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Life History of the Hellbender, Cryptobranchus alleganiensis, in a West Virginia Stream

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ABSTRACT.—Though locally abundant throughout the high mountains of West Virginia, intensive studies on the natural history and population structure of the hellbender, *Cryptobranchus alleganiensis*, have not been conducted in the state. From 1998–2000 we conducted a mark-recapture study within a 216×18 m stream section in east-central West Virginia using diurnal and nocturnal survey methods. Ninety-nine captures of 44 individuals were recorded. Density estimates ranged from 0.8–1.2 individuals/100 m^2. The sex ratio was 1.2:1. Sexual dimorphism was apparent, as females were longer and heavier than males. However, the longest males were underweight compared to their predicted mass. This population was highly skewed toward large adults, and larvae and juveniles were not encountered. The mean inter-capture distance was 35.8 m and 95% MCP home range estimates averaged 198 m^2. Water depth where hellbenders were captured ranged from 16–56 cm and individuals were never captured in heavily silted areas. Hellbender size was not correlated to rock size and not more than one individual was found beneath a single rock. We suggest that more thorough searches focusing on larval and juvenile habitat are needed before accurate assessments of population health can be made in this and other streams in West Virginia.

INTRODUCTION

Hellbenders (*Cryptobranchus alleganiensis* Daudin) are unique aquatic salamanders of the eastern United States that have experienced substantial population declines because of habitat change and degradation (Nickerson and Mays, 1973a; Wheeler *et al.*, 2003), over-collecting, illegal collecting and incidental take by anglers. They range from southern New York, south to Alabama and Mississippi and west to Missouri and Arkansas (Petranka, 1998). In West Virginia, hellbenders occur statewide with the exception of the eastern panhandle (Green and Pauley, 1987). Hellbenders are habitat specialists, completely aquatic throughout their entire lives and are restricted to streams and rivers with cool, swift flowing water, large rocks for hiding and nesting and an abundance of prey species such as crayfish (Netting, 1929; Green, 1935; Nickerson and Mays, 1973a). Because of their high densities in many streams (Hillis and Bellis, 1971; Nickerson and Mays, 1973a, b; Peterson *et al.*, 1988) and their propensity to target crayfish as their major food source (Green, 1935; Swanson, 1948; Nickerson and Mays, 1973a), hellbenders play an important role in stream ecosystem dynamics.

Hellbenders were once considered common throughout West Virginia (Green, 1934), although, until now, baseline data on population size and structure were not available for

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any population within the state. Most published studies concerning the natural history of hellbenders (Taber *et al.*, 1975; Nickerson and Mays, 1973a, b; Peterson *et al.*, 1983; Peterson *et al.*, 1988; Hillis and Bellis, 1971) have dealt with populations in Missouri and Arkansas. A study that compared recent surveys to data from ±20 y ago (Wheeler *et al.*, 2003) showed a drastic decline in population sizes in Missouri and illustrated the importance of gathering baseline population structure data. In this study, we discuss aspects of the life history of hellbenders in a West Virginia stream including: (1) population size and density, (2) demography and morphometrics, (3) movement and home range and (4) habitat use to provide data for comparative studies and as a baseline for future population monitoring.

METHODS

Study site description.—This study took place on a third-order stream in Pocahontas County, West Virginia. We do not report the exact location or name of the stream to avoid attracting collectors to this site. The stream is a tributary of the New River, in the Ohio River drainage. The study area is surrounded by relatively undisturbed forest, and no major development has taken place upstream of the study site except for a U.S. Forest Service road and an abandoned railroad bed. The mapped study area, with an elevation of 838 m, contained three pools and two areas of riffles, and was approx. 216×18 m (3888 m^2) at normal water level. During periods of normal water level, maximum depth in the pools was 1 m and riffles averaged 15–30 cm deep. Water depth in the riffles was as low as 8 cm during the driest part of the summer (August). Mean water discharge ranged from <1.4 m^3/s in late summer to >14.2 m^3/s in November, December and March (USGS gauging station data 1996–1997). Observed water temperatures ranged from 1.5 C in November to 22.5 C in July 1998, with an average water temperature of 17.7 C between April and October. During the winter of 1998–1999, ice formed in November and spring thaw occurred in March.

Survey techniques.—Surveys for hellbenders were performed from 1998 to 2000. Twenty-five surveys were performed during 1998, from 24 April to 10 October. Two surveys were performed during 1999, on 1 June and 17 July. In 2000 two surveys were performed, on 16 March and 16 April. Both nocturnal and diurnal survey techniques were employed to capture hellbenders. In total, 24 nocturnal surveys encompassing 74 person hours, and 5 diurnal surveys encompassing 20 person hours were performed. Nocturnal surveys involved 2–4 people walking the stream with headlamps and capturing active hellbenders by hand; rocks were not turned at night unless a hellbender was noticed at the rock's entrance hole. Nocturnal surveys began just after dark and continued for 2 to 5 h, ending no later than 2:30 AM. The entire mapped study area was searched during each nocturnal survey. During diurnal surveys, a log peavey was used to lift rocks and hellbenders were captured by hand. Upon capture, individuals were weighed to the nearest 5 g with a Pesola© spring scale, measured for total length (TL) in a half PVC pipe with a measuring tape affixed to it and tagged by injecting a PIT tag into the dorsum of the base of the tail. Sex determination was based on presence or absence of a swollen ring around the cloaca of males. Based on observations of males captured at different times of the year, sex of hellbenders could be accurately assessed from mid-June through mid-September. Individuals captured outside of that timeframe that did not exhibit cloacal swelling were recorded as unknown sex. Each hellbender was returned to its exact capture location immediately after processing.

Home range and movement.—In order to map the movements of individuals, a grid system was placed along a section of stream using numbered flags anchored to bricks and each capture location was placed on a map of the grid system. Surveys for hellbenders focused on sampling the mapped study area, but areas up to 1 km upstream and downstream were also periodically sampled. Hellbenders captured within and outside the study site were included in morphometric and habitat use analyses, but not in population size and density analyses. We determined maximum inter-capture distance for hellbenders recaptured once by measuring the distance between the two capture points. Time between captures for inter-capture distance measurement ranged from 5–432 d. For individuals captured three or more times, we determined 95% Minimum Convex Polygon (MCP) home range estimates using CALHOME (Kie *et al.*, 1996). Time between captures for MCP estimates ranged from 75–448 d.

Statistical analysis.—All statistical analyses were performed using SAS (vers. 9.00, SAS Institute, Inc., Cary, NC). TL of males and females was compared using a two-sample *t*-test. Length-mass sexual dimorphism was examined using ANCOVA to test for different slopes, with mass as the covariate. Pearson correlation was used to examine the relationship between rock size and hellbender size and a Wilcoxon Rank Sums test was used to compare rock size used between the sexes. Linear regression was used to examine the relationship between MCP home range estimates and elapsed time between captures. Population estimation was performed using Program Capture (Otis *et al.*, 1978; White *et al.*, 1982 revised by Rexstad and Burnham, 1991). Only captures from the first season (1998) were used in population estimation to reduce the risk of violating the closed population assumption. Movements of individuals into or out of the study site were never detected during the study.

RESULTS

Population size and density.—Ninety-nine captures of 44 individuals were recorded, and 29 of those individuals were captured within the mapped study area. Of the 29 individuals marked within the study area, 19 were recaptured at least once and the frequency of capture of any individual ranged from once to 14 times. We captured 20 males, 17 females and 7 unknown individuals, giving a sex ratio of 1.2:1. Sexually immature individuals, juveniles and larvae were not observed. The best model selected for the population estimation was M(o), and the population estimate of hellbenders was 31 (95 % CI = 29–39) individuals. Estimated density within the study site was 0.8 individuals/100 m^2, but was as high as 1.2 individuals/100 m^2 in one section of the study site. Estimated biomass, calculated by estimated density × mean individual mass, was 39.2 kg/ha.

Demography and morphometrics.—Body size-class histograms for males and females are presented in Figure 2. All individuals captured were mature adults, and only one individual less than 30 cm TL was found. Mean total length (TL) of hellbenders was 45.2 cm (range = 29.5–56.5 cm) and mean mass was 490 g (range = 150–900). Sexual dimorphism was apparent in TL and mass. Females had a significantly larger TL than males ($t = 2.99$; df = 34; $P = 0.002$). Mean TL was 48.3 cm (SE = 1.18) for females and 42.7 (SE = 1.41) for males. Females were also significantly heavier than males ($t = 3.01$; df = 34; $P = 0.002$). Mean mass was 571 g (SE = 42.7) for females and 414 g (SE = 31.3) for males. However, mass-TL regression line slopes were significantly different for males and females ($F = 9.31$; df = 1, 32; $P = 0.0045$) and intercepts were also different ($F = 8.54$; df = 1, 32; $P = 0.0063$) (Fig. 2). At large TL, females were heavier than males, and several of the longest males were well below their predicted mass compared to TL. However, because few small females were captured, differences in mass of individuals with shorter TL could not be compared using this model.

Movement and home range.—Mean inter-capture distance for hellbenders recaptured once (n = 10) was 35.8 m (range = 2.3–70.2). Mean 95% MCP home range estimate for hellbenders captured at least 3 times (n = 9) was 198 m^2 (range = 10–511). The relative size and location of home ranges are depicted in Fig. 1. Time between captures was positively correlated with home range size ($F = 23.77$; $R^2 = 0.75$; $P = 0.0012$), suggesting that our home range estimates were conservative.

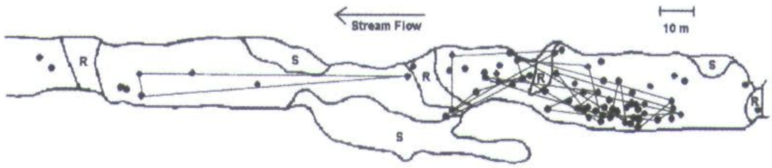

FIG. 1.—Map of the study site showing location of all hellbenders captured and overlap of individual home ranges in a West Virginia stream. 'R' represents rapids, and 'S' represents heavily silted areas

Habitat use.—The mean water depth where hellbenders were captured was 32.6 cm (range = 16–56 cm). Hellbenders were not distributed evenly throughout the study site, but were concentrated in the upper section of the stream (*see* Fig. 1 for capture locations). Individuals were never found in areas that were heavily silted (Fig. 1). Mean size of rocks under which hellbenders were found (n = 29) was 5535 cm^2, and hellbender TL was not correlated with the size of the rock used for shelter ($r = -0.063$; $P = 0.74$). There was also no difference in the size of rocks used by males compared to females ($Z = -0.28$; $P = 0.39$). Twenty-three hellbenders (18 males, 9 females, 2 unknown) were found beneath rocks at least once. One individual (adult male, TL = 52 cm) was found under the same rock during every survey between July and early September (68 d). Although on different occasions, only one rock was used by two different individuals.

DISCUSSION

Population size and density.—Green (1934) wrote that the hellbender "is found more abundantly in West Virginia, perhaps, than in any other region throughout its area of distribution." However, until the present study, only anecdotal data on the abundance and

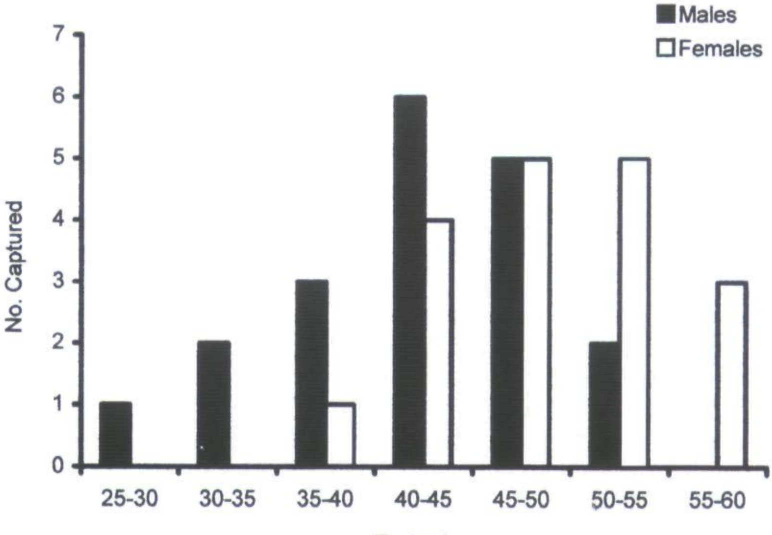

FIG. 2.—Body size histogram of total length (TL) of male and female hellbenders in a West Virginia stream

density of hellbenders in West Virginia were available. Our study indicated that hellbenders were very abundant in this stream, though density estimates in our study were not as high as those reported for several streams in Missouri and Arkansas several decades ago (Nickerson and Mays, 1973a, b; Peterson *et al.*, 1988). Our results were similar to those reported for a Pennsylvania stream (Hillis and Bellis, 1971), and higher than those reported for a stream in New York (Blais, 1996). Hellbender density could be influenced by numerous variables including prey abundance (Nickerson *et al.*, 2002), stream size and habitat structure. Nickerson and Mays (1973b) showed that density of hellbenders tended to relate directly to the number of suitable large rocks for shelter. In our study, we found that density in the upper section of the study site was higher than in other sections. Large rock slabs on top of many smaller rocks dominated the upper section, but rock density was not quantified.

Demography and morphometrics.—Taber *et al.* (1975) suggested that survivorship may be very low in eggs and larvae, which may explain the low numbers of small individuals in most populations, including this study (Hillis and Bellis, 1971; Nickerson and Mays, 1973a, b; Peterson *et al.*, 1983; Taber *et al.*, 1975; Swanson, 1948). We found only a single individual under 30 cm TL, and did not find larvae or juveniles during our surveys. Our body size histogram (Fig. 1) is very similar to those recently reported in recent Missouri surveys (*see* Wheeler *et al.*, 2003), after a noticeable decline in the occurrence of small individuals. This may indicate similar population decline issues in West Virginia; however, we were probably not searching the correct habitat or using the best methods for locating larvae or young individuals. Researchers in Tennessee (Nickerson *et al.*, 2002, 2003) recently showed that larvae can be very abundant in some populations, though meticulous searches involving diving and searching the interstices of gravel beds and piles of small rock are most productive in uncovering small size classes. Techniques employed in our study (which did not include diving) probably biased our captures toward larger individuals. Surveys focused on smaller size classes of hellbenders are undoubtedly needed in West Virginia before conclusions about population health can be made.

Sexual dimorphism has been reported in at least one other study (Taber *et al.*, 1975), though little or no sexual dimorphism has been reported for most populations (Bishop, 1941; Nickerson and Mays, 1973a). In general, females were significantly longer and heavier than males at our site. However, the mass of some of the largest males tended to decrease with respect to total length (Fig. 3). In one Missouri stream, males and females tended to grow at the same rate, though studies indicated that adult males were smaller than females, and the authors suggested that survivorship may have been lower in adult males (Taber *et al.*, 1975). In support of that, we suggest that the largest males may invest more time in maintaining territories and intraspecific aggression during the breeding season, and less time feeding. The three longest males that were of lower mass compared with TL were badly injured by another hellbender during the study; they had bite marks on their heads that matched the dentition of another hellbender. One of these males was also found under or near the same rock over a several month period. In addition, males in this population were not as nocturnally active as females, even outside of the breeding season (Humphries and Pauley, 2000) and, thus, females may maintain higher body mass by foraging more often than males. Further study is needed to determine factors that influence growth and body size differences in hellbenders.

Movement and home range.—Recaptured individuals tended to move very short distances throughout the study site. Hellbenders in this study were captured a mean of 35.8 m from their previous capture location. MCP home range estimates averaged 198 m^2 and one individual's home range was 511 m^2. However, observed home range estimates increased with the time between capture of an individual, indicating that our estimates were conservative.

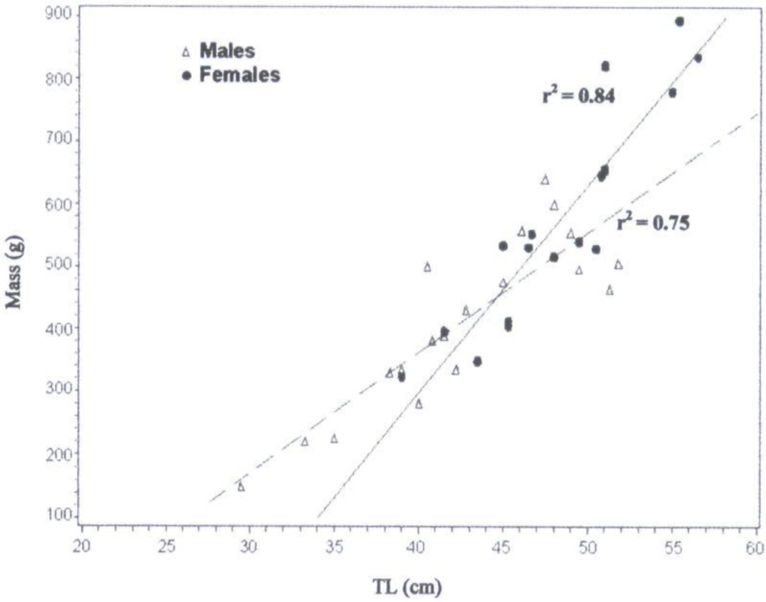

FIG. 3.—Relationship between mass and total length (TL) of hellbenders in a West Virginia stream. Regression lines are represented by dashes for males and a solid line for females. Slopes are significantly different (ANCOVA; $F = 9.31$; df $= 1, 32$; $P = 0.0045$)

The MCP method is also known to be very biased with few capture locations (Jenrich and Turner, 1969). Home ranges of individuals overlapped greatly (Fig. 1), but because of relatively few recaptures, we could not determine if hellbenders became more territorial during any particular season. Small inter-capture distances or home ranges have also been shown in other studies (Hillis and Bellis, 1971; Nickerson and Mays, 1973a; Coatney, 1982; Peterson and Wilkinson, 1996). Hillis and Bellis (1971) reported maximum inter-capture distances of 160 m in Pennsylvania. MCP home range estimates by Peterson and Wilkinson (1996) in Missouri were much lower than ours; average home range size was 28 m^2 for females and 81 m^2. However, individuals with the largest home ranges in our study were captured over a 318–448 d period, compared to 169 d sampled in their study. In another study (Nickerson and Mays, 1973b), hellbenders were rarely found more than 90 m from previous tagging sites; however, several individuals were found between 500 m–990 m from their original tagging sites. Using radiotelemetry, Ball (2001) found that females moved farther than males, and that one male used the same rock every day for a year. Another telemetry study (Coatney, 1982) reported elliptical home range size of 90 m^2 for seven hellbenders, but they were tracked for a maximum of two weeks. Hellbenders we studied usually emerged from their hiding rock just after dark and were generally found prowling 10–20 m from the rock throughout the night.

Habitat use.—We encountered hellbenders most often in shallow water, and individuals were not often encountered in the fastest riffles at night. Instead, most nocturnally active hellbenders were found in slower water with a calm surface, just upstream from areas of riffles. The majority of our nocturnal observations of hellbenders throughout the central and southern Appalachians have also occurred in this type of habitat (WJH and TKP, unpubl. data). However, riffles are difficult to search during both day and night. During the day, hellbenders may be swept away as rocks are turned, and it is difficult to see individuals through the surface of riffles during nocturnal surveys. We also did not capture hellbenders in areas of the study site that were heavily silted (Fig. 1), despite having searched these areas thoroughly.

Similar to Hillis and Bellis (1971), rock size was not correlated with hellbender TL in this study. There was also no difference between size of rocks used by males or females. From our observations, rocks that were partially imbedded into the substrate and that had an entrance hole on the downstream side were most often used by hellbenders. Perhaps these attributes, rather than size *per se*, were more important in determining the suitability of a rock. Hillis and Bellis (1971) found that hellbenders tended to occupy a rock immediately after being vacated by another individual. Use of a rock by two different hellbenders in our study (on different occasions) was only observed once, though this was probably a result of the low number of diurnal searches. We noticed some fidelity to rocks by individuals; on several occasions the same individual was found under the same rock as the previous survey. One particular individual, a large, presumably very old male, could invariably be found under the same rock over a period of a few months, and was often seen actively prowling within 10 m of this rock during nocturnal surveys. We never found more than one hellbender under a single rock, but up to three individuals have been found beneath the same rock in other studies (Hillis and Bellis, 1971; Nickerson and Mays, 1973a).

Information presented in this paper provides a baseline for hellbenders in West Virginia, though further study on population demography, movements and habitat use is clearly needed. Hellbenders were abundant in this population, but we only captured mature adults. Future research would benefit from meticulous searches of gravel beds and areas containing small rocks and cobble, to better define population structure and determine whether reproductive recruitment is taking place in this and other hellbender populations. We also stress that the population discussed in this paper resides in one of the most pristine mountain streams in the state. Virtually nothing is known about the status of other hellbender populations in West Virginia.

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