

## SPATIAL ECOLOGY OF THE EASTERN HELLBENDER (*CRYPTOBRANCHUS ALLEGANIENSIS ALLEGANIENSIS*) IN INDIANA

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**ABSTRACT:** Few studies have examined the spatial ecology of the Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*). We used radiotelemetry to examine the seasonal home range, movement patterns, and habitat use of 21 individuals within the Blue River drainage of southern Indiana, USA. Individuals were located up to three times weekly from July 2008 through October 2009. Mean 100% minimum convex polygon (MCP) home-range sizes were much larger than previously reported and largest during the summer. Male MCPs were significantly larger than those of females. Mean linear home-range sizes were also significantly longer in the summer, but did not differ between the sexes. Hellbenders moved very little throughout the year ( $\bar{X}$  5 14.1 movements per individual) and over relatively short distances ( $\bar{X}$  5 27.5 m) to nearby shelter rocks. Most Hellbenders were routinely located under large, flat shelter rocks; however, five individuals periodically used bedrock, downed trees, and submerged tree root masses along the riverbank. Habitat use of Hellbenders was similar to that found in other studies, with 79.5% of our locations found on a gravel substrate. Our results provide essential information about a declining, low-density population of Hellbenders in need of management.

**Key words:** Habitat use; Home range; Minimum-convex polygon; Radiotelemetry; Salamander

A THOROUGH UNDERSTANDING of spatial movement patterns and habitat use can have important implications for successful management activities. At present, much is known regarding the spatial ecology of mammals and birds, whereas fewer studies have examined amphibian spatial ecology. This is due, in part, to their generally secretive nature (Pough, 2007), limited availability during much of the year (Williams et al., 2009), complex life histories (Duellman and Trueb, 1986), and small body sizes (Wells, 2007). Few techniques allow researchers to collect spatial data as efficiently and effectively as radiotelemetry. Although radiotelemetry has been widely used with larger vertebrates, transmitter size has precluded its use on smaller amphibians until relatively recently. This technique has been particularly effective for studies of cryptic species such as aquatic salamanders, for which traditional methods of observation are difficult or impossible (e.g., Peterman et al., 2008).

Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) are large, fully aquatic salamanders that occur in parts of the eastern

United States (Petranka, 1998). They require cool, rocky, swift-flowing streams and rivers with high levels of dissolved oxygen (Guimond and Hutchison, 1973; Hillis and Bellis, 1971; Smith, 1907). During the day, they spend most of their time under large, flat rocks, which they require for shelter and will defend from other conspecifics (Hillis and Bellis, 1971; Nickerson and Mays, 1973; Peterson and Wilkinson, 1996). Gravel and cobble substrates provide important areas for prey items and habitat for larvae. Hellbenders forage nocturnally and are thought to play an important role in influencing aquatic invertebrate populations, especially crayfish (Humphries and Pauley, 2005; Netting, 1929; Peterson et al., 1989). Hellbender populations have experienced dramatic population declines throughout their range (Mayasich et al., 2003). Despite this drastic reduction in range and population density, little research has been done regarding Hellbender movements and home-range size in declining, low-density populations.

Previous attempts to document the spatial patterns of Hellbenders have been limited in scope, occurred over a short duration, or suffered from inadequate sample sizes (Blais, 1996; Hillis and Bellis, 1971; Humphries and

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Pauley, 2005; Peterson and Wilkinson, 1996). Moreover, these studies focused on areas of high population densities (Ball, 2001; Hillis and Bellis, 1971; Humphries and Pauley, 2005; Peterson and Wilkinson, 1996). The factors influencing home-range size are largely unknown, but variance in population densities could greatly affect the movements and behaviors of individuals as resource availability changes (Hillis and Bellis, 1971). As Hellbender population densities continue to decrease, empirical data focused on spatial patterns, movements, and habitat use in declining populations will become increasingly important.

The Midwest region of the United States is likely experiencing the most dramatic declines in Hellbender populations. In Indiana, USA, historic Hellbender distribution included most of the Ohio and Wabash River drainages (Petranka, 1998). However, during the past several decades, populations have been reduced to a single low-density population within the Blue River drainage. Given that Indiana populations occur at densities much lower than previously reported (Burgmeier et al., in press), empirical data on the spatial ecology within this context are both unique and needed. The objectives of this study were to (1) describe Hellbender seasonal and spatial movement patterns, (2) estimate home-range sizes across seasons and sexes, and (3) document habitat use in relation to river and benthic microhabitats in Indiana.

## MATERIALS AND METHODS

### *Study Area and Site Selection*

Eastern Hellbenders were studied along a 112-km stretch within the Blue River drainage of southern Indiana. The Blue River intersects two of Indiana's ecoregions, originating in the Mitchell Karst Plain Section of the Highland Rim and crossing into the Escarpment Section of the Shawnee Hills region. The river winds through a complex of agriculture, forest, and rocky cliffs until ultimately converging with the Ohio River. The Blue River is comprised of long stretches of deep pools interspersed with riffles and runs. Average summer depth of our study area was 37.2  $\pm$  20.5 cm, and average wetted width was 19.3  $\pm$  5.0 m. The

river includes long stretches containing a predominately bedrock bottom, whereas other areas consist of gravel and cobble. Most of the substrata, regardless of type, are covered by a thin layer of silt. Boulder-sized rocks ( $\approx$  256-mm diameter) suitable for Hellbender refuges are spread throughout the river. We selected eight sites for study based on habitat suitability, ease of access, and the presence of Hellbenders documented by previous surveys by the Indiana Department of Natural Resources (IDNR) over the past 10–12 yr.

### *Capture and Surgery*

We collected Hellbenders from June through August 2008 and in July 2009 by hand or net. We wore underwater goggles to aid in visibility when needed. To minimize struggling, we placed individual Hellbenders ventral side up in a custom squeeze box, the 'bender board' (Burgmeier et al., 2010). We recorded total length (cm), snout–vent length (cm), weight (g), gender, and any noticeable physical abnormality on all captured individuals. Hellbenders are sexually dimorphic for only a short period during the breeding season (Smith, 1907), which limited our ability to assess gender prior to surgeries. We conducted surgeries outside the breeding season to minimize interference with reproduction. This precautionary effort made accurate gender differentiation impossible in the field unless developing ova were detected during the procedure. We scanned all captured Hellbenders with Biomark FS2001F-ISO and AVID Multiscan 125 PIT tag readers. If no tag was found, then we implanted a Biomark 12.5-mm, 134.2-kHz tag in the dorsal side of the tail approximately 8 cm posterior to the hind leg. Immediately after processing, we released all animals at their point of capture.

We selected 21 individuals from eight sites to be implanted with radiotransmitters. The eight sampling sites were spaced at equal distances along the river, and we attempted to maintain equal sex ratios among sites. All radiotelemetered individuals were adults, ranging in snout–vent length from 26.6 cm to 38.5 cm and weighing 370–960 g before surgery. We generally followed the surgical procedures described in Stouffer et al. (1983), with notable exceptions to transmitter and

suture type. To anesthetize individuals, we used tricaine methanesulfonate (MS-222) buffered with baking soda, following Stouffer et al. (1983) except that in a few cases, we used unbuffered MS-222 because the buffer was not available at the time. MS-222 has frequently been used as an anesthetic for both fish and amphibians in the field due to its short induction and recovery times, its wide margin of safety, and its convenience. However, previous studies have suggested MS-222 might cause deleterious effects, which can include burns due to low pH if the solution is not buffered properly (Byram and Nickerson, 2009). We did not see any signs of burns in the anesthetized animals during or at any time after the surgeries. We implanted a 13-g SI-2 transmitter (Holohil Systems Ltd., Carp, Ontario, Canada) into each animal, and sutured the incision with an absorbable Ethicon 3-0 PDS\*II suture. The transmitters did not exceed 5% of presurgery total body weight. Following surgeries, we placed the animals within a screened enclosure in slow-moving freshwater until recovery (all animals recovered from surgeries). The average time of recovery was approximately 30–35 min, but this was not specifically recorded for each individual. We implanted transmitters in four additional salamanders to replace individuals that died, were lost, or experienced transmitter failure after approximately 11 mo of the study.

#### *Radiotelemetry and Data Collection*

We tracked individuals twice weekly (on average) during the spring, summer, and autumn of 2008 and 2009. During the breeding season, we increased tracking to three times weekly, and in winter we decreased it to once weekly. In September 2008, we tracked four individuals at one site during a 24-h period to gather preliminary data on diel movement patterns and to confirm that our tracking efforts captured fine-scale diurnal movements. When we located individuals, we recorded habitat measurements including Global Positioning System coordinates (Garmin GPSmap 76; Garmin LTD., Olathe, Kansas, USA; UTM, accuracy #4 m), water temperature ( $^{\circ}\text{C}$ ), water depth (cm), distance to shore (m), distance (cm) to nearest shelter

rock  $\approx$  25.6 cm in diameter, number of shelter rocks within 6-m radius, weather (sunny, partially cloudy, cloudy, raining), substrate type (bedrock, silt, sand, gravel, cobble), flow type (riffle, run, pool), and rock length (cm), width (cm), and depth (cm). Flow-rate data (discharge, measured as  $\text{m}^3/\text{s}$ ) were acquired from the US Geological Survey National Water Information System (USGS, 2010). We conducted Wolman pebble counts at six of eight radiotelemetry sites to determine streambed substrate composition at the time of the study (Wolman, 1954); we did not conduct the counts at the remaining two sites due to extensive flooding.

#### *Data Analysis*

We used ArcGIS 9.2 (ESRI, Redlands, California) and the Hawth's Tools extension (Beyer, 2004) to develop intermovement distances, directions of movement, 100% minimum convex polygons (MCP) and linear home ranges (LHR) for all Hellbenders with at least two or three recorded movements (Mohr, 1947). Individuals that did not move during a given season were not included in the standard analyses. Although there is some criticism of MCPs encompassing nonuse areas, the sites used were mostly linear and confined by riverbanks, making any such scenarios easily noticed and rectifiable (White and Garrott, 1990). In the few cases in which MCPs did include areas of documented nonuse (i.e., land), we conservatively modified the MCPs before calculation to minimize overestimation of home-range size. This modification resulted in a more realistic representation of Hellbender home ranges. Linear home range provides information regarding the length of stream used by individuals and is suitable for species living in fairly homogeneous, linear environments such as small streams and rivers (Skains and Jackson, 1995). Herein, we define LHR as the distance between the two most extreme locations of a single animal.

We estimated MCP and LHRs at multiple levels. First, we wanted to obtain an average home-range estimate using all individuals across all seasons. We also wanted to estimate seasonal home ranges. To obtain these seasonal estimates, we used the combined data

sets for males and females for each of the four seasons based on changes in water temperature in a manner similar to that of Daugherty and Sutton (2005). Lastly, we wanted to compare the home-range sizes between males and females during the breeding and non-breeding seasons.

The numbers of locations found in both types of flow and substrate were compared for all individuals to assess habitat use. We used linear regression to evaluate the influence of flow rates on the number of movements. We analyzed the Wolman pebble counts using the size-class pebble-count analyzer developed by the US Department of Agriculture (Potyondy and Bunte, 2002). We used a *t*-test to determine any differences between seasons or genders for home range and movements. To analyze habitat use relative to habitat availability, we used a chi-square goodness-of-fit test. Where appropriate, results are presented as mean  $\pm$  SD. Whenever normality assumptions were not met, we log- or square-root-transformed the data. We used nonparametric Mann-Whitney *U*-tests whenever normality could not be achieved via transformations. In cases of normality but nonconstant variance, we used a Satterthwaite's Approximate *T*-test. We used SAS 9.1.3 or JMP 8.0 for all statistical analyses, and considered results significant whenever  $\alpha < 0.05$ .

## RESULTS

We recorded 1193 total locations ( $\bar{X} = 57.6 \pm 23.9$ /individual; median = 65) from 21 radio-tagged adult Hellbenders (13 males, 4 females, and 4 unsexed individuals) from June 2008 through October 2009. Transmitter failure was low throughout the study, with only one transmitter failing in 2009. However, we lost an additional three telemetered animals due to unknown causes during the spring of 2009. In each of these cases, the radiotagged Hellbender was never located, but the transmitters were found along the bank ridge several meters from the water. Although we considered the possibility, it is unlikely that losses were related to anesthesia or surgery, because the earliest loss was recorded 11 mo into the study, when all individuals had displayed multiple movements

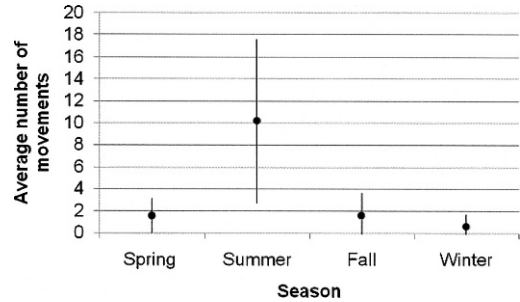


FIG. 1.—Average numbers of movements per season for 21 (summer–fall) and 17 (spring–winter) Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) from southern Indiana, USA. Circles and lines represent the mean and SDs for each season, respectively. The tracking period was from June 2008 through October 2009.

typical for their locations, and because two of the three animals had been recaptured prior to loss and displayed full suture closure and no noticeable health problems at the time of capture.

### Movement Patterns and Site Fidelity

We detected 297 movements over the entire tracking period. For the 21 telemetered Hellbenders, the mean number of movements per individual was  $14.1 \pm 9.1$ . Hellbenders moved a mean of  $10.2 \pm 3.4$  times during the summer, more than all other seasons ( $t = 5.437$ ,  $P < 0.00002$ ; Fig. 1). Very few movements were recorded outside of summer, and no differences could be detected among spring, fall, or winter ( $F_{2,52} = 1.991$ ,  $P = 0.147$ ; Fig. 1). Nearly all spring movements took place within the final 3 wk of the season leading into summer. When season lengths were taken into account, Hellbenders moved more ( $n = 120$ ) during the breeding season than during the nonbreeding season ( $n = 170$ ;  $\chi^2 = 194.01$ ,  $P < 0.05$ ). With the exception of one sampling site, individuals typically moved within the same small areas throughout all seasons.

The mean intermovement location distance by 20 Hellbenders was  $27.5 \pm 6.5$  m. One individual of unknown gender moved downstream 347 m between successive tracking events shortly after its initial capture, but only moved once during the remainder of the study and, thus, was excluded from the analysis. There were no differences between the numbers of upstream and downstream move-

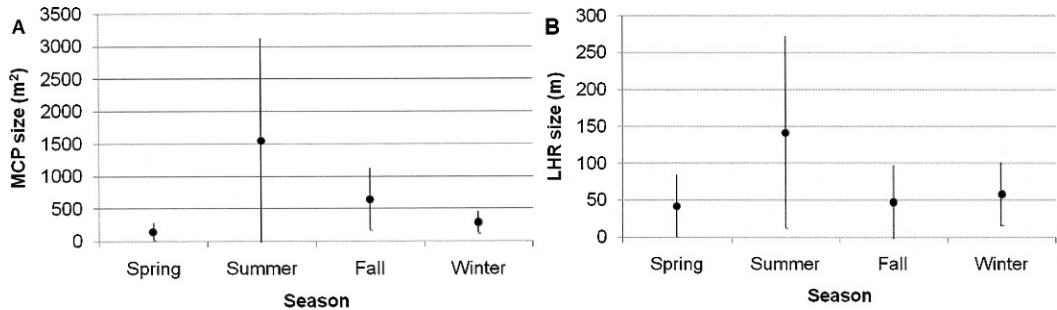


FIG. 2.—(A) Average seasonal MCP home-range size (m<sup>2</sup>) for all Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) with at least three recorded movements during a given season. (B) Average seasonal LHR size (m) for all individuals with at least two movements recorded during a given season. Circles and lines represent the means and SDs for each season, respectively. The tracking period took place from June 2008 through October 2009 in southern Indiana, USA.

ments for the overall population ( $\chi^2 = 5.016$ ,  $P = 0.9$ ). We found no relationship between discharge and the initiation of movement ( $r^2 = 0.032$ ,  $P = 0.05$ ). During one 24-h tracking period conducted on four individuals, only a single movement was recorded by one individual, which occurred shortly before 2200 h.

#### Home Range Estimation and Overlap

Estimates of home-range size differed considerably among individuals, seasons, and sexes. The mean MCP for all individuals (i.e., when data for the sexes were combined) was  $2211.9 \pm 990.3$  m<sup>2</sup> ( $n = 16$ ). Mean LHR for all individuals was  $144.0 \pm 57.7$  m ( $n = 21$ ). Mean MCP home-range sizes differed between climatic seasons ( $\chi^2 = 9.30$ ,  $P = 0.026$ ; Fig. 2A). In general, Hellbenders maintained the largest MCPs during the summer, averaging  $1544.8 \pm 785.5$  m<sup>2</sup> ( $n = 18$ ). During fall, the mean home-range size decreased to an average of  $643.9 \pm 442.2$  m<sup>2</sup> ( $n = 7$ ). Home-range sizes were smallest throughout the winter and spring at  $290.0 \pm 402.8$  m<sup>2</sup> ( $n = 3$ ) and  $150.6 \pm 121.0$  m<sup>2</sup> ( $n = 7$ ), respectively. Spring MCPs differed from both summer ( $t = 4.14$ ,  $P = 0.0004$ ) and fall ( $t = 2.63$ ,  $P = 0.0302$ ) values, but no other seasonal differences were detected (Fig. 2A). A difference was detected between summer and spring LHR ( $U = 21.96$ ,  $P = 0.0495$ ), but no other seasonal differences in LHR were detected (Fig. 2B).

When combining data from both sexes, the mean breeding MCP home-range size was  $1132.9 \pm 635.7$  m<sup>2</sup> ( $n = 18$ ), which was not

significantly different from the mean non-breeding MCP of  $1395.3 \pm 501.5$  m<sup>2</sup> ( $n = 16$ ;  $t_{32} = 1.01$ ,  $P = 0.3184$ ). No gender differences were detected for either mean breeding or nonbreeding MCP home-range sizes (Fig. 3A). No breeding season versus nonbreeding season LHR comparisons were significant (Fig. 3B). MCP sizes for males and females across all seasons were  $2844.6 \pm 1493.1$  m<sup>2</sup> ( $n = 9$ ) and  $675.8 \pm 1648.4$  m<sup>2</sup> ( $n = 3$ ), respectively. Male MCP size was larger than that of females ( $t = 3.06$ ,  $P = 0.01$ ).

Home-range overlap occurred at all sites and with multiple individuals of each gender, but only during the summer (which included portions of both breeding and nonbreeding seasons). The greatest overlap between two individuals ( $2685.4$  m<sup>2</sup>) occurred at one site with four radiotagged animals (three males, one unknown). All individuals at this site overlapped with at least two other individuals. The smallest overlap involved a 12.7-m movement by one individual into another individual's home range. Only once were two individuals (one male, one female) located under the same shelter (which was comprised of two large rocks stacked one on top of the other) during the breeding season.

#### Habitat Use and Selection

Seventy-nine percent of all Hellbender locations were associated with gravel, compared to 11.5% associated with silt and mud. Gravel was overrepresented relative to its availability, and all other categories were underrepresented relative to their availability.

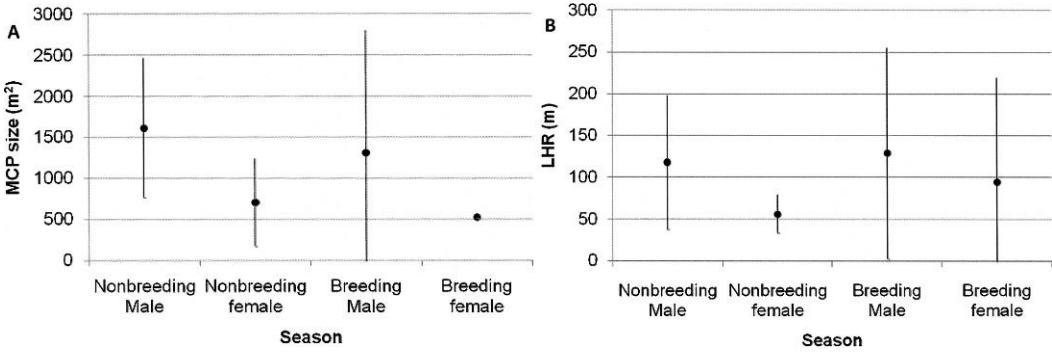


FIG. 3.—(A) Comparison of average breeding versus nonbreeding MCP home-range size (m<sup>2</sup>) by gender for all Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) with at least three recorded movements during a given season. (B) Comparison of average breeding versus nonbreeding LHR size (m) by gender for all individuals with at least two recorded movements during a given season. Circles and lines represent the mean and SDs for each season respectively. The tracking period took place from June 2008 through October 2009 in southern Indiana, USA.

ties ( $\chi^2 = 5.93153, P = 0.05$ ). Wolman pebble counts revealed that gravel made up the majority (38.9%) of the substrate in most cases (Fig. 4); when the boulder size classes were excluded from our analysis, the actual percentage of gravel as available substrate was approximately 42.1%.

Flow-type use was skewed heavily toward runs, which contained 77% ( $n = 925$ ) of all locations. Pools were used 22% ( $n = 267$ ) of the time and riffles only 1% ( $n = 5$ ) of the time. Runs and pools were overrepresented and riffles underrepresented relative to their availabilities ( $\chi^2 = 407.53, P = 0.05$ ). Throughout the study, Hellbenders were found at water depths ranging from 7.4 cm to greater than 177 cm. Mean summer depths

at Hellbender locations were 59.9  $\pm$  2.1 cm, and overall mean depth was 66.6  $\pm$  1.9 cm. At one site, all four individuals (three males, one unknown) moved into deep pools during the breeding season. One individual returned to shallow water shortly thereafter, but all three males overwintered in these and then moved back to their normal areas of activity in late spring or early summer.

The most frequently used shelter rocks detected via radiotelemetry were between 5000 cm<sup>2</sup> and 15,000 cm<sup>2</sup> (60.16%), but shelter sizes ranged from 1033.9 cm<sup>2</sup> to 159,448.3 cm<sup>2</sup> (Fig. 5). Shelter rocks used during the spring, fall, and winter were larger than those used during the summer ( $\chi^2 = 39.69, P = 0.0001$ ). Shelter rocks

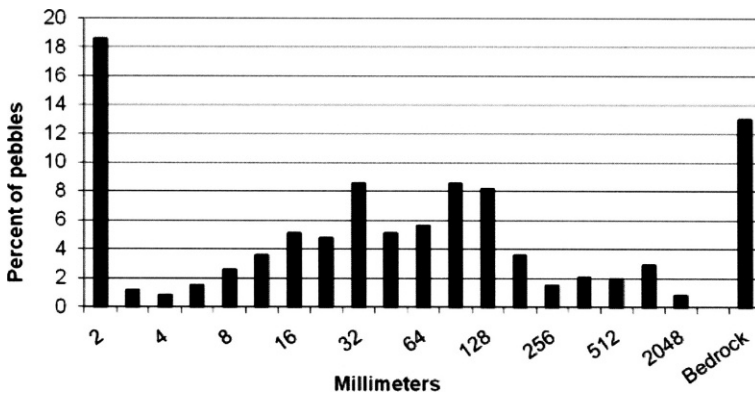


FIG. 4.—Particle size distribution, determined via Wolman pebble counts, for six sites in the Blue River, Indiana, USA, at which Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) were studied during 2008. Vertical bars represent the percentage of the total particle substrate represented by each size class.

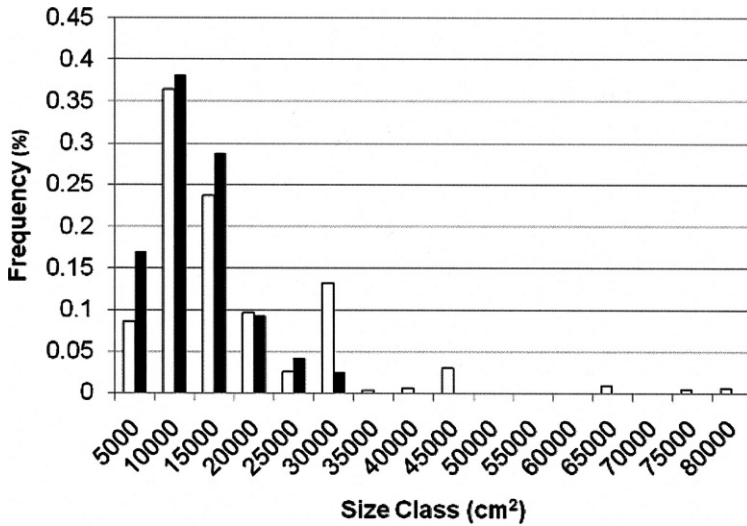


FIG. 5.—Frequency distribution of shelters used by Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) in the Blue River, Indiana, USA that were found during a radiotelemetry study (gray bars) and those found during a mark–recapture study (black bars; Burgmeier et al., in press). Both studies were conducted from June 2008 through October 2009.

detected via radiotelemetry were similar to those detected during mark–recapture surveys, in which 83.90% were #15000 cm<sup>2</sup> in area (Burgmeier et al., in press; Fig. 5). Hellbenders disproportionately used large boulders ( $\approx 10,485.8$  cm<sup>2</sup>) as shelters compared to rocks in smaller size classes ( $\chi^2$  5 1803.39,  $P$  , 0.05). The mean distance of shelter rocks from the shoreline was 5.1  $\pm$  0.2 m ( $n$  5 584). The mean distance from located shelter rocks to the nearest adequate shelter rock was 17.2  $\pm$  3.2 cm ( $n$  5 540). The mean number of adequate shelter rocks within a 6-m radius of a located Hellbender was 50.6  $\pm$  4.7 rocks ( $n$  5 405).

## DISCUSSION

### *Movement Patterns and Site Fidelity*

Hellbenders are thought to be relatively sedentary, with only subtle differences in the numbers of movements during certain periods throughout the year. Ball (2001) reported that only 108 of 989 (11%) observations revealed movements in a North Carolina (USA) population of Hellbenders. In this study, however, we found that roughly 25% (297 of 1193) of our observations revealed movements. We detected more movements during

the summer months than all other seasons. Our results are concordant with Blais (1996), but are in stark contrast to Ball (2001), who reported increased activity in the spring, intermediate activity in the summer, and decreased activity in the fall and winter. Hellbenders are thought to spend a considerable amount of time searching for prey during late spring and early summer leading into the breeding season, when they begin searching for nesting sites and mates (Blais, 1996; Nickerson and Mays, 1973; Smith, 1907). Indeed, those activities occur within our summer tracking season (May–September) and represent the most likely explanations for the increased movements we observed during that season. After accounting for the difference in the lengths of the nonbreeding and breeding seasons, Hellbenders were found to move more during the breeding season than during the nonbreeding season.

Other factors may limit movement during other times of the year. Hellbenders may seek refuge under shelter rocks and limit their movements in direct response to extensive flooding events. Our analysis corroborates that of Nickerson et al. (2007), in which movement was unaffected by either high or low flow events. Furthermore, Topping and Peterson

(1985) reported significantly more upstream than downstream movements. Our results, however, supported those of Peterson (1987), who found that flow direction had no effect on the direction of movements.

Hellbenders generally do not move large distances (Mayasich et al., 2003), although there are accounts of relatively long-distance movements, from 990 m (Nickerson and Mays, 1973) up to 5 km (P. Petokas, personal communication). We documented a single long-distance movement (347 m) by an individual of unknown sex. However, the majority of the movements in this study averaged 28 m, which is consistent with the mean linear movements reported in previous studies of 20.1 m (Humphries, 1999) and approximately 19 m (Hillis and Bellis, 1971). Most movements were between several frequently used rocks within a small area. The lack of long-distance movements can have profound impacts on populations with low densities by limiting the amount of gene flow and reducing the overall effective population size (Wang, 2009).

*Home Range Estimation and Overlap*

Our results indicate that Hellbenders in Indiana maintain much larger home ranges than those reported in other studies (Table 1). Several possible explanations exist for the increased home-range sizes. Several studies relied on mark–recapture methods for home-range estimation (Hillis and Bellis, 1971; Humphries and Pauley, 2005; Peterson and Wilkinson, 1996). This method possesses several drawbacks; most notably, it is time consuming and results in relatively few locations per individual, especially in colder months. As suggested by Humphries and Pauley (2005), these factors create relatively conservative estimates that likely underestimate true home-range sizes.

A second possible explanation for our increased home-range estimates is that we used radiotelemetry and collected a much larger number of locations over a much longer period than in many other studies. These factors decreased the likelihood of home-range underestimation with the use of MCP methods (Arthur and Schwartz, 1999; Boulanger and White, 1990; Humphries and Pauley, 2005). A third potential explanation

TABLE 1.—Previous studies providing home-range estimates for Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) throughout their range.

Blais	Author	Date	No. individuals	No. locations/ individual	Study duration	Method <sup>a</sup>	HR estimator <sup>b</sup>	HR size (mean) <sup>c</sup>	Location
		1996	16	30	3–36 wk (varied among individuals)	RT	LHR	23.2–110.3 m	NY
Coatney		1982	7	—	2 wk	RT	Elliptical	90 m <sup>2</sup>	MO
Gates		1983	5	—	4 mo	RT	MAR	4 m	MD
Hillis and Bellis		1971	73	\$2	3 mo (9 surveys)	MR	MAR	346.4 m <sup>2</sup>	PA
Humphries and Pauley		2005	9	\$3	2 yr (29 surveys)	MR	MCP	198 m <sup>2</sup>	WV
Peterson and Wilkinson		1996	26	\$14	5 mo (33 surveys)	MR	MCP	36 m <sup>2</sup> (f), 95 m <sup>2</sup> (m)	MO

<sup>a</sup> Method: RT 5 radiotelemetry, MR 5 mark–recapture.

<sup>b</sup> HR (Home Range) Estimator: LHR 5 linear home range, MAR 5 mean activity radius, MCP 5 minimum convex polygon.

<sup>c</sup> HR Estimator: f 5 female, m 5 male.



of our large home-range estimates is that home-range sizes may reflect population densities. Unfortunately, there are no experimental studies that have examined the relationship between density and home range for Hellbenders. Humphries and Pauley (2005) calculated a mean MCP of 198 m<sup>2</sup> for a high-density population (0.8–1.2 individuals/100 m<sup>2</sup>) of Hellbenders in West Virginia. Conversely, the home-range sizes found in this study were much larger, yet the population density was extremely low (0.038 individuals/100 m<sup>2</sup>; Burgmeier et al., in press). Home-range sizes in this study were largest during the summer months and correspond with the breeding season. Given the low population densities, it is plausible that the increase in home-range size results from individuals moving greater distances in search of mates.

Finally, differences in home ranges among studies might be due to habitat differences among the study sites. Different types and availabilities of refuges might affect the distance that an individual needs to move to reach a new shelter. Kleeberger (1985) found no effect on the home-range size of *Desmognathus monticola* when cover objects were added to study plots. However, Spieler and Linsenmair (1998) reported that with increasing cover (i.e., bushes), the home-range size of the frog *Hoplobatrachus occipitalis* decreased considerably compared to their home-ranges in areas containing fewer bushes. Our study areas are replete with adequately sized shelter rocks. Males typically display territorial behavior over specific shelter rocks; however, this behavior might be reduced given the high density of available shelter and the lack of competition from other individuals. It is important to note that we conducted all tracking during the daylight hours, when Hellbenders are typically inactive. It is possible that movements could have occurred between the tracking periods and, therefore, our estimates should be viewed as conservative (Hayne, 1949). However, our results during a 24-h summer tracking session showed very little movement, which was consistent with the results of previous studies (Noeske and Nickerson, 1979). Moreover, the IDNR has reported a lack of success in observing Hellbender movements during

nighttime surveys in these same areas (Z. Walker, personal communication).

Few differences in home-range sizes were found between seasons or genders for either MCP or LHR methods. This outcome is likely due to the high variance found within categories and the small female sample size, which artificially inflated variance estimates, and required there to be a large difference in mean home-range size between genders for statistical significance to be detected (Gravetter and Wallnau, 2008). We found that seasonal MCP home-range size was different between summer–fall and spring. This result corresponds with known Hellbender behavior, because foraging movements typically do not begin until late spring or early summer and the breeding season does not end until early autumn (Kern, 1986). Male 100% MCP home-range size was larger than that of females. Peterson and Wilkinson (1996) found a similar relationship using MCPs, but Hillis and Bellis (1971) reported no difference between sexes while using mean activity radii. Blais (1996) found female LHR to be slightly larger than that of males. In light of this information, it is important to consider that the Blue River population is of low density and may be restricted to only adult individuals. Results could vary in populations with higher population densities or multiple age classes.

Home-range overlap has been reported in other studies, particularly during the breeding season (Blais, 1996; Humphries and Pauley, 2005). During this study, overlap among individuals occurred at all sites with multiple Hellbenders, and increased with increasing numbers of individuals. However, Coatney (1982) reported that individuals typically avoided areas of overlap. The frequent overlap in our study area was likely due to a combination of factors, including high shelter density and decreased Hellbender density.

#### *Habitat Use*

We found that Eastern Hellbenders in Indiana typically occur in cool, moderately flowing waters with a substantial amount of gravel or cobble substrate and large, flat rocks as shelters. These results are consistent with studies conducted in other portions of their range (Ball, 2001; Humphries and Pauley,

2005; Keitzer, 2007; Nickerson et al., 2003). Humphries and Pauley (2005) reported that Hellbenders were associated with gravel substrates and that no individuals were found in heavily silted areas. Although the majority of the Hellbenders in this study were associated with gravel substrates, over 11.5% of the locations occurred in heavily silted areas.

Large, fast-flowing riffles are often cited as critical habitat for Hellbenders (Humphries and Pauley, 2005; Mayasich et al., 2003; Smith, 1907), but the majority of Hellbender locations in this study were associated with runs, not riffles. Riffle areas in the Blue River tend to be short, shallow, and comprise a small proportion of the available habitat relative to other flow types. However, we did detect an underrepresentation of riffle use relative to riffle availability. It is possible that the patchy distribution of riffles within our study area accounts for their relative lack of use when compared to the longer, more prevalent runs.

Previous research has highlighted the importance of large, flat rocks as critical shelter for Hellbenders (Hillis and Bellis, 1971; Humphries and Pauley, 2005; Keitzer, 2007). Although our data are generally consistent in that regard, we have documented several discoveries. Overall, Hellbenders seemed to use the medium and larger size classes of boulders ( $\approx 2621.44 \text{ cm}^2$ ) at a higher frequency than expected. This trend was more apparent when comparing radiotelemetry results to those from traditional mark-recapture methods (Burgmeier et al., in press). We discovered that Hellbenders frequently used shelter rocks that are too large for researchers to lift during traditional rock-flipping surveys. At least six of the largest size classes of shelter rocks were underrepresented and could lead to a bias in the importance of smaller rock size classes. We also found that Hellbenders used larger rocks during nonsummer months. It is possible that Hellbenders are taking refuge under larger shelter rocks to reduce disturbance during colder months, when energy conservation is important. Alternatively, it may simply be that smaller rocks do not fully shelter the large individuals in this population or provide the necessary protection from current or light.

Populations across the entire range of Hellbenders are beginning to experience shifts in

demography similar to those in Indiana. Results such as ours on the habits of eastern Hellbenders should help managers to develop conservation plans that target severely declining populations.

*Acknowledgments.*—Animals were collected under permit #09-0162 issued to NGB by the Indiana Department of Natural Resources and protocol #08-025 issued by the Purdue University Animal Care and Use Committee. Financial support for this project was provided by the Indiana Division of Fish and Wildlife, Wildlife Diversity Section state wildlife improvement grant (E2-07-WD0007) and Purdue University. We thank the Williams Lab and several anonymous reviewers for comments on previous versions of this manuscript. We thank O'Bannon Woods State Park and staff for providing housing and maintenance assistance. We give a sincere thanks to S. Unger and our technicians G. Connette, C. Earle, J. Fihe, B. Haslick, B. Kraus, C. Marks, E. McGee, D. Smith, A. Switalski, and L. Woody for several successful field seasons.

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Accepted: 17 February 2011  
Associate Editor: Stephen Mullin