body mass between weekly measurements, it was moved to isolation and offered the turtle jello diet and chopped earthworms until its mass increased. We also occasionally fed turtles ReptoMin® and live foods (insects, worms, small

Figure 2. Head-started Blanding's Turtles (*Emydoidea blandingii*) being maintained in a high school greenhouse in winter 2009–2010. Newly-emerged hatchlings were initially reared in small, shallow plastic bins. (Photographed by Brian A. Bastarache).

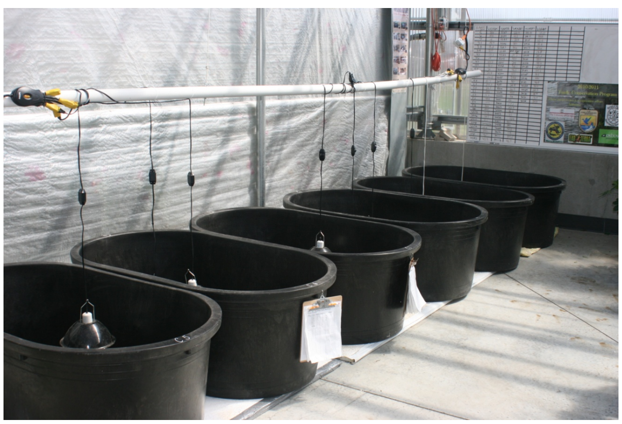

Figure 3. Head-start rearing facilities for Blanding's Turtles (*Emydoidea blandingii*) in high school greenhouse. Once head-started hatchlings start to grow, they were sorted by size and transferred to 1471 L tubs, where they were maintained until release. (Photographed by Brian A. Bastarache).

crayfish, and tadpoles). In the month before release, meal worms (*Tenebrio* for small turtles and *Zophobas* for the larger ones) replaced jello and ReptoMin® for the afternoon feeding.

We released head-started hatchlings in late May when freezing nights were no longer likely to occur. The largest head-started hatchling was large enough (115.5 g) to hold a radio-transmitter (Model R1680, 3.6 g; Advanced Telemetry Systems, Isanti, MN) at the time of release in late May, and we maintained four additional head-start turtles in captivity for the summer and then released them with radio-transmitters. Radios and epoxy added 6–8 g to each turtle and were no more than 7% of the individual turtle's body weight. We radio-tracked the head-started turtle released in May all summer and we recaptured, re-measured, and fitted it with a new radio prior to winter torpor.

Translocated sub-adults.—We captured sub-adult Blanding's turtles at the donor site using baited hoop traps. We selected 12 of the captures (known ages 4–11 yr) that were large enough to carry radio transmitters (Model R1680 weighing 3.6 g or Model R1920 weighing 14 g, depending on turtle weight; Advanced Telemetry Systems, Isanti, Minnesota, USA). We chose sub-adults to avoid removing reproductive individuals from the donor population. We trapped May-June 2008, May 2009, and August 2010. We translocated these 12 sub-adults to the recipient site and released them into the same wetlands as the hatchlings. We radio-tracked these sub-adults at least weekly to obtain information about habitat selection, site fidelity, and winter torpor that we could not obtain from the direct-release hatchlings and most head-start turtles, which were too small to carry radio-transmitters. Monitoring the habitat selection by translocated sub-adults was designed to help us determine the best future suitable sites for release of head-started and direct-release hatchlings.

Results

Evaluating the appropriateness of reintroduction.—We answered the 15 decision tree questions (Table 1) and determined that few viable populations existed in the local landscape and that the species was not secure in the region (Q1). The proposed recipient site (Refuge) was within the species' natural range (Q2), did not have an extant population (Q3), was large enough with appropriate habitat (Q4), and was secure (Q5). We were not certain of the initial cause of decline (Q6), but prior military use of the site and hydrologic manipulation for cranberry cultivation and other farming activities (e.g., ditching and draining of wetlands for arable land) may have had negative effects. There were no identifiable contemporary threats to the site. We identified a suitable donor site (Q7) that had a sizeable Blanding's Turtle population and a history of nest protection, nesting habitat management, and population monitoring. In addition, we reserved half of the hatchlings from each clutch for release at the donor site, thus minimizing impacts to the donor population (Q8) as its viability remains paramount to Blanding's Turtle conservation in the region. The donor site and recipient site are within the same greater river basin, and would likely be part of the same metapopulation in an unfragmented pre-European landscape, thus both genetic (Q9) and disease transmission issues (Q10) are probably largely negated. Head-started animals were not exposed to other species during captivity. Selection of appropriate life stages (Q11) and numbers needed (Q12) are addressed below. Habitat management projects were in place at recipient (Q13) and donor (Q14) sites and are discussed below, as well as adaptive management plans for long-term monitoring (Q15).

Evaluation of potential release scenarios.—Our source model predicted a growth rate of 0.01 for the source population under a scenario of no manipulations (i.e., no nest protection or harvest; Fig. 4). Scenarios based on protection of 30 nests predicted population growth rates of 0.009–0.011, depending on the number of hatchlings harvested for release at the recipient site (Fig. 4). Thus, protecting a small portion (n = 30) of total nests should be adequate to compensate for animals harvested from the donor site under any of the scenarios we modeled. In our recipient site model scenarios (Fig. 5), the predicted number of adult Blanding's Turtles begins accelerating at Year 15 around the time when the first introduced turtles reach maturity (males mature at age 14 y, females at age 17 y; Congdon et al 1993). By that time, all hatchling releases have been completed. The number of adults then plateaus once all surviving introduced turtles reach maturity, after which time population growth is dependent on their nesting and reproductive success after population manipulations are discontinued. All release scenarios predict a stable recipient population by the end of the 50 y simulations (Fig. 5), but head-starting appears to be twice as effective as direct-release of hatchlings (assuming that head-started turtles do behave normally after release). For example, our model predicts that annual releases of 50 head-starts per year results in a predicted population similar to directly-releasing 100 hatchlings per year, and that it will reach a stable population size sooner. However, because head-starting is more intensive in terms of time and resources and because no data were available to determine whether released head-starts were likely to behave similarly to wild-recruited Blanding's Turtles, we chose a release strategy initially comprised of both head-started and direct-release hatchlings.

Direct-release hatchlings at recipient site.—We released 81 direct-release hatchlings from 36 nests in the refuge in autumns of 2007, 2008, and 2009 (Table 3). Direct-release hatchlings averaged 36.3 mm CL and 8.8 g over the three years, were similar in size among years, and were comparable in size to hatchlings selected for head-starting (Fig. 6). A 2008 DR hatchling (#3294) was incidentally recaptured 18 October 2010 in the Pump Station Wetland, although it had been originally released in the Taylor Brook Wetland. This capture was in the same area where translocated, radio-tracked, sub-adults hibernated in previous years. This head-started turtle had increased in size from 37.9 mm CL and 10.1 g at time of release on 9 September 2008 to 88.4 mm CL and 105.4 g.

Head-started hatchlings.—Survivorship of head-started animals in captivity ranged from 91–100% among cohorts (Table 3). Three of the 2008 cohort died from accidental exposure to hot water. One of the 2009 cohort died the first day in captivity of unknown causes, and two drowned accidentally after getting trapped under the basking structures on 31 January and 30 April 2010. Head-started hatchlings averaged 36.8 mm CL and 9.3 g at hatching and 61.7 mm CL and 44.1 g at the time of release (Table 3; Fig. 6). We introduced 161 head-started hatchlings from 59 nests to the refuge during 2008–2011 after being maintained in captivity for 9 mo. In addition, we released seven head-started animals from 2006 in the autumn of 2007; these were the only animals maintained in captivity for a full year (Table 3).

The largest head-started hatchling produced to date (#3253; 99.5 mm CL, 163.5 g at release) was from the 2008 cohort. It was fitted with a transmitter and released into the Pump Station Wetland on 27 May 2009. This turtle was recaptured on 13 October 2009 in the same wetland and had decreased in weight from 163.5 g to 143.0 g, although it was larger than a wild-caught 4–yr old turtle from the donor site (Fig. 7). Based on telemetry data, we believe the animal survived the winter but then died of unknown causes; we retrieved it from the Pump Station Wetland on 25 May 2010. In February 2011, all five head-started hatchlings from the 2009 cohort were tracked to hibernation locations below the ice. Four were in the Pump Station Wetland and one was in the Taylor Brook Wetland. The latter was found dead in March, as was a Snapping Turtle (*Chelydra serpentina*), presumably as a result of winter kill.

Discussion

Appropriateness of reintroduction at the candidate recipient site.—Our decision to reintroduce Blanding's Turtles to the Assabet River National Wildlife Refuge appears to be an appropriate conservation action based on the results of our decision tree. This large refuge with extensive and diverse wetland habitats provided, in our opinion, an opportunity for proactive Blanding's Turtle conservation by potentially increasing the number of viable populations. This becomes especially significant given that at most only three populations in New England currently contain > 50 turtles (Compton 2007). Although we are not certain that a previous population was extirpated from the site, the habitat currently appears appropriate and is no longer subject to heavy human use. In addition, a 2000 record for a road-killed gravid female Blanding's Turtle (Massachusetts Natural Heritage and Endangered Species Program Database, Westborough, MA) on the two-lane road adjacent to the east boundary of the refuge argues strongly for the historical presence of Blanding's Turtles in this exact portion of the New England landscape. The refuge is large enough to encompass the large home ranges that have been reported for Blanding's Turtles (63.0 ha, Piepgras and Lang 2000; 24.8 ha, Babbitt and Jenkins, unpubl. report; 27.5 ha, Grgurovic and Sievert 2005). The refuge can also accommodate some, but not all, long distance movements

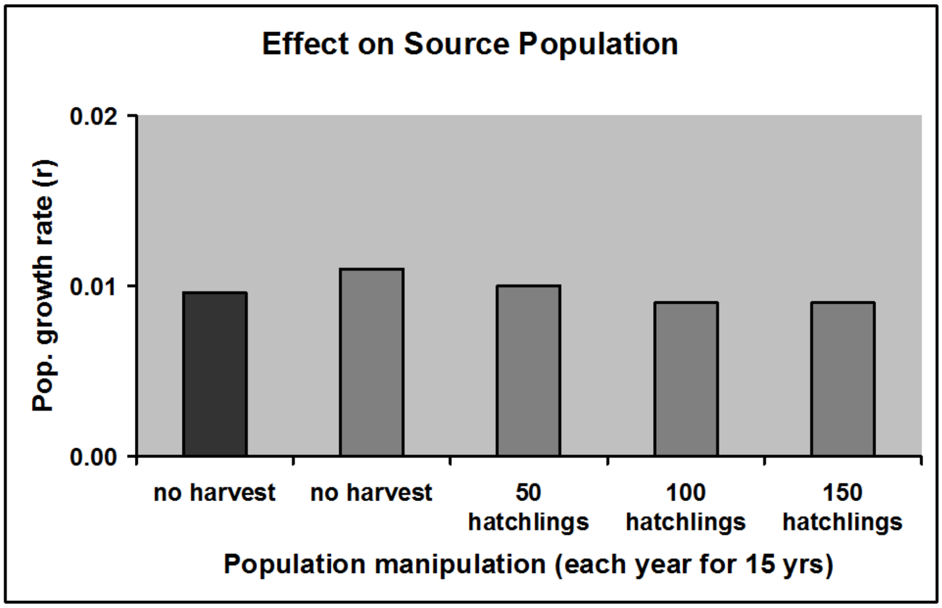

Figure 4. Effect of potential population manipulations on the growth rate of the source population of Blanding's Turtles (*Emydoidea blandingii*) released 2006–2011 at the Assabet River National Wildlife Refuge, Massachusetts, USA. The dark bar on the left predicts population growth rate under no manipulations (i.e., no nest protection, no harvest). The light bars to the right predict population growth rate under varying harvest scenarios when 30 nests are protected. Note that all predicted population growth rates are > 0.

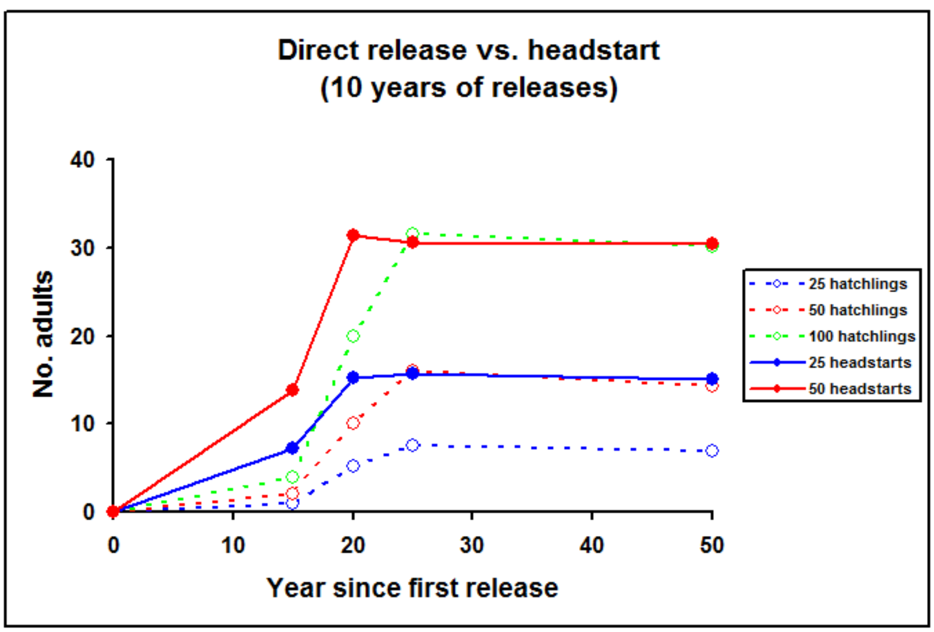

Figure 5. Predicted number of adult Blanding's Turtles (*Emydoidea blandingii*) at the Assabet River National Wildlife Refuge, Massachusetts, based on introducing 25, 50, or 100 direct-release hatchlings or 25 or 50 head-started turtles. Simulations were based on 10 y of releases with results after 15, 20, 25 and 50 y presented. The lines are color coded by the number of animals released in each scenario; dashed lines correspond to direct-release scenarios, solid lines to head-start scenarios.

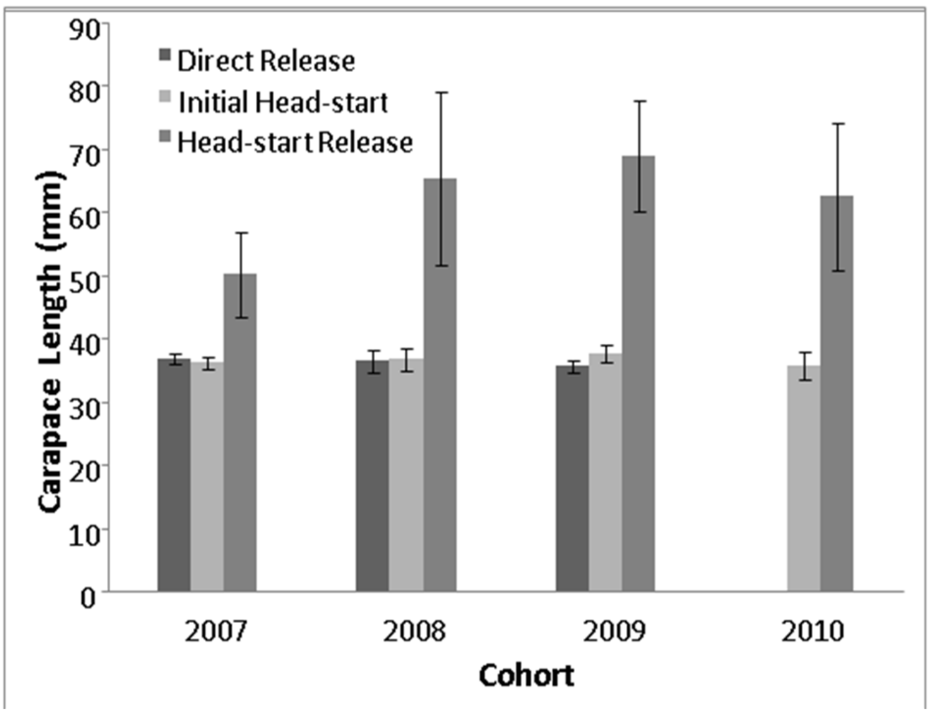

Figure 6. Yearly (2007–2010) comparisons of initial hatchling sizes for cohorts of Blanding's Turtles (*Emydoidea blandingii*) selected for direct-release in autumn (first column) and those retained for head-starting over one winter (second column). The third column in each yearly comparison shows the release size of the head-started turtles the following May. No direct releases were made in 2010. Means ± 1 SD are presented.

TABLE 3. Comparison of carapace length (CL) and mass (g) of 242 hatchling (81 direct-released [DR] and 161 head-started [HS]) Blanding's Turtles (*Emydoidea blandingii*) released 2006–2011at the Assabet River National Wildlife Refuge, Massachusetts, USA. Dates and wetlands of release and survivorships for HS while in captivity are also given. Release sites were Taylor Brook Wetland (TB) and Pump Station Wetland (PS). NN = number of nests. The means ± S.D. and ranges are presented in each category.* the seven head-started turtles from 2006 cohort were retained in captivity for one year before release. All subsequent head-starts have only been kept in captivity over one winter (approx. 9 mo). ** there were no direct-releases in 2010; all were kept for head-starting.

Year Co-hort	# DR	DR $\bar{X}$ CL mm ± 1 SD (range)	DR $\bar{X}$ g (range)	NN	DR release date (Wetland)	# HS	HS-release $\bar{x}$ CL mm ± 1 SD (range)	HS-release $\bar{x}$ g (range)	# nests	HS winter Sx (Survival in captivity)	HS release date (Wetland)
2006*	–	–	–	–	–	7	50.4 (46.0-54.7)	21.4 (17.6-26.8)	4	100%	4 Oct 2007 (TB)
2007	25	36.7 ± 0.9 (35.4-38.3)	9.1 (6.9-10.4)	6	4 Oct 2007 (TB)	22	50.1 ± 6.6 (38.0-65.0)	22.8 (10.9-41.0)	5	100%	22 May 2008 (TB)
2008	34	36.4 ± 1.7 (32.8-38.9)	8.7 (6.6-10.7)	20	9 Sep 2008 (TB)	31	65.2 ± 13.7 (41.0-99.5)	52.2 (10.5-163.8)	20	91% 3 died	19 May 2010 (PS)
2009	22	35.5 ± 0.9 (34.2-37.5)	8.7 (7.3-10.4)	10	13 Oct 2009 (PS)	47	68.9 ± 8.8 (50.0-86.0)	57.7 (19.7-115.5)	15	94% 3 died	19 May 2010 (PS)
2010**	–	–	–	–	–	54	62.5 ± 11.6 (40.0-83.0)	43.7 (11.2-91.1)	15	95% 3 died	25 May 2011 (PS)
TOTAL	81	–	–	36	–	161	–	–	59	–	–

Figure 7. Head-started hatchling (#3253, left) Blanding's Turtle (*Emydoidea blandingii*) from the 2008 cohort, recaptured in October 2009, compared to a 4-yr old wild-caught turtle (right) from the donor site. (Photographed by Kurt Buhlmann).

reported (1400 m, Rowe and Moll 1991; 2900 m, Piepgras and Lang 2000). It is inevitable that some of the reintroduced Blanding's Turtles will migrate off site and into unfavorable situations, but if an 880 ha refuge is not able to sustain a Blanding's Turtle population, then the species is unlikely to persist anywhere in New England.

Evaluating alternate release strategies.—We constructed a simple population model based on available life-history and behavioral data to evaluate five logistically feasible release strategies. We based implementation decisions on published literature and our model results. We made an early decision not to use adult Blanding's Turtles because survivorship of adult turtles in the donor population was of paramount conservation concern; removal of adults would be equivalent to lowering the annual survivorship there. In addition, observations of homing and site fidelity in translocated adults of other species (Tuberville et al. 2005) suggest that adults are more likely than juveniles to disperse from reintroduction sites. Protecting nests and using half of each female's clutch for the reintroduction and returning the other portion to the donor site was predicted to maximize genetic diversity at the recipient site yet also minimize loss of genetic diversity and enhance recruitment at the donor site. Similarly, the effective 50% nest survivorship resulting from nest protection and the release of half clutches directly to the donor wetland (eliminating nest-to-water journey) provided greater survivorship for the residents during their first year than typically reported for un-manipulated clutches of this species.

Thus, our reintroduction strategy included direct release of hatchlings in autumn, head-starting of hatchlings for 9 mo over-winter with release in May, and translocation and radio-telemetry of sub-adults of known age 4–11 y. We did not consider sub-adult translocation as a long-term management strategy but rather as a means to obtain information about habitat preferences of juvenile

Blanding's Turtles in the refuge. We used information from radio-tracking the translocated sub-adults and the larger head-starts to guide selection of subsequent release sites for direct-release hatchlings and head-started turtles.

Our population model assumed that head-started turtles would behave similarly and exhibit comparable survivorship to wild-recruited juveniles of similar size. Based on this assumption and the predicted higher survivorship of head-started turtles relative to smaller direct-release hatchlings, our models suggested that head-starting should be twice as effective in reaching the target population size as direct releasing hatchlings. Releasing either 100 direct-release hatchlings per year for 10 y or 50 head-start turtles per year for 10 y were both predicted to result in a population of approximately 30 adult turtles in 20 y. However, because head-starting is much more time and resource demanding, our initial approach has been a combination of head-start and direct release. However, all partners are now in place for nest protection at the donor site and for standardized head-starting of the hatchlings. We will continue to direct-release and head-start and to hopefully increase effort as personnel and funding allow.

Head-starting techniques and survivorship in captivity.—Overall size of head-started hatchlings by time of release has increased with each year of the project (2007:1.39-fold; 2008: 1.78-fold; 2009:1.83-fold), with slight decrease in 2010 (1.75-fold) presumably as a result of standardization and improvement in husbandry techniques. Survivorship during captivity has ranged from 91–100% among cohorts. In comparison, Mitrus (2005) reported 85% survival during captivity of his head-started European Pond Turtles (*Emys orbicularis*), a closely related species. The few mortalities to date in our project have resulted from accidents (i.e., drowning under basking logs); our husbandry techniques have been altered to prevent such accidents. Our collaboration with a dedicated local high school teacher and students to carefully maintain holding facilities, take weekly growth and weight measurements, and provide consistent monitoring and feeding has been the key to a successful head-starting program. In addition, segregating head-started turtles by size helped ensure that smaller turtles were not harassed by larger turtles and did not lose out in competition for food.

The turtle "jello" diet we used since 2009 provides a diverse, nutritious diet and most hatchlings fed on it readily. Use of live foods, such as meal worms, was successful in stimulating the few reluctant hatchlings to feed. Introduction of live food items to all head-starts prior to release may help condition them to search for prey in the wild. None of the head-started hatchlings exhibited knobby shells or "pyramiding" as has been described in a captive program where turtles (i.e., desert tortoise, *Gopherus agassizii*) maintained their activity year-round and were fed frequently (Jackson et al 1976). Our intention was to produce normal-looking turtles that were too big for American Bullfrogs (*Rana catesbeiana*) and other presumed predators (Haskell et al. 1996). At the time of release, the head-started hatchlings were in the size range of wild 2–4 y old turtles and presumably would experience comparable survivorship.

Post-release survival of direct-release and head-started hatchlings.—We have limited data on survivorship of the direct-release hatchlings. The recapture of a 2008 direct-release hatchling (88 mm CL) in summer 2010 is worth note. First, the hatchling was slightly larger than the largest head-started turtle from the 2009 cohort, but smaller than the largest head-started turtle (99.5 mm CL) from the 2008 cohort at time of release. Second, this hatchling had moved to the location where radio-tracked, translocated sub-adults have also congregated, which requires overland movement across a dirt road. Third, we caught this hatchling where translocated sub-adults had previously successfully spent the winter in torpor.

We have radio-tracked six head-started hatchlings. One (#3253) died after 11 mo; it had lost 12% body weight when recaptured in September 2009 prior to winter hibernation and was found dead in Spring 2010. Its cause of death is unknown. We released five head-started turtles from the 2009 cohort with radio-transmitters, which are being tracked. Mitrus (2005) reported a first-year recapture rate of 0.24 and a second-year recapture rate of 0.43 for head-started European Pond Turtles (*Emys orbicularis*). Vander Haegen et al. (2009) reported a survival rate of first-year head-started Western Pond Turtles that ranged 83–91%. These observed survival rates are higher than the rate we used in our models, thus our models are conservative. Congdon and van Loben Sels (1993) estimated 72% survivorship for juvenile (> 1 y age) Blanding's Turtles. We have limited data to estimate survival of our head-starts after release, but we will continue to monitor head-starts with a combination of radio-telemetry and mark-recapture to evaluate their survivorship, habitat selection, site fidelity, and growth.

Our reintroduction project includes monitoring of direct-release hatchlings and head-starts at the recipient site, as well as monitoring and nest protection at the donor site. Thus, we are working to enhance the population at the donor site, as well as establish a new population at the recipient site. This experimental design will allow us to evaluate the performance of head-started turtles when compared to direct-release hatchlings at the same site (i.e., recipient site). Monitoring of direct-release hatchlings via mark-recapture at the donor site will provide a control to compare survivorship of direct-release hatchlings at the recipient site.

***Adaptive management and other management considerations.*—**Our ultimate goal is to establish a viable, self-sustaining population of Blanding's Turtles at the recipient site. We will evaluate a suite of interim benchmark goals, including survivorship, site fidelity, and eventually reproduction. To further increase the likelihood of success, our reintroduction strategy was designed to accommodate adaptive management. For example, monitoring the head-started and direct-released hatchlings will allow us to develop site-specific survivorship estimates and to evaluate our assumption that head-started turtles do not behave abnormally after extended captivity. Such data can be used to update our model and adapt our release strategies accordingly. Likewise, radio-tracking of translocated sub-adult and head-started turtles in the first few years of the reintroduction project has already led to the identification of future release sites for hatchlings.

Lastly, although monitoring of both the donor site and recipient site populations are valuable components of this reintroduction project, habitat management and communication with stakeholders should be continued and expanded. The new Blanding's Turtle population will need nesting sites, and such habitat requirements have already been addressed early in this reintroduction project. Creation of new nesting sites has been shown to successfully attract female turtles (Buhlmann and Osborn 2011). Our project represents an important partnership among federal and state agencies, private consultants, a university, a local high school, Friends of the Assabet National Wildlife Refuge, and numerous volunteers. Diverse stakeholder involvement, presentations to the public, and newspaper articles have garnered support for the reintroduction project, helping assure the project's long-term viability. Sustained project effort and long-term monitoring will be necessary to determine whether this venture will ultimately be successful. We suggest that our approach can serve as a model for others who wish to consider reintroduction and head-starting as parts of their conservation strategy.

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Kurt A. Buhlmann is a Conservation Ecologist whose research interests include life history and evolutionary ecology with application for conservation and management of amphibians and reptiles. He has worked with non-profit, state, and federal agencies on habitat management projects, including prescribed fire and wetlands restoration. He is involved in reintroduction projects for tortoises and freshwater turtles. He holds a B.S. in Environmental Studies from Stockton State College (New Jersey), a M.S. in Wildlife Sciences from Virginia Tech, and a Ph.D.

in Ecology from the University of Georgia. He is a Senior Research Associate at the University of Georgia's Savannah River Ecology Laboratory. (Photographed by George Cevera).

Stephanie L. Koch is a Wildlife Biologist with the U.S. Fish and Wildlife Service at Eastern Massachusetts National Wildlife Refuge Complex, where she oversees the biological programs on eight different National Wildlife Refuges. She earned her Ph.D. in Environmental Science at the University of Rhode Island (2010) and her B.S. in Wildlife Biology at the University of Massachusetts (1996). Her interests include research and management of freshwater and coastal habitats with an emphasis on minimizing impacts of habitat loss and disturbance to benefit native wildlife species in decline. (Photographed by Kurt A. Buhlmann).

Brian O. Butler is President of Oxbow Associates, Inc., an environmental consulting company located in Massachusetts that specializes in wetlands and endangered species permitting and field studies. He received a B.S. in Marine Biology from Southampton College of Long Island University and a M.S. from Worcester State University. (Photographed by Kurt A. Buhlmann).

Tracey D. Tuberville is an Associate Research Scientist at the University of Georgia's Savannah River Ecology Laboratory, near Aiken, South Carolina. Tracey received her Ph.D. in Ecology (2008) and her M.S. in Conservation Ecology and Sustainable Development (1998) from University of Georgia and her B.S. in Biology from Furman University (1993). Tracey's research interests are in applied conservation and management research for reptiles and amphibians, including translocation and reintroduction as conservation tools, use of microsatellite markers to understand population ecology and individual behavior, and ecotoxicology. (Photographed by Kurt A. Buhlmann).

Veronica J. Palermo worked as a Field Technician at Oxbow Associates, Inc., a Massachusetts based wetlands and wildlife consulting company specializing in rare amphibian and reptile study and mitigation. She earned her B.S. in biology from the University of Massachusetts Lowell. (Photographed by Anonymous).

Brian A. Bastarache is the Natural Resources Management Division Head at the Bristol County Agricultural School in Dighton, Massachusetts, USA. He earned an M.A. in Environmental Management from Harvard University and a B.S. in Wildlife Biology from the University of Massachusetts at Amherst. In addition to teaching courses in wildlife biology, fisheries and outdoor skills, he oversees several cooperative conservation projects in partnership with universities, corporations, government agencies and NGOs. (Photographed by Mike Gay.)

Zachary A. Cava is a Biological Science Technician with the Henderson, NV branch of the U.S. Geological Survey (USGS), where he is assisting in a Desert Tortoise translocation project. Zach is especially interested in herpetological conservation and in recent years has worked with Diamondback Terrapins, western rattlesnake species, and Blanding's Turtles, among other species. He received a B.A. in Biology from Ithaca College in 2009. (Photographed by Kristin Godfrey.)

Errata. Zachary A. Cava's name was incorrectly spelled with a middle initial of D instead of A in both the author line and bio sketch of the original version of this manuscript. On 18 July 2015, the correction was made and corrected manuscript posted online. The co-author' name Veronica J. Palermo was spelled wrong.