Growth and Survival of Wild and Head-Started Blanding’s Turtles (Emydoidea Blandingii)

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ABSTRACT

GROWTH AND SURVIVAL OF WILD AND HEAD-STARTED BLANDING’S TURTLES (*EMYDOIDEA BLANDINGII*)

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Northern Illinois University, 2019
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Blanding’s turtles (IUCN Endangered) are long-lived reptiles with delayed sexual maturity. Anthropogenic landscape changes have increased threats to juvenile turtles, resulting in unnaturally low recruitment. Head-starting has become a popular conservation strategy that aims to increase juvenile recruitment by avoiding the increased predation of the vulnerable nest and hatchling age class. However, there is still debate about whether or not it is an effective management tool. Assessments of head-starting are becoming more prevalent, but long-term studies are needed to critically evaluate the success of such interventions. In particular, information is needed on how head-starts fare compared to wild-born turtles. The Lake County Forest Preserve District (LCFPD) in northeastern Illinois initiated a long-term capture-mark-recapture (CMR) project in 2004. As of 2018, 127 wild-born juvenile turtles had been captured (59 of which had been captured in multiple years) and 148 adult turtles had been captured (116 of which had been recaptured in multiple years). Since 2010, LCFPD has released 491 head-started turtles during the year following hatching, 138 of which have been recaptured during successive years. I used van Bertalanffy growth analysis to compare growth trajectories and Cormack-Jolly-Seber (CJS) modelling techniques to compare survival rates of wild-born and head-started turtles. At release, head-started turtles were about the size of 2-year-old wild-born turtles and grew in parallel to their wild-born counterparts. The top-ranked survival models demonstrated that survival increased with age for both wild-born (71%-98%) and head-started
turtles (63-90%), with overlapping confidence intervals. These results suggest that head-started juveniles perform similarly to like-aged wild-born juveniles despite head-starts having attained greater body size. I estimated adult survival to be 95% with an environmental variance of 0.0011. Although the success of head-starting cannot be fully assessed until turtles are recruited into the adult population and successfully reproduce, patterns of head-start growth and survival provide positive intermediate measures of success. My estimation of juvenile and adult survival, along with other demographic information from this population, will provide for more accurate population projections that will aid in evaluating conservation strategies for this population and potentially for Blanding’s turtles elsewhere.
GROWTH AND SURVIVAL OF WILD AND HEAD-STARTED BLANDING’S TURTLES

(EMYDOIDEA BLANDINGII)

BY
CALLIE KLATT GOLBA
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A THESIS SUBMITTED TO THE GRADUATE SCHOOL
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INTRODUCTION

Wildlife populations are in decline and are in need of conservation interventions, but management strategies must be evaluated to ensure they are effective (Martin et al. 2018). The unique life history strategy of long-lived species with delayed sexual maturity as found in many chelonian species presents unique challenges for management. These species require unconventional strategies to conserve their populations. This is due to their long life span that presents different threats to each of their distinct different life stages (Canessa et al. 2016).

Anthropogenic landscape changes have increased threats, especially to juvenile turtles (exposure, lack of suitable habitat, subsidized predators), resulting in unnaturally low juvenile recruitment (Gibbon et al. 2000). This has led many managers to focus on mitigating threats to this age class (Seigel and Dodd 2000).

Head-starting has become a popular conservation strategy used for turtle management (Burke 2015). The goal is to increase juvenile recruitment by incubating eggs and rearing hatchling turtles in captivity, which avoids predation of the vulnerable nest and hatchling age class. It is hoped that this will boost the number of young turtles entering the population and halt population decline. However, there is still debate about whether head-starting is an effective management tool (Bennett et al. 2017). Critics point to the lack of follow-up monitoring (to assess the actual recruitment into the population and fitness of head-started turtles as compared to wild-born turtles) and the failure to address more important causes of population decline (adult mortality, habitat degradation and fragmentation; Buhlmann et al. 2015; Green 2015; Thompson et al. 2019).
The Blanding’s turtle (*Emydoidea blandingii*) is a long-lived species of freshwater turtles for which head-starting has been used frequently (Buhlmann et al. 2015; Thompson et al. 2019). Populations of Blanding’s turtles are facing imminent threats including habitat loss and degradation, reduced adult survival, and reduced recruitment of young turtles. To properly evaluate the efficacy of head-starting as a management strategy, long-term data are required. Although assessments of head-starting are becoming more prevalent (Thompson et al. 2019), long-term studies are needed to critically evaluate the success of such interventions. To evaluate head-starting in the shorter term, analyses of growth and survival can be used as intermediate measures of the success of head-starting.

Growth and survival over the ca. 14-year juvenile stage is less established than other demographic parameters for both wild-born and head-started Blanding’s turtles. Even in longer term studies, these younger age classes are infrequently encountered, able to be aged, and then recaptured. This makes it difficult to obtain a large enough sample size to accurately estimate their growth and survival.

The relationship between size and age of Blanding’s turtles has been estimated in several populations, demonstrating a steady increase in size of juvenile turtles until reaching sexual maturity (Congdon et al. 2001; Germano et al. 2000; Lefebvre et al. 2011; Reid et al. 2016). A few studies have looked at shorter term growth of wild-born juveniles (Arsenault 2011; D’Entremont 2014), but rarely has growth of wild-born and head-started juveniles been compared in the same population.

Juvenile survival of wild-born and head-started Blanding’s turtles has been estimated in several ways. In a widely cited study, Congdon et al. (1993) inferred juvenile survival to be 78.3% from information on hatching success and adult survival coupled with the assumption of a
stable population size. Cormack-Jolly-Seber (CJS) analyses have been used to estimate survival of wild-caught juveniles, but because of small sample size, only two age classes (“younger” and “older”) could be recognized (Kuhns 2010). Known-fate analyses of using radio telemetry data has produced widely varying results (66-93%), perhaps because of small sample size (n=13-83) (Arsenault 2011; D’Entremont 2014; Kuhns 2010; Ross and Dreslik 2018; Starking-Szymanski et al. 2018; Windmiller et al. 2016). Furthermore, these studies have generally failed to relate survival of head-starts to that of wild turtles of similar size. Adult survival is known with high precision from a number of studies (Congdon et al. 1993; Congdon et al. 2001; Kuhns and Phillips 2010; Reid et al. 2016; Ross and Dreslik 2018; Ruane et al. 2008; Rubin et al. 2004; Windmiller et al. 2016), but the environmental (process) variance has rarely been explored.

This creates a need for quantitative analyses of the success of head-starting conservation strategies. This can be achieved by using long-term data of Blanding’s turtle populations that allow comparison of wild-born and head-started juveniles. Although the success of head-starting cannot be fully assessed until turtles are recruited into the adult population and successfully reproduce, patterns of head-start growth and survival can provide intermediate measures of success. By obtaining a more accurate estimate of year-to-year variation in adult survival (via process variance), we can apply these numbers for a more accurate population projection into the future, further assessing the value of head-starting.

The Lake County Forest Preserve District (LCFPD) in northeastern Illinois initiated a long-term capture-mark-recapture (CMR) project of Blanding’s turtles in 2004. An initial population viability analysis, completed in 2010, reported a low number of juveniles in the population and an unsustainably high rate of nest predation as well as the need for habitat restoration and lower than ideal rates of adult survival (Kuhns 2010). Habitat management and
predator removal management strategies were not predicted to be enough to create a viable population. Consequently, in 2012, LCFPD initiated a head-starting program to increase juvenile recruitment in tandem with other management strategies aimed at addressing threats to the population. An analysis of the effects of head-starting on turtle body size distributions suggests head-starting has had a positive effect (Thompson et al. 2019).

These 14 years of intensive monitoring provide a unique data set from which I can compare growth and survival of wild-born juveniles to head-started juveniles. I also estimate adult survival and its environmental (process) variance. In order to consider head-starting an effective tool, I expect to see head-started turtles to have larger sizes at release than that of their wild-born counterparts of equivalent age, for head-starts to grow in a species-typical manner following release, and that survival of head-starts equals or exceeds that of their wild-born counterparts of equivalent age.
MATERIALS AND METHODS

Field Methods

Blanding’s turtle monitoring was initiated in 2004 within the Spring Bluff-Chiwaukee Prairie (SBCP, Figure 1) complex in Lake County, Illinois and Wisconsin. SBCP is a protected natural area consisting of 215 ha. of high-quality coastal wetland habitat. It is located along the coast of Lake Michigan in Illinois and Wisconsin. This land is managed by Lake County Forest Preserve District (LCFPD) and Wisconsin Department of Natural Resources. From 2004 to 2018, mark-recapture data were collected using baited collapsible minnow traps (Promar, 30 X 30 X 60 cm, 0.6-cm mesh) and incidental captures during the active season (April-August). Little or no trapping occurred during 2011 and 2012 (Table 1). Captured turtles were marked for future identification with PIT tags and notching of marginal scutes, and a plastron photo was taken (Buhlmann and Tuberville 1998; Cagle 1939). Turtles weighing less than 750g were classified as juveniles and were assigned ages by counting annuli from photos (Figure 2) or from known hatch dates from turtles that were nest-caged (Castanet 1988; Wilson et al. 2003). Photos that could not be scored consistently by two independent observers were excluded (n=40 older juveniles with indistinct annuli). Sex of adults was determined by observing the concavity of the plastron (Graham and Doyle 1979).
Figure 1. Blanding’s turtle project area within the Spring-Bluff-Chiwaukee Prairie complex.
Figure 2. Example of a 4-year-old wild-born turtle aged using annuli counts. “0” represents the natal scute.
Table 1. Yearly sampling efforts for Blanding’s turtles within the Lake Plain (Spring Bluff-Chiwaukee Prairie complex) as part of the Lake County Forest Preserve District’s Blanding’s Turtle Recovery Plan. Occasions refer to sample periods used for survival analyses of wild-born juveniles and adults (2004-2018). The numbers in parentheses in the occasion column refer to the sample periods used for survival analyses of head-started juveniles (2012-2018). Sampling effort refers to the number of trap nights (number of traps placed*number of nights deployed).

| Year | Occasion | Sampling Effort (trap nights) |
|------|----------|-------------------------------|
| 2004 | 1        | 473                           |
| 2005 | 2        | 2488                          |
| 2006 | 3        | 3438                          |
| 2007 | 4        | 2711                          |
| 2008 | 5        | 1638                          |
| 2009 | 6        | 3696                          |
| 2010 | 7        | 1636                          |
| 2011 | -        | 0*                            |
| 2012 | NA (1)   | 32**                          |
| 2013 | 8 (2)    | 490                           |
| 2014 | 9 (3)    | 741                           |
| 2015 | 10 (4)   | 855                           |
| 2016 | 11 (5)   | 1081                          |
| 2017 | 12 (6)   | 1305                          |
| 2018 | 13 (7)   | 1086                          |
| Totals | -     | 21,576                        |
Head-Starting

LCFPD began a head-starting program at SBCP in 2011. The goal of this program was to increase juvenile recruitment by mitigating threats to the vulnerable nest and hatchling life stage by rearing them in captivity. Generally, head-starting involves collecting eggs from wild telemetered adult females, incubating the eggs in captivity, and then rearing the young turtles in captivity (Thompson et al. 2019). In 2012, LCFPD began releasing individually marked young turtles. They were individually identified by notching marginal scutes when the young turtles were released and either PIT tagging prior to release or upon subsequent recapture of head-started turtles into the SBCP population (detailed in Thompson et al. 2019). Releases have continued annually, releasing from 52-118 turtles one year post-hatching per year and 0-46 older turtles per year. Some of the releases were delayed due to slow growth during captivity. I include only head-started turtles released approximately one year post-hatching in my analyses because this is a homogeneous group that have a normal distribution of size at release.

Growth Analysis of Wild and Head-Started Turtles

Turtles are typically measured by carapace length (CL), which is the longitudinal distance between the front and back of the carapace (Bjorndal and Bolten 1989). Using methodology common for reptile growth studies (Arsenault 2011; Germano et al. 2000), I used non-linear regression methods in SPSS to model growth data (measured in carapace length) collected from known-aged animals. I measured age by using the date of capture in fractional years, computed from January 1st of the hatch year (Andrews 1982). I then explored the age-size relationship using the three-parameter von Bertalanffy growth equation: $CL_t = CL_A - (CL_A - CL_0)e^{-kt}$. In this growth equation, the carapace length at known ages ($CL_t$) is used to obtain
three mean population growth parameters: the population mean asymptotic carapace length ($CL_A$), the carapace length at time 0 ($CL_0$), and the growth rate constant ($k$; Anthony et al. 2015; Arsenault 2011; King et al. 2016).

I analyzed wild-born and head-started juveniles separately because age span differs dramatically between these two groups (1-26 years of age for wild-born turtles, 1-7 years post-release for head-started turtles).

**Survival Analysis**

Capture-mark-recapture modelling techniques based on individual capture histories were used to estimate survival rates for wild-born juveniles, head-started juveniles, and adult turtles in three separate analyses (Cooch and White 2000; Lebreton et al. 1992; McCallum 2000). Survival ($\phi$) and recapture ($p$) rates were estimated using live recapture Cormack-Jolly-Seber (CJS) models using the log link function (Cooch and White 2019; Cormack 1964; Jolly 1965; Seber 1965) in Program MARK (White & Burnham 1999; White 2001) and in R (R Core Team 2017) through the *RMARK* package (Laake 2013). The CJS model assumes that each animal has the same probability of being encountered during each occasion, the same probability of surviving until the next occasion, and any emigration is permanent. It also assumes that sampling occasions are short, animals are released immediately after capture, and individual marks are not lost or interpreted incorrectly. Last, it assumes that the fate of individual animals is independent of that of other animals (Cooch and White 2019; Cormack 1964; Jolly 1965; Seber 1965).

In all analyses I created encounter histories for each individual animal by assigning a “1” if the animal was encountered that year and a “0” if they were not encountered. Multiple captures within a single year were treated as a single capture. I performed goodness-of-fit (GOF) tests on global models to assess if overdispersion was present in the data. If any lack of fit was detected, I
adjusted for overdispersion with the largest estimate (furthest from 1) of the variance inflation factor ($\hat{c}$) following the recommendations of Cooch and White 2019. Candidate models were ranked by comparing Akaike’s information criterion values adjusted for small sample size ($\text{AIC}_c$) or corrected quasi-Akaike information criterion (QAICc) if overdispersion was detected. I examined all top-ranked models within 2 $\Delta\text{AIC}_c$ or 2 $\Delta\text{QAIC}_c$ to determine if model averaging should be employed to account for model uncertainty (Akaike 1973; Burnham and Anderson 1998).

**Survival Analysis of Wild and Head-Started Turtles**

Analysis of age-specific juvenile survival had the potential for numerous candidate models and a risk that more fully parameterized models would result in inestimable parameters (Cooch and White 2019). To avoid overparameterization and data dredging, knowledge of the study organism and study design was considered to formulate an appropriate set of biologically justified candidate models (Brown et al. 2007; Burnham and Anderson 1998). Therefore, I selected a reduced set of candidate models based on *a priori* knowledge of Blanding’s turtle life history, sample sizes and recapture heterogeneity as detailed below.

Age-specific survival rates were estimated separately for two groups of juvenile turtles (<750g): wild-born juvenile turtles of known ages and head-started turtles that were released approximately one year post-hatching. I did not combine these groups into a single analysis because of differences in time spans (13 vs. 7 sampling occasions) and number of age groups (1-26 yr of age vs. 0-6 yr post-release). For both groups, I employed a step-wise model selection process to first optimize recapture ($p$) while keeping survival ($\phi$) at the most inclusive parameterization identified by the candidate model selection process. Then I held recapture
constant at the most parsimonious age-by-time structure identified in the first step to explore age-specific effects on survival. This step-wise methodology provides me with more power to detect age effects and obtain meaningful estimates of survival (Arskovski et al. 2018; Briggs-Gonzalez et al. 2017; Brown et al. 2007; Lebreton et al. 1992).

Wild-Born Juveniles

I created encounter histories for wild-born juveniles during each sampling occasion from 2004-2018. The sampling interval between occasions 7 (2010) and 8 (2013) was set to three because little or no trapping occurred in 2011 and 2012; other intervals were set to one, resulting in 13 sampling occasions and 12 intervals. Wild-born juveniles were grouped by age at initial capture and only wild-born turtles that were initially captured as juveniles (≤ 13 yr) were included.

The global model for wild-born juveniles included the discrete effect of age class and the additive effect of time on recapture probability. I only included the additive effect of time because recaptures spanned 14 years, with only a few recaptures of any given age classes during each year. To avoid overparameterization, I considered a maximum of six age classes (1, 2-3, 4-6, 7-10, 11-14, 15+ yr), selected to provide similar size increments and sample sizes. The global model included age as a linear covariate of survival. In evaluating candidate models nested within this global model, I first optimized recapture by considering models with fewer than six age classes with and without the additive effect of time. Using the top-ranked model for recapture, I then evaluated models in which survival reached a plateau at successively younger ages (following Arsovski et al. 2018). Finally, I compared the top-ranked model that included age as linear covariate of survival with models that included age as a logarithmic or quadratic covariate or that included age as a discrete grouping variable (Arsovski et al. 2018).
**Head-Started Juveniles**

For the analysis of head-started juveniles, I created encounter histories for each sampling occasion from 2012-2018 (releases of head-starts began in 2012), resulting in seven sampling occasions and six intervals. Year of release was treated as the first capture for head-started turtles.

The global model for head-started juveniles included the discrete effect of age class and the interactive effect of age class and time on recapture probability. I included the interactive effect of time to account for observed complexity in year- and age-specific recapture numbers that suggested possible cohort (=year*age) effects. I considered a maximum of four age classes (1, 2, 3, 4+ yr post-release), selected to provide similar sample sizes, as the number released each year varied. The global model included age as a linear covariate of survival (ages 1-6). In evaluating candidate models nested within this global model, I first optimized recapture by considering models with fewer than four age classes with the additive or interactive effect of time. Using the top-ranked model for recapture, I then evaluated models in which survival reached a plateau at successively younger ages (following Arsovski et al. 2018). Finally, I compared the top-ranked model that included age as linear covariate of survival with models that included age as a logarithmic or quadratic covariate or that included age as a discrete grouping variation (Arsovski et al. 2018).

**Survival Analysis of Adult Turtles**

I created encounter histories for adult turtles during each sampling occasion from 2004-2018. The sampling interval between occasions 7 (2010) and 8 (2013) was set to three because little or no trapping occurred in 2011 and 2012; other intervals were set to one, resulting in 13 sampling occasions and 12 intervals. Although some turtles were affixed with radio transmitters,
only trap and hand captures were utilized in the survival analysis. Adult turtles were grouped by sex, and individuals that were initially captured as subadults were included only after they reached adulthood.

I considered two global candidate models and selected the higher ranked of these two global models for GOF testing. The first global model included a sex-by-time interaction for survival and a sex-by-time interaction for recapture. I chose to test for an effect of time on recapture probability because of the extent of year-to-year variation in effort (see Table 1). The second global model included a sex-by-time interaction for survival and a sex-by-effort interaction for recapture to determine if sampling effort could be used as an environmental covariate to replace time and reduce the total number of parameters. Candidate models included all possible combinations of models nested within both global models. I estimated variance components for adult turtles in Program MARK using the highest ranked model that included time-dependence for survival to determine temporal (process) variance in annual survival (Cooch and White 2019).
RESULTS

Field Results

Over 13 mark-recapture sampling occasions from 2004 to 2018, 127 unique wild-born Blanding’s turtles, initially encountered as juveniles, were captured a total of 265 times (Table 2). Over seven mark-recapture sampling occasions from 2012-2018, 491 head-started turtles were released approximately 1 year post-hatching, with 174 subsequent recaptures (665 total captures, Table 3). Over 13 mark-recapture sampling occasions from 2004 to 2018, 148 unique adult Blanding’s turtles (80 M, 68 F) were captured a total of 540 times (Table 4).

Growth Analysis of Wild and Head-Started Turtles

I analyzed growth from 265 encounters of 127 unique wild-born turtles that ranged from age 1 to 26 years old and 665 encounters (including the size at release) of 491 unique head-started turtles that ranged from 0 to 7 years post-release. The growth equation for both groups fit the data well (wild-born $r^2 = 0.891$; head-start $r^2 = 0.714$, Table 5). Growth trajectories of wild-born and head-started turtles were similar in shape (Figure 3), but head-started turtles had a larger body size at release in comparison to like-aged wild-born turtles, shifting the head-started turtle growth curve upwards. This is reflected in the difference in the estimated carapace length at time 0 ($CL_0$) for head-starts (55.1 mm) versus wild-born turtles (23.3 mm; Figure 4). The mean asymptotic carapace length ($CL_A$) differed between groups; however, this asymptote for head-started turtles may not be accurate because of the short duration of the study, with no turtles yet attaining this adult size (Frazer et al. 1990).
Table 2. The number of unique wild-born turtles at the age in which they were initially captured (age at initial encounter) and the number of encounters at each age class.

| Age Class (Years) | Age at Initial Encounter (Years) | Total # of Encounters |
|------------------|----------------------------------|-----------------------|
| 1                | 9                                | 9                     |
| 2                | 9                                | 10                    |
| 3                | 9                                | 12                    |
| 4                | 22                               | 24                    |
| 5                | 12                               | 17                    |
| 6                | 13                               | 17                    |
| 7                | 11                               | 15                    |
| 8                | 11                               | 16                    |
| 9                | 12                               | 23                    |
| 10               | 6                                | 14                    |
| 11               | 8                                | 17                    |
| 12               | 2                                | 14                    |
| 13               | 3                                | 10                    |
| 14               |                                  | 12                    |
| 15               |                                  | 9                     |
| 16               |                                  | 4                     |
| 17               |                                  | 3                     |
| 18               |                                  | 6                     |

(Continued on the following page)
| Age Class (Years) | Age at Initial Encounter (Years) | Total # of Encounters |
|------------------|----------------------------------|-----------------------|
| 20               |                                  | 7                     |
| 21               |                                  | 4                     |
| 22               |                                  | 5                     |
| 23               |                                  | 5                     |
| 24               |                                  | 4                     |
| 25               |                                  | 2                     |
| 26               |                                  | 1                     |
| **Total**        | **127**                          | **265**               |
Table 3. Number of head-started turtles released in the year following hatching by release year and cohort (birth year; bold along the diagonal) and the number of recaptures in subsequent years. For example, 83 head-started turtles born in 2011 were released in 2012, 12 of which were recaptured in one or more subsequent times for a total of 19 recaptures.

Recapture Year

| Release Year | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Recaptures | Recaptured |
|--------------|------|------|------|------|------|------|------|------------|------------|
| 2011         |      |      |      |      |      |      |      | 19         | 12         |
| 2012         |      |      |      |      |      |      |      | 51         | 33         |
| 2013         |      |      |      |      |      |      |      | 35         | 28         |
| 2014         |      |      |      |      |      |      |      | 5          | 4          |
| 2015         |      |      |      |      |      |      |      | 32         | 25         |
| 2016         |      |      |      |      |      |      |      | 36         | 36         |
| 2017         |      |      |      |      |      |      |      | 74*        |            |

Total: 1 4 20 31 43 75
Table 4. Number of adults captured each year by sex. Little or no sampling occurred in 2011 and 2012.

| Year | Total Number of Individuals Captured (female, male) |
|------|-----------------------------------------------------|
| 2004 | 9 (2,7)                                             |
| 2005 | 61 (18,43)                                          |
| 2006 | 69 (27,42)                                          |
| 2007 | 56 (21,35)                                          |
| 2008 | 37 (13,24)                                          |
| 2009 | 38 (17,21)                                          |
| 2010 | 24 (11,13)                                          |
| 2011 | -                                                   |
| 2012 | -                                                   |
| 2013 | 34 (15,19)                                          |
| 2014 | 26 (13,13)                                          |
| 2015 | 45 (22,23)                                          |
| 2016 | 42 (24,18)                                          |
| 2017 | 45 (24,21)                                          |
| 2018 | 53 (23,30)                                          |
| Totals | 540 (230,310)                                        |
**Table 5.** Mean population growth parameter estimates for wild-born and head-started juvenile turtles.

| Origin                  | N   | CL\(_A\)     | CL\(_0\)     | k        | r\(^2\)   |
|-------------------------|-----|--------------|--------------|----------|-----------|
| Wild-caught Juveniles   | 265 | 234.0 (8.06) | 23.3 (4.53) | 0.082 (0.007) | 0.891     |
| Head-started Juveniles  | 665 | 211.1 (41.00)| 37.0 (2.69) | 0.109 (0.037) | 0.714     |
Figure 3. Growth curves for wild-born (green) and head-started (blue) turtles with reference line. Wild-born: carapace length = 234.1-(234.1-31.7)*e^{(-0.082*age)}; head-starts: carapace length = 211-(211-37.0)*e^{(-0.109*age)}.
Figure 4. Zoomed-in growth curves for wild-born (green) and head-started (blue) turtles with reference line. Wild-born: carapace length = 234.1-(234.1-31.7)*e^{(-0.082*age)}, head-starts: carapace length = 211-(211-37.0)*e^{(-0.109*age)}. 
Survival Analysis of Wild and Head-Started Turtles

Wild-Born Juveniles

To optimize recapture, I compared 16 candidate models in which survival was a linear function of age (Table 6). Models differed in how age classes were grouped and in whether time was included. The top-ranked model (weight=0.512) specified two discrete groups, age classes 1-6 and age classes 7 and greater. The next three top-ranked models had increased numbers of age groups but no reduction in model deviance, suggesting that the inclusion of additional age classes was uninformative. Models that contained the additive effect of time on recapture were consistently ranked lower than models that lacked a time effect (ΔAICc > 10, Table 6).

Maintaining this best parameterization of recapture, I compared 12 candidate models for which survival was a linear function of age but varied in the age at which survival reached a plateau (Table 7). I considered three additional candidate models for which survival was a logarithmic or quadratic function of age or included age as a discrete variable. The highest ranked model with age as a linear covariate for survival specified a plateau in survival at age 4. Logarithmic and quadratic covariate models were within 2 ΔAICc but had similar deviances to the top-ranked model, suggesting little improvement. The discrete model was ranked the lowest with a ΔAICc of 5.97 (Table 7). Based on the model-averaged results, survival increased from ages 1-6 (71% - 98%; Figure 5, Table 8A). Recapture estimates varied by age from 0.26-0.37 (Appendix A).
Table 6. Candidate model rankings for the recapture optimization of wild-born juveniles in order of ranking. Recapture refers to the structure of the recapture parameter (p) in the model, k refers to the number of parameters, AICc refers to Akaike information criteria, ΔAICc refers to the difference in AICc from the top-ranked model, weight refers to the relative weight of the model, and deviance refers to the residual deviance. In all models, survival was modeled with age as a linear covariate. Models are distinguished by the number and delineation of distinct age groups, with ages specified numerically (#g) and whether the additive effect of time or was included (+ time). For example, 2g;1-6, 7+ refers to a two-group model with age classes 1 through 6 grouped together and age classes 7 and above grouped together. Global model is denoted by an asterisk.

| Recapture, p                  | k | AICc  | ΔAICc | Weight | Deviance |
|-------------------------------|---|-------|-------|--------|----------|
| [2g; 1-6, 7+]                 | 3 | 705.70| 0.00  | 0.51   | 586.40   |
| [3g; 1, 2-6, 7+]              | 4 | 707.77| 2.07  | 0.18   | 586.40   |
| [4g; 1, 2-3, 4-6, 7+]         | 5 | 709.58| 3.88  | 0.07   | 586.13   |
| [4g; 1-2, 3-5, 6-9, 10+]      | 5 | 709.74| 4.04  | 0.07   | 586.29   |
| [2g; 1, 2+]                  | 3 | 709.99| 4.30  | 0.06   | 590.70   |
| [3g; 1, 2-3, 4+]              | 4 | 710.03| 4.33  | 0.06   | 588.66   |
| [5g; 1, 2-3, 4-6, 7-10, 11+]  | 6 | 711.53| 5.83  | 0.03   | 585.97   |
| [6g; 1, 2-3, 4-6, 7-10, 11-14, 15+] | 7 | 713.64| 7.94  | 0.01   | 585.96   |
| [2g; 1-6, 7+] + time          | 14| 715.80| 10.10 | 0.00   | 572.69   |
| [2g; 1, 2+] + time            | 14| 717.25| 11.55 | 0.00   | 574.14   |
| [3g; 1, 2-3, 4+] + time       | 15| 718.07| 12.37 | 0.00   | 572.68   |
| [3g; 1, 2-6, 7+] + time       | 15| 718.08| 12.39 | 0.00   | 572.69   |
| [4g; 1, 2-3, 4-6, 7+] + time  | 16| 719.86| 14.16 | 0.00   | 572.16   |
| [4g; 1-2, 3-5, 6-9, 10+] + time| 16| 720.06| 14.37 | 0.00   | 572.37   |
| [5g; 1, 2-3, 4-6, 7-10, 11+] + time | 17| 722.06| 16.37 | 0.00   | 572.04   |
Table 7. Candidate model rankings for survival optimization of wild-born juveniles in order of ranking. Survival refers to the structure of the survival parameter ($\phi$) in the model, $k$ refers to the number of parameters, AICc refers to Akaike information criteria, $\Delta$AICc refers to the difference in AICc from the top-ranked model, weight refers to the relative weight of the model, and deviance refers to the residual deviance. In all models, recapture was modeled as a two-group model with age classes 1 through 6 grouped together and age classes 7 and above grouped together (2g; 1-6, 7+). Models are distinguished by modeling survival as a linear covariate varying the age at which survival reaches a plateau (Lin_#), a logarithmic (Log), quadratic (Quad) function of age, or included age as a discrete variable (DiscreteAge), all with survival reaching a plateau at age 4. For example, Lin_4 refers to a model with age as a linear covariate of age where survival reaches a plateau at age 4. The global model is denoted by an asterisk.

| Survival  | $k$ | AICc  | $\Delta$AICc | Weight | Deviance |
|-----------|-----|-------|--------------|--------|----------|
| Lin_4     | 3   | 700.47| 0.00         | 0.21   | 581.18   |
| Lin_5     | 3   | 700.93| 0.45         | 0.17   | 581.63   |
| Lin_3     | 3   | 701.25| 0.77         | 0.14   | 581.95   |
| Lin_6     | 3   | 701.88| 1.40         | 0.10   | 582.58   |
| Quad_4    | 4   | 702.37| 1.89         | 0.08   | 581.00   |
| Log_4     | 4   | 702.54| 2.06         | 0.08   | 581.17   |
| Lin_7     | 3   | 702.88| 2.40         | 0.06   | 583.58   |
| Lin_8     | 3   | 703.73| 3.25         | 0.04   | 584.44   |
| Lin_9     | 3   | 704.82| 4.34         | 0.02   | 585.53   |
| Lin_10    | 3   | 705.57| 5.10         | 0.02   | 586.28   |
| Lin_12    | 3   | 705.69| 5.21         | 0.02   | 586.40   |
| Lin_14    | 3   | 705.70| 5.22         | 0.02   | 586.40   |
| Lin_16    | 3   | 705.70| 5.22         | 0.02   | 586.40   |
| *Lin_Age  | 3   | 705.70| 5.22         | 0.02   | 586.40   |
| DiscreteAge_4 | 6   | 706.45| 5.97         | 0.01   | 580.89   |
Figure 5. Survival estimates generated from top-ranked models or model averaging of multiple top-ranked models for head-started juvenile (blue) and wild-born juvenile and adult (green) Blanding’s turtles for the Spring Bluff-Chiwaukee Prairie population.
Table 8. Survival estimates generated from top-ranked models or model averaging of multiple top-ranked models for wild-born juvenile, head-started juvenile, and wild-born adult (age 15+) Blanding’s turtles for the Spring Bluff-Chiwaukee Prairie population.

| Age | Estimate | lcl  | ucl  |
|-----|----------|-----|-----|
|     | A. Wild-caught |     |     |
| 1   | 0.7114   | 0.6159 | 0.7912 |
| 2   | 0.8543   | 0.7215 | 0.9300 |
| 3   | 0.9308   | 0.8056 | 0.9776 |
| 4   | 0.9637   | 0.8870 | 0.9890 |
| 5   | 0.9750   | 0.9344 | 0.9907 |
| 6-14| 0.9778   | 0.9432 | 0.9915 |
|     | B. Head-starts |     |     |
| 1   | 0.6310   | 0.5690 | 0.6891 |
| 2   | 0.7452   | 0.6354 | 0.8308 |
| 3   | 0.8333   | 0.6969 | 0.9158 |
| 4   | 0.8774   | 0.7229 | 0.9515 |
| 5   | 0.8970   | 0.7100 | 0.9687 |
| 6   | 0.9033   | 0.6946 | 0.9746 |
|     | C. Adults |     |     |
|     | 0.9473   | 0.9266 | 0.9624 |
**Head-Started Juveniles**

To optimize recapture, I compared eight candidate models in which survival was a linear function of age. Models differed in how age classes were grouped and in whether there was an additive or interactive effect of time. After comparing the eight candidate models for recapture optimization, the top-ranked model (weight=0.71) specified three discrete age groups (1, 2, 3+) with an interactive effect of time. The other candidate models had ∆AICc > 2 (Table 9).

Maintaining this best parameterization of recapture, I compared four candidate models for which survival was a linear function of age but varied in the age at which survival reaches a plateau. I considered three additional candidate models for which survival was a logarithmic or function of age or included age as a discrete variable. The highest ranked model with age as a linear covariate for survival specified a plateau in survival at age 3. Logarithmic and quadratic covariate models were within 2 ∆AICc but had similar deviances to the top-ranked model, suggesting little improvement. The discrete model was ranked the lowest, with a ∆AICc of 3.60. The remaining four linear models have a combined weight of 0.78 and are within 2 ∆QAICc, so I employed model averaging to obtain model-averaged estimates of age-specific survival and recapture (Table 10). Based on the model-averaged results, survival increased from ages 1-6 (63% - 90%) (see Figure 5, Table 8B). Recapture estimates varied by age and year ranging from 0.02-0.72 (Appendix B).
Table 9. Candidate model rankings for the recapture optimization of head-started juveniles in order of ranking. The overall goodness-of-fit test of the global model revealed slight overdispersion of the data, so the most conservative estimated variance inflation term from bootstrapping (c-hat=1.48) was used to correct for overdispersion and QAICc was used to rank the candidate models. Recapture refers to the structure of the recapture parameter (p) in the model, k refers to the number of parameters, AICc refers to quasi-Akaike information criteria, ΔQAICc refers to the difference in QAICc from the top-ranked model, weight refers to the relative weight of the model, and deviance refers to the residual deviance. In all models, survival was modeled with age as a linear covariate. Models are distinguished by the number and delineation of distinct age groups, with ages specified numerically (#g) and whether the additive or interactive effect of time was included. For example, 3g; 1, 2, 3+ refers to a three-group model with age class 1 grouped together, age class 2 grouped together, and age classes 3 and above grouped together. The global model is denoted by an asterisk.

| Recapture            | k  | QAICc | ΔQAICc | Weight | Qdeviance |
|----------------------|----|-------|--------|--------|-----------|
| [3g; 1, 2, 3+] * time | 18 | 704.44| 0.00   | 0.71   | 50.04     |
| [4g; 1, 2, 3, 4+] * time | 22 | 706.45| 2.01   | 0.26   | 43.46     |
| [4g; 1, 2, 3, 4+] + time | 10 | 712.11| 7.66   | 0.02   | 74.52     |
| [2g; 1, 2+] * time | 13 | 713.59| 9.15   | 0.01   | 69.75     |
| [2g; 1, 2+] + time | 8  | 716.07| 11.63  | 0.00   | 82.62     |
| [3g; 1, 2, 3+] + time | 9  | 717.90| 13.46  | 0.00   | 82.39     |
| [3g; 1, 2-3, 4+] + time | 9  | 719.10| 14.66  | 0.00   | 83.58     |
| [3g; 1, 2-3, 4+] * time | 18 | 722.47| 18.03  | 0.00   | 68.07     |
Table 10. Candidate model rankings for survival optimization of head-started juveniles in order of ranking. Goodness-of-fit testing of the top-ranked model for recapture revealed slight overdispersion of the data, so the most conservative estimated variance inflation term from bootstrapping (c-hat=1.45) was used to correct for overdispersion and QAICc was used to rank the candidate models. Survival refers to the structure of the survival parameter (φ) in the model, k refers to the number of parameters, QAICc refers to quasi-Akaike information criteria, ΔQAICc refers to the difference in QAICc from the top-ranked model, weight refers to the relative weight of the model, and deviance refers to the residual deviance. In all models, recapture was modeled as a three-group model with age class 1 grouped together, age class 2 grouped together, and age classes 3 and above grouped together with the interactive effect of time (3g; 1, 2, 3+) * time. Models are distinguished by modelling survival as a linear covariate varying the age at which survival reaches a plateau (Lin_#), a logarithmic (Log), quadratic (Quad) function of age, or included age as a discrete variable (DiscreteAge), all with survival reaching a plateau at age 3. For example, Lin_4 refers to a model with age as a linear covariate of age where survival reaches a plateau at age 4. The global model is denoted by an asterisk.

| Survival   | k | QAICc | ΔQAICc | Weight | Qdeviance |
|------------|---|-------|--------|--------|-----------|
| Lin_3      | 18| 706.53| 0.00   | 0.23   | 49.79     |
| Lin_4      | 18| 706.96| 0.43   | 0.19   | 50.22     |
| *Lin_6     | 18| 706.97| 0.44   | 0.18   | 50.23     |
| Lin_5      | 18| 706.99| 0.46   | 0.18   | 50.25     |
| Quad_3     | 19| 708.32| 1.78   | 0.09   | 49.44     |
| Log_3      | 19| 708.53| 2.00   | 0.08   | 49.65     |
| DiscreteAge_3| 20| 710.13| 3.60   | 0.04   | 49.11     |
Survival Analysis of Adult Turtles

I examined 40 candidate models based on the two global models. The first global model included survival depending on the interactive effect of sex and time and recapture depending on the interactive effect of sex and time. The second global model included survival depending on the interactive effect of sex and time and recapture depending on the interactive effect of sex and effort (Table 11). The most parsimonious model (weight= 0.49) was a 13-parameter model that held survival constant over time and between sexes and recapture rate dependent on time. The next three top-ranked models (combined weight= 0.51) added an additional parameter of a sex effect on survival or recapture. Model deviance was similar among these top four models, suggesting that sex is a “pretending variable” and should be treated as an uninformative parameter (Arnold 2010). Models that included an effect of effort on recapture were consistently low ranking.

For estimated survival of adult turtles, \( \phi = 0.95 \) (95% CI= 0.93 – 0.96; see Figure 5, Table 8C). The 7th-ranked model \( \phi(t) p(t) \) was used to calculate process variance of survival rate because this was the highest ranked model that incorporated time dependence for survival. The process variance for all adults was 0.0011 with 95% CI (0.0003 to 0.0059) and was just 3% of the total variance. Recapture estimates varied by year ranging from 0.30-0.89 (Appendix C).
Table 11. Candidate model rankings for survival and recapture optimization of adult turtles in order of ranking. The models are described by $\phi$ referring to the survival parameter in the model and $p$ refers to the recapture parameter in the model, $k$ refers to the number of parameters, AICc refers to Akaike information criteria, $\Delta$AICc refers to the difference in AICc from the top-ranked model, weight refers to the relative weight of the model, and deviance refers to the residual deviance. The global model is denoted by an asterisk. Models 25 and 38 are the alternative global models. Model 7 was used to estimate process variance.

| Rank | Model                  | $k$ | AICc  | $\Delta$AICc | Weight | Deviance |
|------|------------------------|-----|-------|--------------|--------|----------|
| 1    | $\phi(.) \ p(t)$       | 13  | 1298.79 | 0.00        | 0.49   | 688.92   |
| 2    | $\phi(.) \ p(sex + t)$ | 14  | 1300.49 | 1.71        | 0.21   | 688.51   |
| 3    | $\phi(sex) \ p(t)$    | 14  | 1300.60 | 1.81        | 0.20   | 688.61   |
| 4    | $\phi(sex) \ p(sex + t)$ | 15  | 1302.03 | 3.24        | 0.10   | 687.91   |
| 5    | $\phi(.) \ p(sex * t)$ | 25  | 1309.12 | 10.34       | 0.00   | 673.19   |
| 6    | $\phi(sex) \ p(sex * t)$ | 26  | 1311.21 | 12.42       | 0.00   | 673.04   |
| 7*   | $\phi(t) \ p(t)$      | 23  | 1312.56 | 13.78       | 0.00   | 681.07   |
| 8    | $\phi(t) \ p(sex + t)$ | 24  | 1314.45 | 15.66       | 0.00   | 680.74   |
| 9    | $\phi(sex + t) \ p(t)$ | 24  | 1314.47 | 15.68       | 0.00   | 680.76   |
| 10   | $\phi(sex + t) \ p(sex + t)$ | 25  | 1316.10 | 17.32       | 0.00   | 680.17   |
| 11   | $\phi(sex + t) \ p(sex * t)$ | 36  | 1326.11 | 27.33       | 0.00   | 665.04   |
| 12   | $\phi(t) \ p(sex * t)$ | 36  | 1326.16 | 27.38       | 0.00   | 665.09   |
| 13   | $\phi(sex * t) \ p(t)$ | 34  | 1333.55 | 34.76       | 0.00   | 677.14   |
| 14   | $\phi(sex * t) \ p(\neg sex + t)$ | 35  | 1335.62 | 36.83       | 0.00   | 676.88   |
| 15   | $\phi(.) \ p(Effort)$ | 3   | 1341.26 | 42.47       | 0.00   | 752.13   |

(Continued on the following page)
| Model Rank | Model                                  | k | AICc    | ΔAICc | Weight | Deviance |
|------------|----------------------------------------|---|---------|-------|--------|----------|
| 16         | φ(.) p(sex + Effort)                    | 4 | 1341.57 | 42.78 | 0.00   | 750.40   |
| 17         | φ(sex) p(sex + Effort)                  | 5 | 1342.86 | 44.08 | 0.00   | 749.65   |
| 18         | φ(sex) p(Effort)                        | 4 | 1343.01 | 44.22 | 0.00   | 751.84   |
| 19         | φ(.) p(sex * Effort)                    | 5 | 1343.61 | 44.82 | 0.00   | 750.39   |
| 20         | φ(.) p(.)                               | 2 | 1343.96 | 45.17 | 0.00   | 756.85   |
| 21         | φ(.) p(sex)                             | 3 | 1344.12 | 45.33 | 0.00   | 754.98   |
| 22         | φ(sex )p(sex * Effort)                  | 6 | 1344.89 | 46.11 | 0.00   | 749.63   |
| 23         | φ(sex) p(sex)                           | 4 | 1345.45 | 46.66 | 0.00   | 754.28   |
| 24         | φ(sex) p(.)                             | 3 | 1345.73 | 46.95 | 0.00   | 756.60   |
| *25        | φ(sex * t) p(sex * t)                   | 48| 1348.81 | 50.02 | 0.00   | 658.86   |
| 26         | φ(t) p(Effort)                          | 14| 1353.88 | 55.09 | 0.00   | 741.90   |
| 27         | φ(t) p(sex + Effort)                    | 15| 1354.44 | 55.65 | 0.00   | 740.32   |
| 28         | φ(sex + t) p(sex + Effort)              | 16| 1355.44 | 56.66 | 0.00   | 739.19   |
| 29         | φ(sex + t) p(Effort)                    | 15| 1355.47 | 56.68 | 0.00   | 741.35   |
| 30         | φ(t) p(sex * Effort)                    | 16| 1356.49 | 57.70 | 0.00   | 740.23   |
| 31         | φ(t) p(.)                               | 13| 1356.92 | 58.14 | 0.00   | 747.06   |
| 32         | φ(t) p(sex)                             | 14| 1357.18 | 58.39 | 0.00   | 745.20   |
| 33         | φ(sex + t) p(sex * Effort)              | 17| 1357.57 | 58.79 | 0.00   | 739.17   |
| 34         | φ(sex + t) p(sex)                       | 15| 1358.27 | 59.48 | 0.00   | 744.15   |

(Continued on the following page)
| Model Rank | Model                     | k  | AICc  | ΔAICc | Weight | Deviance |
|-----------|---------------------------|----|-------|-------|--------|----------|
| 35        | φ(sex + t) p(.)           | 14 | 1358.53 | 59.74 | 0.00   | 746.54   |
| 36        | φ(sex * t) p(Effort)      | 26 | 1375.59 | 76.80 | 0.00   | 737.42   |
| 37        | φ(sex * t) p(sex + Effort)| 27 | 1376.33 | 77.55 | 0.00   | 735.92   |
| *38       | φ(sex * t) p(sex * Effort)| 28 | 1378.50 | 79.71 | 0.00   | 735.83   |
| 39        | φ(sex * t) p(.)           | 25 | 1378.56 | 79.77 | 0.00   | 742.62   |
| 40        | φ(sex * t) p(sex)         | 26 | 1379.01 | 80.22 | 0.00   | 740.84   |
DISCUSSION

Head-starting is a conservation strategy that is widely used in turtle species (Burke 2015) but is less often evaluated for its effectiveness (Bennett et al. 2017). My comparison of the growth and survival of wild-born and head-started juveniles within the same population provides us with a quantitative perspective to evaluate head-starting as a population management tool for Blanding’s turtles.

The results of my growth analysis support the idea that head-starting increases the size of turtles as compared to equivalent-aged wild-born turtles. Head-starts released approximately one-year post-hatching were about the same size as 2-year-old wild-born turtles. Importantly, growth of head-starts parallels that of wild-born turtles such that this difference in size persists for at least six years post-release with head-started turtles consistently achieving the size their wild-born counterparts that are one year older. In other turtle species, such as Redbelly turtles, it has been long established that the process of head-starting increases the size of turtles at release (Haskell et al 1996). My results are similar to findings in other studies of Blanding’s turtle head-starting (Arsenault 2011; D’Entremont 2014). In Nova Scotia, head-started turtles of equivalent ages were larger than their wild-born counterparts (Arsenault 2011). Data on post-release growth of head-starts of Blanding’s turtles are more sparse, especially in comparison to like-aged wild-born turtles. Arsenault (2011) found that growth rates were significantly different between wild-born and head-started turtles, with wild-born turtles growing at a faster rate. In other reptiles, such as the Plains garter snake, growth rates of head-started snakes were found to be similar to that of their wild-born counterparts (King and Stanford 2006).
The results of my survival analysis demonstrate that head-started Blanding’s turtles have moderately high annual survival (63%) during the first year post-release and that survival increases in subsequent years, approaching 90% in their sixth year post-release. In telemetry studies of head-started Blanding’s turtles, survival was estimated within the same range as my findings: 63-96% (Szymanski 2016), 70% (Arsenault 2011; D’Entremont 2014), 89-98% (Carstairs et al. 2019). These studies were short term (based on 1-2 years of telemetry data) and used small sample sizes. In other mark-recapture studies of head-started Blanding’s turtles, survival was estimated at 72% for the first year post-release using three years of data (Green 2015) and between 77-87% with few recaptures over four years of data (Ross and Dreslik 2018). This short-term monitoring post-release of head-started turtles is similar to what was found in other species, such as the Gopher tortoise (Tuberville et al. 2015), where survival is lowest immediately post-release but then continues to increase.

Overall, my results support head-starting as an effective tool for turtle conservation. I found that the survival of head-starts was similar to like-aged wild-born Blanding’s turtles despite head-starts having attained greater body size. Prior analyses have demonstrated that head-starting has been successful in shifting Blanding’s turtle population body size distributions to include a broader array of juvenile and adult-sized turtles and promoting juvenile and adult recruitment (Carstairs et al. 2019; Thompson et al. 2019) and that spatial ecology of head-starts is similar to that of wild-born turtles (Starking-Symanski et al. 2018). My results build on these studies by demonstrating that head-start growth and survival are comparable to that of wild-born turtles. This has implications for efforts to use head-starting to establish new Blanding’s turtle populations (Buhlmann et al. 2015). For example, the survival rates of head-started turtles can be used for population viability analyses to plan start-from-scratch experimental population
establishment. In future studies, it would be useful to compare growth and survival of directly released, first-year head-starts like those analyzed here and second-year head-starts to refine head-starting methodology. Also needed are analyses of the reproductive competence of head-started turtles once they reach reproductive maturity. At another northeastern Illinois site, head-started females that attained reproductive maturity were captured and induced to oviposit in captivity (Thompson et al. 2019). Demonstrating successful nesting in the wild will be an important next step in evaluating Blanding’s turtle head-starting.

My estimation of juvenile survival fills a data gap in Blanding’s turtle demography. The rates I estimated for wild-born juvenile survival are surprisingly high. The most utilized estimate for juvenile survival comes from Congdon et al. (1993), who inferred necessary juvenile (1 – 13 yr) survival to maintain a stable population to be 79%, a value less than all but the youngest age class of juveniles in my analysis. Other Blanding’s turtle studies have wide ranges of estimated juvenile survival (from 33-100%) with wide confidence intervals but are often based on very small sample sizes (Arsenault 2011; D’Entremont 2014; Kuhns and Phillips 2010). My survival estimates for adult Blanding’s turtles are comparable with other long-term studies, showing high (approaching or exceeding 90%) survival of this adult age class (Congdon et al. 1993; Congdon et al. 2001; Reid et al. 2016; Ross and Dreslik 2018; Rubin et al. 2004). The exception is found in a population in Nebraska where adult survival is estimated at 69% (Ruane et al. 2008). Although survival of adults is well studied, establishing site-specific estimates of survival and its environmental (process) variance will be useful in planned population viability analysis.

Accurate and site-specific demographic parameter estimates are essential for reliable projection of effects of management on populations (Congdon et al. 1993; Heppell et al. 1996).
Using the demographic rates that I estimated, I can create site-specific population viability analyses and the survival of head-started turtles can be used to model start-from-scratch populations. Population viability analyses are useful tools for such species because they allow the comparison of conservation strategies over time frames that would not be possible experimentally. Together with other demographic information from this population (adult survival, fecundity), I anticipate generating more accurate population projections that will aid in evaluating conservation strategies for this population and potentially for Blanding’s turtles elsewhere.
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APPENDIX A

RECAPTURE ESTIMATES FOR WILD-BORN JUVENILES
Appendix A. Recapture estimates for wild-born juveniles from model averaging of the top four linear models.

| Age | Estimate | se   | lcl   | ucl   |
|-----|----------|------|-------|-------|
| 1->7| 0.3748   | 0.0752| 0.2422| 0.5292|
| 7+  | 0.2622   | 0.0241| 0.2178| 0.3121|
APPENDIX B

RECAPTURE ESTIMATES FOR HEAD-STARTED JUVENILES
**Appendix B.** Recapture estimates for head-started juveniles from model averaging of the top four linear models. Cohort refers to year of hatching, age refers to chronological age (years), year refers to the recapture estimate for each cohort, estimate refers to the recapture estimate, SE refers to the standard error, and LCL and UCL are the upper and lower confidence intervals.

| Cohort | Age | Year | Estimate | SE  | LCL | UCL |
|--------|-----|------|----------|-----|-----|-----|
| 2011   | 2   | 2013 | 0.02     | 0.02| 0.00| 0.19|
| 2011   | 3   | 2014 | 0.03     | 0.04| 0.00| 0.26|
| 2011   | 4   | 2015 | 0.23     | 0.12| 0.08| 0.52|
| 2011   | 5   | 2016 | 0.29     | 0.09| 0.15| 0.48|
| 2011   | 6   | 2017 | 0.31     | 0.08| 0.17| 0.49|
| 2011   | 7   | 2018 | 0.20     | 0.07| 0.10| 0.37|
| 2012   | 2   | 2014 | 0.05     | 0.03| 0.01| 0.16|
| 2012   | 3   | 2015 | 0.22     | 0.07| 0.10| 0.39|
| 2012   | 4   | 2016 | 0.29     | 0.09| 0.15| 0.48|
| 2012   | 5   | 2017 | 0.31     | 0.08| 0.17| 0.49|
| 2012   | 6   | 2018 | 0.20     | 0.07| 0.10| 0.37|
| 2013   | 2   | 2015 | 0.06     | 0.04| 0.02| 0.21|
| 2013   | 3   | 2016 | 0.25     | 0.09| 0.12| 0.46|
| 2013   | 4   | 2017 | 0.31     | 0.08| 0.17| 0.49|
| 2013   | 5   | 2018 | 0.20     | 0.07| 0.10| 0.37|
| 2014   | 2   | 2016 | 0.05     | 0.04| 0.01| 0.23|
| Year1 | Year2 | Year3 | Value1 | Value2 | Value3 | Value4 |
|-------|-------|-------|--------|--------|--------|--------|
| 2014  | 3     | 2017  | 0.03   | 0.04   | 0.00   | 0.29   |
| 2014  | 4     | 2018  | 0.20   | 0.07   | 0.10   | 0.37   |
| 2015  | 2     | 2017  | 0.42   | 0.11   | 0.22   | 0.64   |
| 2015  | 3     | 2018  | 0.72   | 0.17   | 0.32   | 0.93   |
| 2016  | 2     | 2018  | 0.48   | 0.08   | 0.33   | 0.64   |
APPENDIX C

RECAPTURE ESTIMATES FOR ADULT TURTLES
Appendix C. Estimated yearly capture probabilities for adults.

| Year | Capture Probability | SE  | Lower | Upper |
|------|---------------------|-----|-------|-------|
| 2005 | 0.89                | 0.10| 0.50  | 0.98  |
| 2006 | 0.81                | 0.05| 0.69  | 0.90  |
| 2007 | 0.65                | 0.06| 0.53  | 0.75  |
| 2008 | 0.47                | 0.06| 0.38  | 0.58  |
| 2009 | 0.48                | 0.06| 0.37  | 0.60  |
| 2010 | 0.31                | 0.06| 0.22  | 0.43  |
| 2013 | 0.31                | 0.06| 0.21  | 0.44  |
| 2014 | 0.30                | 0.05| 0.20  | 0.42  |
| 2015 | 0.38                | 0.06| 0.28  | 0.50  |
| 2016 | 0.40                | 0.06| 0.30  | 0.51  |
| 2017 | 0.44                | 0.06| 0.33  | 0.55  |
| 2018 | 0.47                | 0.06| 0.36  | 0.59  |