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Survival Estimates for Adult Eastern Hellbenders and Their Utility for Conservation

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Abstract.—The Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*) is a large, completely aquatic salamander native to the eastern United States. Hellbender populations have experienced numerical declines and range contractions over a large geographic area, but few demographic data are available to allow biologists to diagnose specific causes of the declines. We estimated survival of Hellbenders in Indiana using radio telemetry. We monitored 21 adult eastern Hellbenders during July 2008–October 2009 and documented three mortalities. Using a known-fate model, we estimated annual survival as 0.804 (±0.089 SE). This estimate is lower than expected for a long-lived species and signals the continued decline of Hellbenders in Indiana. Estimates of survivorship such as this provide baseline data for translocation programs and are useful in parameterizing population models.

Many amphibian taxa are experiencing numerical declines and range contractions (Houlahan et al., 2000; Stuart et al., 2004). The disappearance of these species is noteworthy because amphibians are important in the delivery of ecosystem services (Davic and Welsh, 2004). Factors involved in these global declines are numerous and complex (Collins and Storfer, 2003) and may include interactions between disease, climate change, and habitat degradation or loss (Blaustein et al., 1994; Kiesecker et al., 2001; Gallant et al., 2007; Rohr et al., 2008). At more-local scales, the factors affecting declines may be species- or even life stage-specific (Lips et al., 2003; Green, 2005). Therefore, the availability of species- and location-specific data is crucial for efforts designed to uncover the causal mechanisms behind population declines and to aid in the recovery of species of conservation concern (Bailey et al., 2011; Currylow et al., 2011).

The Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*) is a large, aquatic salamander native to the eastern United States. Hellbenders require cool, well-oxygenated streams or rivers throughout all stages of their development (Smith, 1907), and adults likely occupy one of the top trophic positions in these ecosystems. The decline of Hellbender populations has been documented across much of their range (Trauth et al., 1992; Wheeler et al., 2003; Foster et al., 2009; Burgmeier et al., 2011a). These numerical declines and range contractions are hypothesized to result from a variety of anthropogenic influences such as habitat degradation (Nickerson and Mays, 1973; Williams et al., 1981) and destruction (Bury et al., 1980), the removal of individuals for scientific collections or illegally for the pet trade (Nickerson and Briggler, 2007), and via angling-related mortality (Kern, 1984). Similar to other long-lived species (e.g., Box Turtles, Heppell, 1998; Dodd et al., 2006), removal of even a small number of adult Hellbenders from populations may exacerbate population declines by limiting reproduction and, thus, the potential for population recovery.

The majority of published reports focus on estimating abundance and age-distribution data to elucidate trends in the dynamics of Hellbender populations (Wheeler et al., 2003; Foster et al., 2009). While these efforts have established the scope of declines, demographic data are necessary to diagnose the importance of particular factors associated with the decline of Hellbender populations. Our objective was to estimate survival of adult eastern Hellbenders in Indiana. As conservation efforts for Hellbenders progress, estimates of survival for Hellbenders are a critical component of stage-structured life-history models and may also provide a useful baseline by which to document the efficacy of future translocations.

Materials and Methods

The Blue River is located in southern Indiana and flows south to its confluence with the Ohio River approximately 45 linear km west of Louisville, Kentucky. Summer wetted width of the Blue River is 19.3 ± 5.0 m (mean ± SD) and summer depth at the thalweg is 37.2 ± 20.5 cm (Burgmeier et al., 2011a). We sampled Hellbenders from eight sites within a 120-km stretch of the river. Sites were selected based on habitat suitability, ease of access, and the presence of Hellbenders based on surveys conducted annually by the Indiana Department of Natural Resources.

Field Methods.—Hellbenders were captured at the eight study sites during June–August 2008 and again during July 2009. All procedures related to capture, handling, surgical implantation of radio-transmitters, and recovery of study animals from anesthesia after surgery are reported in Burgmeier et al. (2011b). We located study animals via homing using radio-telemetry equipment (two element H antenna coupled with a TRX-1000S receiver from Wildlife Materials Inc., Murphysboro, Illinois) approximately twice per week from June 2008 to October 2009. The intensity of our efforts to locate study animals varied from once per week during winter (approximately November through February) to no more than three times per week during the breeding season (approximately September through October). Additional locations for study animals were obtained during a larger and concomitant mark–recapture study of Hellbenders (Burgmeier et al., 2011a). Once a study animal was located, we recorded the universal transverse Mercator (UTM) coordinate using a handheld global positioning system (GPS) unit (accuracy to ≤4 m, GPS map 76, Garmin, Olathe, Kansas, USA). We collected all locations during daylight hours.

Statistical Analyses.— We used the known-fate model of Pollock et al. (1989) to estimate survival of adult Hellbenders. This method modifies the Kaplan-Meier estimator to incorporate staggered entry of animals throughout the study and right-censoring (or removal from further calculation) when the fate of an animal is not known. We collapsed our data into 16 monthly intervals for analysis (i.e., July 2008–October 2009).

Determining the fate of hellbenders using radio telemetry is a challenge. Hellbenders are long-lived and often remain under the same shelter rock for extended periods of time, especially during cold-water months (October–March in our study area;

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TABLE 1. Survival of adult Eastern Hellbenders (*Cryptobranchus a. alleganiensis*) in Indiana calculated using the known-fate model of Pollock et al. (1989). The conditional survival rate was estimated for each month and survival was the product of conditional survival rates. Individuals were monitored via radio telemetry from July 2008 through October 2009.

Time period	No. at risk	Mortality	Censored	Added	Conditional survival rate	Survival	SE
Jul '08	12	0	0	0	1.000	1.000	0.000
Aug '08	17	0	1	5	1.000	1.000	0.000
Sep '08	16	0	0	0	1.000	1.000	0.000
Oct '08	16	0	0	0	1.000	1.000	0.000
Nov '08	16	0	0	0	1.000	1.000	0.000
Dec '08	16	0	0	0	1.000	1.000	0.000
Jan '09	16	0	0	0	1.000	1.000	0.000
Feb '09	16	0	0	0	1.000	1.000	0.000
Mar '09	16	0	0	0	1.000	1.000	0.000
Apr '09	16	1	1	0	0.938	0.938	0.059
May '09	14	1	0	0	0.929	0.871	0.084
Jun '09	13	1	0	0	0.923	0.804	0.099
Jul '09	16	0	0	4	1.000	0.804	0.089
Aug '09	16	0	0	0	1.000	0.804	0.089
Sep '09	16	0	2	0	1.000	0.804	0.089
Oct '09	14	0	10	0	1.000	0.804	0.095

Burgmeier et al., 2011b). In such scenarios, an activity switch or mortality sensor would inaccurately reflect the fate as dead for a relatively immobile study animal. In addition, any fine-scale movements (e.g., movements under the same shelter rock) by study animals would be undetectable using homing methods. Therefore, we developed two criteria to determine the fate of each Hellbender in each month of the study.

First, we considered movements of >4 m between locations as indicative that the study animal was alive (i.e., if the individual moved between shelter rocks). Second, if a study animal was physically recaptured during the mark–recapture surveys, we considered the study animal to have been alive in all previous months. As the study progressed, for example, an individual would be initially right-censored in any month during which we did not detect a movement. If that individual moved during the following month, we updated its fate to 'alive' in all previous months. If the individual did not move, but was physically recaptured subsequently, we also updated its fate as alive in all previous months. If the individual neither moved nor was physically recaptured, we had no opportunity to verify its fate; in this situation, we right-censored the individual from the month of its last movement or capture. We considered the possibility of this latter outcome to be relatively rare considering the timeframe of our study: nearly two full summers and breeding seasons during which Hellbenders moved relatively frequently (Humphries and Pauley, 2000; Phillips and Humphries, 2005; Burgmeier et al., 2011b). Finally, study animals were also right-censored as a result of transmitter failure or migration from the study areas.

RESULTS

We monitored the fates of 21 adult Eastern Hellbenders: 13 males, four females, and four individuals for which we could not determine sex. We recorded 57.7 ± 24.1 (mean ± SD) locations per individual during our 16-month study. We supplemented our radio-telemetry data with 16 recaptures of 12 study animals. While handling the recaptured individuals, we documented complete incision closure along with no obvious complications associated with the surgeries. The number of study animals at risk (i.e., the number being monitored) per month varied from 12 in July 2008 to 17 in August 2008 (Table 1). We documented three mortalities. All mortalities were immediately evident (i.e., during the next tracking session). Unfortunately, carcasses were not recovered and, therefore, we could not determine causes of mortality with certainty.

We right-censored one individual after it moved under a large boulder in August 2008, where it stayed for the duration of the study. The size and shape of the boulder prevented us from verifying the individual's fate. We right-censored a second individual from the point of its last verified movement in April 2009 after its transmitter failed in June 2009. Interestingly, using radio telemetry, we detected no movements from 10 of the 17 study animals for at least three consecutive months. However, these 10 study animals were subsequently determined to be alive. Ten months was the longest duration over which we detected no movement by a study animal that was eventually determined to be living (October 2008–July 2009). Monthly survival ranged from 0.929 to 1.000, and we calculated an annual survival rate of 0.804 (±0.095, 1 SE; Table 1). No attempt was made to calculate sex-specific survival estimates due to the small number of known females in our sample.

DISCUSSION

This is the first study to investigate survival of adult Eastern Hellbenders using radio-tagged individuals. In Indiana, Hellbenders are limited in range to a single tributary of the Ohio River (Kern, 1984; Burgmeier et al., 2011a). Recent surveys of this population have revealed low recruitment, an age class shift towards older individuals, and marked population declines when compared with surveys conducted over the last two decades (Burgmeier et al., 2011a). Our estimate of approximately 80% survival among adult Hellbenders during the 16 months of our study is lower than we would expect for a long-lived animal (Bailey et al., 2011; Currylow et al., 2011). Peterson et al. (1988) reported a very low estimate of annual survival (28%; Table 2) calculated from a mark–recapture study of four populations of Hellbenders. However, the authors noted that their estimate was confounded with losses due to emigration (Peterson et al., 1988). Wheeler (2007) also reported survival estimates calculated within a mark–recapture framework for three populations of *Cryptobranchus alleganiensis bishopi*, but cautioned that the pattern of recaptures in their study indicated a violation of the assumption of equal catchability. Indeed, several authors have now identified violations of equal catchability in mark–recapture studies of Hellbenders (Peterson et al., 1988; Humphries and Pauley, 2005; Wheeler, 2007), which likely reflects the difficulties associated with sampling for this cryptic species. As an alternative to a mark–recapture framework for estimates of survival, radio telemetry can be useful in studies of cryptic species because the fate of each animal can be determined with some level of certainty (White and Garrot, 1990).

Bodinof (2010) calculated survival estimates for captive-reared juvenile Hellbenders using known-fate models based on radio-telemetry data after the juveniles were released into the wild (Table 2). Our estimate of survival for adult Hellbenders was higher (7% and 66%, respectively) than estimates of annual survival for two groups of captive-reared juveniles (Bodinof, 2010; Table 2). Interestingly, studies of Hellbenders typically

TABLE 2. Estimates of longevity and annual survival reported for Hellbenders (*Cryptobranchus alleganiensis*).

Author	Location	Subspecies	Type of estimate	Method	Longevity	Annual survival
Oliver, 1955	Captive hellbender		Adult longevity	Known age	29 years	-
Taber et al., 1975	Missouri	*C. a. alleganiensis*	Adult longevity	Growth curve	30+ years	-
Peterson et al., 1983	Missouri	*C. a. bishopi*	Adult longevity	Growth curve	20+ years	-
Peterson et al., 1988	Arkansas and Missouri	Both	Adult longevity	Growth curve	25+ years	-
Peterson et al., 1988	Arkansas and Missouri	Both	Adult survival	Mark–recapture	-	0.280
Wheeler, 2007	Arkansas	*C. a. bishopi*	Adult survival	Mark–recapture	-	0.86, 0.87, 0.92[a]
Bodinof, 2010	Missouri	*C. a. bishopi*	Juvenile survival	Known-fate model	-	0.747, 0.482[b]
Current study	Indiana	*C. a. alleganiensis*	Adult survival	Known-fate model	-	0.804

[a] Jolly-Seber survival estimate for three populations of *C. a. bishopi*.
[b] Annual survival of two groups of captive-reared, juvenile *C. a. bishopi* released into the wild at two sites.

have focused on survivorship or longevity of life rather than on the calculation of survival, which is defined as the probability of living through a specific time period (Table 2). However, as conservation efforts for Hellbenders progress, the importance of robust, age-specific baseline demographic parameters likely will continue to grow. For example, formulating the optimal size of future translocation cohorts will depend on prior knowledge of expected levels of mortality.

We consider three possible causes for the mortalities we observed: surgery related complications, predation, and angling mortality. Other researchers have documented mortality associated with the surgical implantation of transmitters in Hellbenders, but these generally occurred within the first month postrelease (or approximately 2 months postsurgery; Bodinof, 2010) and can be contrasted with the 10 months that elapsed between our surgeries and first mortality. Predation was a more-probable cause of mortality in our study. One of the transmitters originally implanted in each of these study animals was tracked onto the bank, one above flood-level flows near a bridge, and one was found in shallow water near the bank. No teeth marks were observed on the recovered transmitters. Although adult Hellbenders are not generally considered to be prey items, previous researchers have identified the potential negative impacts of angler mortality (Kern, 1984) and illegal harvest (Nickerson and Briggler, 2007) on Hellbender populations. Interestingly, the mortalities in our study all occurred during a period of increased human recreational activity on the river (April–June). Alternatively, natural death followed by scavenging of the carcasses could have resulted in a similar transport of the two transmitters onto the bank. Unfortunately, we were unable to recover any of the carcasses for examination and, consequently, were not able to determine the cause of death for these animals with certainly. Nonetheless, our results highlight the fact that Hellbenders in Indiana are in critical need of conservation action, considering that the level of mortality we identified is clearly not sustainable for a population with negligible recruitment (Burgmeier et al., 2011a).

The fact that the mortalities in our study were immediately evident served to demonstrate the efficacy of our methods for estimating survival in adult Hellbenders. Each study animal that we later documented as a mortality had moved between shelter rocks during the tracking session prior to our discovery of their transmitter on the bank. Thus, we could be confident that we were detecting mortalities efficiently. The availability of capture data to supplement our telemetry locations improved the estimate of survival in our study by allowing us to verify the fates of four individuals during July–September 2009 that otherwise would have been right-censored due to immobility. Notably, 10 individuals were right-censored in October 2009, the last month of our study, because we did not detect any further movements from these individuals. Although censoring these individuals did not alter our survival estimate, if a single mortality event occurred during this period when our sample size was effectively reduced, it would have disproportionately lowered our estimate of survival when compared with a change due to mortality during another time period. Therefore, as a proactive measure, researchers should plan to verify the fate of each individual at the end of the study when using known-fate models to estimate survival in Hellbenders.

Range-wide declines among Hellbender populations have been linked to a variety of large-scale anthropogenic influences. However, without rigorous demographic data from populations across the range of Hellbenders, it is difficult to implicate specific factors, such as adult mortality or poor recruitment, as drivers of decline or to recommend specific conservation actions. Moreover, demographic data such as our survival estimates are critical to parameterize life-history models useful in conservation planning. In the face of environmental changes such as those due to climate change and an abundance of emerging pathogens (Kiesecker et al., 2001), the conservation of declining amphibian populations will require more studies focused on gathering and interpreting demographic data.

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