Ecology and population demography of the hellbender, *Cryptobranchus alleganiensis*, in West Virginia

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Abstract

Ecology and population demography of the hellbender,
Cryptobranchus alleganiensis, in West Virginia

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Using mark-recapture, I studied the population demography and habitat use of the hellbender, *Cryptobranchus alleganiensis*, in the West Fork of the Greenbrier River, Pocahontas County, West Virginia. Eighteen nocturnal surveys were conducted between April and October, 1998, during which 29 hellbenders were implanted with permanent tags. Male to female sex ratio was 1.06:1. Hellbenders were sexually dimorphic, as females were significantly longer and heavier than males. Total lengths for all captured animals ranged from 29.5 - 56.5 cm and mass ranged from 150.0 - 905.8 g. Seasonal linear movements for 12 individuals ranged from 0.8 - 70.2 m (mean = 19.8 m). The density was 0.8 hellbenders per 100 m^2. I did not find evidence of reproduction at the study site, however, the timing of cloacal swelling of males suggested that mating took place in late August and early September. Larvae or subadults were not observed during this study. A decrease in nocturnal activity of hellbenders was observed beginning in mid July, suggesting the importance of the implementation of surveys for the species early in the year. Aggressive interactions may have been common among hellbenders at this site, indicated by wound patterns on large, adult individuals. Color variation and change was examined and compared to other sites throughout the range of the hellbender. Finally, management recommendations were suggested for the hellbender and its habitat in West Virginia.

Chapter 1: Species Description

The hellbender, *Cryptobranchus alleganiensis*, is one of the largest salamanders in the new world. *Cryptobranchus* may reach total lengths up to 74 cm (Bishop, 1941; Nickerson and Mays, 1973). They are also very long-lived salamanders, living up to 55 years in captivity (Nigrelli, 1954). Hellbenders are recognized by dorso-ventrally flattened bodies, laterally compressed tails, small eyes, and lateral folds of skin (Fig. 1). Dorsal patterns vary among geographical locations, ranging from grayish brown to orange or red. Darker spots or blotches are often present on the dorsum and tail. The ventral surface is usually uniformly gray to orange.

The hellbender is a habitat specialist, completely aquatic throughout its life and restricted to streams and rivers with a number of specific habitat requirements. Gas exchange occurs almost entirely through the skin (Ultsch and Duke, 1990). Thus, the hellbender is usually restricted to streams with oxygen tensions near air saturation and temperatures below 25° C. Such an environment is necessary for an animal restricted in its gas exchange capabilities (Beffa, 1976; Nickerson and Mays, 1973). A clean gravel bottom with numerous large, flattened rocks is also required for providing hiding places and nesting sites.

The range of the eastern hellbender, *Cryptobranchus alleganiensis alleganiensis*, is restricted to eastern North America, from southern New York south to Alabama and Mississippi, and west to Missouri (Fig. 2). The eastern continental divide, which separates the Mississippi and Atlantic drainages, provides the eastern boundary of the range of the hellbender. However, populations of hellbenders in southeastern New York occur in the Atlantic drainage. In West Virginia, the hellbender occurs statewide with exception of the Potomac and James River systems, which are east of the Allegheny front (Green and Pauley, 1987).

The Ozark hellbender, *Cryptobranchus alleganiensis bishopi*, occurs in southern Missouri and northern Arkansas (Fig. 2). This subspecies is distinguished by smaller spiracle size, increased blotching on the chin, smooth lateral line system in the pectoral region, and dorsal blotches instead of spots (Nickerson and Mays, 1973).

Because of the very specific habitat requirements of the hellbender, changes to stream systems are likely to result in declines in the abundance or in the complete extirpation of the species in many areas. Declines in the abundance and distribution of the hellbender have been recognized throughout much of its range, mainly attributed to habitat degradation (Nickerson and Mays, 1973). The status of most populations of hellbenders in the United States is unknown; some are considered stable, but most are considered to be in peril. The species is believed to be extirpated from Illinois, Iowa, and Kansas (it is uncertain whether it ever existed in Iowa). The hellbender is apparently secure in Mississippi, Missouri, Pennsylvania, and Tennessee. It is listed as a species of concern in West Virginia and New York, as Rare in Georgia, and as Endangered in Ohio, Illinois, Indiana, and Maryland. Changes which impact the natural thermal and dissolved oxygen regime or the bottom habitat in streams which contain hellbenders can threaten the health of those populations. Excess siltation and the impoundment of streams are the most common threats to the habitat of the hellbender (Nickerson and Mays, 1973).

Hellbenders are known from the Ohio River and were considered common in the river near Ohio and West Virginia in the 1930's (Green, 1934). However, it is unlikely that hellbenders still exist in many large river like the Ohio because of dams, channelization, and heavy siltation. Acid mine drainage from abandoned coal mines causes acidification, anoxia, and generalized sterilization of streams in the Appalachian Mountain region. The lack of hellbenders in what appear to be "healthy" streams today may be explained by past acid mine drainage problems that have since undergone remediation (pers. obs.). Other threats to local populations include stream channelization, eutrophication as a result of sewage plants or farm runoff, chemical pollution, and thermal pollution (Nickerson and Mays, 1973).

Though the hellbender is recognized as endangered or of concern in many states, it is generally considered stable and widespread in the central and southern Appalachians. However, very little is known about the historic distribution of the hellbender throughout its range, other than sparse records of sightings of the species. In West Virginia, studies have not been performed concerning the ecology or status of the hellbender. However, a study by Green concerning the stomach contents of several hellbenders was conducted in 1933. There are few historic records of the hellbender in West Virginia, and information concerning how abundant or extensive populations of the species may have been earlier this century, or even 20 years ago, is non-existent.

Chapter 2: Introduction and Overview

In 1934, N. Baynard Green stated that the hellbender "is found more abundantly in West Virginia, perhaps, than in any other region throughout its area of distribution." Sixty-five years later West Virginia may still have more populations of hellbenders than any other state. However, little is known about the hellbender in West Virginia. There are sporadic records of the occurrence of the hellbender throughout the state, but population demography or life history studies have not been performed in West Virginia. We have most likely lost the hellbender from entire watersheds in West Virginia. All of these extirpations have gone undocumented because of the lack of information on the historic abundance and distribution of the species. Only recently have major efforts been implemented to study the hellbender. These efforts have come mainly from the Natural Heritage Program, a joint effort between the West Virginia Division of Natural Resources and The Nature Conservancy. This study is the first step in understanding the ecology of the hellbender in West Virginia, and how to protect this species in the future.

In this study, aspects of the life history and population demographics of the hellbender were documented in a relatively pristine stream for the purpose of conservation and management of other similar areas. Judging from trends in suitable habitat declines, the hellbender is a species in need of conservation efforts. Learning more about the demography of a population of a long-lived vertebrate, such as the hellbender, is a key step in the management and conservation of this species. Migrations and seasonal activity patterns were also examined to determine the time frame in which future surveys for the species should take place. The timing of surveys for the hellbender could be very important in the accuracy of presence or absence surveys.

Second, and perhaps most importantly, baseline data were provided for future monitoring of populations. Global amphibian decline has become a major issue in the scientific community (Blaustein, 1994) and studies such as this one are an essential step in the study of changes to populations of animals. Understanding the dynamics of the population studied as well as simply documenting the abundance and density in this stream is necessary to study future changes that may occur, and to compare this site to others throughout the Appalachians.

Chapter 3: Study Site Description

This study took place on the West Fork of the Greenbrier River, 1.7 miles north of Durbin, in northern Pocahontas County, West Virginia (Fig. 3). The Greenbrier River flows in a southwest direction and is a tributary of the New River, in the Mississippi drainage. The West Fork of the Greenbrier River begins on the eastern slopes of Shaver's Mountain, and forms a watershed that is part of the Monongahela National Forest. There is no development other than several camping areas between the head of the West Fork and the study site location. However, most of the forest in this watershed was cleared at the turn of the century and some logging still takes place.

In the vicinity of the study site, the stream consists of a series of fast flowing rapids, fast flowing calm water, and few deep pools. Most of this part of the river is less than 60 cm deep at normal water levels. The deepest pools are generally less than 2 m deep. The stream bottom consists of gravel and cobble with some finer sand accumulating in the slower portions. A shale or limestone bedrock underlies the entire stream, and narrow chutes of rapids occur where slabs of bedrock protrude from the stream bottom. Underwater shelf-like rock outcrops in the stream provide hiding places for aquatic organisms, probably including hellbenders. Many large rocks are present in the stream which consist of both jagged slabs of limestone bedrock, but mostly of rounded, weathered pieces of limestone and igneous rocks. Many of the rocks are flattened and provide adequate cover for hellbenders. Due to the limestone dominated nature of the bedrock in this part of West Virginia, the water is generally alkaline. The elevation of the study site is approximately 838 m (2,750 ft.). A steep hillside on the south side of the study site is densely vegetated by a mixture of rhododendron, hemlock, and northern hardwoods. To the north is a narrow floodplain area sparsely vegetated by shrubs and rhododendron, with few large hardwoods.

The study site consisted of a stream section 216 meters long and approximately 20 meters wide. A grid system was set up at the study site by attaching orange construction flags to bricks and lodging them in the stream substrate so that flags were visible several inches above the water surface (Fig. 4). Each quadrat within the grid was 9 m x 9 m (the odd number due to stream width restrictions in some areas). The grid consisted of three flags across the width of the stream and twenty-four flags along the length. A map of this grid was made so exact hellbender locations could be recorded.

Within the study site there were three relatively deep, slow areas and two shallow areas of faster rapids (Fig. 5 and 6). Relative water depth, taken at a single point in the study site is shown in Figure 7. During the lowest water periods in August, rapid areas appeared to be a barrier to migration as water levels dropped below 8 cm. Water depths during low water conditions varied from less than 10 cm in the rapids to nearly 1 m in the deepest pools. Flooding occurred during every major rain event (the field site was flooded almost the entire month of June) and water levels often rose to two meters for periods of several days. During some flooding events, the stream maintained its clear visibility, however the water appeared muddy after many heavy rains. Water temperatures ranged from less than 2° C in winter to 23° C in July, however most of the summer the water temperature remained below 20 ° C. During winter months, the stream generally froze around the edges.

Chapter 4: Study Site Surveys and Marking Techniques

Study Site Surveys

The study site was surveyed both day and night, but most effort was focused on night searches. Water temperature, air temperature, and weather conditions were taken at the beginning of each survey. Dissolved oxygen (model no. YSI 55) and pH (Oakton pH meter 2) were taken at approximately 10 A.M. on the day after each night survey in order to correct for diel fluctuations in these parameters. The water depth was taken at the same point at the beginning of each survey (near a piece of attached bedrock for consistency) and this measurement was used as a point of reference for stream depth. Streamflow data were provided by the U.S. Geological Survey, from a gauging station at Durbin, West Virginia. Though the data are from the year before this study (October, 1996 to September, 1997), they provide an estimate of the stream discharge on a seasonal basis.

Night surveys were performed as follows: Beginning just before dark, between two and four people searched the stream bottom with flashlights. When a hellbender was located, all searching ceased and it was grabbed by hand, put into a dipnet, and taken to the water edge for processing. During the day, a log peavey was used to lift as many rocks within the study site as possible.

After the capture of a hellbender (day or night) the following tasks were performed: The capture location was placed on a stream map and the distance to the nearest shore, the water depth at capture, and the activity of the hellbender at time of capture were recorded. If the hellbender was obviously emerging from a hiding rock or was barely visible under a rock (as was often the case), the greatest length, width, and height of the rock were measured, as was the depth of water to the top and bottom of the rock. The position of the entrance hole on each rock (facing upstream/downstream/side) was noted and a specific number or letter was engraved into each rock with a metal file. The hellbender was weighed to the nearest gram using a 2,500 g Pesola scale. Total length measurements (to the nearest 1/10 cm) were taken using a 15 cm diameter PVC pipe cut in half with a sewing tape-measure glued along the inside. This aided in keeping the hellbender straight during measurements. Maximum head width (to the nearest millimeter) was measured with a plastic vernier caliper placed over the width of the head until the greatest skull width was found. This point was generally found just behind the eyes. Any wounds, including missing toes, limbs, or divots in the tail were noted as were dorsal color, ventral color, and blotches or spots. Sex was determined by the presence or absence of a swollen cloaca.

Most of the surveys performed for this study took place at night. Night surveys began in late March and continued through mid October. Each survey began at dusk and ended only after the entire study site was searched at least once. All surveys were ended by 2:00 A.M., and usually encompassed about 1.5 to 2 hours of actual searching time. If the searches were ended prematurely by storms or other problems and only a portion of the site was searched, the search was continued the next night and both days were included as a single sample period. In addition to searching the study site regularly, we searched approximately 0.25 mile upstream and downstream of the study site when possible to document movement in and out of the study site. Those hellbenders captured outside of the study site were not included in abundance and density estimates, but were included in all other aspects of the study.

Marking Technique

Each hellbender was marked with a passive integrated transponder (P.I.T.) tag (Avid #2003) during its initial capture. A syringe was used to inject the tag under the fatty layer of skin in the dorsal region of the base of the tail, starting from the posterior end. Tags and syringes were sterilized with isopropyl alcohol before injection, though preparation was not made at the injection site on the hellbender either before or after injection. Immediately after injection, the tag number was recorded and the hellbender was taken back to the site of capture and released. If the individual was initially under a rock, care was taken to put the rock back in its original position and the head of the hellbender was placed near the entrance hole until it voluntarily crawled back under the rock. The processing procedure generally took between five and ten minutes per hellbender. When hellbenders were re-captured, the same measurements were taken, but the tag only had to be scanned using an electronic reader. Wounds from the injection of P.I.T. tags healed with no sign of complications within a day (as observed in several individuals) and there was no evidence to suggest that any individuals shed their tags. No shifting of tags within the body was observed, probably because the fatty layer on the tail aided in holding the tag in place. This method of tagging is assumed to have no adverse effects on the movement or behavior of individuals, and should last the life of the hellbender.

Overview of Findings

Nineteen mark and recapture surveys were performed between April 24, 1998 and October 10, 1998. Only 18 mark-recapture periods were used in population calculations because two night surveys were combined into one due to bad weather interrupting survey efforts. The study site was surveyed 73 person hours during the summer.

Air temperature and water temperature show normal seasonal fluctuations (Fig. 8 and 9). The mean water temperature between April 24 and October 10 was 17.7 ° C, and the maximum temperature was 22.5 ° C. The lowest water temperature recorded was 1.5 ° C on November 22. Dissolved oxygen in the study site ranged from 5.3 mg/L during July to 14.5 mg/L in November. The accuracy of the equipment used to measure dissolved oxygen is questionable and the values reported may not reflect the actual dissolved oxygen of the stream. The pH of the study site ranged from 7.2 to 8.8, with a mean of 7.8. Water depth within the study site varied 30 cm between low water and high water events (Fig. 7). However, water depth was not measured after heavy rainfalls when the river became too dangerous to work in; the water probably rose over 1 meter from its normal levels. Mean and maximum discharges were highest in November, December, and March, and lowest from July through September (Fig. 10).

Forty-one hellbenders were marked during the 1998 season. Table 1 is a list of all hellbenders captured, including their tag number, gender, mass, total length, and color. Twenty-nine hellbenders were captured within the study site and were used in abundance and density calculations. Of the 29 individuals found within the study site, 13 were captured once, 8 were captured twice, 1 three times, 4 four times, 2 six times, and 1 was captured thirteen times. Among all hellbenders captured, 19 were males, 18 were females, and 4 were of unknown sex. The sex ratio was 1.06:1.

Chapter 5. Population Demography

Introduction

Population demography includes information about the population size, age structure, reproduction, and spatial characteristics of a species (Primack, 1993). Such information is important in predicting the future of a population; whether it is stable, decreasing, or increasing. However, it is sometimes difficult to predict the future of a species or population because of difficulty in studying all size and age classes within that population. This was the case for the hellbender population examined in this study. In this chapter, I provide a population and density estimate of hellbenders within the study site. I also present morphometric data and use these data to examine the size and age structure of the population studied. Finally, the reproductive status of hellbenders within the study site was examined. All of this information is a key step in understanding the population demography of hellbenders in the West Fork of the Greenbrier River. As stated before, it is also important as baseline data for long-term monitoring at this location.

Methods

Calculation of Population Estimates

Population estimates of hellbenders within the study site were calculated based on 18 survey days, 29 individuals permanently marked, and 71 total captures. Population estimators can be divided into two groups: open models and closed models. Open models allow for immigration and recruitment as well as death or emigration. Closed models assume no gains or losses of animals within the population. I considered the population studied to be a closed population. No emigration or immigration was observed at the study site; no animals marked inside the site were captured outside of the site and no animals marked outside of the site were captured within the site at a later time. No deaths were noticed within the study site, however a dead individual was discovered 50 meters upstream during the summer. Despite this finding, the hellbender is a long-lived species and predation on adults is probably infrequent.

Despite the assumption that the study site represented a closed system, both open and closed models of population estimates were used. Assuming a closed model, the computer program CAPTURE (Otis *et al.* 1978; White *et al.* 1982; revised by Rexstad and Burnham 1991) was used to analyze the data collected in this study. This program analyzes mark-recapture data through a series of tests looking for time, behavior, and heterogeneity effects within the population. The best estimator is suggested by the program and 95 percent confidence intervals of populations estimates are given.

The computer program JOLLEY 3.6 (Center for Conservation Biology, Stanford University; Dunn and Hellmann 1997) was also used as an abundance estimator, assuming an open population. It uses the basic algorithm of Jolly (1965) to calculate population estimates. Because this program assumes additions or reductions in the study population, changes in capture probability can greatly affect the population estimation calculated.

Densities were calculated using the population estimate from the closed model and the surface area of the stream and are presented as number of individuals per 100 m^2. Biomass was calculated using the density of hellbenders within the study site and the mean mass of all individuals marked in the stream.

Morphometric Data

Morphometric data were determined for all hellbenders captured in the vicinity of the study site (n=41). Thirty-seven hellbenders (19 males, 18 females) were used in comparisons between the sexes because four of the 41 were of unknown sex. The average of measurements (total length and mass) taken during all captures of an individual were used in calculations. All statistics reported in description of the data and comparisons between the sexes were performed using SigmaStat version 2.0 for Windows. I will describe and compared data among sexes including: (1) total length in centimeters, (2) mass in grams, (3) relative head width, found by dividing the head width (mm) by the total length (cm), and (4) girth, found by dividing mass by total length. T-tests were performed to compare morphometric data between the sexes.

Size Classes and Age Estimates

Histograms were produced using total length data from all hellbenders captured during this study (n=41). Ages of hellbender size classes were calculated using the length-age relationship derived from hellbender data from the North Fork of the White River, Missouri (Peterson *et al.*, 1983). Though populations in Missouri may have different growth rates, other growth studies have not been performed. Thus, the age estimates calculated for individuals in this study are only approximations. The equation used was as follows:

$$Age_{(months)} = (1/-0.0127)\ln(5.2193 + (-0.0127)TL_{(mm)}) + 120$$

This equation can only be used to calculate ages of hellbenders up to about 40 cm total length. Because growth becomes very slow in older adults, hellbenders over 40 cm total length are assumed to be at least 25 years old, but more precise age estimates for adults are not possible.

Reproduction

Several techniques were used to determine the extent to which reproduction occurred at the field site. I seined for larvae, lifted rocks and searched for eggs, and examined the condition of the male cloaca at various times of the year. Larvae searches were performed using a 4' x 4' mesh seine stretched across areas just below rapids and by stirring up the gravel with a potato rake. Searches for eggs were performed from August to mid-October. Finally, the condition of the male cloaca was used as an indicator to gauge the timing of possible reproduction. All male hellbenders captured in or near the study site were included in this portion of the study. The time at which the cloaca was most swollen was assumed to be when fertilization of eggs would most likely take place. Also, the presence of milt seeping out of the cloaca in males was assumed to be a strong indicator of breeding periods. The extent of cloacal swelling in males was grouped into four categories: Not swollen (NS) indicates that no sign of swelling was apparent; Slightly swollen (SS) indicates that it was apparent that the hellbender captured was a sexually mature male, but significant swelling was not present; Fairly swollen (FS) indicates that significant swelling was apparent; Very swollen (VS) indicates that the cloaca had reached its maximum extent of swelling -- during such time a ring of small tubercles was apparent around the opening of the cloaca, the opening was often dilated, and milt could be seen on the external portion of the cloaca (Fig. 11).

Results

Population Estimates

Closed Population: The model selected to calculate a population estimate within the study site by the program CAPTURE was M (o), which assumes constant probability of capture. The population estimate was 31 individuals (SE = 2.017). With a 95 percent confidence level, the study site contained between 29 and 39 individuals during the summer of 1998.

Open Population: The population estimate of hellbenders within the study site throughout the summer of 1998, as calculated by the program JOLLEY, is found in Figure 12. The estimated population size was 63.2 individuals. However, using this method the population fluctuated greatly over the sample period, ranging from only a few individuals to 100 individuals.

Density: Using the closed population estimate of 31 individuals, the density of hellbenders within the study site was 0.80 individuals per 100 m^2. However, the area between quadrat 2 and 12 contained a much greater density of hellbenders than the rest of the study site. Based on actual captures in this section, the density was 1.17 individuals per 100 m^2. The biomass of hellbenders within the study site, using the density estimate, was 39.8 kg/ha. Density and biomass are reported in Table 2, and are also compared to other streams throughout the range of the hellbender.

Morphometrics

Mean total length of all hellbenders was 45.3 cm, varying from 29.5 cm to 56.5 cm. Females ranged from 39.0 cm to 56.5 cm total length, and males ranged from 29.5 cm to 51.9 cm. Females (48.3 cm) had significantly greater mean total lengths than males (42.7 cm) (p=0.004).

Mean mass of all hellbenders was 496.9 g, ranging from 150.0 g to 905.8 g. Females ranged from 323.0 g to 905.8 g, and males ranged from 150.0 g to 640.0 g. Females (584.2 g) had significantly greater mass than males (414.7 g) (p=0.003).

A measure of relative width of the head was determined by dividing the head width (mm) by the total length (cm) of each hellbender and is presented as a unitless number. Relative head width was not significantly different between the sexes. Males had a relative head width of 1.082 compared to females with 1.079.

Females (11.91 g/cm) had a significantly greater mean girth (mass / TL) than males (9.50 g/cm) (p=0.006).

Size Classes and Age Estimates

A histogram comparing total length and age to frequency of all hellbenders captured during this study is shown in Figure 13. Eighty-three percent of all hellbenders captured were large adults, over 40 cm total length, and were considered to be over 25 years of age. Only three hellbenders were 11.5 years of age and the youngest was approximately seven years old. Only two individuals were amongst the largest group of hellbenders (55-60 cm total length). Figure 14 is a histogram comparing total length to frequency of males and females captured during this study. There is a distinct shift in the histogram from male to female body size compared with frequency. The majority of females were over 45 cm total length, whereas the majority of males were under 45 cm total length. Females under 35 cm total length were not captured during this study, whereas six males were under 35 cm total length, and one male was under 30 cm total length.

Reproduction

All animals captured during the summer were mature adults. However, actual signs of successful reproduction were not apparent during this study. Seine surveys failed to yield larvae. Likewise, eggs were not found during the study period. Several females found during July and August appeared to be gravid, based on their swollen abdomens.

Examination of the swelling of the male cloaca indicated the timing of fertilization of eggs that would take place if gravid females were also present. Nineteen males were examined during the course of the summer. Some variation existed in the extent of swelling in individual hellbenders, but trends remained fairly constant. Cloacas of all male individuals exhibited a continuum from non-swollen to very swollen and back to only slightly swollen during the course of the summer. Two hellbenders (determined to be males later in the season) had non-swollen cloacas on May 16 and June 26. Slightly swollen cloacas were apparent from May 22 to July 25. Fairly swollen cloacas were found from July 18 to August 15. Very swollen cloacas were observed from August 20 to September 11, and milt was also apparent externally in several of the individuals in this category. Cloacas returned to a slightly swollen state between September 6 and October 10.

Discussion

Population Estimates

Population estimates are oftentimes difficult to determine because of constraints in the effectiveness of searching efforts or because of the cryptic nature of many animals. Changes in the nocturnal activity of hellbenders during the summer and the apparent ability of hellbenders to escape detection from researchers for long periods of time can make estimating their numbers difficult. For instance, several unmarked individuals were captured on the same night during the end of August. This influx of previously undiscovered individuals translated to a dramatic population increase (to 100 individuals) according to the Jolley plot of population over time. For this reason, I believe the open model for estimating the hellbender population within this study site has too many flaws to be used. I do not doubt that some migration into and out of the study site occurred, but I think changes to the population were exaggerated using this method.

The closed population estimate of 31 +/- 2.017 seems reasonable from my experience searching for hellbenders within the study site. However, unmarked hellbenders were still being captured on occasion when the study ended in the fall of 1998. Only 12 individuals were captured and marked outside of the study site. I did not find any individuals entering or leaving the study site. However, it is important to note that most animals marked in this study were captured early in the summer, but were not found again later in the summer.

Thirteen of the 29 hellbenders marked were only captured once. How these individuals avoided capture again during the summer remains unknown. It may be explained by the number of hiding places that existed within the study site. I oftentimes observed presumably the same head of a hellbender protruding from an imbedded piece of bedrock every week. These individuals were in inaccessible hiding places and may have been some of the same hellbenders which were active, and which I marked early in the summer. We would oftentimes turn most of the rocks in the study site during the day without finding hellbenders, but during the same night many individuals would be active. Many of the same individuals may have always been within the study site, but eluded our searching efforts. For example, we captured hellbender no. 0A00083714 (a large female) regularly and in nearly the same place on most of the nocturnal surveys early in the summer, always actively walking the river bottom. This individual was not captured between July 27 and October 3, despite intensive searching during that period. It was diurnally active when it was found in October and was less than 10 meters from where it had last been observed in June. During the time it was “missing” we would regularly see the head of a very large hellbender protruding from beneath a massive slab of bedrock near were it had last been seen in the open. This may have been the same hellbender, simply avoiding detection by using cover inaccessible to our searching efforts.

Rivers in the eastern U.S. tend to have lower densities and thus lower biomass of hellbenders than those in the Ozark Mountain region (Table 2).

Butternut Creek in New York (Blais, 1996) had the lowest density of hellbenders reported, whereas all of the rivers in Missouri and Arkansas (Peterson *et al.*, 1988) had relatively high densities of hellbenders. West Virginia and Pennsylvania (Hillis and Bellis, 1971) are in the middle with regard to density. It is important to note that the studies in New York, Pennsylvania, and this study are only based on a single section of one stream. Other streams or sections of streams could have higher or lower densities than those reported from the central Appalachians. Density is probably highly correlated with the number of large rocks available for cover.

Size Classes and Age Estimates

The shift in female body size, towards a greater number of larger individuals compared to males in this study suggests several things. First, the survivorship of young females may be low. Why survivorship in young females would be low is uncertain. The other possibility is that small female hellbenders may have evaded our search efforts, perhaps because they are less active than males of the same size.

Peterson *et al.* (1983) and Ingersol (1982) found that females over 32.3 cm total length in Arkansas and Missouri were sexually mature. Assuming there is not a great difference in size of maturity between hellbenders from West Virginia and those from the Ozarks, all of the females in this study were most likely sexually mature. Several researchers have stated that males mature at a smaller size (Dundee and Dundee, 1965) and at a younger age than females (Taber et al., 1975; Peterson *et al.*, 1983). The smallest male hellbender found in this study, at 29.5 cm total length, was sexually mature based on its swollen cloaca. Based on this information, all hellbenders in this study were sexually mature adults. The age estimates for hellbenders in this population also indicate that the study site contained a large proportion of old individuals (25 + years) and few young individuals (7-25 years old). Perhaps differences in the activity of hellbenders of differing sizes could explain why small, young individuals were not found. However, the large proportion of large, old individuals could be an indication of the health of this population. This type of population shift may be the result of low recruitment over the past decade, indicating a population that is unstable and susceptible to extirpation as the large adults die off. Unfortunately, data are not available concerning the demography of this population several decades ago for comparison. It is possible that the population is cyclic and the proportion of animals in the smaller size class may shift within the next decade.

Reproduction

Green (1934) stated that the spawning season of hellbenders in the vicinity of Elkins (35 kilometers from my study site) was from the middle of August to the first week in September. He wrote that they come out boldly during the day in the spawning season, often congregating with many others. Scott Blackburn (pers. comm.) found an egg mass of a hellbender on the Williams River, West Virginia, in September 1997. Both of these reports, coupled with the reproductive state of hellbenders at my field site, indicate that the breeding season is in late August and early September in the mountains of West Virginia. However, there is obviously little information about the reproductive success of hellbenders in any rivers in West Virginia. Some of the females I captured appeared gravid during August, and some of those same females appeared spent by October. However, eggs were not discovered within the study site. Perhaps there is an area where congregations of breeding adults occur that I did not find. I also seined for larvae on many occasions, but found none. The lack of hellbender larvae from rivers with apparently stable populations of adult hellbenders seems to be commonplace for other research sites. Either hellbenders have very low recruitment, they have not been breeding for the past ten years in the West Fork of the Greenbrier River, or the larvae simply evaded our search efforts.

Chapter 6: Movements, Habitat Use, Interactions Among Individuals, and Coloration

Introduction

This section investigates the interactions among hellbenders and their environment, as well as interactions among individual hellbenders. Studying the movement, habitat use, and seasonal activity of hellbenders is important for conservation efforts that may take place in the future. Also, aspects such as seasonal activity are important for the success of future surveys for the hellbender in other streams. Presence or absence studies will be more precise if searches for the species are performed during peak activity periods. In this section, I also discuss some interesting aspects of hellbenders found during this study. These include wounds and scars, and how they may relate to interactions among individuals. Also, color variability and change are discussed, as several theories have been proposed concerning of color variation in hellbenders.

Methods

Movements

Because of the low recapture rate of hellbenders in this study, reporting movement data in terms of home range is not appropriate. Instead, linear movements were calculated by measuring the greatest distance between capture points, measured lengthwise along the stream. Because the study site averaged only 18 m in width, movements tended to be generally upstream or downstream. Linear movements were calculated for animals recaptured at least once and for those with at least a one month interval between captures. Comparisons of linear movements among the sexes were made using a t-test.

Habitat Use

Methods for studying habitat use are given in chapter 2. They included the measurement of water depth, distance to shore, and hiding rocks at each hellbender capture point. Each time a hellbender was captured, its location was placed on a map of the study site to determine spatial distribution of individuals and the entire population.

Seasonal Nocturnal Activity

Seasonal activity of hellbenders was determined by standardized nocturnal searches within the study site. The number of individuals active at night (not hidden under rocks) was compared to the number observed with only a small portion of their bodies visible from beneath a rock; usually their snouts were barely visible (Fig. 15). Since nocturnal searches were generally performed with the same effort during each sample period and within the same timeframe, data presented concerning activity during the course of the summer reflects relative nocturnal activity of hellbenders. This information is provided so that future nocturnal searches in other streams can be focused around the time of year that hellbenders exhibit the highest degree of nocturnal activity.

Wounds and Color Variability

Patterns and the extent of wounding and scarring on individual hellbenders were recorded at each capture. Dorsal color and blotching patterns of each individual were also recorded at each capture. These data are descriptive and will be presented in the discussion section of this chapter.

Results

Movements and Home Range

The mean linear movement of 14 hellbenders within the study site was 20.1 +/- 4.7 m. Linear movements ranged from 0.8 - 70.2 m. Males did not differ significantly from females (p=0.674). The mean linear movement of six males was 17.7 +/- 4.3 m and the mean for eight females was 22.0 +/- 7.8 m. Refer to the Appendix for diagrams of the actual movement patterns of selected individual hellbenders within the study site.

Habitat Use

The mean water depth at which hellbenders were found was 32.7 +/- 8.7 cm. The minimum depth was 16.0 cm and the maximum was 56.0 cm.

The mean distance to the nearest shore from each hellbender capture point was 6.34 +/- 2.89 m (the average width of the stream was 18 m). The minimum distance a hellbender was captured to the nearest shore was 1.0 m and the maximum distance was 13.0 m.

The mean size of hiding rocks used by hellbenders (LxWxH) was 81.0 cm x 64.1 cm x 12.9 cm. The smallest rock used by a hellbender was 45 cm x 40 cm x 4 cm. The largest was 125 cm x 128 cm x 12 cm.

The location of all captures of hellbenders within the study site during the summer of 1998 is shown in Figure 16. The most densely populated portion of the study site occurred within the first 90 meters.

Seasonal Changes in Nocturnal Activity

Numbers of hellbenders hidden and active during nocturnal searches from April through October, 1998 are shown in Figure 17. Seasonal activity was also presented as the percent of active hellbenders captured during each month out of the total active hellbenders captured during the summer (Fig. 18). The highest probability of finding hellbenders nocturnally active was in May and June. A higher proportion of animals was hidden during nocturnal searches as the summer progressed. By October, very few individuals were active or barely visible during nocturnal searches – it was difficult to find any individuals during nocturnal searches.

Discussion

Movements and Home Range

Though I could not determine home range because of the low recapture rate of hellbenders, the linear movements of most hellbenders in this study indicate that they remain within a rather small area throughout the summer. Other researchers have reported similar results. Hillis and Bellis (1971) found that the average inter-capture distance for males was 18.8 m and 18.7 m for females in French Creek, Pennsylvania. They also used a measure of home range by determining the mean activity radius (MAR), which is a mean of distances from the center of the activity of an individual to all capture points. The average MAR for 73 hellbenders was 10.5 m. If the average MAR was used as a circular home range, the average home range size was 346.4 m^2. Coatney (1982) calculated an elliptical home range size of 90 m^2 for seven Ozark hellbenders radiotracked nocturnally for two weeks. Peterson and Wilkinson (1996) used minimum area convex polygon (MCP) to calculate home range of 50 adult hellbenders in Missouri. The average home range size of females was 28 m^2 and 81 m^2 for males. All of these values are relatively small, and even though I could not determine home range in the West Virginia population, trends indicate relatively small areas of activity (refer to the Appendix).

Coatney (1982) suggested that the home ranges of hellbenders overlapped, but they avoid being in the area of overlap at the same time. This is supported by the fact that hellbenders are rarely found under the same shelter rock, except during breeding. Several researchers have reported that hellbenders will defend shelter rocks (Peterson and Wilkinson, 1996; Hillis and Bellis, 1971). Peterson and Wilkinson (1996) also suggested that defensive behavior in a home range is related to shelter rock use. Many of the hellbenders I studied had what could be referred to as overlapping home ranges. During several nights in May and June, I witnessed up to five hellbenders within about a 20 m diameter area, all presumably foraging for crayfish. I also witnessed two individuals within several centimeters of each other on several occasions. They did not appear to be exhibiting defensive behavior, and on all of the occasions both hellbenders would eventually walk away from each other and continue with their normal behavior. All combinations of sexes exhibited this behavior (male-male, male-female, female-female). Perhaps such non-aggressive interactions cease during the breeding season when males may be competing for both shelter rocks and females.

Habitat Use: Shelter Rocks

Of the 29 hellbenders marked within the study site, 15 were found under rocks at least once. Nine were males and six were females. Of the 19 rocks used by hellbenders, only one rock was used by two different hellbenders (on different occasions). Since little effort was made to find hellbenders within the study site by turning rocks during daytime, most of the hellbenders found under rocks were using them for cover at night, waiting at the entrance hole with their head visible. Twenty captures of hellbenders under rocks were made at night while 10 captures were made during the day. Twelve hellbenders used a particular rock only once, one used a particular rock twice, one used a particular rock three times, and one four times. However, since the study was not focused around daytime surveys, these numbers are probably not indicative of actual shelter rock use or fidelity.

Hiding rocks were generally flattened and most were imbedded in the stream substrate. An entrance hole was usually present on the downstream or, less often, the perpendicular side of the rock to the stream flow. The entrance hole was easily recognized because it had a small ramp of sand that was apparently pushed out by the hellbender. The substrate beneath most hiding rocks consisted of sand or very small gravel and an area was usually dug out to accommodate the body of the hellbender. Several hellbenders used rocks that were leaning on other rocks, almost vertically, with entrance holes at the top of the rock. Every hellbender found in association with such rocks exhibited the behavior of having its head and arms protruding out into the water current. When these individuals were spotted with a flashlight they would always quickly retreat into the hole. As was generally the case in other studies, we never found more than one hellbender under a hiding rock.

Seasonal Changes in Nocturnal Activity

Hellbenders became active just after dark during the summer months. We witnessed many individuals halfway out of their hiding rocks at dusk and out walking around several meters away within minutes after the onset of darkness. Between 1 and 2 hours after dark was the period when hellbenders were most active and the time when the highest densities of active hellbenders were observed. The latest active hellbenders were observed was 3:30 A.M., but surveys were not made any later than that time. Noeske *et al.* (1979) and Coatney (1982) found that maximum activity of hellbenders occurred between 2 - 2.5 hours after dark. Noeske *et al.* (1979) also recognized a second, smaller activity period of activity at dawn.

When hellbenders were observed at night, they were either completely in the open or only a small portion of their body was visible from beneath a rock. These two scenarios will be referred to as either active or hidden, respectively. “Hidden” hellbenders oftentimes had their heads protruding out from a hiding rock and would quickly pull back under if approached. “Active” hellbenders seemed oblivious to our flashlights and would continue in their normal activity unless they were touched. They would slowly walk the stream bottom, sometimes prodding under rocks with their heads, presumably in search of crayfish. In this section, I will describe the changes in the nocturnal activity of hellbenders within the study site, as this information is important to future surveys of the species. I will be as specific as possible about the activity of hellbenders in relation to time of year; though sometimes anecdotal, I believe the information is useful.

When this study began, I had intended to perform both diurnal and nocturnal searches to study this population. However, after several nights in the field at the beginning of the summer, it seemed that nocturnal searches were more productive and required fewer hours to perform. May and June were the months during which nocturnal searches for hellbenders were most productive. Unfortunately, these months are also the flood season in the mountains of West Virginia and searching had to be done during low water. We conducted nocturnal searches during March and April, but did not encounter the first hellbender until April 24. The study site was then flooded for the next two weeks. On May 16 we found six active hellbenders, though the water was still fairly high; more hellbenders were probably active but the high water inhibited searching. Nocturnal activity of hellbenders was highest on May 22. Our actual searching time was approximately 2.5 person hours and we found ten hellbenders within the site and four outside of the site. All hellbenders encountered on that night were completely in the open and appeared to be foraging. One individual was swallowing a crayfish when we caught it. In the upper 60 meters of the study site, several individuals were observed within 1 meter of each other. Two hellbenders encountered were on top of a stoneroller (*Campostoma anomalum*) nest and were touching noses. On no other night were hellbenders as active and visibly abundant as on May 22. The field site was flooded for the next four weeks and the next time the site was searched was June 26. June 27 marked the beginning of decreased hellbender activity.

During July, few hellbenders were observed at night and several were only barely visible under hiding rocks. By early August, the water level in the stream was very low, relative to the beginning of the summer. The rapids within the stream decreased to only several centimeters in depth and the stream became a series of pools separated by trickling water. Many of the hiding rocks that hellbenders had been observed under earlier in the summer were on dry land during the low water period. The water was also very still and any active hellbenders, or even those hiding under rocks, were easily visible. A majority of the hellbenders encountered during August were beneath their hiding rocks with only their snouts protruding. They were weary of our flashlights, quickly retreating if approached. Many of the hellbenders in such positions were males, though females also exhibited the same behavior. The same scenario of decreased nocturnal activity continued through September and early October.

Why did hellbenders decrease their nocturnal activity as the summer progressed? When I first noticed the decrease in activity during July, the water was very low and clear. It seemed possible that the hellbenders were remaining hidden because predation by bears or raccoons may have been very easy in such shallow and calm water. However, even when water levels rose later in the summer, activity did not show a correlated increase. Other possibilities include changes in food availability or changes in nutritional needs by hellbenders throughout the season. Blais (1996) witnessed very little nocturnal activity in hellbenders in south-central New York, and he described them as "sit and wait" predators. He hypothesized that since there were relatively few hellbenders at his study site and an excess of available crayfish and other food items, there was no need for hellbenders to actively pursue their prey. The population I studied is relatively dense, though whether crayfish are a limiting factor is unknown. I noticed several large crayfish walking in the open on the stream bottom during all of the nocturnal searches throughout the summer. There were also many small fish (minnows, sculpins, suckers, bass) in the open during the night on all of the searches. Perhaps prey availability was high enough in the second half of the summer that hellbenders did not need to actively pursue it. But why were hellbenders more active in the spring?

Since hellbenders apparently enter a state of torpor for several months during the winter in West Virginia, their energy needs may be very high during the spring when water temperatures rise and hellbenders come out of winter torpor. I hypothesize that hellbenders must actively forage during the spring in order to supply the energy demands for producing ova in females, and for the enlargement of testes in males. Ingersol (1982) found that the deposition of yolk in the ova of the female was most rapid and dramatic from the period between May until late June, increasing the oocyte diameter by approximately 2.5 mm. Ingersol (1982) stated that yolk deposition was much slower during the period between late July and September, with the oocytes increasing 0.8 mm during that time. In addition, Ingersol found that the percent of body weight testes composed in male hellbenders increased dramatically from June until late July, reaching 3.73 percent. Testes regressed beginning in October, and remained regressed through the following May. Because both of these activities, yolk deposition and testes enlargement, occur within a relatively narrow time-frame during early summer, there is probably a high nutritional demand on the hellbenders just prior to this period. Therefore, hellbenders may need to consume prey quickly to supply this demand during May and June. This would correspond to the high activity levels in May and June observed in the population I studied. Perhaps the nutritional demand in hellbenders is lower later in the summer and "sit and wait" foraging strategies provide enough food to sustain them. However, a "sit and wait" strategy may not be adequate during periods of high nutritional demands, and this may be one reason for increased active foraging behavior early in the summer.

Wounds: an indication of hellbender interactions?

A high percentage of hellbenders captured during this study were wounded in some manner; missing toes, missing feet, missing eyes, deep lacerations on their heads or limbs, and divots on their tails. Forty-nine percent of all hellbenders captured were missing toes or feet and 29 percent had major wounds or the scars of major wounds on their bodies. Nickerson and Mays (1973) suggested that canoe traffic on rivers may account for such wounds by displacing rocks and crushing the hellbender hiding underneath. However, canoe traffic does not exist on the West Fork of the Greenbrier River. I suggest several other causes of wounds. All terrain vehicles (ATV's) oftentimes cross the river in areas of shallow rapids and the weight of the ATV's would most likely have detrimental effects on hellbenders beneath rocks. Second, bear and deer walk through the river regularly and could also crush hellbenders beneath hiding rocks. Presumably anglers or researchers could have the same effect. Finally, the wounds could be caused by attempted predation by bear, raccoons, or large fish. Though all of these scenarios may account for some harm to hellbenders, I believe that most of the wounds may be the result of hellbenders inflicting bites on each other. William Flannagan (pers. comm.) was attempting to breed several hellbenders at the Toledo Zoo during the fall of 1998. When males were placed with females, the female frequently bit the "intruding" male, inflicting very deep wounds to the male's body similar to those observed on wild hellbenders during this study. Males also tended to bite females when the two were placed together.

The patterns of scarring (on either males or females and the time of year they occur) may be indicative of interactions among hellbenders. In this study, 42 percent of males were missing toes whereas only 28 percent of females had similar injuries. Similarly, 32 percent of males had major wounds (*eg*. legs torn open, deep gashes in their heads) whereas only 17 percent of females were wounded in such a manner. Of hellbenders with major wounds, all were over 41 cm in total length (n=9), and most were over 47 cm. Most of the "young adults" found in this study were not wounded in any manner, suggesting that older hellbenders may be confronting each other more often. It also appears that males were involved in more confrontations with each other than females. Alternatively, males may be receiving bite wounds from females, perhaps during courtship. In support of this, five of the six males with major wounds had large pieces of flesh taken off the top of their heads. This is the same type of wound inflicted on the captive male by the female at the Toledo Zoo. Nickerson and Mays (1973) also reported head biting between two Ozark hellbenders. One Ozark hellbender had the head of a larger individual in its mouth and there was "considerable blood in evidence." Both hellbenders were 35-40 cm total length, but they were not sexed. William Flannagan (pers. comm.) also reported a male hellbender having the entire head of a female in its mouth in captivity.

A correlation was not found between the breeding season (August and September in this population) and the time in which most hellbenders received fresh wounds. A female had a torn leg and tail on May 16, a male had a fresh divot in its head on July 25, and another male had a similar wound on September 5. A male had a patch of skin ripped off of its venter on September 11 and a female had a fresh wound on its face on September 12. One particular male that was covered in old scars had its leg ripped open on September 5. This male, no. 0A00083814, appeared to "defend" a territory in which it was the sole inhabitant of several rocks in the same vicinity throughout the entire summer.

Regardless of the cause of wounds on hellbenders, most of them healed rather quickly. One individual was observed with its right rear leg ripped completely open and its foot dangling by a small piece of skin on May 16. By October 10, its leg was healed and though it only had two toes left, its leg and foot were fully functional again. Another individual was wounded in a similar manner, with its leg torn open and bone visible, on September 5. It took less than one month for the wound to completely heal. Hellbenders obviously receive many wounds during their lives, considering the number of scars on individuals. Such wounds appeared to have little effect on their ability to function normally. Netting (1929) referred to a hellbender that "was shot three times with a .32 cal. revolver and only temporarily stunned, for it was quite active until it was killed 24 hours later."

Color Variability and Change

The dorsal ground color of hellbenders captured during this study are given in Table 1. A high percentage of individuals (34 %) had an orange dorsal color at some point during the summer (n=41). Forty-four percent of females and 32 percent of males were orange. Two individuals were black with small white spots and scars, and the rest were olive-green to brown. Holbrook (1842) thought the red or orange variant of the hellbender was a separate species, *C. fuscus*. Grote (1877) believed it to be only a color variant, and Reese (1903) thought females maintained the red color during the breeding season to attract males. However, the high percentage of individuals exhibiting an orange color is apparently uncommon among hellbender populations. Nickerson and Mays (1973) found one hellbender out of 2,000 which maintained an orange color in the North Fork of the White River, Missouri. Only one of 83 individuals maintained an orange color in the Niangua River, Missouri. Why are so many individuals in the West Fork of the Greenbrier River in West Virginia orange? Fauth *et al.* (1996) found two individuals in Giles Co., Virginia with a red coloration and they suggested the color variant to be indicative of "chronic physiological stress." This hypothesis was based on the observation by Grote (1877) of a hellbender that escaped from a tank and was found three weeks later and had "changed color very decidedly, becoming a reddish-brown." Fauth *et al.* (1996) also described the stream from which the red variants came from as being impacted by siltation, and perhaps having high water temperatures and low dissolved oxygen during the summer, causing stress on hellbender populations.

The West Fork of the Greenbrier River appears to have healthy populations of hellbenders. Siltation is not impacting the stream to a great extent and water temperatures remain low even during mid-summer. I believe the orange or red hellbenders may be geographical color variants. The orange variant is very common in the mountains of West Virginia. During a survey of the Elk River, West Virginia, in early 1999, all of 13 individuals captured exhibited a bright orange dorsal color. Obviously, more study is needed to determine if there is a link between geographical proximity and high proportions of orange and red color variants, or if the idea of physiological stress is merited.

Another interesting observation among the hellbenders in this study is that three individuals changed from orange to brown or brown to orange. The most dramatic of these changes was hellbender no. 0A00083714, a large female which was bright orange both dorsally and ventrally with no blotching early in the summer. This individual maintained the orange coloration from April 24 to July 27, after which time it was not captured until later in the summer. When it was recaptured again on October 3, it was completely brown, except for one 1/4" spot of orange on its dorsum. Another female and a male changed from olive green to bright orange during the course of this study. Green (1934) suggested that the color of hellbenders varied with age, food, or water quality. Nickerson and Mays (1973) suggested that temperature and light apparently affects the color of hellbenders, causing them to change from brown to orange. Some individuals captured in this study changed from bright orange to a darker orange when they were captured and pulled out of the water. However, the female mentioned above definitely showed the most dramatic permanent change. In terms of cryptic coloration, the orange variants definitely stand out against the dark color of the river substrate. Orange hellbenders could be seen from 20 meters away using a flashlight at night whereas darker individuals were difficult to spot while standing within a meter of them. An explanation for color variation and change remains debatable.

Chapter 7: Status and Conservation

Extent of the Hellbender Population in the West Fork of the Greenbrier River

I surveyed for hellbenders at random places along the West Fork of the Greenbrier from my study site to the headwaters during the summer of 1998 and 1999. Hellbender populations are apparently continuous within the stream from its confluence with the East Fork of the Greenbrier River, upstream to the junction of the West Fork with the Little River at Burner. Above the town of Burner, the habitat becomes marginal for hellbenders. There are no major barriers within the West Fork of the Greenbrier River, and it is likely that the river contains what could be referred to as a single population. This situation is unique among rivers which contain hellbenders. Many rivers throughout the range of the hellbender consist of stretches of "usable" habitat and stretches of habitat uninhabited by hellbenders due to heavy siltation or man-made lakes. Such situations create sub-populations which may not interact, leading to genetically isolated populations. Disjunct sub-populations of hellbenders within rivers may also be more likely to be disrupted, or extirpated, by changes to the environment or by collecting.

Management Recommendations

Management for the hellbender in West Virginia should consist of preserving the quality of rivers that still contain this species. There are many rivers in the state that contain hellbenders, but very few that are in relatively pristine condition and have what are probably "natural densities" of the species. The West Fork of the Greenbrier River may still contain relatively unaltered populations of hellbenders. There are not large amounts of sedimentation in this river that separate sub-populations from each other, as is the case in other rivers. For instance, in Twelve Pole Creek in Wayne County, West Virginia, there is only one known population of hellbenders remaining in the entire stream (pers. obs.). The stream has become heavily silted, and the only place hellbenders persist is where a dam built early in the century has since crumbled, providing slabs of rock for hellbender cover. There may be several other populations along the stream that I am unaware of, but in general, the stream now houses very few, small (5-10 individuals) sub-populations of hellbenders. This scenario may be the norm for streams in the Appalachian Plateau portion of West Virginia, as such streams are more susceptible, and have been suscepted to more siltation than streams in the mountains. However, many of the mountain streams in West Virginia still have high densities of hellbenders (*eg.* Williams River, Cranberry River, upper Elk River, and Shavers Fork of the Cheat River).

There are continued threats to all of the possible hellbender streams in West Virginia. A dam and/or channelization is planned for the Greenbrier River, near Marlinton, West Virginia in the near future. Obviously either of the two options would destroy much of the hellbender habitat in this section of river. Siltation remains probably the greatest problem in West Virginia. Shavers Fork of the Cheat River has relatively high levels of siltation, and unless it is reduced, hellbender populations may be impacted. The upper end of the Gauley River, just above Bolair, West Virginia, is an example of incredibly high siltation. There is a hellbender record from this site from 1938. Now, it is hard to find a single rock in the stream because of the several feet of sand and mud which cover the streambed.

Finally, acid mine drainage is another problem that must be considered. The problem is that once a stream is disturbed by acid mine drainage, hellbender populations are most likely extirpated indefinitely. Whether hellbenders can be reintroduced after remediation is unknown.

Management for the hellbender should simply include protecting streams from impacts such as siltation, damming, channelization, excess nutrient loads, and acid mine drainage. The same efforts implemented to protect habitat for many other non-game and game species such as trout, mussels, and aquatic invertebrates also protect habitat for hellbenders. Reducing sedimentation in streams through better land use is probably the most important step in protecting streams which contain hellbenders.

Finally, I recommend that the collection of hellbenders from streams in West Virginia be made illegal for any reason. Companies which provide animals to classrooms for dissection are able to collect hellbenders freely from streams in the Appalachian mountains. Other collectors include zoos, commercial amphibian dealers, and those wishing to ship hellbenders overseas, as interest is growing to have them as pets. Hellbenders are long-lived vertebrates with apparently low reproductive recruitment, and populations are highly vulnerable to local extirpation if adults are removed from populations. Excessive collection can be directly attributed to catastrophic reductions in the abundance and distribution of some long-lived species of reptiles (*eg.* spotted turtles, bog turtles, wood turtles). The demand for hellbenders is growing and protective laws are needed before major losses are also seen in this species.

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Tables and Figures

Table 1. Gender, Size, and color of hellbenders captured in the West Fork of the Greenbrier River in 1998 ("U" indicates unknown sex; * indicates color change).

P.I.T. Tag No.	Sex	Mass (g)	Total Length (cm)	Color
0A00085615	F	323	39.0	orange
0A00086177	F	395	41.5	orange
0A00081432	F	348	43.5	olive
007-634-111	F	533	45.0	orange
008-127-071	F	405	45.2	olive
0A00082228	F	413	45.3	olive
0A00084955	F	560	46.8	olive to orange*
0A00087233	F	540	47.0	na
0A00081201	F	515	48.0	olive
not recorded	F	775	48.0	orange
0A00082146	F	540	49.5	olive
0A00083437	F	528	50.5	brown
0A00087268	F	645	50.8	orange
007-829-630	F	655	51.0	olive
016-279-597	F	821	51.0	brown
0A00087142	F	780	55.0	orange
0A00083714	F	906	55.3	orange to brown*
0A00083717	F	835	56.5	olive
Mean		**584**	**48.3**	
007-625-867	M	150	29.5	orange
0A00083525	M	221	33.2	olive
0A00060115	M	225	35.0	brown
006-798-526	M	330	38.0	na
0A00085974	M	350	39.0	brown
0A00085612	M	280	40.0	olive
0A00054800	M	500	40.5	brown
0A00083847	M	377	41.0	olive to orange*
0A000100207	M	390	41.5	brown
0A00081464	M	335	42.2	brown
0A00083243	M	433	43.0	orange
0A00055828	M	475	45.0	brown
0A00081426	M	558	46.0	orange
008-866-349	M	640	47.5	na
019-590-068	M	598	48.0	orange
007-864-097	M	555	49.0	orange
0A00081711	M	495	49.5	brown
0A00084548	M	463	51.3	black
0A00083814	M	505	51.9	black
Mean		**415**	**42.7**	
0A00081134	U	350	40.5	gray
0A00080924	U	400	42.5	na
0A00087302	U	570	47.0	na
006-572-610	U	660	49.0	gray
Mean		**495**	**45**	

Table 2. Density and biomass of hellbenders from several streams throughout their range. Density and biomass calculations based on data reported by the following researchers: [1] Blais (1996), [2] Hillis and Bellis (1971), [3] Peterson *et al.* (1988).

Location	Hellbender Density (individuals/100m^2)	Biomass (kg/ha)
West Fork of the Greenbrier River, West Virginia	0.8	39.8
Butternut Creek, New York [1]	0.1	5.3
French Creek, Pennsylvania [2]	1.0	na
Spring River, Arkansas [3]	4.3 0.9	418 69
Eleven Point River, Missouri [3]	4.3 6.1	92 208
Gasconade River, Missouri [3]	1.1	66
Big Piney River, Missouri [3]	2.4 5.8	117 309

Figure 1. Typical adult hellbender, *Cryptobranchus alleganiensis*, from the West Fork of the Greenbrier River, West Virginia. Photo taken in October, 1998. This individual was bright orange in color earlier in the summer.

Figure 2. Range of the hellbender, *Cryptobranchus alleganiensis.*

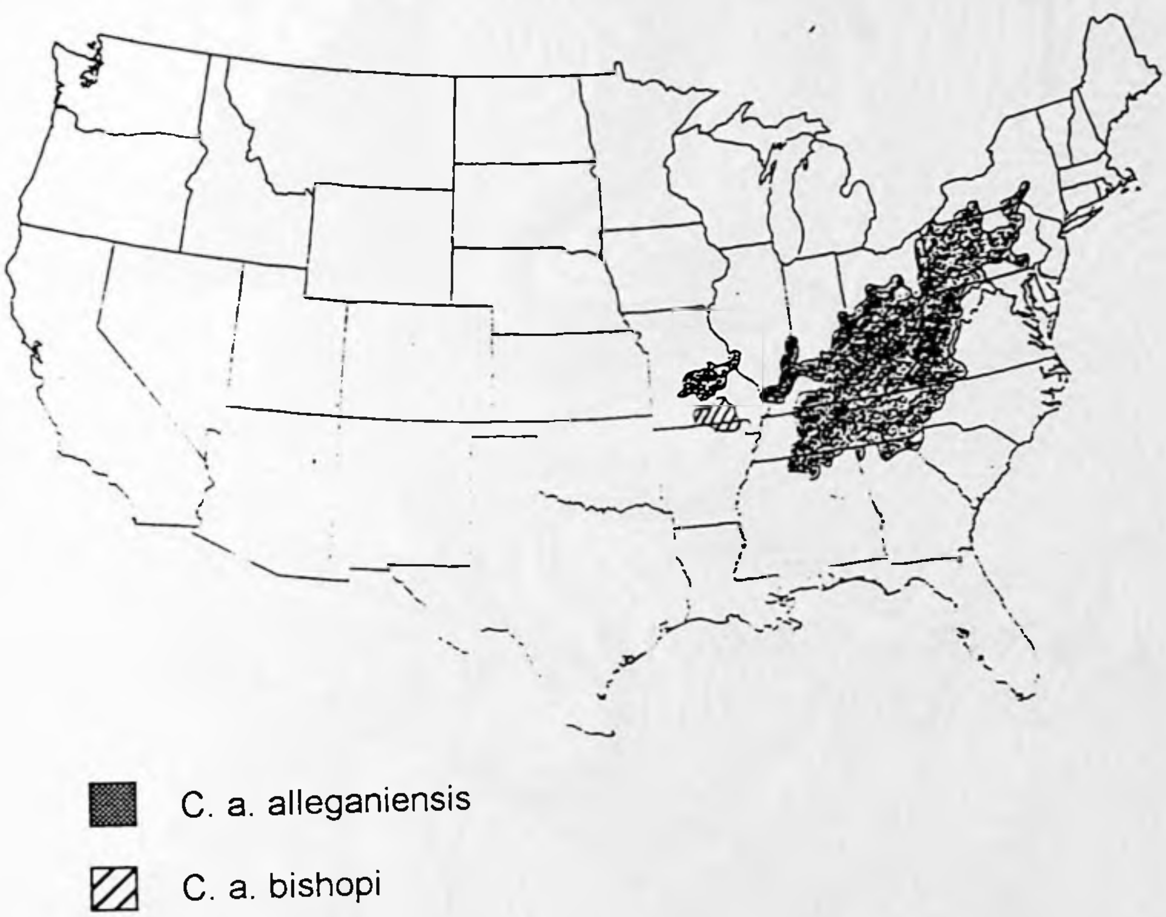


Figure 3. Location of study site on the West Fork of the Greenbrier River, Pocahontas County, West Virginia. General location is shown on inset map.
Actual study site was in the area approximately between the arrows on larger map.

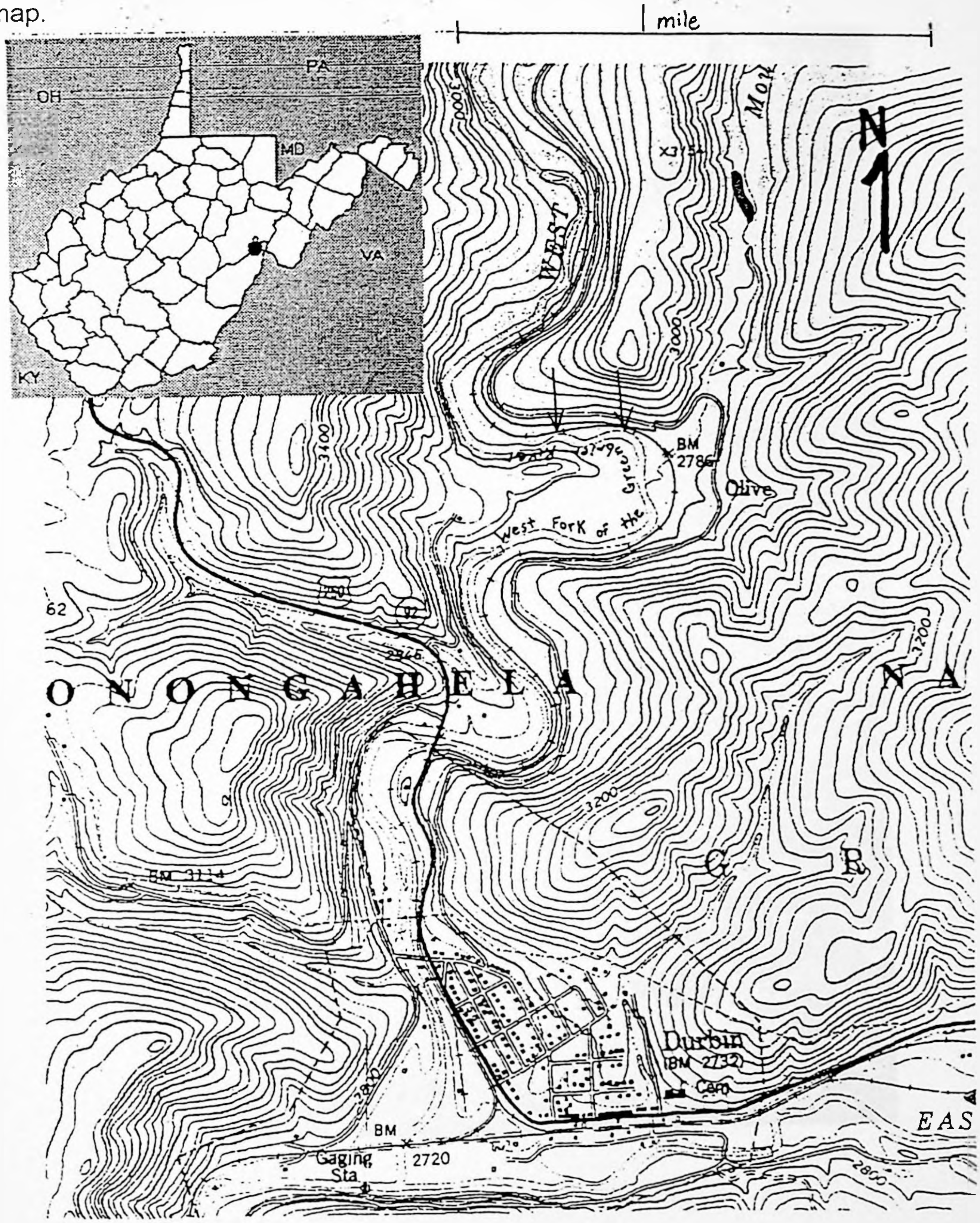


Figure 4. Photo showing grid system (orange flags) used to follow movements of hellbenders at the study site on the West Fork of the Greenbrier River.

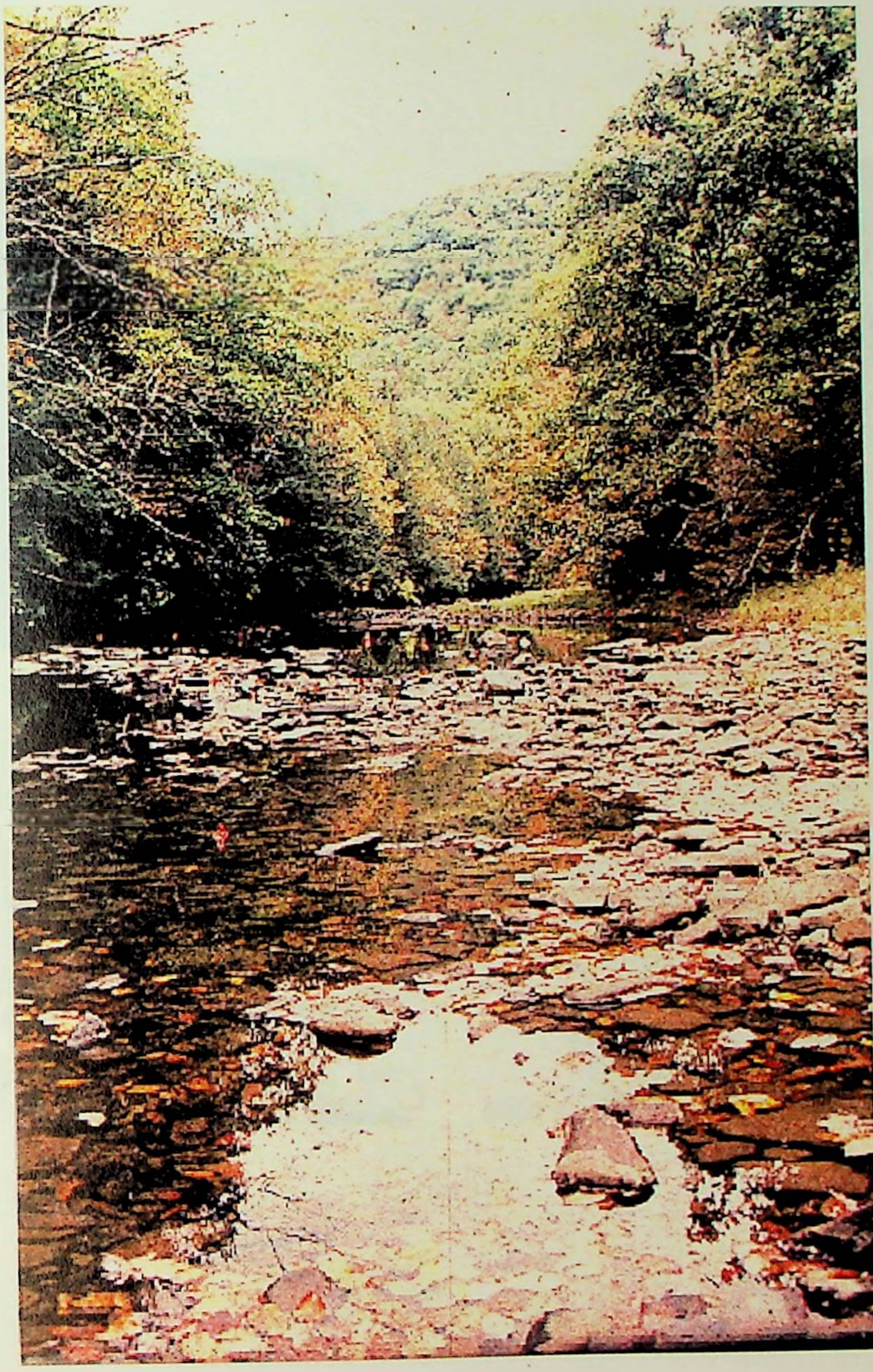


Figure 5. Upper portion of the study site on the West Fork of the Greenbrier River. The pool depicted had the highest density of hellbenders within the study site (1.17 individuals per 100 m^2).

Figure 6. Middle portion of the study site on the West Fork of the Greenbrier River.

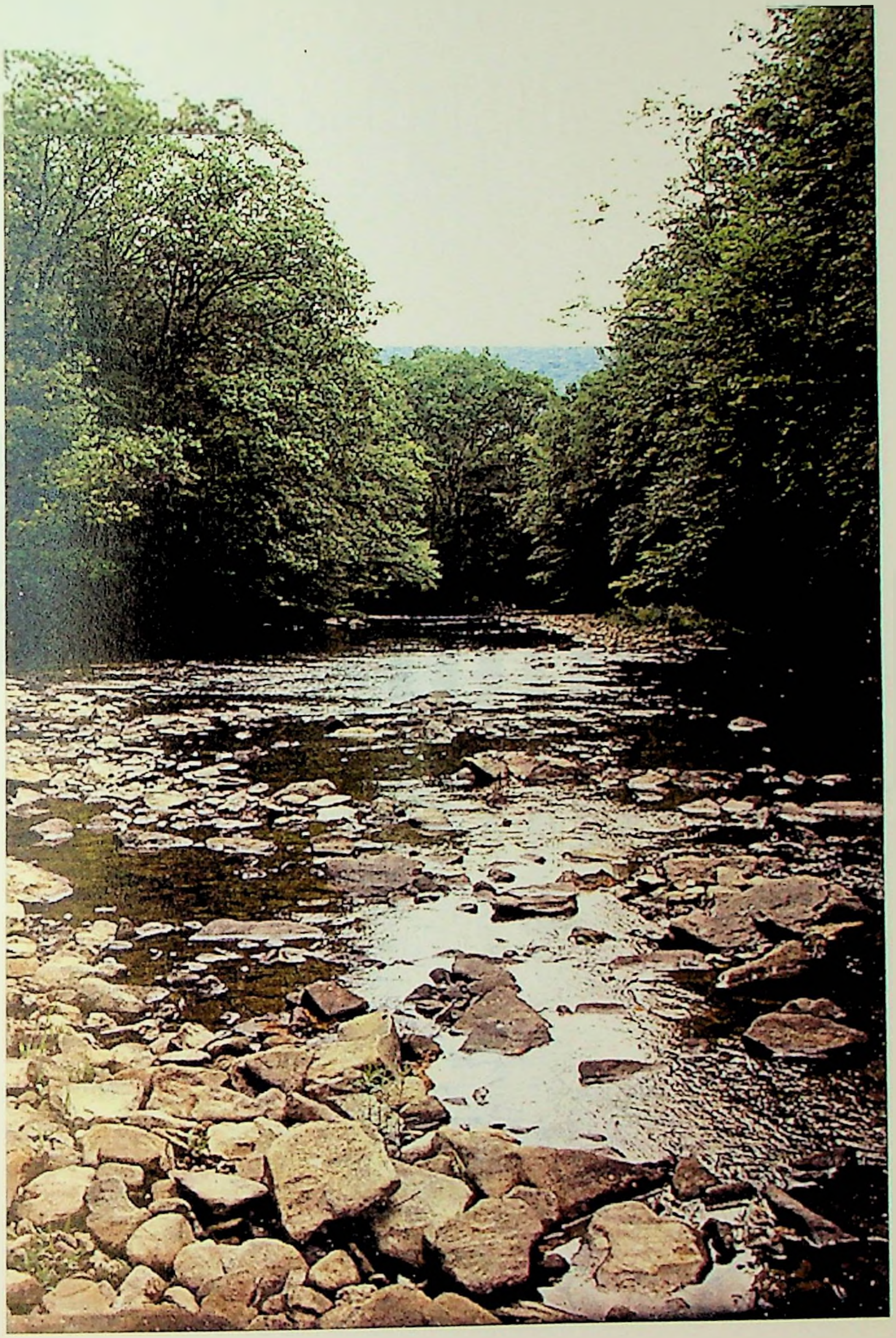


Figure 7. Water depth of a central location in the study site on the West Fork of the Greenbrier River, West Virginia, during the summer of 1998.

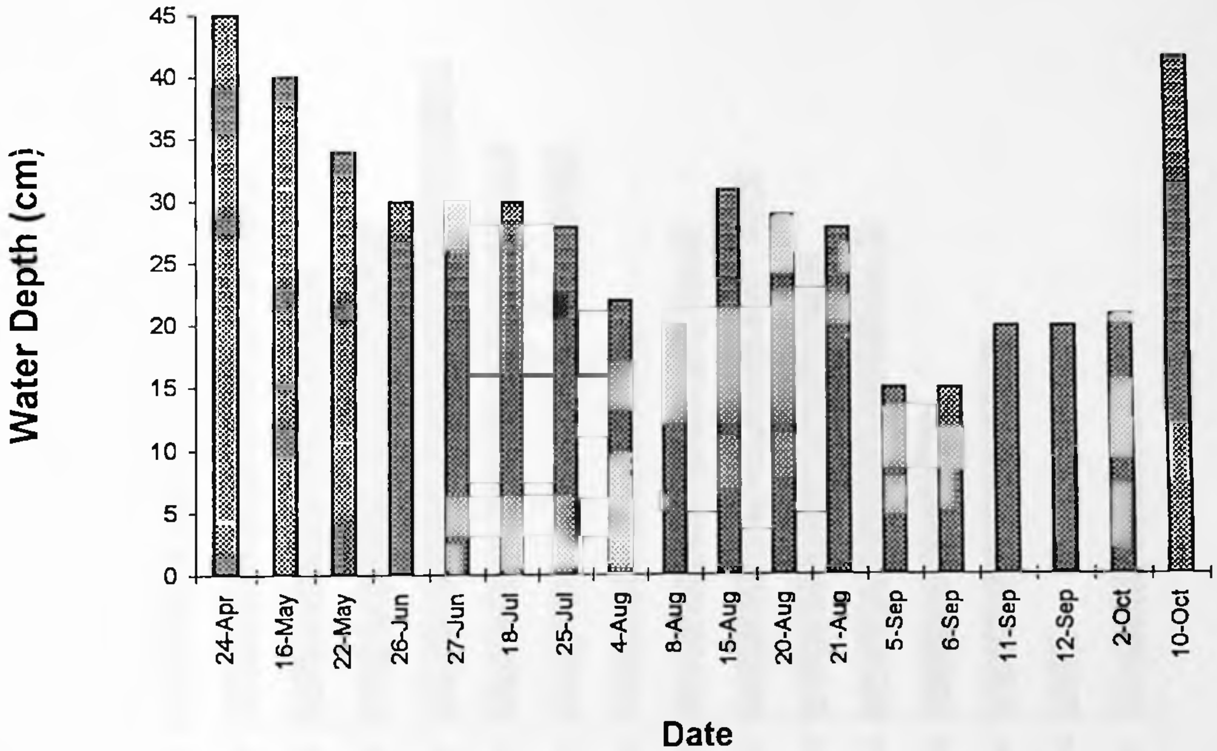


Figure 8. Air temperature at the study site on the West Fork of the Greenbrier River, West Virginia, during the summer of 1998 (temperatures taken at sundown on nights surveys for hellbenders were conducted).

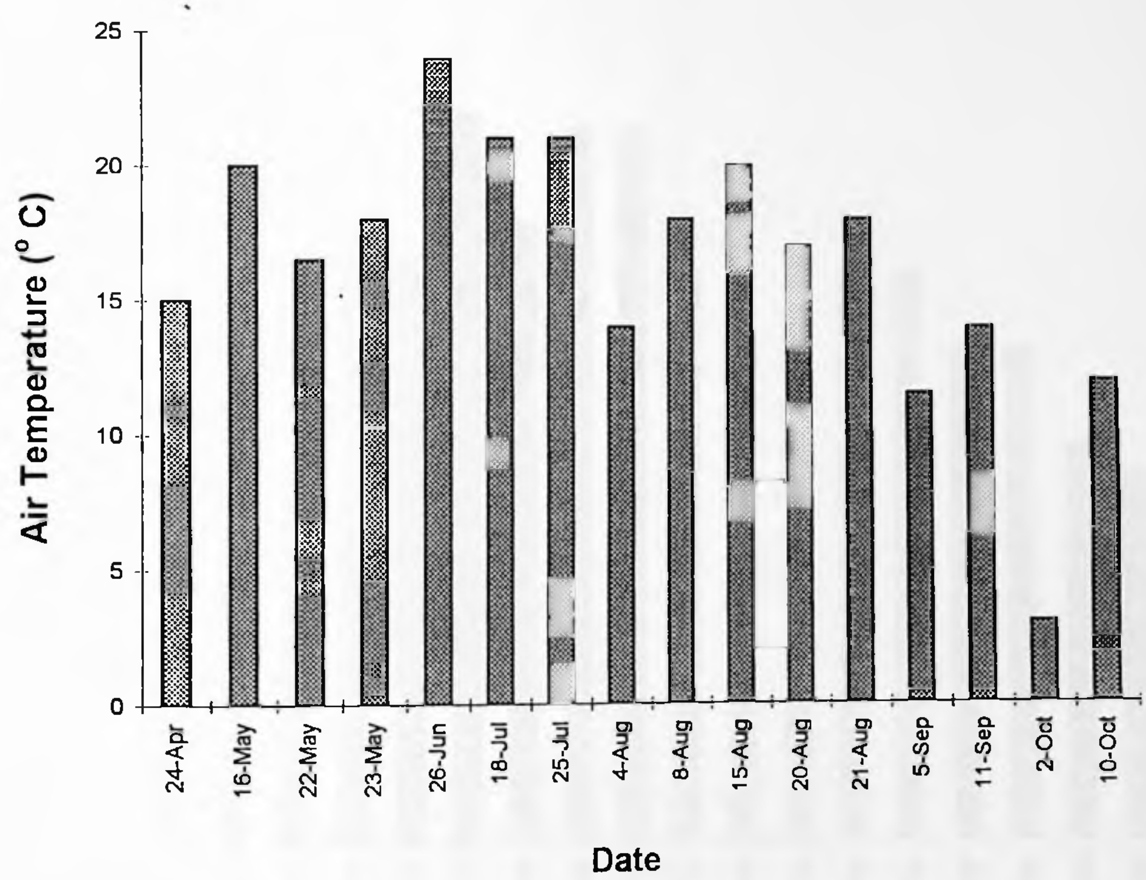


Figure 9. Water temperature of the study site on the West Fork of the Greenbrier River, West Virginia (temperatures taken at sundown on nights surveys for hellbenders were conducted).

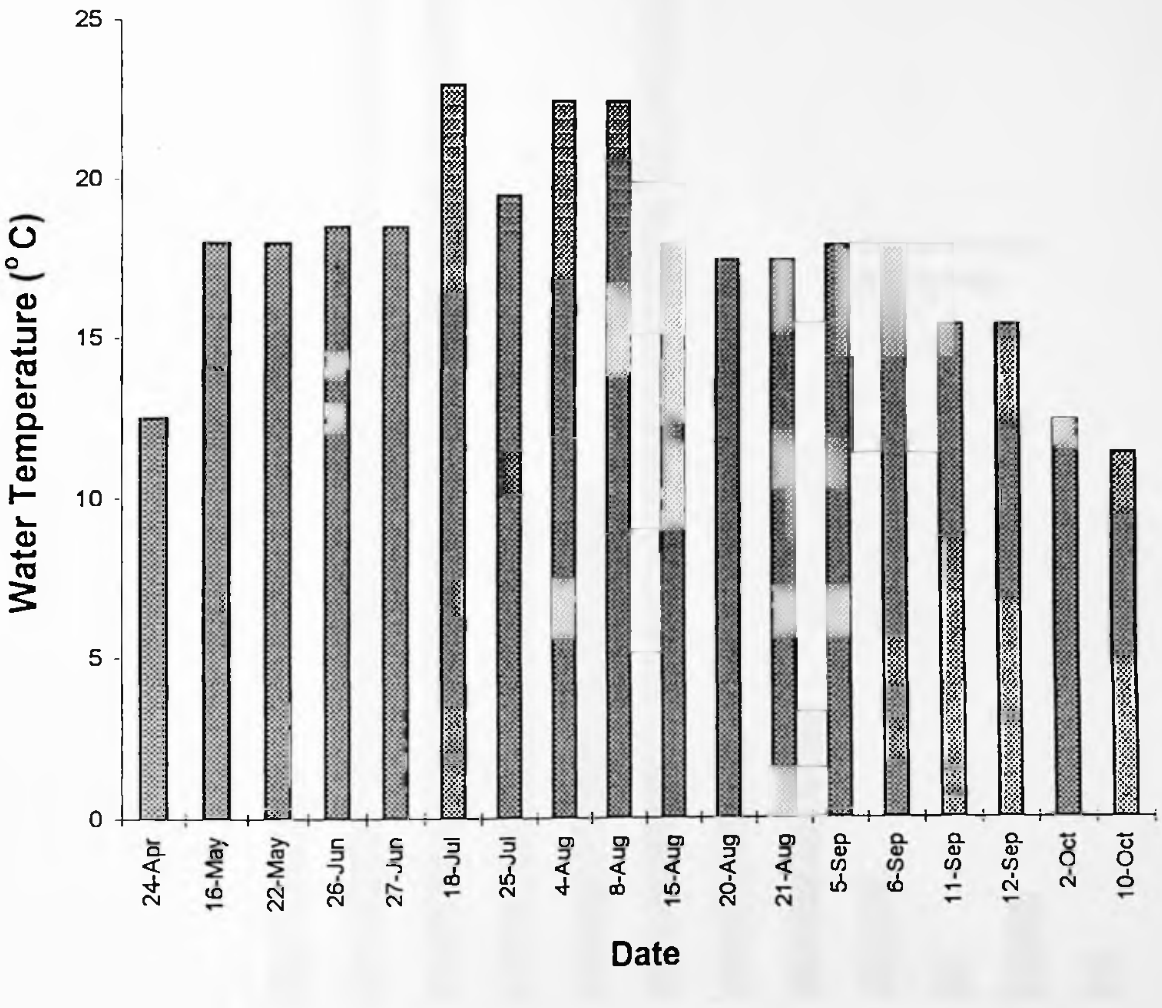


Figure 10. Average and maximum water discharge of the West Fork of the Greenbrier River from October, 1996 to September, 1997. Data from U.S. Geological Survey gauging station at Durbin, West Virginia.

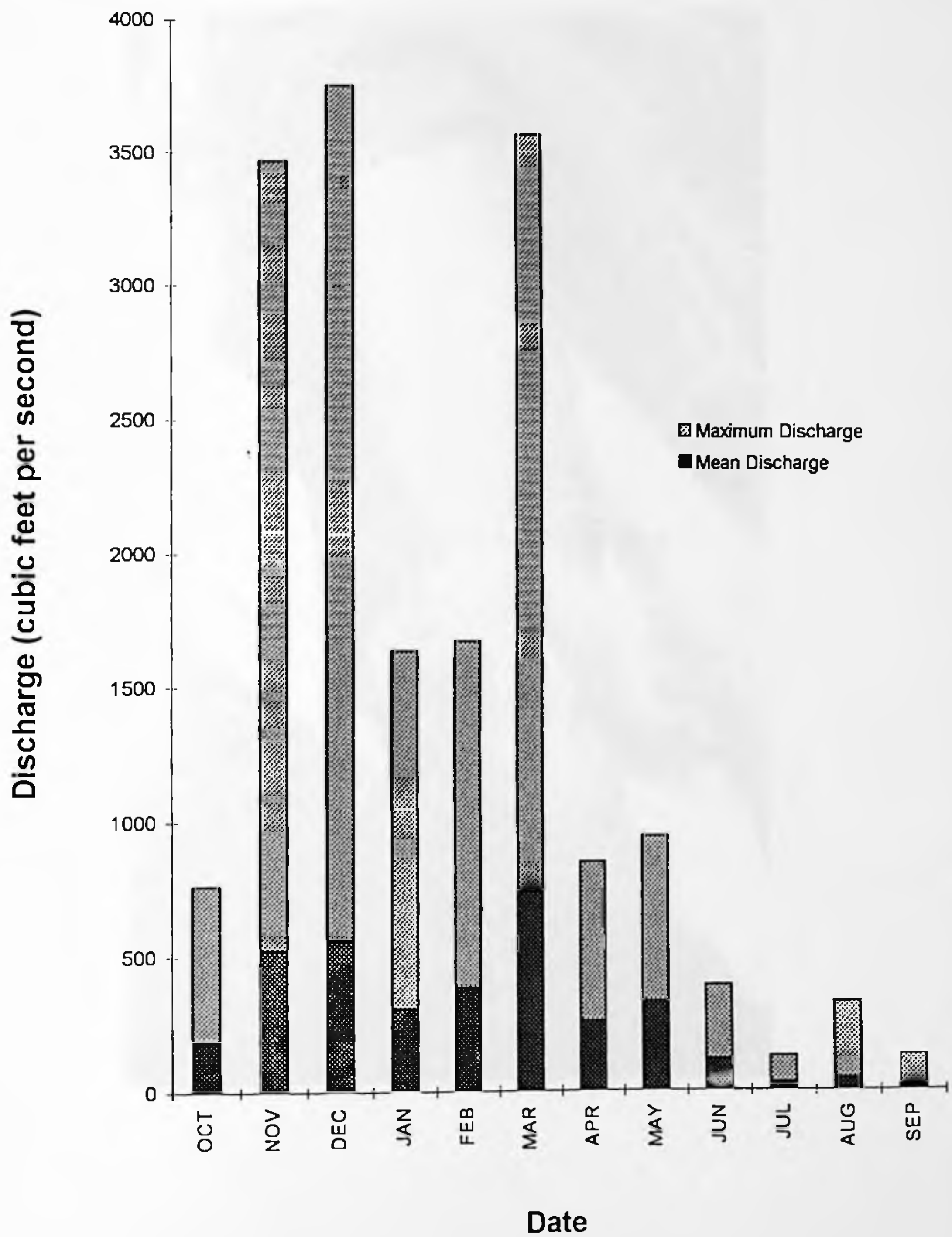


Figure 11. Male cloaca in maximally swollen state during breeding season. Photo taken in late August at field site on the West Fork of the Greenbrier River, West Virginia.

Figure 12. Plot of hellbender population size during the summer of 1998 within the study site on the West Fork of the Greenbrier River, West Virginia, using an open population model based on Jolly, 1965.

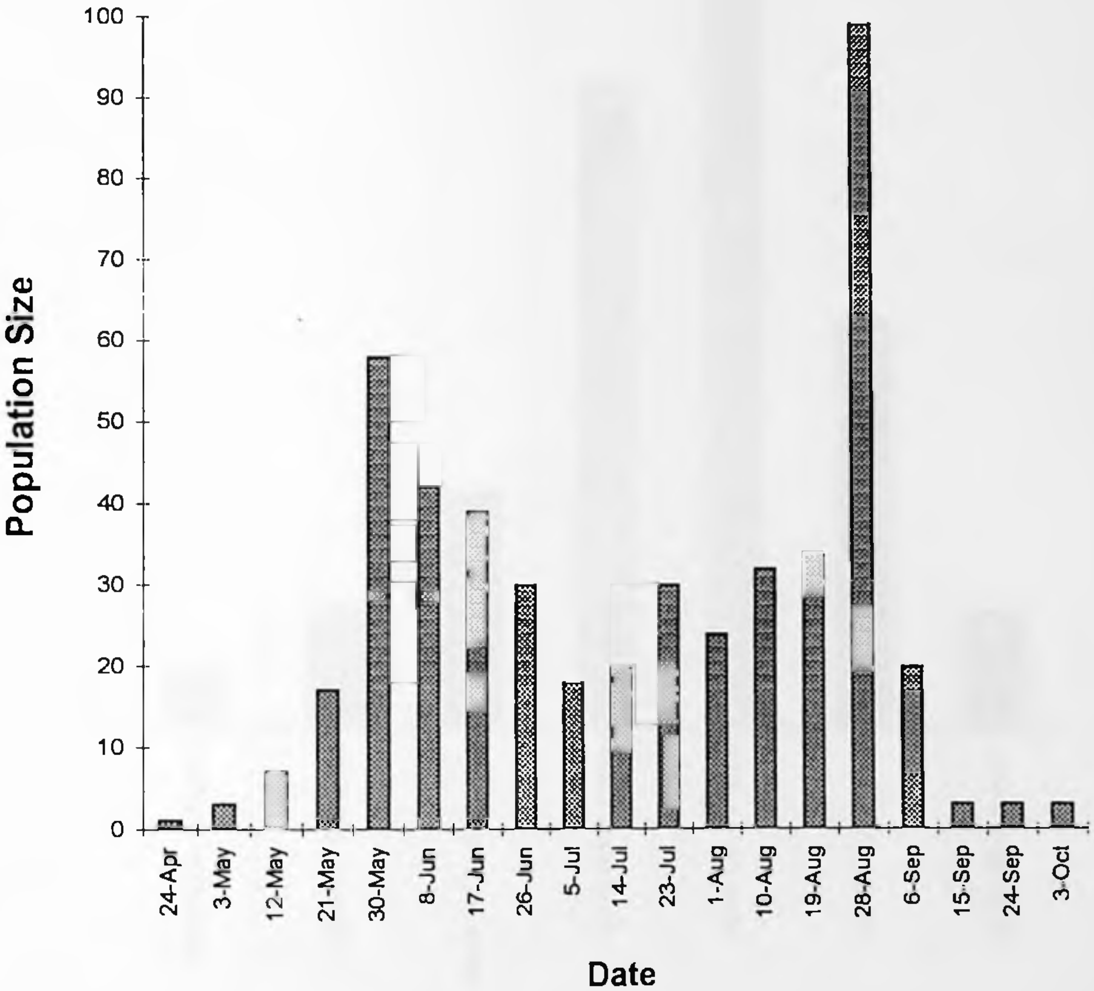


Figure 13. Size distribution and age of all hellbenders captured in the West Fork of the Greenbrier River (n=41). *Age data calculated using the length-age relationship derived from growth data of hellbenders from the North Fork of the White River, Missouri (Peterson *et al.*, 1983).

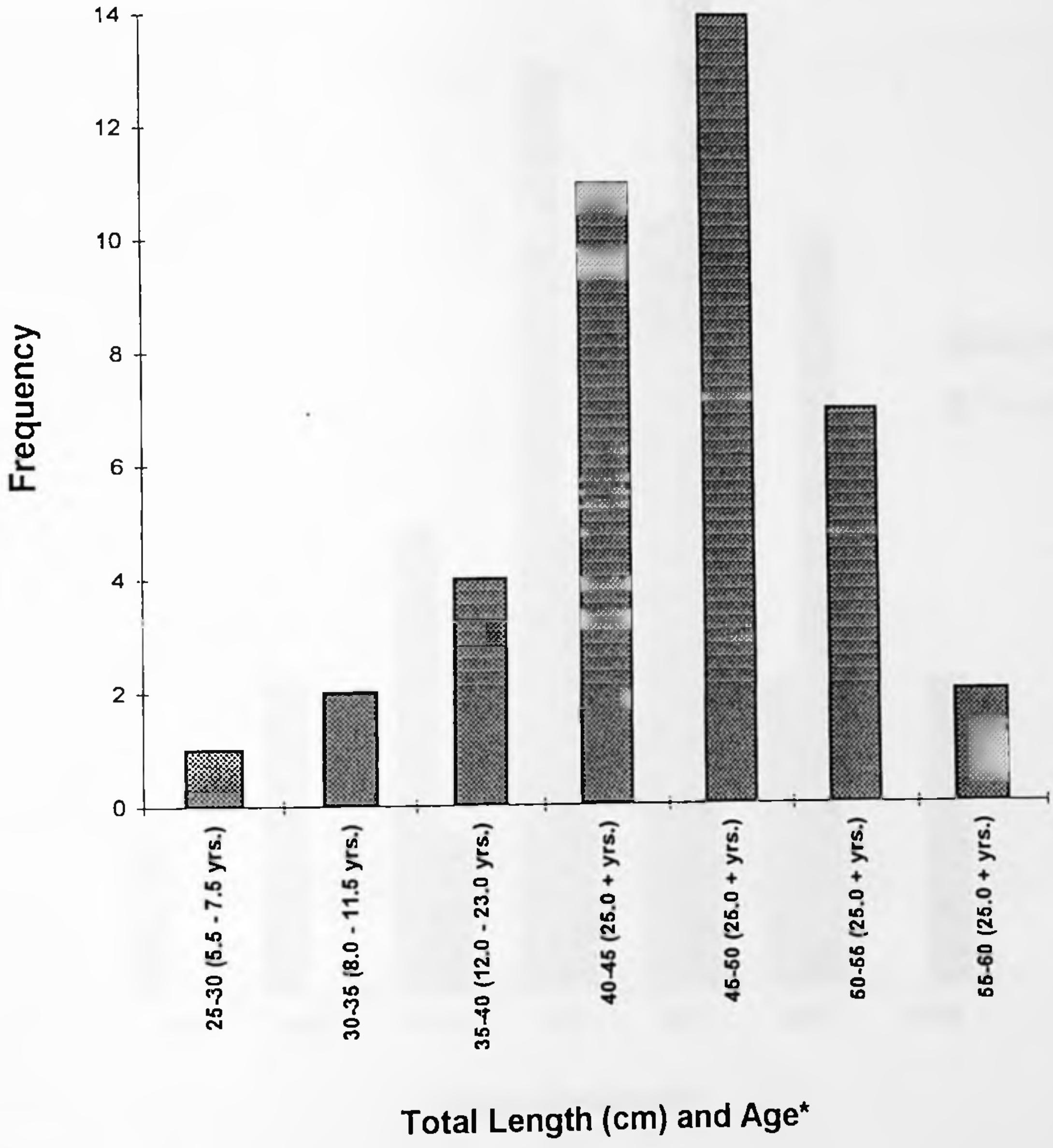


Figure 14. Size distribution of male and female hellbenders captured in the West Fork of the Greenbrier River, West Virginia (n=19 males, 18 females).

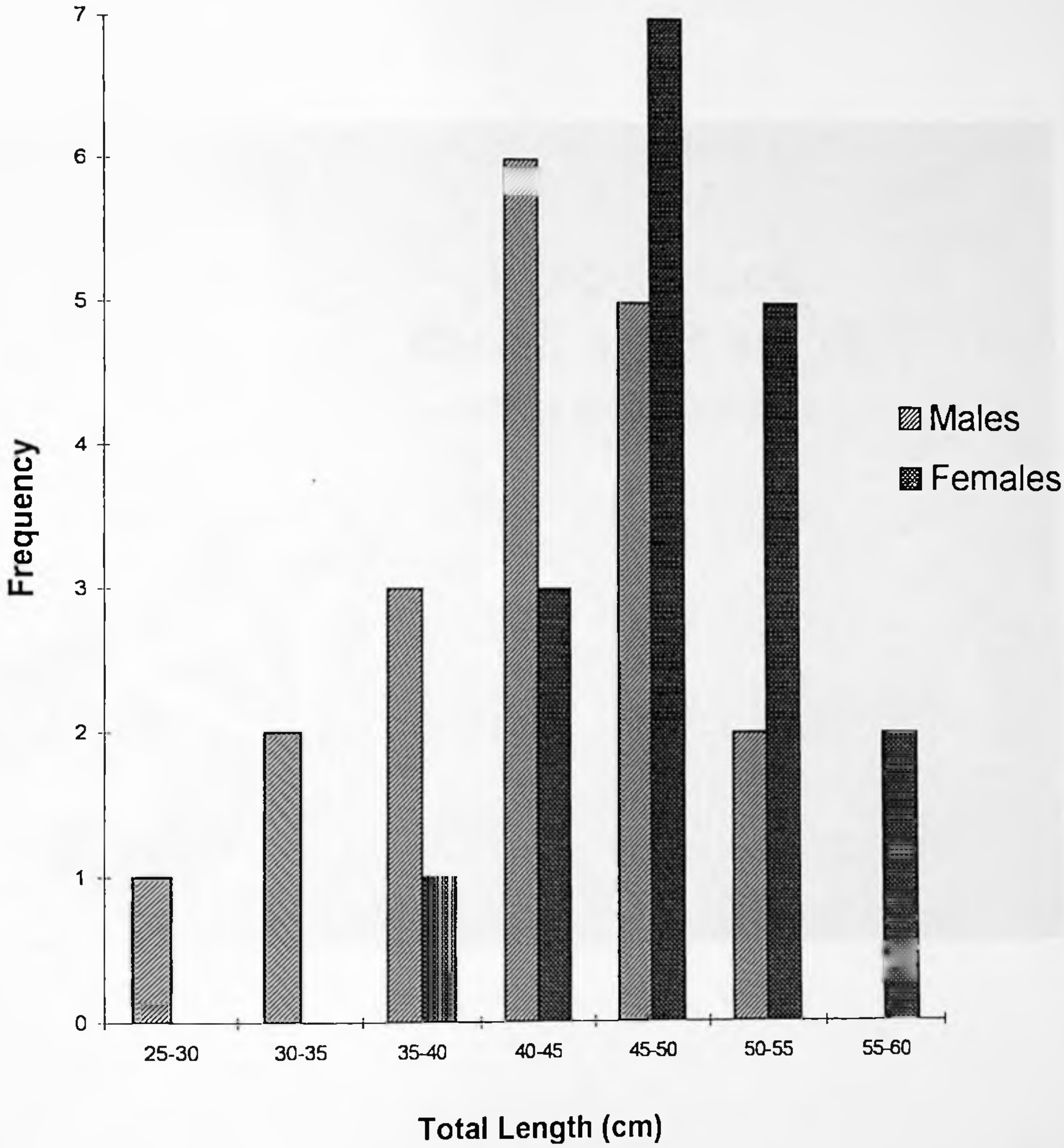


Figure 15. Typical position of "nocturnally hidden" hellbenders. Photo taken at 11:30 P.M. at study site on the West Fork of the Greenbrier River.

Figure 16. Locations of all captures of hellbenders within the study site, West Fork of the Greenbrier River, West Virginia, during the summer of 1998.

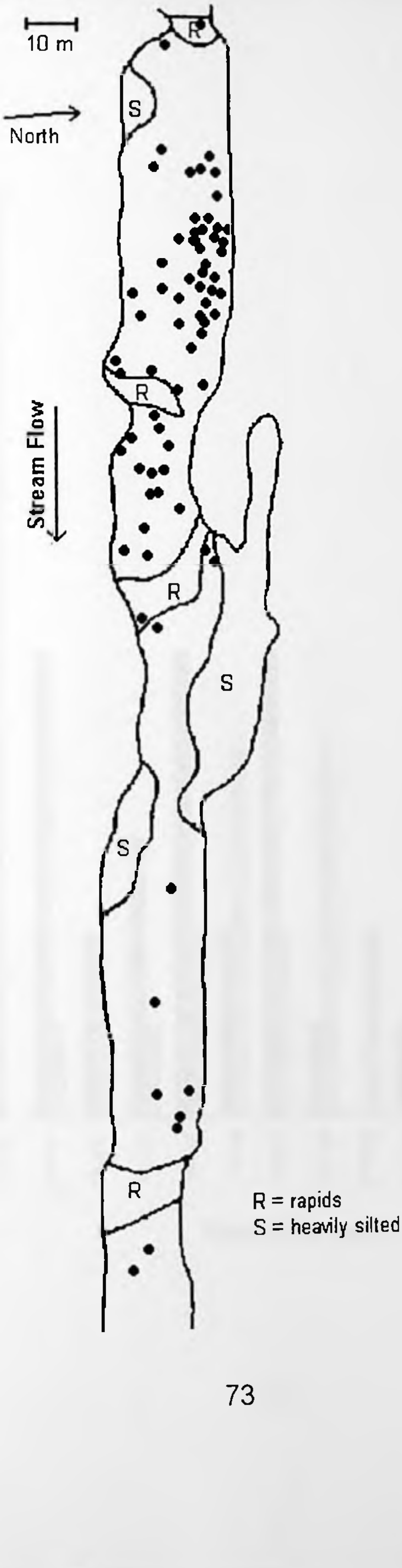


Figure 17. Number of hellbenders active or hidden during night surveys within the study site (active indicates hellbenders were in the open; "hidden" indicates hellbenders were under a rock with only their snouts visible).

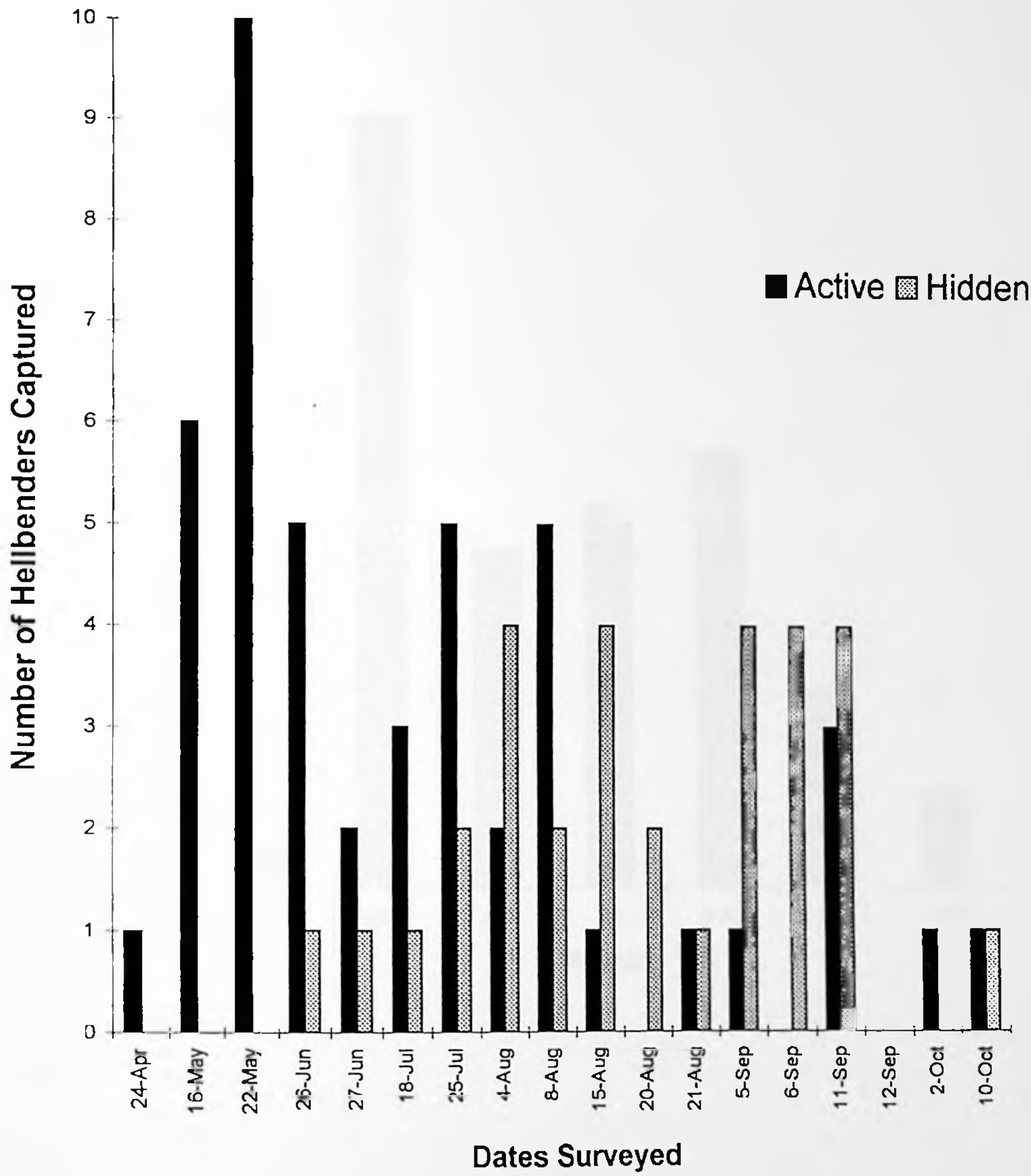
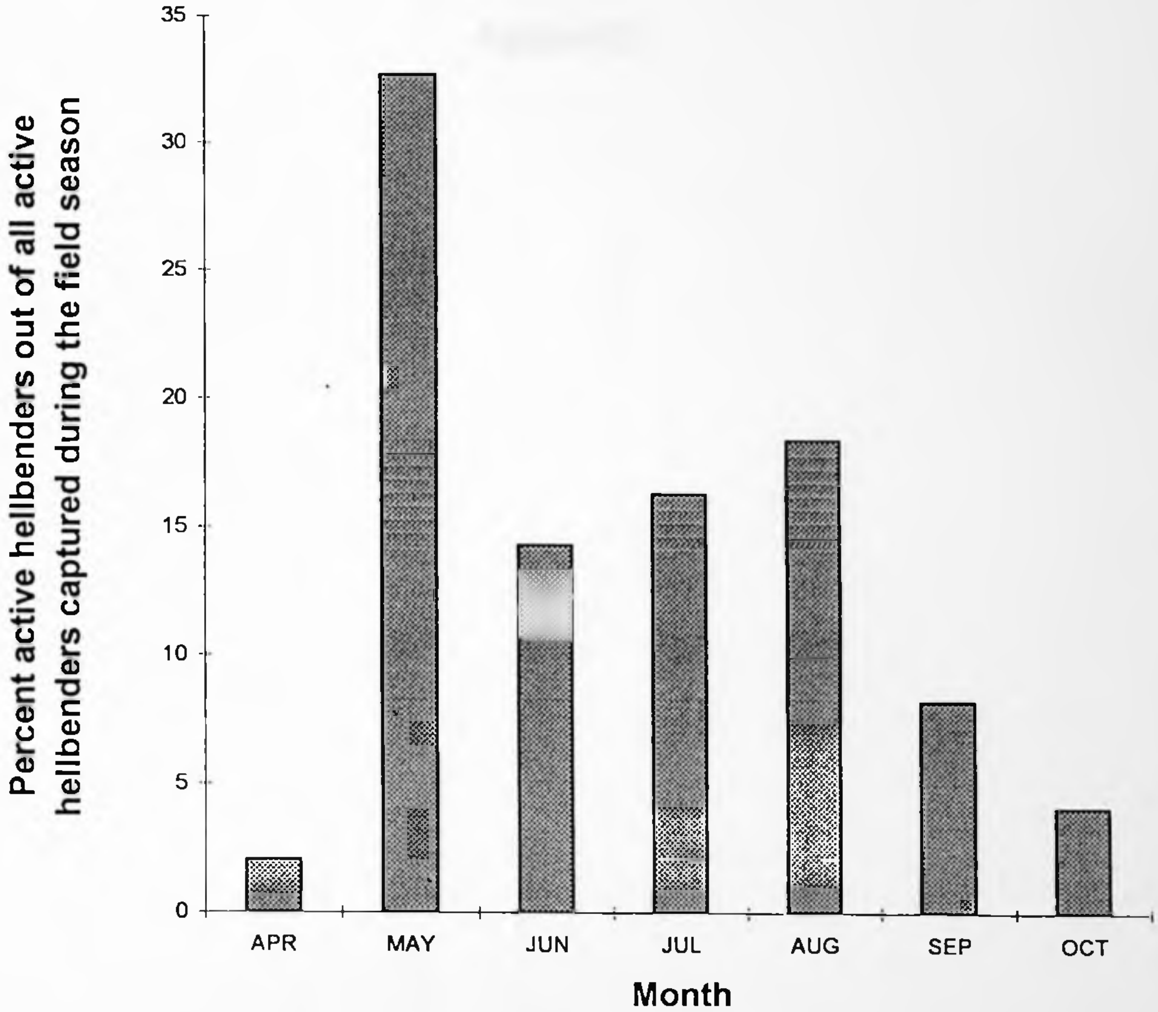
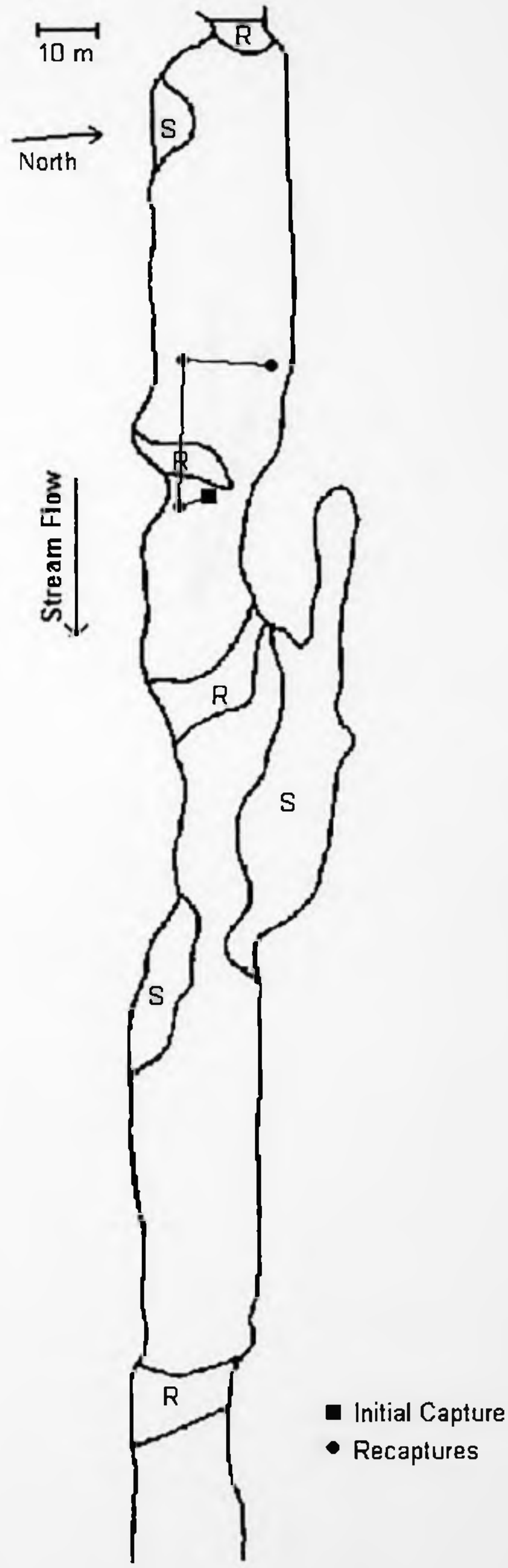


Figure 18. Seasonal activity of hellbenders within the study site based on the percentage of active hellbenders captured during each month out of all active hellbenders captured during the summer (n=49 captures). "Active" refers to those hellbenders in the open during nocturnal searches.



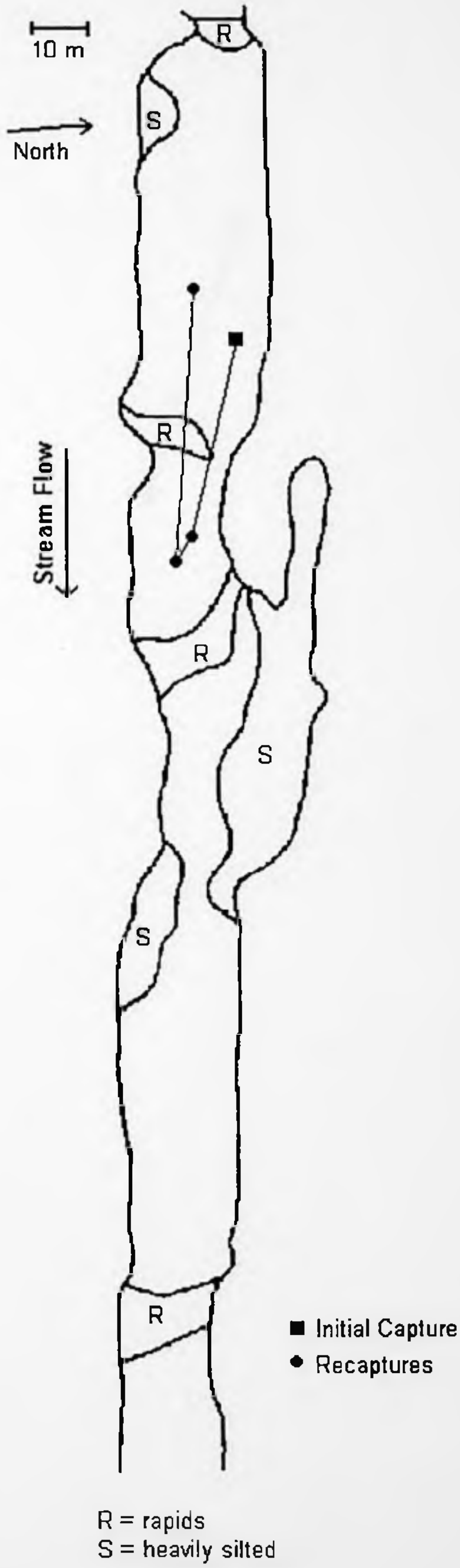
Appendix

Movement history of hellbender no. 0A00081426 within study site.
Capture dates: 5/16, 5/22, 8/8, 8/20

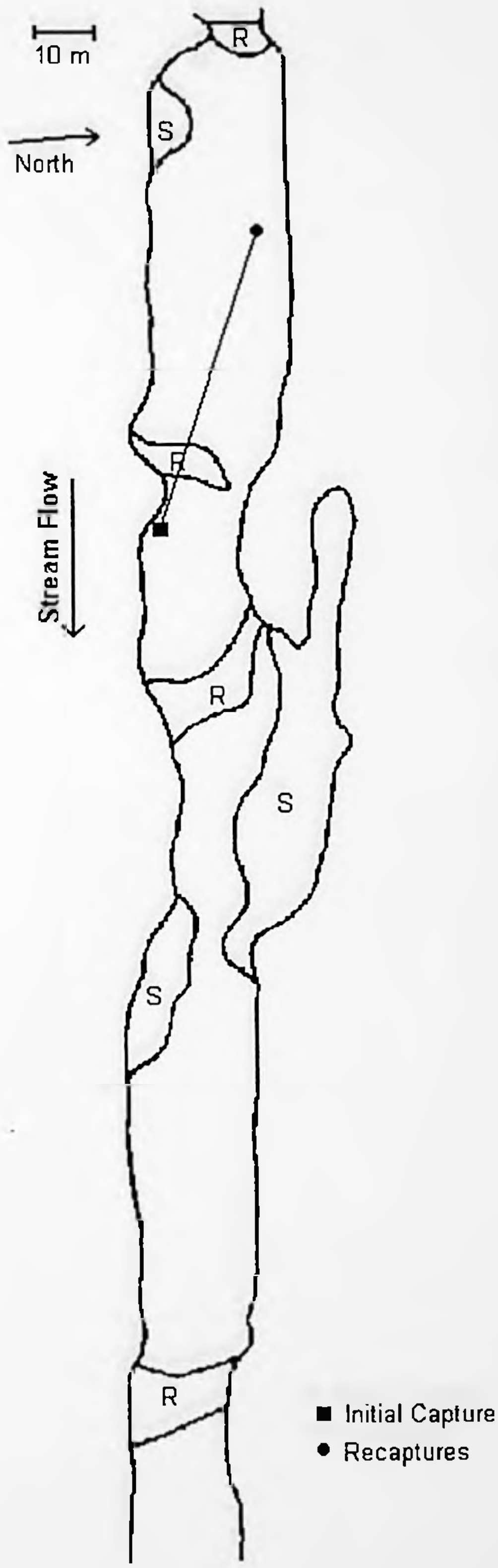


R = rapids
S = heavily silted

Movement history of hellbender no. 016-279-597 within study site.
Capture dates: 5/16, 5/23, 7/18, 10/10

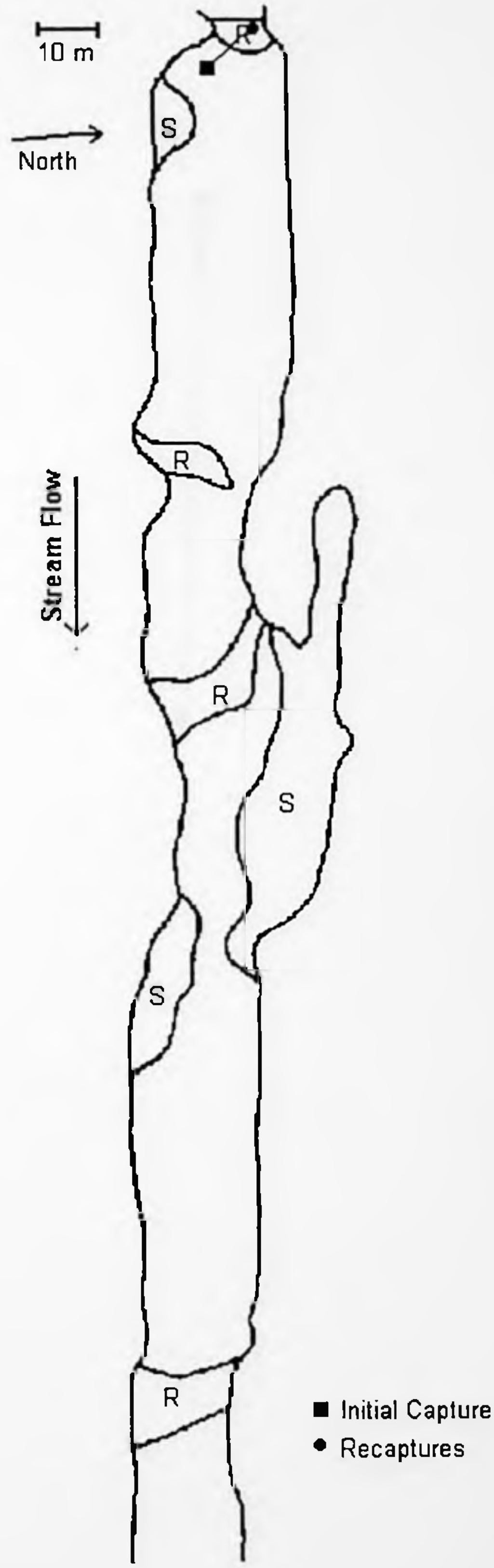


Movement history of hellbender no. 0A00081432 within study site.
Capture dates: 9/6, 9/11



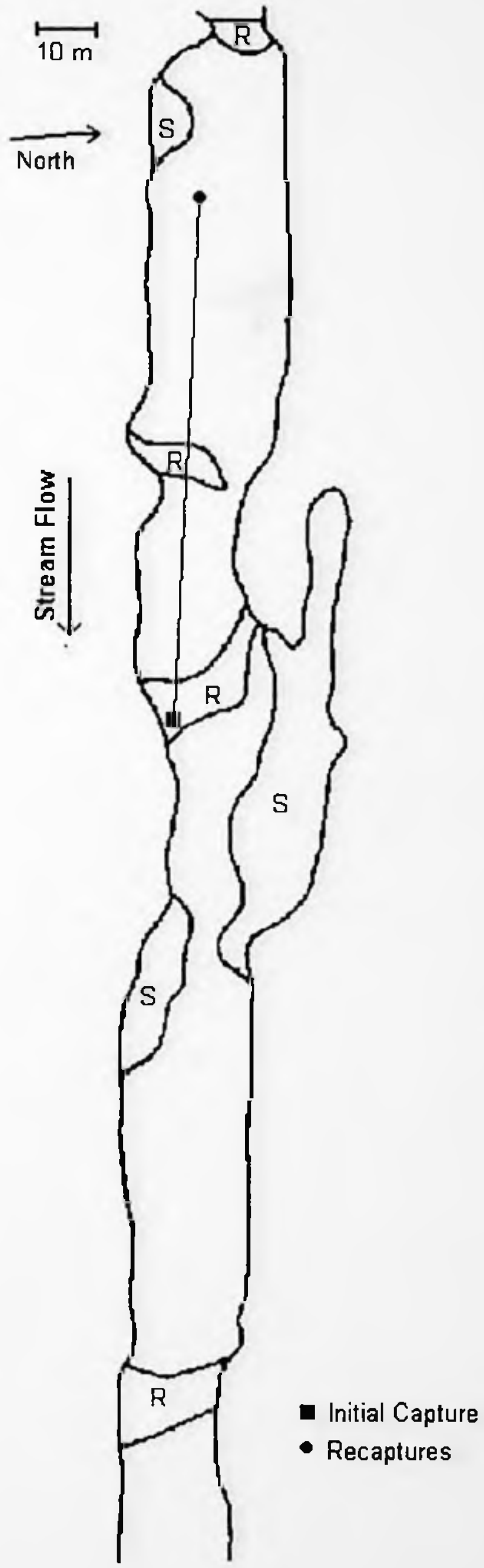
R = rapids
S = heavily silted

Movement history of hellbender no. 0A00082228 within study site.
Capture dates: 8/4, 9/11



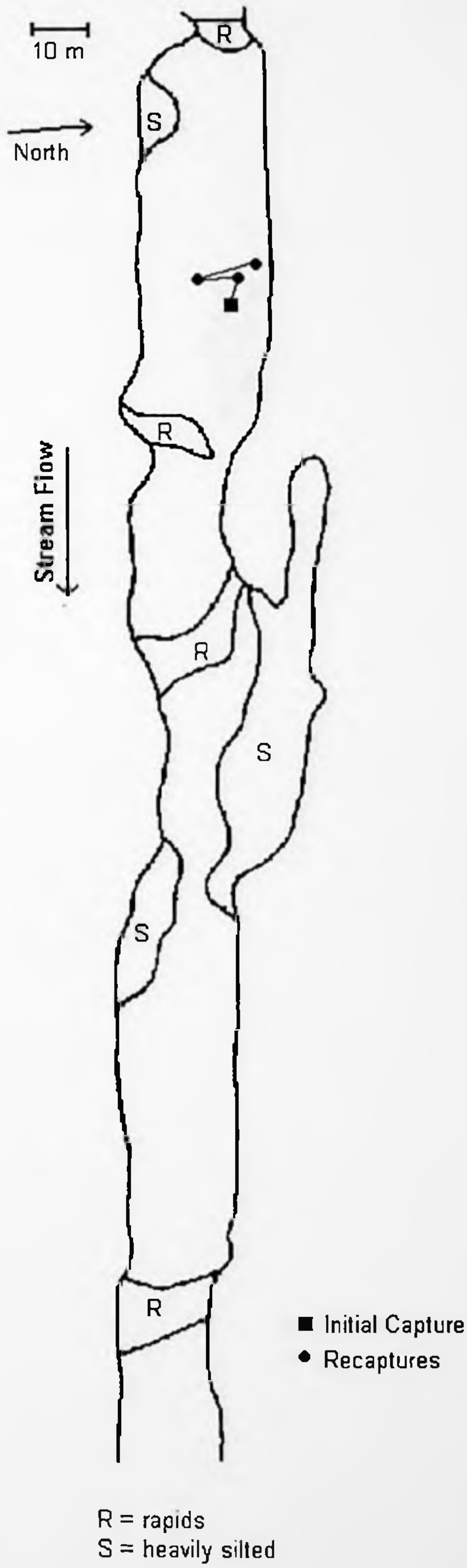
R = rapids
S = heavily silted

Movement history of hellbender no. 0A00083437 within study site.
Capture dates: 5/23, 9/6

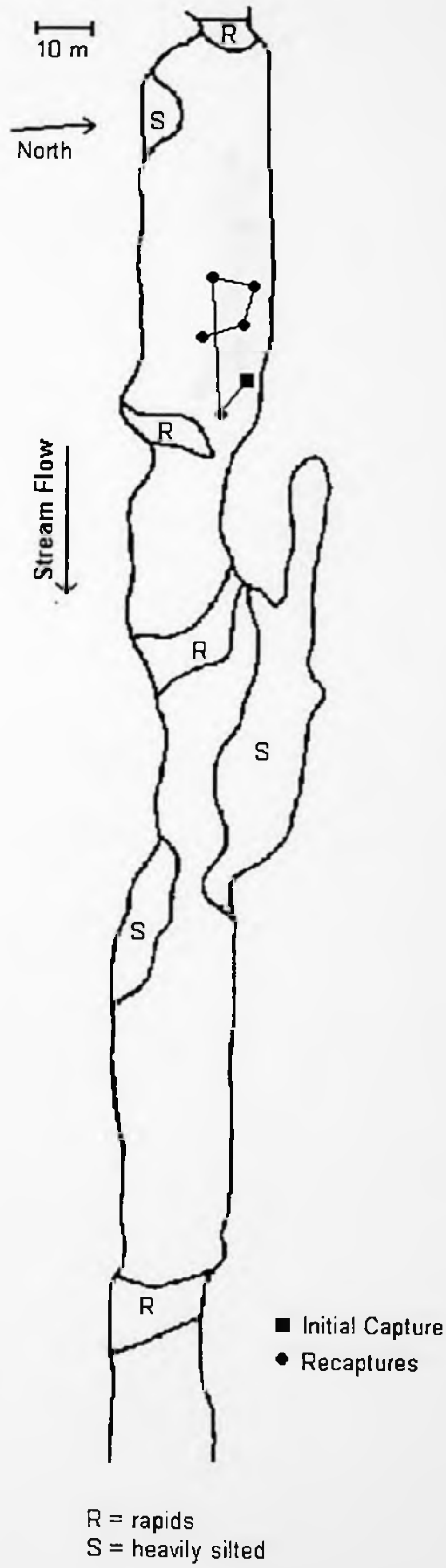


R = rapids
S = heavily silted

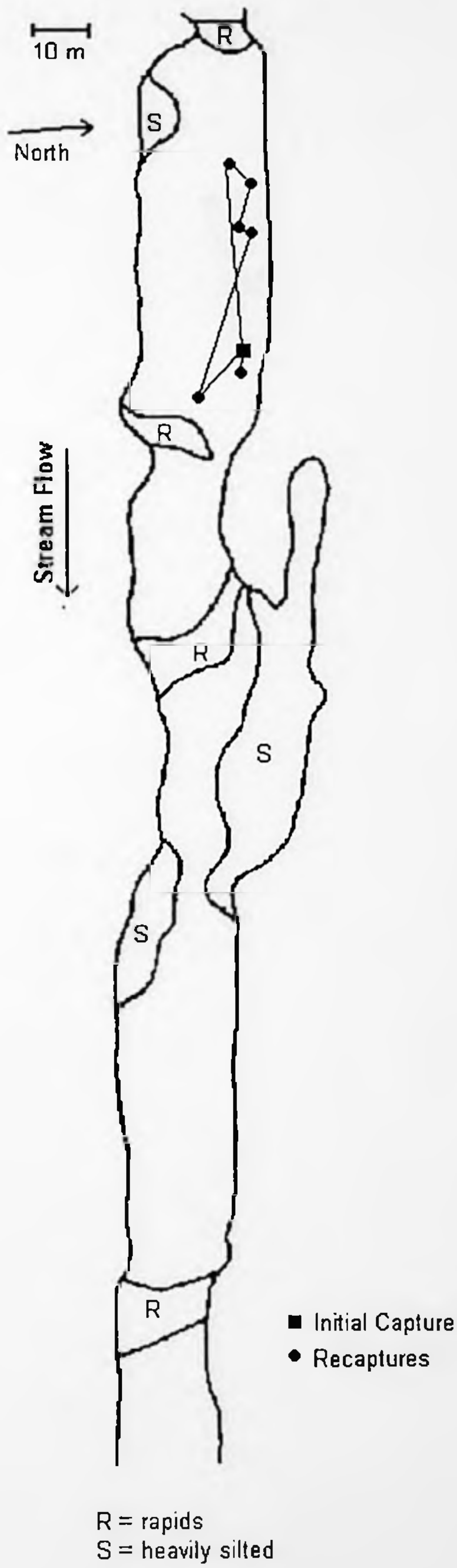
Movement history of hellbender no. 0A00083525 within study site.
Capture date: 6/26, 7/18, 8/4, 9/11



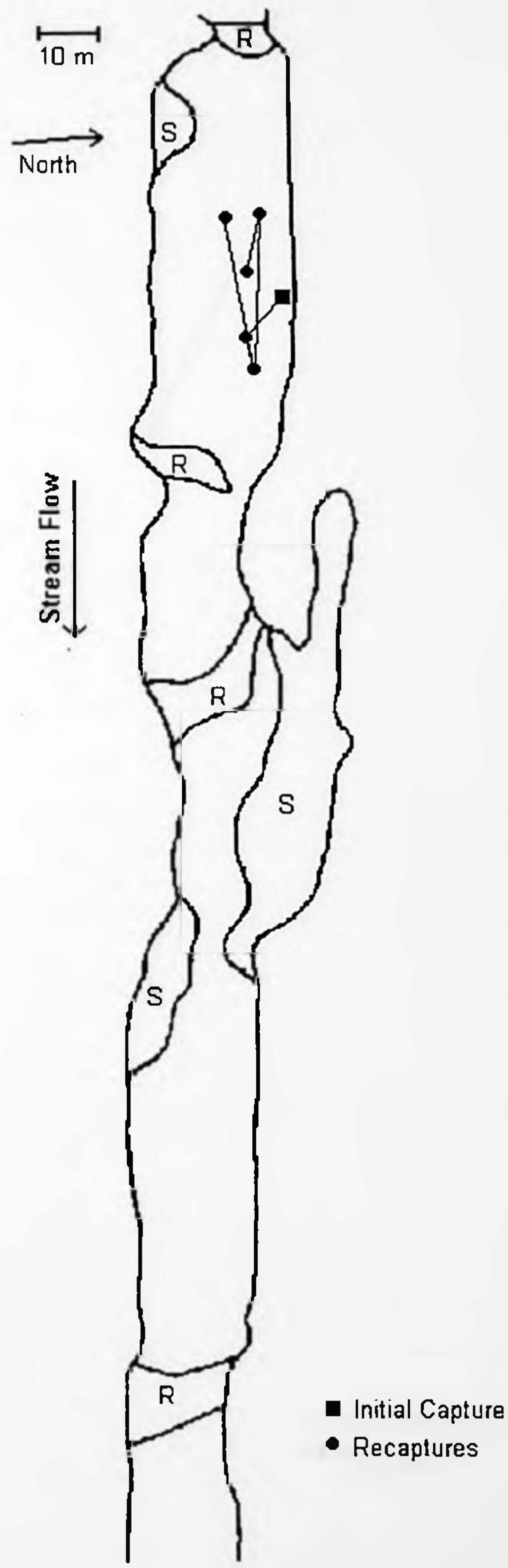
Movement history of hellbender no. 0A00083714 within study site.
Capture dates: 4/24, 5/16, 5/22, 7/26, 7/27, 10/3



Movement history of hellbender no. 0A00083814 within study site.
Capture dates: 6/26, 7/19 (under adjacent rocks until 9/5), 9/6, 9/11, 10/2

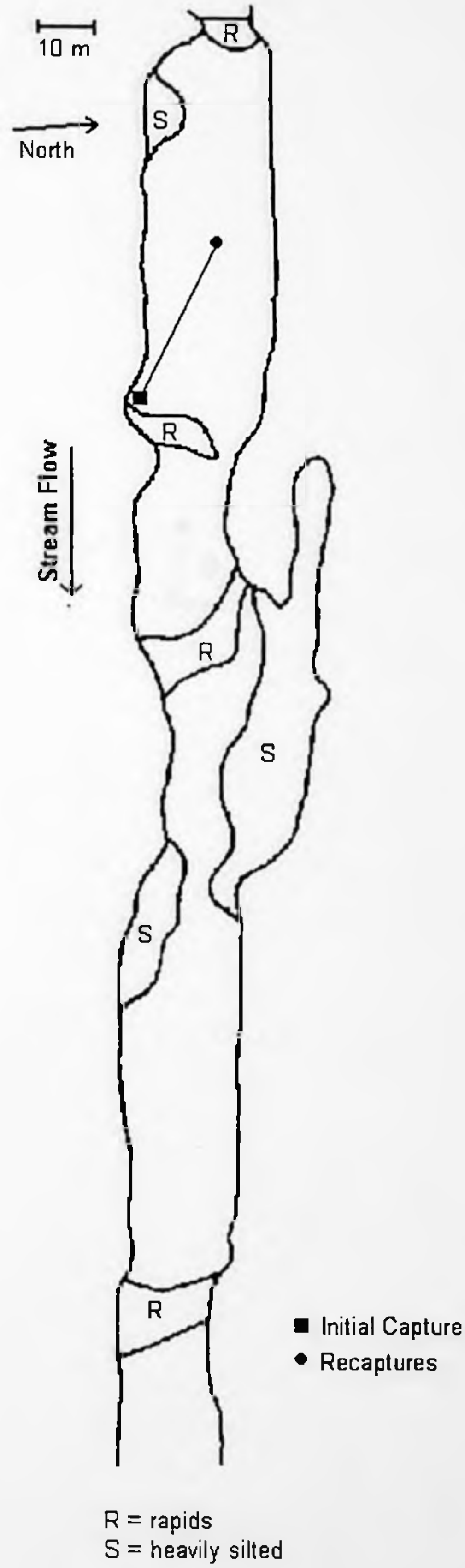


Movement history of hellbender no. 0A00083847 within study site.
Capture dates: 6/26, 6/27, 7/25, 8/4, 8/8, 9/11

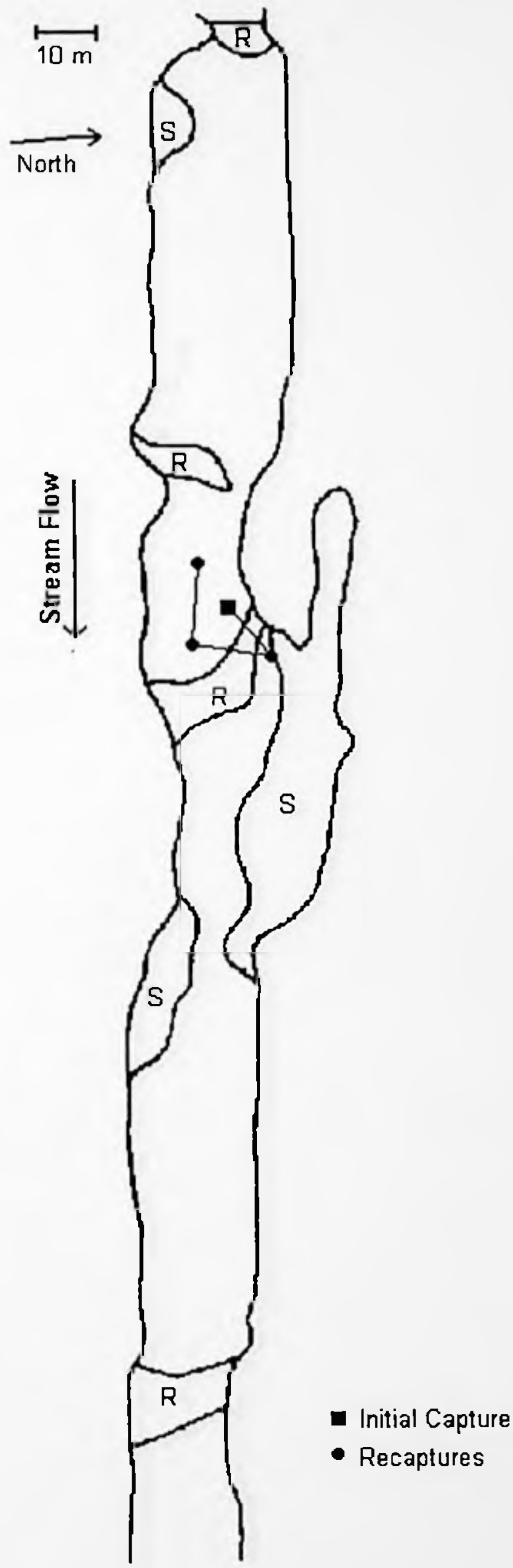


R = rapids
S = heavily silted

Movement history of hellbender no. 0A00084548 within study site.
Capture dates: 5/22, 9/6

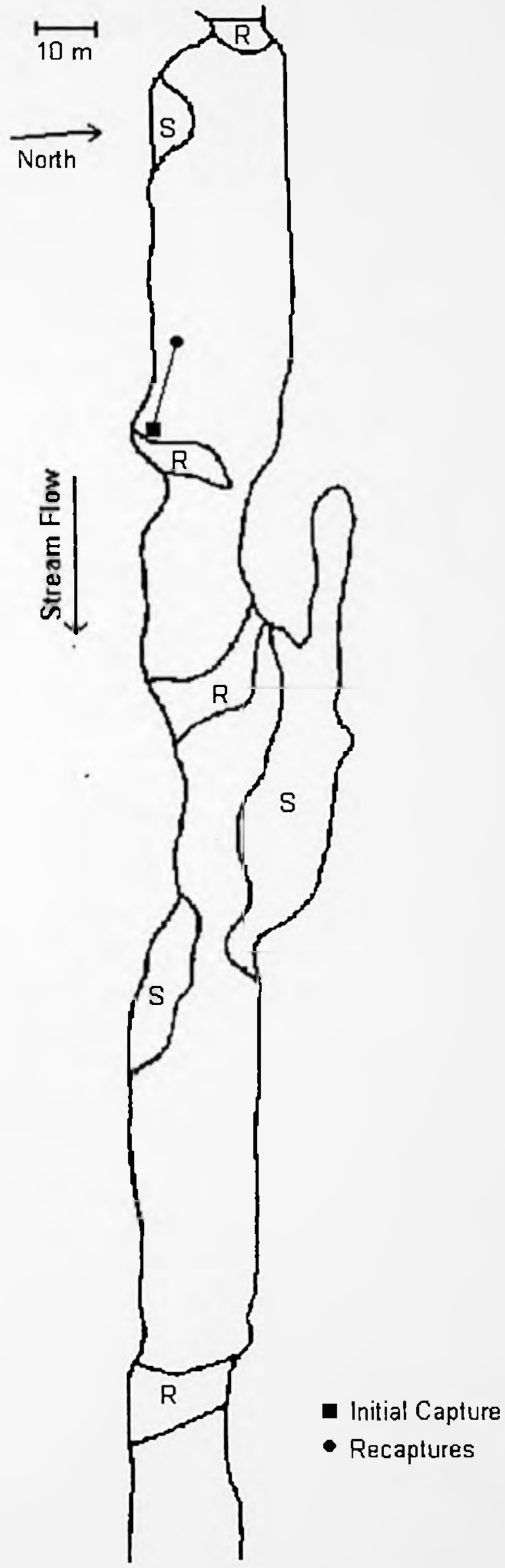


Movement history of hellbender no. 0A00084955 within study site.
Capture dates: 5/16, 5/22, 7/18, 8/15



R = rapids
S = heavily silted

Movement history of hellbender no. 0A00087268 within study site.
Capture dates: 5/22, 6/26



R = rapids
S = heavily silted