HABITAT USE AND MOVEMENTS OF EASTERN HELLBENDERS, *CRYPTOBRANCHUS ALLEGANIENSIS ALLEGANIENSIS:* A RADIOTELEMETRIC STUDY

A Thesis

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ABSTRACT

HABITAT USE AND MOVEMENTS OF EASTERN HELLBENDERS, *CRYPTOBRANCHUS ALLEGANIENSIS ALLEGANIENSIS:* A RADIOTELEMETRIC STUDY

(May 2001)

Brian Sinclair Ball, B.S., Appalachian State University

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Movement and habitat use were studied for 12 eastern hellbenders, *Cryptobranchus alleganiensis alleganiensis*, in the Watauga River, Watauga County, North Carolina, U.S.A. Positions were located by radiotelemetry every 3-7 days from 16 May 1999 until 27 August 2000. Water depth, habitat type, and salamander position were mapped using ArcView® 3.2 GIS software.

A total of 1009 ($\bar{X}$=84.7 per individual, $\bar{X}$=189.3 days) salamander positions were recorded for twelve adult salamanders (5m, 7f). Hellbenders in the Watauga River were extraordinarily sedentary; only 11% of 989 observations revealed changes in position. The number of moves per animal was quite variable (n = 0-35, $\bar{X}$=9.5). One male used the same rock every day for one year. Females moved farther ($\bar{X}$=14.67 m, n = 38) than did males ($\bar{X}$=10.14 m, n

= 71). Only one hellbender was seen active on the substrate in daylight, but 18.9 % of 222 night observations were "out" on the substrate.

The use of substrates and water depths differed among individuals, seasons, and photoperiod (day or night). Boulders were preferred shelters in all seasons and times of day, but hellbenders used larger boulders in fall and winter ($\bar{X}$=5.190 m^2 and $\bar{X}$=4.992 m^2, respectively) than in spring and summer ($\bar{X}$=1.997 m^2 and $\bar{X}$=2.763 m^2, respectively). Hellbenders were always in 30 to >120 cm of water and used deeper water in fall and winter ($\bar{X}$=0.92 m and $\bar{X}$=0.92 m, respectively) than in spring and summer ($\bar{X}$=0.68 m and $\bar{X}$=0.717 m, respectively). Several individuals remained under large boulders in deep water throughout the year. Salamanders that were detected on substrates selected cobble-gravel-sand substrates much more often than expected (X^2=49.8, df=9, P<0.001). Cobble-gravel-sand substrate was never used in daytime.

Knowledge about movements and habitat use of these giant salamanders is necessary for developing a conservation plan for this species of Special Concern. Small areas do provide adequate habitat for adult hellbenders. The next steps in understanding hellbenders in the Watauga River (or other areas in North Carolina) are: 1. To determine if these animals exist in series of semi-isolated, sub-populations or demes in areas of optimum habitat scattered along this river, and 2. To study habitat use and movements of juveniles. With this information we can produce meaningful conservation plans for this animal.

Key words: Urodela, Cryptobranchidae, *Cryptobranchus alleganiensis alleganiensis*, radiotelemetry, movements, habitat use

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INTRODUCTION

Amphibian populations seem to be declining throughout the world (Blaustein 1994). The highly permeable skin and complex life cycles of amphibians make them particularly sensitive to environmental changes in both aquatic and terrestrial habitats (Blaustein 1994). These animals are good indicators of overall habitat quality so fluctuations in amphibian populations can give us an early warning of habitat degradation (Blaustein 1994). Many population declines seem to be related to habitat degradation and/or loss of habitat (four-toed salamander, eastern tiger salamander, hellbender salamander, etc.), but other declines are mysterious, sudden, and dramatic. Regional, national, and global tasks forces (e.g., Declining Amphibian Populations Task Force or DAPTF) are currently studying these declines in search of their cause (Vial and Saylor 1993). The evaluation of amphibian decline is difficult due to a lack of long-term data sets. These data sets are needed to separate declines from natural fluctuations (Pechmann *et al.* 1991). DAPTF is attempting to combine data from across the globe to gain a better understanding of this problem.

Salamanders are amphibians with biphasic life-styles with a larval and a adult stage. There are approximately 400 species in ten or eleven families

worldwide (Pough *et al.* 1998). They are geographically widespread but diversity is primarily concentrated in five geographic regions (SE USA, W USA, Mexican highlands, Europe, and China) (Pough *et al.* 1998). North America is home to 127 species of salamanders in nine families and dozens of these salamanders, including the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*), are considered endangered, threatened, or of special concern (Petranka 1998).

Hellbenders, with total lengths of up to 74 cm, are the third largest salamander in the world and the largest in North America (Petranka 1998). *Cryptobranchus* sp. and *Andrias* sp. are the last survivors of a group that was already distinct in the upper Paleocene (Petranka 1998). Conant and Collins (1998) describe the hellbender as a huge, grotesque, thoroughly aquatic salamander. They have a dorso-ventrally flattened head and body, a fleshy skin fold along each side, small eyes, and large size (Petranka 1998). *Cryptobranchus alleganiensis* has two subspecies: the eastern hellbender (*C. a. alleganiensis*) and the Ozark hellbender (*C. a. bishopi*).

Adult hellbenders are generally long-lived. Individuals probably live more than 25 years under natural conditions (Taber *et al.* 1975, Peterson *et al.* 1983). In captivity specimens have survived over 55 years (Nigrelli 1954, *fide* Nickerson and Mays 1973a). Males reach sexual maturity in four to five years but females require seven to eight years (Taber *et al.* 1975, Peterson *et al.* 1983). In spring males find and guard nest sites. Females enter a nest and deposit over 500 eggs, which are fertilized externally (Topping and Ingersol 1981). Incubation lasts between one to three months. Juveniles are rarely observed and are underrepresented in all collections (Petranka 1998). Egg-eating and cannibalistic behavior are common in hellbenders, so low numbers of juveniles may reflect normal population dynamics (Smith 1907). Larvae and juveniles probably utilize different habitats than adults so collecting techniques used by researchers may simply fail to reveal these individuals.

With the exception of basic natural history observations on the general biology of hellbenders, most aspects of their life history, ecology, behavior, and movements remain mysteries (Petranka 1998). Today it is not even clear that hellbenders in different parts of their range are particularly similar in such important aspects of basic biology as breeding phenology and habitat use. For example, hellbenders in Missouri seem to move around a great deal (Coatney 1982), but appear to be sedentary in New York (Blais 1996). Efforts to conserve hellbenders must, therefore, identify specific factors influencing local populations. Very little is known about hellbenders in the Southern Appalachians.

Declines in hellbender populations have been documented across its range for over fifty years (Swanson 1948, Smith and Minton 1957, Williams *et al.* 1981). Prehistorically, mountain streams have been stable systems with clean, well-oxygenated water. Hellbenders are habitat specialists in these habitats and are confined to a mountain streams due to adaptations of the respiratory system (Ultsch and Duke 1990). Recent human activities have altered most streams throughout the range of hellbenders. Pollution, impoundments, and increased

sedimentation exclude these salamanders from much of their historic range (Nickerson and Mays 1973a). Hellbenders are listed as Endangered in Ohio, Illinois, Indiana, and Maryland (Humphries 1999). They are listed as Rare in Georgia, and a Species of Special Concern in North Carolina, West Virginia, and New York. Only populations in Mississippi, Missouri, Pennsylvania, and Tennessee appear stable (Humphries 1999). The majority of hellbender research refers to populations in the Ozarks or in Pennsylvania, New York, and West Virginia, the northern parts of the species' range (Petranka 1998). At present there are few published studies on hellbenders in the Southeastern portion of their range and none in North Carolina.

The present study was designed to ascertain how adult hellbenders in the Watauga River (Watauga County, North Carolina) utilize their environments and to use this information in formulating meaningful conservation plans. Radiotelemetry was used to track individual salamanders for up to one year. Maps of sites selected by individuals should reveal whether sex, season, or time of day influence habitat use and activity. This improved understanding of habitat use and movements of hellbenders will be used to propose ways to protect this giant salamander and the clean mountain streams it needs. If these habitats are not protected, it is certain hellbender populations will continue to decline.

MATERIALS AND METHODS

Study Site

The study site was located on the Watauga River, a fourth order headwater stream in the Holston-Tennessee River system, north of Foscoe (junction Old Shull's Mill Road and Shull's Mill Road) in Watauga County, North Carolina, USA (Figs. 1 and 2). The river was classified as a High Quality Water (HQW) by the North Carolina Department of Environment, Health, and Natural Resources. Criteria used for site selection were habitat diversity, high hellbender density, and accessibility.

The site was 100 m long and approximately 30 m wide and included a variety of habitats, including deep pools, riffles and shallow flats with fast-flowing water. Substrate consisted of a combination of bedrock, boulders, cobbles, gravel and sand. Water depth averaged 56.7 cm with a maximum depth of 140 cm. This stretch of the Watauga River was subject to large fluctuations in water depth associated with rain events. Water levels rose >1 m during significant rain events.

Many fishermen visited the upper Watauga River throughout the study. The North Carolina Wildlife Resources Commission stocked trout in the river several times throughout the study and large sections of river, including the study

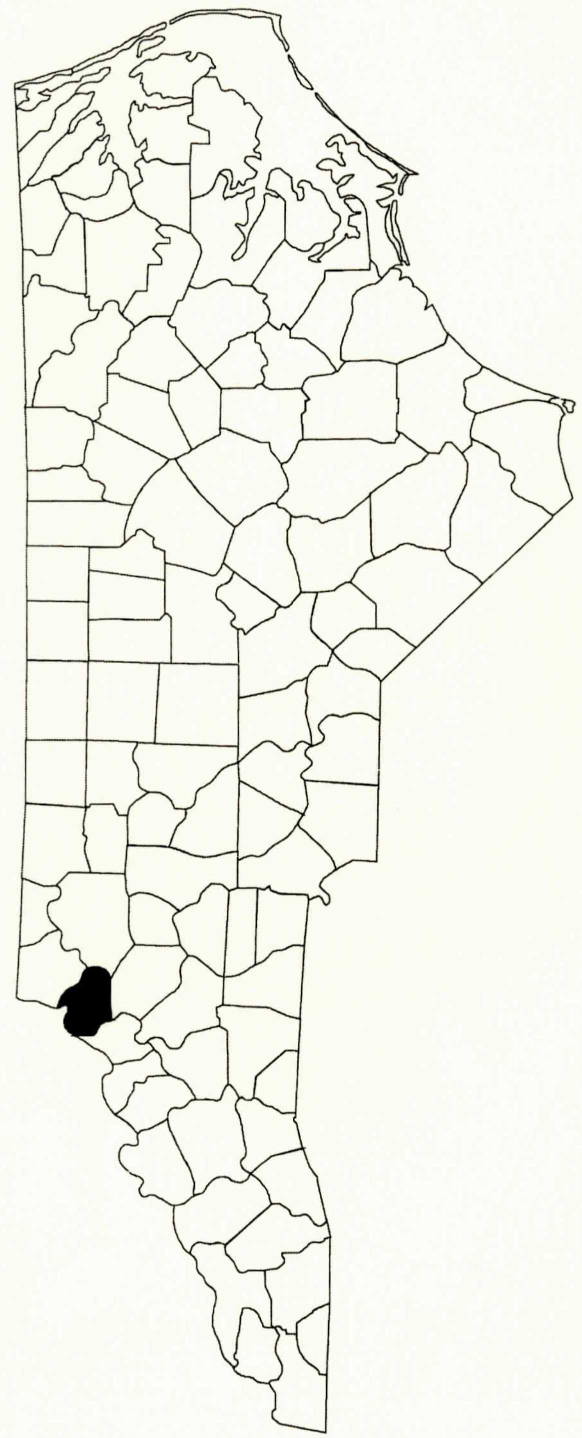


Fig. 1. Location of study site in North Carolina. Watauga County is blackened.

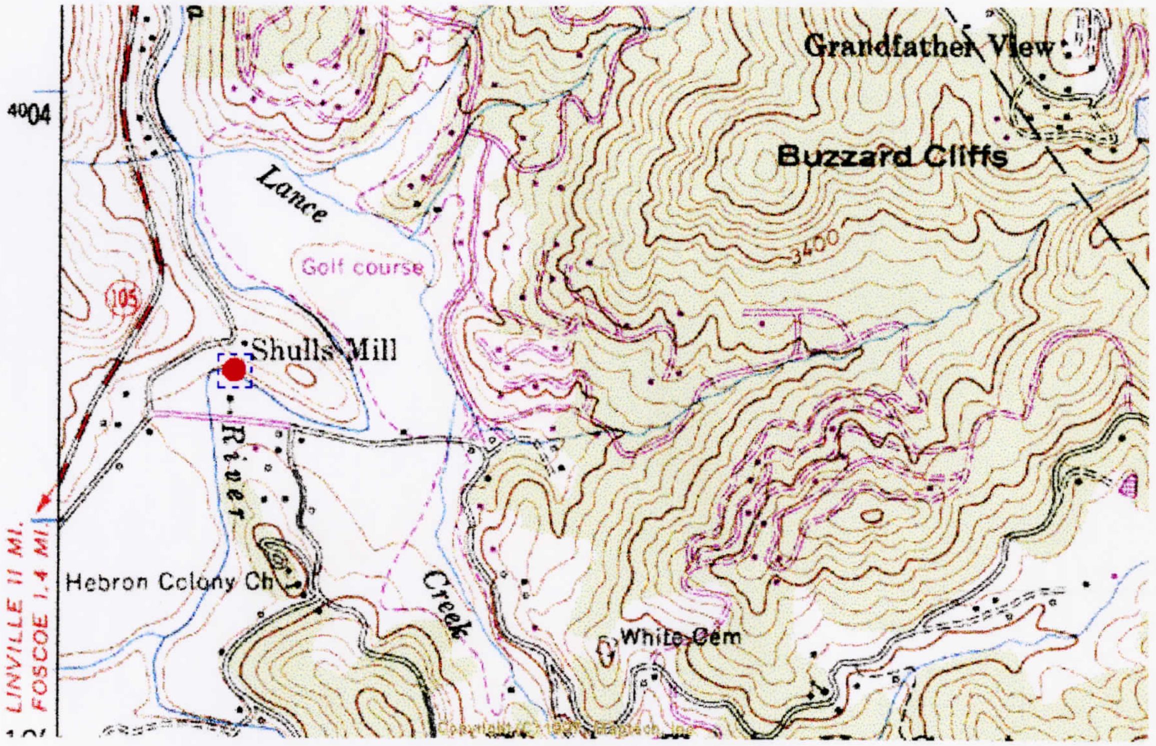


Fig. 2. Topographic map of study site (Maptech® USGS Topographic Series). Study site is located in the Boone quadrangle and is marked by the red dot.

site, received heavy fishing pressure. This section of river was categorized as "delayed harvest". Anglers can keep fish for part of the year, however, the rest of the year catch and release practices are enforced. In 1998 a North Carolina Wildlife Resources Commission enforcement officer counted over a hundred anglers in a single day on a 4.8 km section of this river (Manuel 1999).

Private and commercial developments were common along the river. A golf course and exclusive housing development were located approximately 500 m down stream from the site. Upstream from the site were, in order, a church, Christmas tree farm, and a new housing development with over 50 houses. All sites were adjacent to the river. Although the river appeared to be relatively clean and healthy (HQW), recent construction had increased siltation rates (Anonymous 1997).

Mapping

The site was mapped using a Topcon GTS-304 total station and a HP 48-GX data collector with Tripod Data Systems (TDS) software. An approximate grid system of 440 points was established by eye. Points were most concentrated in areas where substrates and water depth changed sharply. After each point was located, water depth and substrate type were categorized within 0.5 m^2 of the point using methods described in Allan (1995). Maps of substrates and water depth were created using ArcView® 3.2 GIS software.

Specimen Collection and Marking

Collection

Collecting began just after dusk. Hellbenders were collected by hand, held in separate bags in a 5-gallon bucket of river water, and transported to the laboratory for transmitter implantation. Hellbenders with a total length greater than 400 mm were implanted with transmitters. Snout-vent-length (SVL), tail length, and mass were compared for male and female salamanders using a two-sample t-Test (Zar 1999). Transmitter availability determined number of specimens collected.

Surgery

Animals were housed in aquaria with aerated water in a cool room at Appalachian State University. Surgery was conducted one to nine days after collection and followed the procedures of Blais (1996), as modified by Madison (pers. comm. 1998). Animals were anesthetized by immersion in a solution of 16 grams tricaine methanesulfonate (MS222 or TMS) per liter of distilled water (Stouffer *et al.* 1983). Approximately two minutes after specimens stopped responding to stimuli, they were removed from the anesthetic solution and rinsed with distilled water to remove excess anesthetic and initiate salamander recovery.

During surgery animals were covered with paper towels saturated with distilled water to minimize oxygen deprivation and dehydration. A 20 mm transverse incision was made through the skin and abdominal musculature

approximately 35 mm anterior of the vent on the right side of the ventral surface (Blais 1996). Transmitters were sterilized in Nolvansan® and placed in the coelomic cavity. The wound was closed with two sets of 3-O non-absorbable monofilament sutures. One set of sutures closed the musculature and one closed the skin. Sutures were approximately 2 mm apart (Blais 1996). Dermabond™ topical skin adhesive was applied to seal the wound. Postoperative specimens were placed in a temporary holding tank and checked regularly until they recovered from anesthesia. Salamanders were released at their site of capture two to eight days after surgery. Animals were released at dusk to maximize time for the animal to become oriented and to locate a shelter rock before morning. These methods were approved by Appalachian State's Institutional Animal Care and Use Committee (IACUC) on 31 May 1999.

Radiotelemetry

Transmitters

A total of nine specimens were implanted with AVM G3 transmitters (AVM Instrument Company, Limited, Livermore, CA). These units were 25x18x10 mm, weighed 10.1 grams, and had projected life spans of twelve months. Three additional specimens were implanted with WMI SOPI-2190 transmitters (Wildlife Materials, Incorporated, Carbondale, IL). These units were 25x4.6x4.6 mm, weighed 9.1 grams, and had projected life spans of eight months. A Wildlife Materials, Incorporated TRX-1000S receiver and a 3-element Yagi antenna (model F150-3FB) were used to verify transmitter strength and to determine exact location of each specimen.

Since surgical scars were not distinguishable from other, natural injuries; two animals were returned to the laboratory and searched with a handheld Model 99104752 Super Scanner Garrett Medal Detector (supplied by Appalachian State University Security), which did detect one transmitter.

Surveys

Day surveys were the primary focus of this study. During fall, summer, and spring, each hellbender was located and its position mapped at least once every three days. In winter, site visits were reduced to once per week. Location and condition of any untagged hellbenders observed were recorded during each site visit. Salamander locations were determined using radiotelemetry. Location, date, time, photoperiod ("day" or "night"), and hellbender status were recorded for each observation. Hellbenders were "in" if they were under a shelter rock, out of sight, or "out" if on the substrate in full view. Salamanders were tracked for a total of 15 months, 15 May 1999 to 27 August 2000. ArcView® was used to compile and analyze data.

One series of night surveys was conducted during each season: Fall, summer, spring and winter. For three consecutive nights, individuals were located and mapped three times per night: one hour after dusk, the middle of the night and one hour before dawn. Additional unscheduled night visits were conducted when time permitted.

Data Analysis

Individual Behavior

ArcView® was used to project each salamander position onto habitat and water depth maps of the study site. Distances moved were calculated using ArcView®. Substrate type, water depth used, and nocturnal emergences were summarized for each individual and compared between sexes and among seasons.

Analysis of Combined Movements

Effects of sex, photoperiod, and/or season on hellbender movements were compared using a variety of techniques. Effects of sex, photoperiod, and their interaction were examined using analysis of variance (ANOVA, General Linear Model, GLM, Minitab™ 13, Zar 1999). Frequencies of movements (# movements/# observations) were arcsine transformed. Distance moved was analyzed several ways. All data were included in one ANOVA to test for effects of sex and photoperiod. Since most observations were actually zero and non-normally distributed, a second ANOVA was performed using only movements (zeros excluded). Seasonal movements were compared using the same methods. For additional, non-parametetric analysis, movements were also sorted into 5 m intervals for movement comparisons. Dates included in seasons were: Spring (March 20-June 20), summer (June 21-September 21), fall (September 22-December 20), and winter (December 21-March 19).

Chi-square (χ^2) tests for independence (Zar 1999) were used to address a number of questions about movements and status:

1. Movements of males versus females – Are distances moved by males and females the same?
2. Day status versus night status in males – Do male hellbenders behave the same throughout the diel cycle?
3. Day status versus night status in females – Do female hellbenders behave the same throughout the diel cycle?
4. Male status versus female status for daytime observations – Do males and females behave similarly during the day?
5. Male status versus female status for nighttime observations – Do males and females behave similarly during the night?
6. Seasonal influences on movements – Do hellbender movements differ seasonally?
7. Seasonal differences in hellbenders status – Do hellbenders behave the same seasonally?

In each case the null hypothesis was no difference in movement or status.

Habitat Use

To determine whether hellbenders selected particular substrates and/or water depths, observations were compared with habitat availability. Chi-square (χ^2) goodness of fit tests (Zar 1999) were used to compare observations in each substrate and water depth with values predicted assuming random usage. Substrate was divided into ten categories (Cobble-Gravel-Sand, Cobble, Bedrock, Boulder, Bedrock-Cobble, Cobble-Gravel, Boulder-Cobble, Sand-Gravel, Bedrock-Sand, and Sand) and water depth into twelve10 cm intervals (<20 to >120 cm). Total area and percent area of each substrate and water

depth were calculated using ArcView® to generate expected values (For example, if 20% of available substrate was sand then, 20% of observations should be in sand substrates if substrate use was random). A Chi-square (χ^2) test for independence was used to determine if hellbenders used substrates similarly throughout a daily cycle. Seasonal uses of substrate and water depth for day observations were tested using the same method. Seasonal variation in depths selected was analyzed using ANOVA (Zar 1999). Size of boulders used as daytime shelters was examined to determine if hellbenders use similar shelters seasonally. ArcView® was to calculate area of boulders used as daytime shelters. Boulder size was separated by season and compared using ANOVA.

Water Temperature

Water temperature was recorded every 3 hours using a HOBO data logger placed in the river from 21 December 1999 to 27 July 2000. The data logger was attached to a bridge pylon at a depth of 70 cm.

RESULTS

Substrate

Ten substrate types covered more than ten m^2 of the site (Table 1; Fig. 3). Cobble-gravel-sand category comprised almost 30% of the substrates at the site while sand and bedrock-sand were relatively rare (<1%).

Table 1. Substrate classifications (Allan 1995) and their coverage in the study area. Substrate types are arranged from most common to least common.

Classification	Abbreviation	Area (m^2)	Area (%)
Cobble-Gravel-Sand	C-GV-SD	547.22	29.27
Cobble	C	353.90	18.93
Bedrock	BDR	330.57	17.68
Boulder	BLD	212.27	11.35
Bedrock-Cobble	BDR-C	161.92	8.66
Cobble-Gravel	C-GV	93.56	5.00
Boulder-Cobble	BLD-C	90.70	4.85
Sand-Gravel	SD-GV	48.71	2.61
Bedrock-Sand	BDR-SD	17.72	0.95
Sand	SD	13.27	0.71
Total		1869.83	100.0

Water Depth

Water ranged from less than 0.1 m to 1.4 m in depth (Table 2: Fig. 4). The most common depth was 0.4-0.5 m (23%). Very shallow and very deep habitats were uncommon.

Table 2. Water depths and their extent in study area.

Depth (m)	Area (m^2)	Area (%)
0-.1	1.112	0.06
.1-.2	28.163	1.51
.2-.3	165.251	8.84
.3-.4	288.790	15.45
.4-.5	429.973	23.00
.5-.6	321.646	17.20
.6-.7	192.131	10.28
.7-.8	165.517	8.85
.8-.9	165.764	8.87
.9-1	71.024	3.80
1-1.1	25.198	1.35
1.1-1.2	12.846	0.69
>1.2	2.223	0.12
Total	1869.63	100.00

Fig. 3. Map of substrates for study site. Substrate classification followed methods described in Allan (1995).

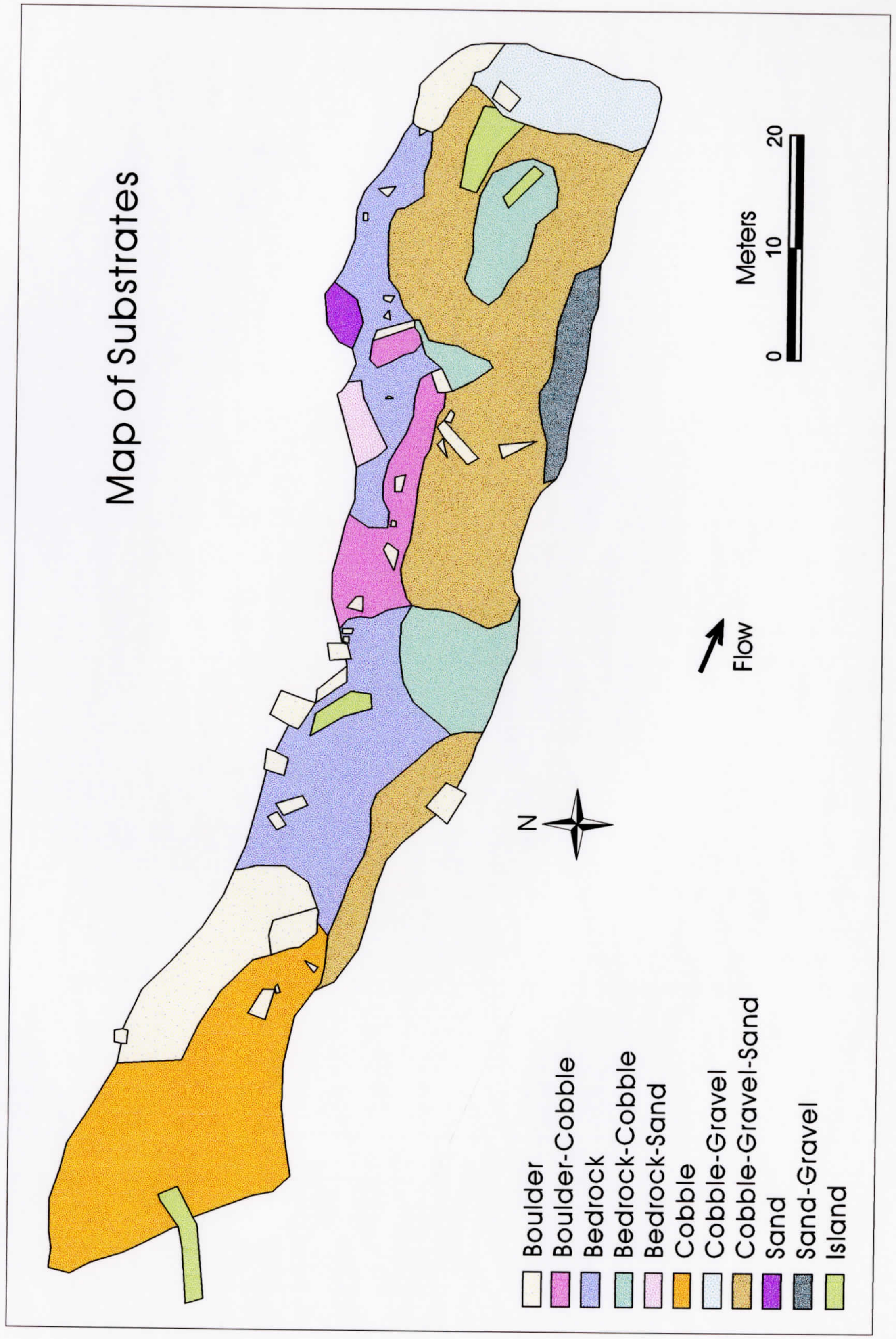


Fig. 4. Map of aquatic contour for study site. Isolines are 10 cm increments.

Specimen Collection and Marking

Collection

Nocturnal searches proved highly productive for these salamanders. Individuals could be located easily and collected at night. Many hellbenders were seen and twelve were collected for transmitter implantation (Table 3). The seven female salamanders were significantly larger than the five males in SVL, tail length, and mass (Table 3).

Surgery

Specimens placed in MS222 solution became non-responsive within five minutes and remained so for two to three hours, allowing ample time for surgery. Surgical techniques were effective and no salamanders died during surgery or recuperation. The stitches of salamander #8 separated during transport to its release site and required repair. No apparent physical or behavioral effects were observed 10 days later when this specimen was released. Salamander #4 was found dead 24 days after surgery (22 days after release). The individual was observed, uncharacteristically, out on the substrate three days earlier. The surgical site appeared intact, but the animal was completely covered with a "fuzzy" growth. Cause of death was undetermined but probably occurred two to three days before discovery. The incision on all other recaptured salamanders appeared completely healed, with or without a visible scar.

Table 3. Summary of implanted *Cryptobranchus alleganiensis*. Measurements and sexual identity were collected during surgery. SVL, tail, and mass were compared for male and female specimens using a two-sample t-Test (*=significant, **=highly significant, NS=not significant).

Specimen #	Sex	SVL (mm)	Tail (mm)	Mass (gr)	Year	Mo	Collected (day)	Surgery (day)	Release (day)	Days Tracked	Observations #
1	F	363	184	685	1999	5	4	7	15	342	155
2	M	296	170	416	1999	5	4	13	15	459	195
3	M	285	161	396	1999	5	4	7	15	0	0
4	F	294	168	439	1999	5	4	13	15	23	17
5	F	340	169	606	1999	5	12	13	15	261	125
6	F	340	190	714	1999	5	4	7	15	380	147
7	M	278	153	392	1999	6	22	25	29	260	112
8	F	329	175	558	2000	3	5	6	19	96	63
9	F	350	201	734	2000	3	5	6	8	89	44
10	M	304	168	417	2000	3	5	6	8	175	74
11	M	308	168	619	2000	5	3	5	8	95	42
13	F	346	187	647	2000	5	3	5	8	92	42
Average	M	294.2	164.0	448.0						197.8	84.6
Average	F	337.4	182.0	626.1						183.3	84.7
t-Test		**	**	**							
Total		319.4	174.5	551.9						189.3	84.7

Radiotelemetry

Transmitter

No transmitter functioned for its entire expected life (Table 4). Transmitter 150.312 was working at the end of the study but was not recovered. Transmitter 150.830 (salamander #1) lasted almost one year and transmitters 150.890 (salamander #2) and 150.380 (salamander #6) lasted approximately ten months. Salamander #2 was recaptured after its transmitter failed and re-implanted with transmitter 150.138. Transmitter 150.276 was implanted first in salamander #4. When salamander #4 died, the transmitter was removed, sterilized, and implanted in salamander #7. The remaining seven transmitters were lost for a variety of reasons, including:

1. Battery failed after transmitter emitted a solid tone for two days.
2. Transmitter emitted an erratic tone two to four days before signal was lost.
3. Transmitter failed with no warning.
4. Transmitter failed immediately after the salamander was released.

Attempts to recover malfunctioning transmitters were unsuccessful because all of these salamanders were last recorded in inaccessible areas and could not be recaptured. Searches 1000 meters upstream and 1000 meters downstream for "lost" transmitters were unsuccessful. The salamander with transmitter 150.890

was recaptured in the study site 38 days after transmitter failure. No external causes for its failure were evident.

Table 4. Summary of transmitters in study specimens. Transmitters which failed and could not be recaptured were considered "lost". Recovered transmitters regardless of condition were considered "recaptured". Salamanders with working transmitters were "liberated" at the end of the study.

Specimen #	Type	Frequency MHz	Date implanted (mm/dy/yr)	End Date (mm/dy/yr)	Status
1	AVM	150.830	5/7/99	4/22/00	Lost
2	AVM	150.890	5/13/99	3/24/00	Recaptured
2	WMI	150.138	5/5/00	8/9/00	Lost
3	AVM	150.868	5/7/99	5/9/99	Lost
4	AVM	150.276	5/13/99	6/7/99	Died
5	AVM	150.909	5/13/99	1/28/00	Lost
6	AVM	150.380	5/7/99	3/16/00	Lost
7	AVM	150.276	6/25/99	3/8/00	Lost
8	AVM	150.231	3/6/00	8/12/00	Lost
9	AVM	150.250	3/6/00	6/6/00	Recaptured
10	AVM	150.312	3/6/00	8/27/00	Liberated
11	WMI	150.109	5/5/00	8/6/00	Lost
13	WMI	150.174	5/5/00	8/3/00	Lost

Survey

One thousand and nine salamander locations were mapped, including 787 observations made during the day and 222 at night. Data from only 10 salamanders (5 male and 5 female) could be used in the analyses. Salamanders #3 and #4 were excluded due to low numbers of observations.

Data Analysis

Individual Behavior

Movement frequency varied greatly among salamanders. Salamander #1 moved 14 times in 155 observations between May 15, 1999 and April 22, 2000 (Fig. 5). For two weeks after release this female used a bedrock crevice for shelter. All remaining day observations (95%) were under two boulders. Initially, the salamander used a small boulder in shallow water from May 29, 1999 to August 20, 2000. The salamander then moved to a large boulder in deeper water, where it remained until spring (August 23, 2000 to March 10, 2000). The salamander moved back downstream to the original boulder and remained there for two weeks before returning to the large boulder used previously. The salamander was "out" on cobble-gravel-sand habitats for two night observations (July 1, 1999 and February 24, 2000).

Salamander #2 moved 23 times in 195 observations from May 15, 1999 to August 6, 2000 (Fig. 6). This individual was tracked for 15 months, the longest in the study. After release this male used a bedrock crevice for shelter for eight observations. He moved to a small boulder in shallow water where he remained for 29 observations from May 26, 1999 to July 29, 1999. He then moved downstream to a large boulder in deep water where he remained for the next year (August 1, 1999 to August 6, 2000) or 149 observations. The salamander remained relatively active throughout the study and was "out" on cobble-gravel-sand habitats for nine night observations (June 8, 1999, June 22, 1999, July 1,

1999, August 23, 1999, February 23, 2000, March 8, 2000, May 17, 2000, May 18, 2000, and May 19, 2000).

Salamander #3 was released on May 15, 1999. By the next observation (May 16, 1999) the transmitter failed and the specimen was lost. It was not included in other analyses.

Salamander #4 was released on May 15, 1999. She moved six times in 23 days (17 observations), before she was found dead on June 7, 1999. Cause of death was undetermined. It was not included in other analyses.

Salamander #5 moved ten times in 125 observations between May 15, 1999 and January 28, 2000 (Fig. 7). For three months this male remained under a large boulder and was "out" on cobble-gravel-sand habitats for two observations. The salamander then moved downstream to a large boulder and remained there for 24 days. All remaining observations the salamander was under the two boulders used previously used for shelter. It was not observed "out" after the two initial observations.

Salamander #6 was relatively sedentary from its release on May 15, 1999 to its last record on March 16, 2000 (Fig. 8). This female moved twice in the first six observations then remained under a large boulder for the next ten months (141 observations) and was never observed "out" on the substrate.

Salamander #7 was the most active individual in the study. It had 35 moves in 112 observations from June 29, 1999 to March 8, 2000 (Fig. 9). After release until October 23, 1999, 59 observations, this salamander used seven different shelters in boulder and cobble habitats. On October 27, 1999 it moved to a large boulder in deep water, where it remained until March 8, 2000, or the next 53 observations. The salamander remained relatively active throughout the study and was “out” on cobble habitats for 5 night observations (July 1, 1999, August 3, 1999, August 4, 2000 (2), August 5, 1999). He was observed “out” on cobble habitat for one day observation on August 30, 1999. This was the only “out” day observation in the study.

Salamander #8 was tracked from March 19, 2000 to August 9, 2000 (Fig. 10). This female moved three times in 63 observations. During the first month the salamander used a crevice in bedrock-cobble habitat. It then moved to a small boulder where she remained for next four months. She was “out” on bedrock-cobble substrate only on May 20, 2000.

Salamander #9 was extremely sedentary for day observations (Fig. 11). She used one boulder for shelter from March 8, 2000 to June 2, 2000 (33 day observations). However, this salamander was relatively active at night with 9 moves in 12 night observations (May 3, 2000, May 4, 2000, May 17, 2000, May 18, 2000 (2), May 19, 2000 (2), and May 20, 2000 (2)). All night observations were on cobble-gravel-sand habitats. She was badly injured when recaptured on June 6, 2000. She died two days later in the laboratory.

Salamander #10 moved three times in 74 observations from March 8, 2000 to August 27, 2000 (Fig. 12). He was observed under a large boulder for one observation before moving to another large boulder located on the riverbank,

where he remained for the remaining 72 observations (March 10, 2000 to August 27, 2000). He was “out” on cobble substrate only once, (May 19, 2000).

Salamander #11 used only one shelter from May 8, 2000 to August 6, 2000 (43 observations) (Fig. 13). This male remained under a small boulder in shallow water and was never observed “out” on the substrate.

Salamander #13 moved six times in 42 observations from May 8, 2000 to August 3, 2000 (Fig. 14). She remained under a large boulder in deep water from the release date until July 16, 2000 (33 observations) before moving to a small boulder in shallow water where she remained until July 18, 2000 (six observations). The salamander remained relatively active throughout the study and was “out” on cobble-gravel-sand habitats for 3 night observations (May 18, 2000, May 19, 2000, and May 20, 2000).

Fig. 5. Movements of Salamander #1. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

William Leonard Eury
Appalachian Collection

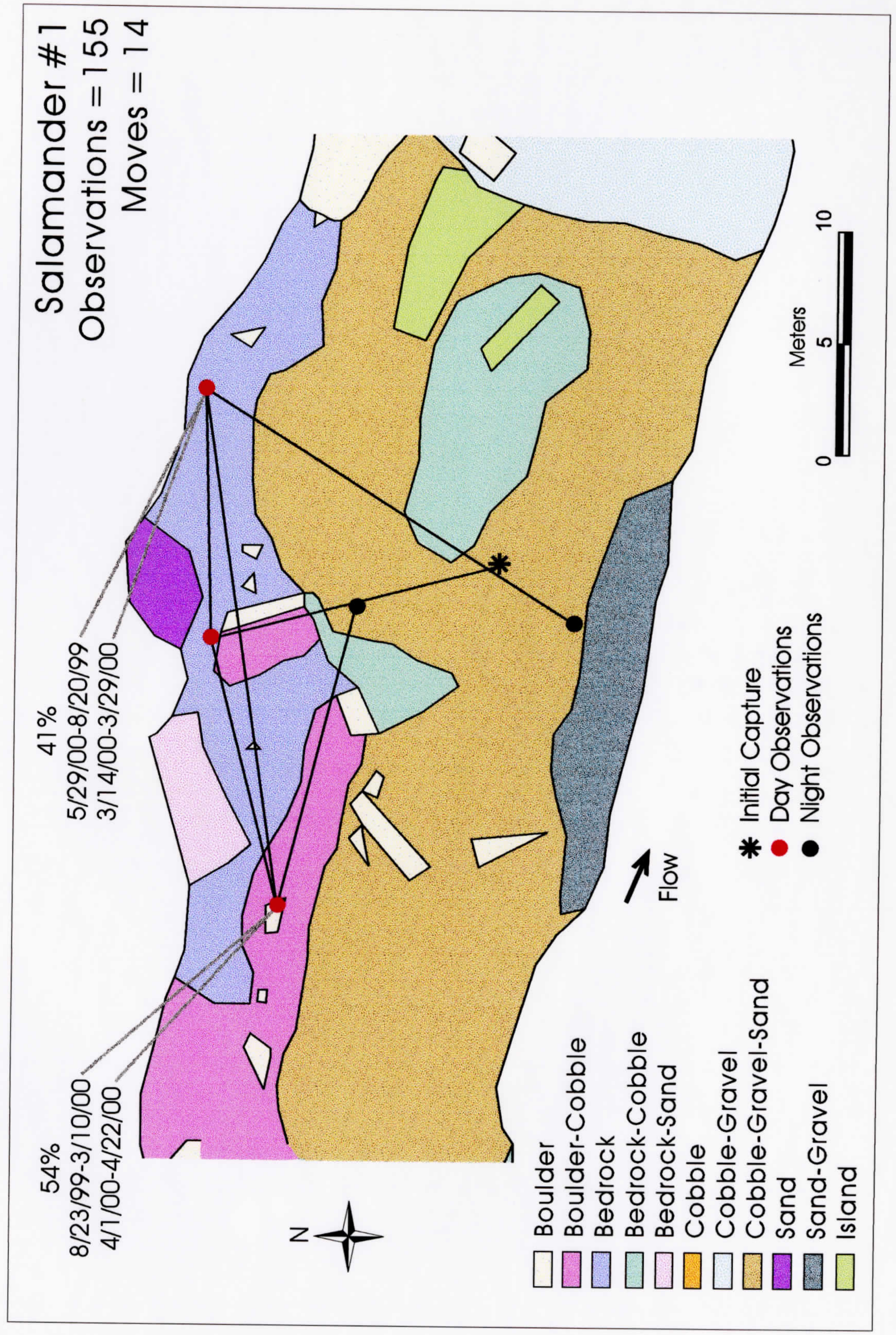


Fig. 6. Movements of Salamander #2. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

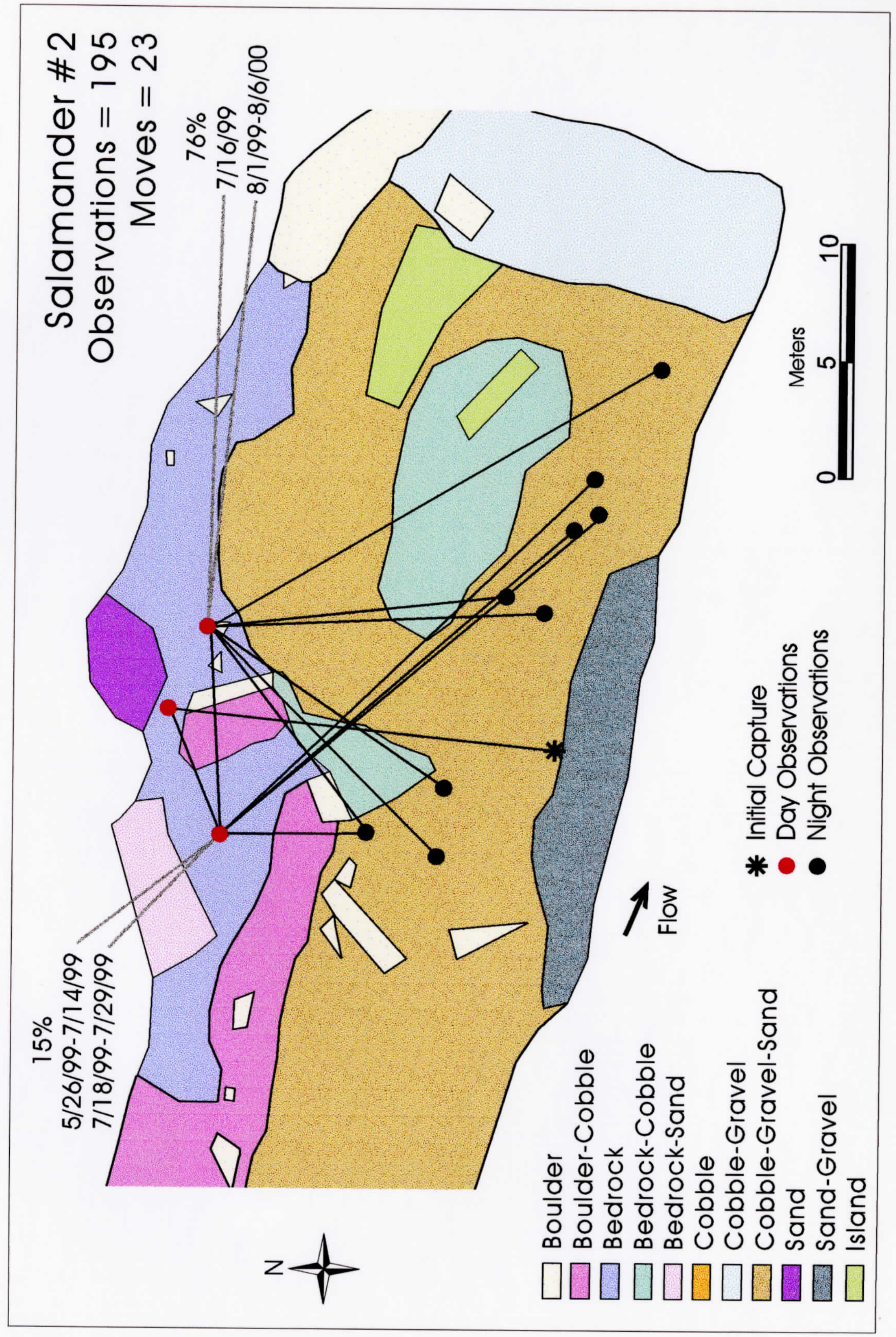


Fig. 7. Movements of Salamander #5. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

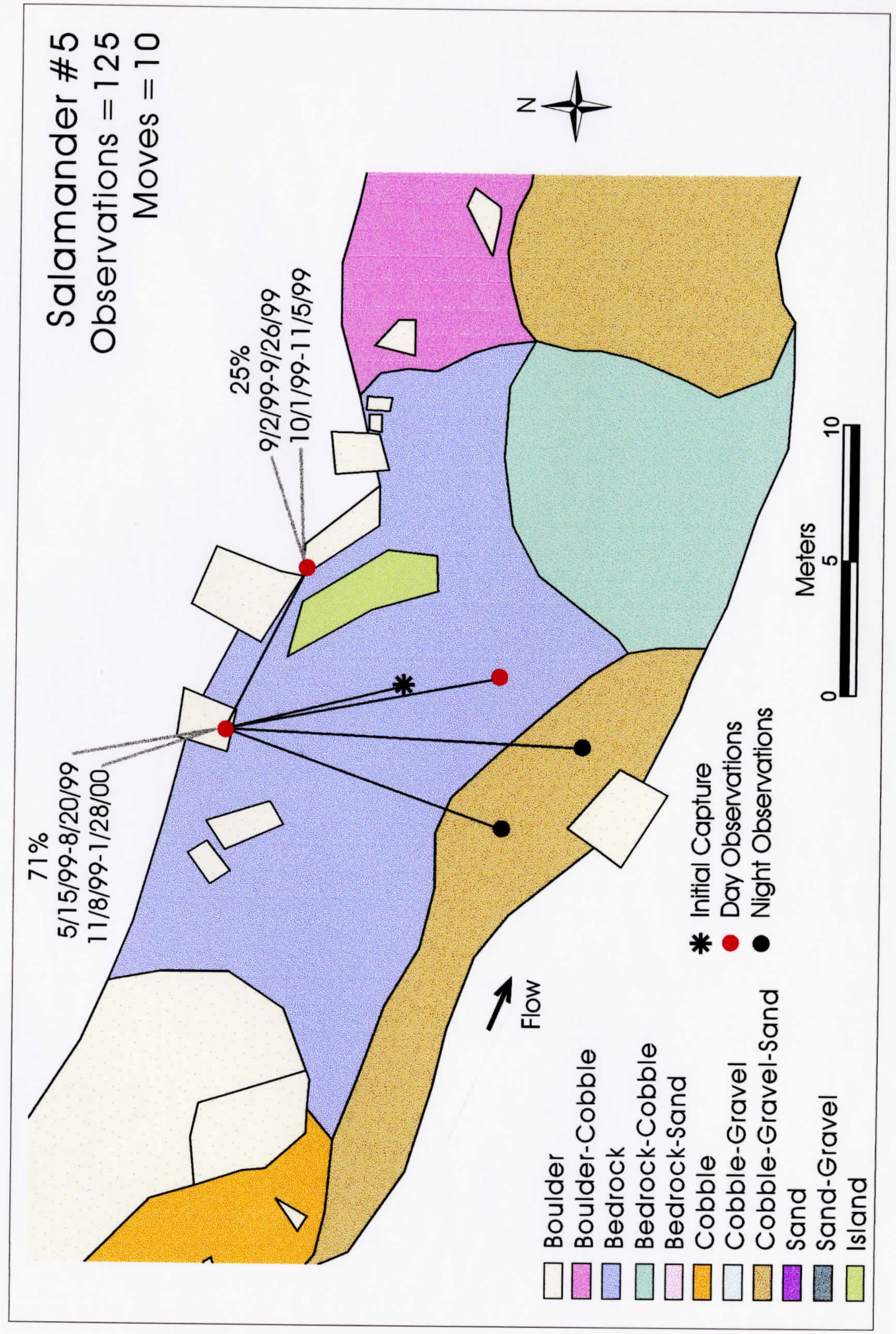


Fig. 8. Movements of Salamander #6. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

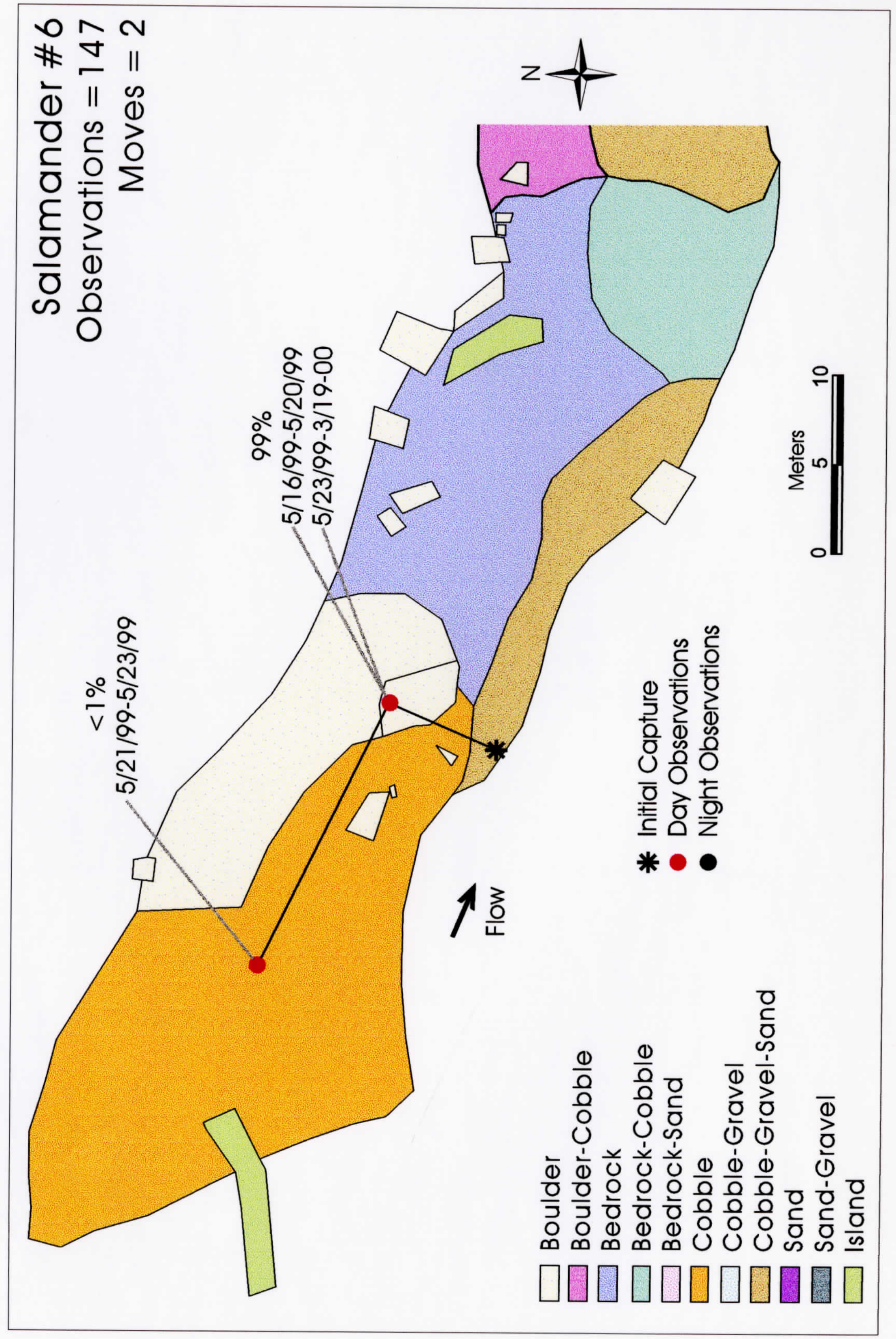


Fig. 9. Movements of Salamander #7. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

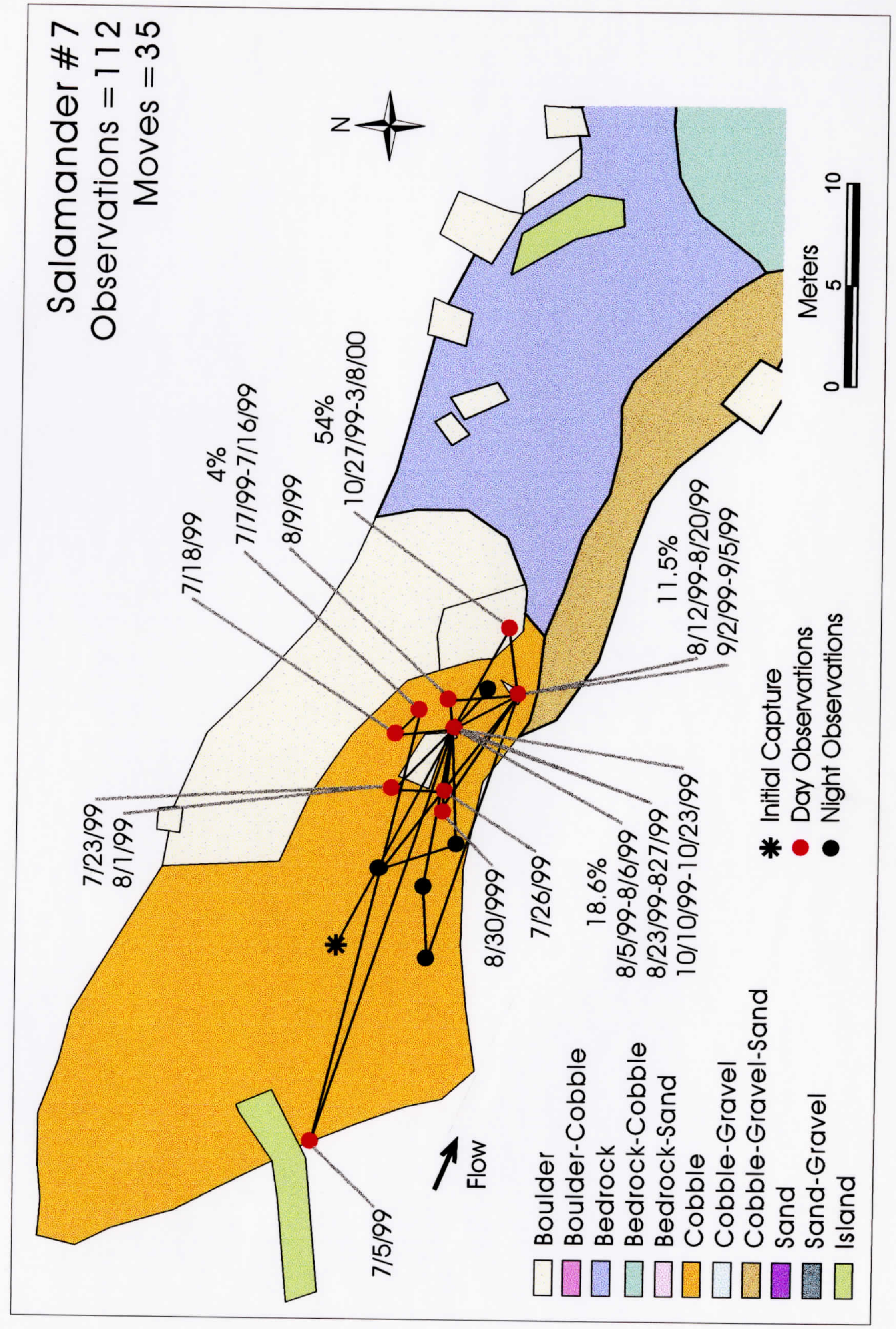


Fig. 10. Movements of Salamander #8. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

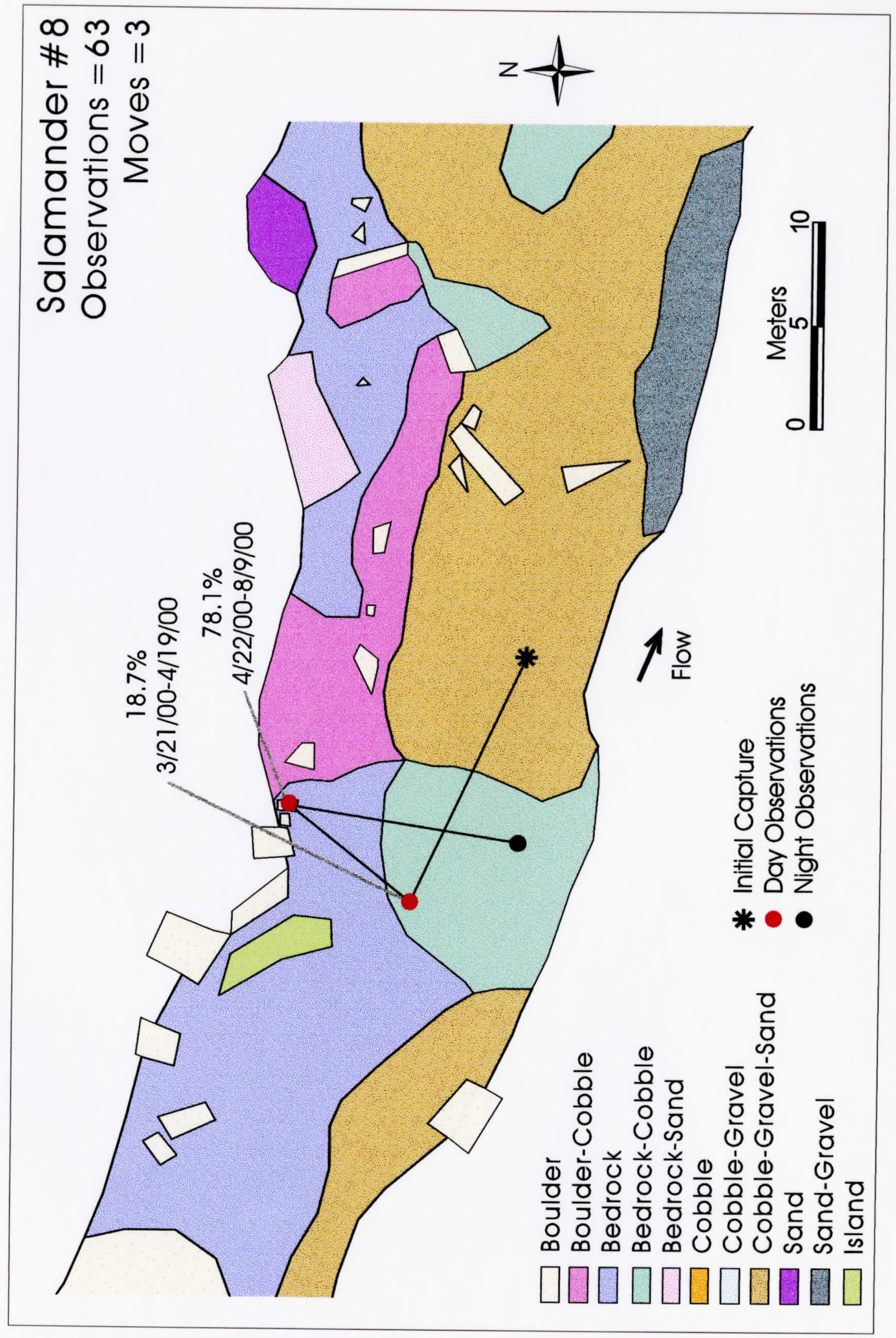


Fig. 11. Movements of Salamander #9. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

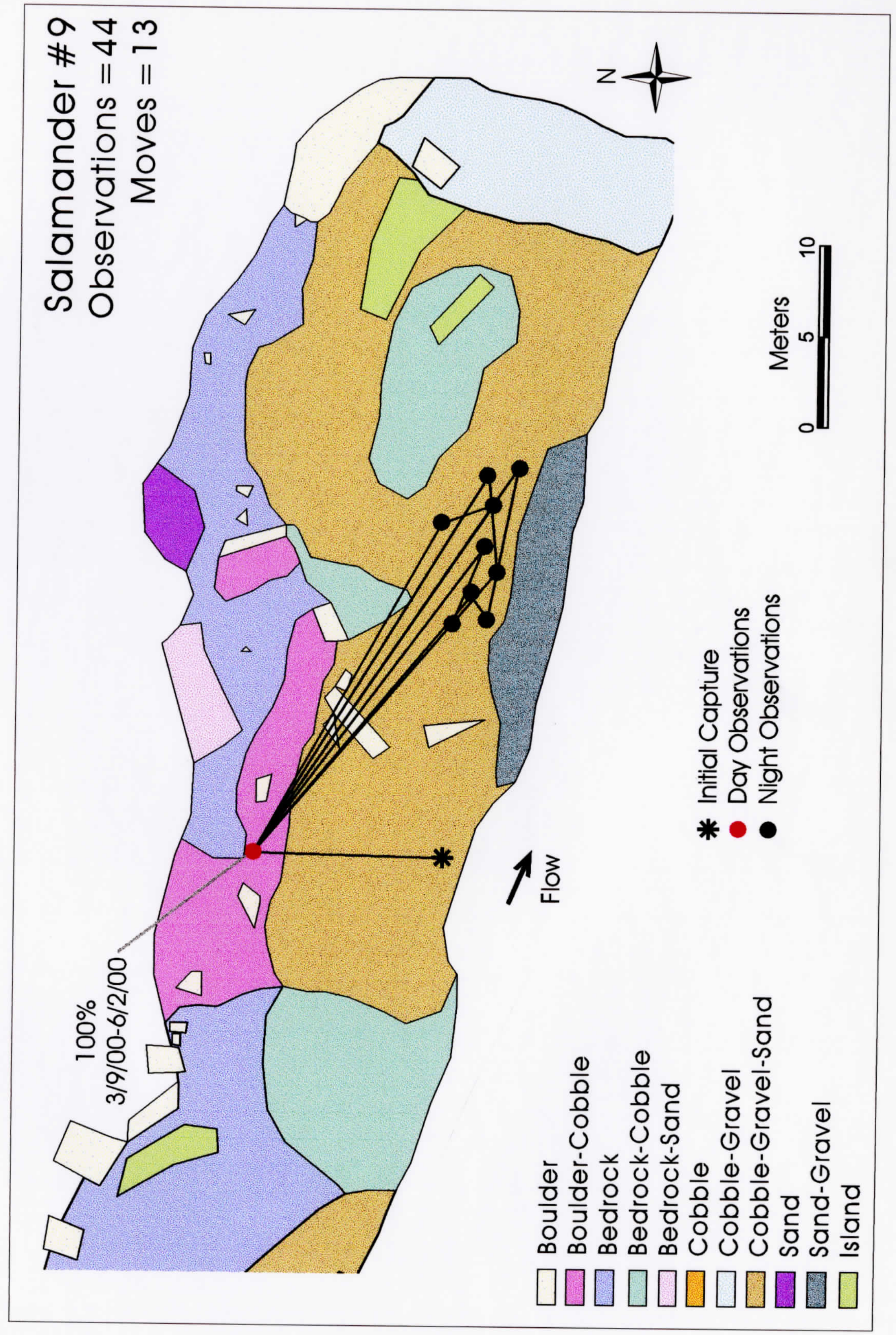


Fig. 12. Movements of Salamander #10. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

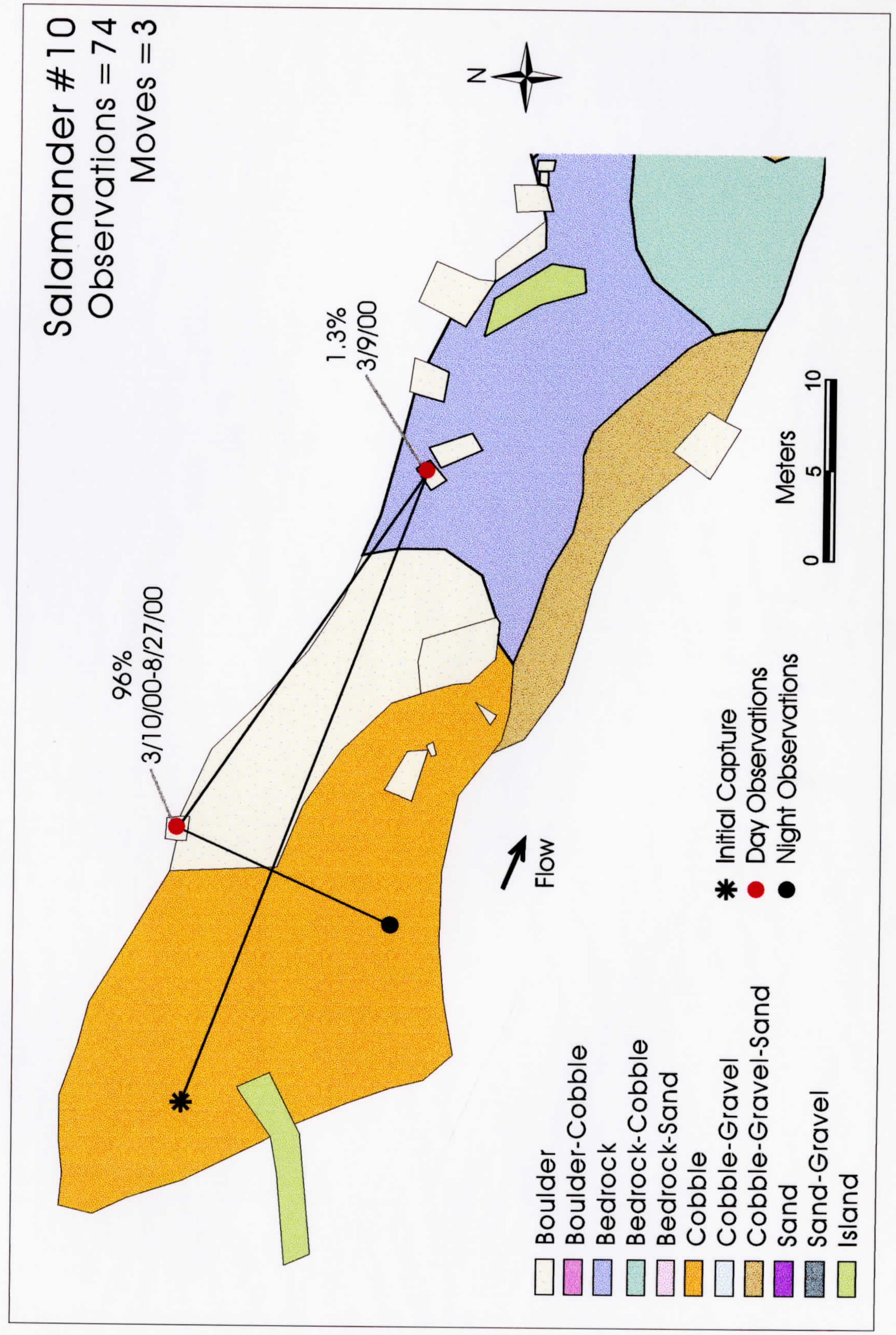


Fig. 13. Movements of Salamander #11. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.

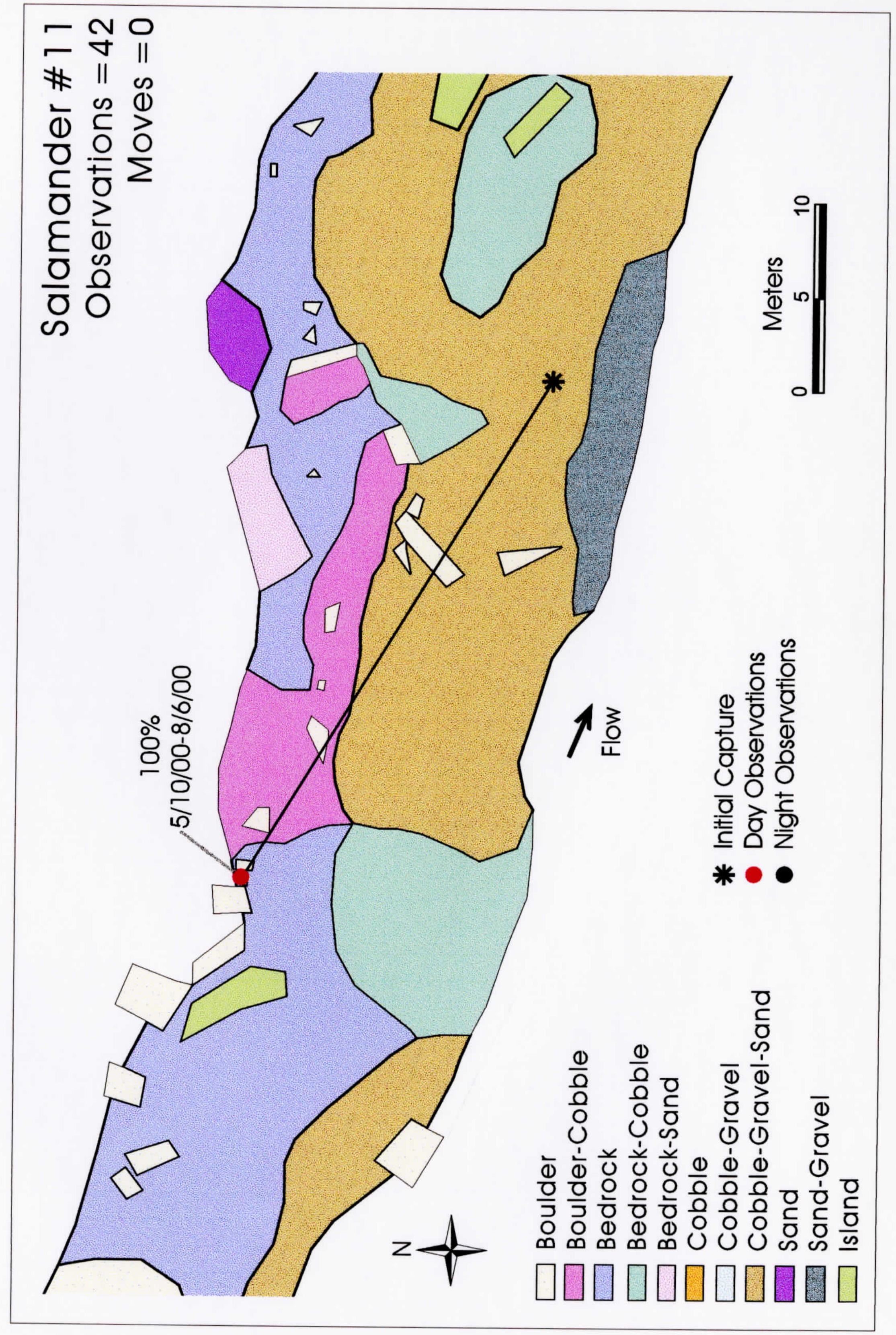
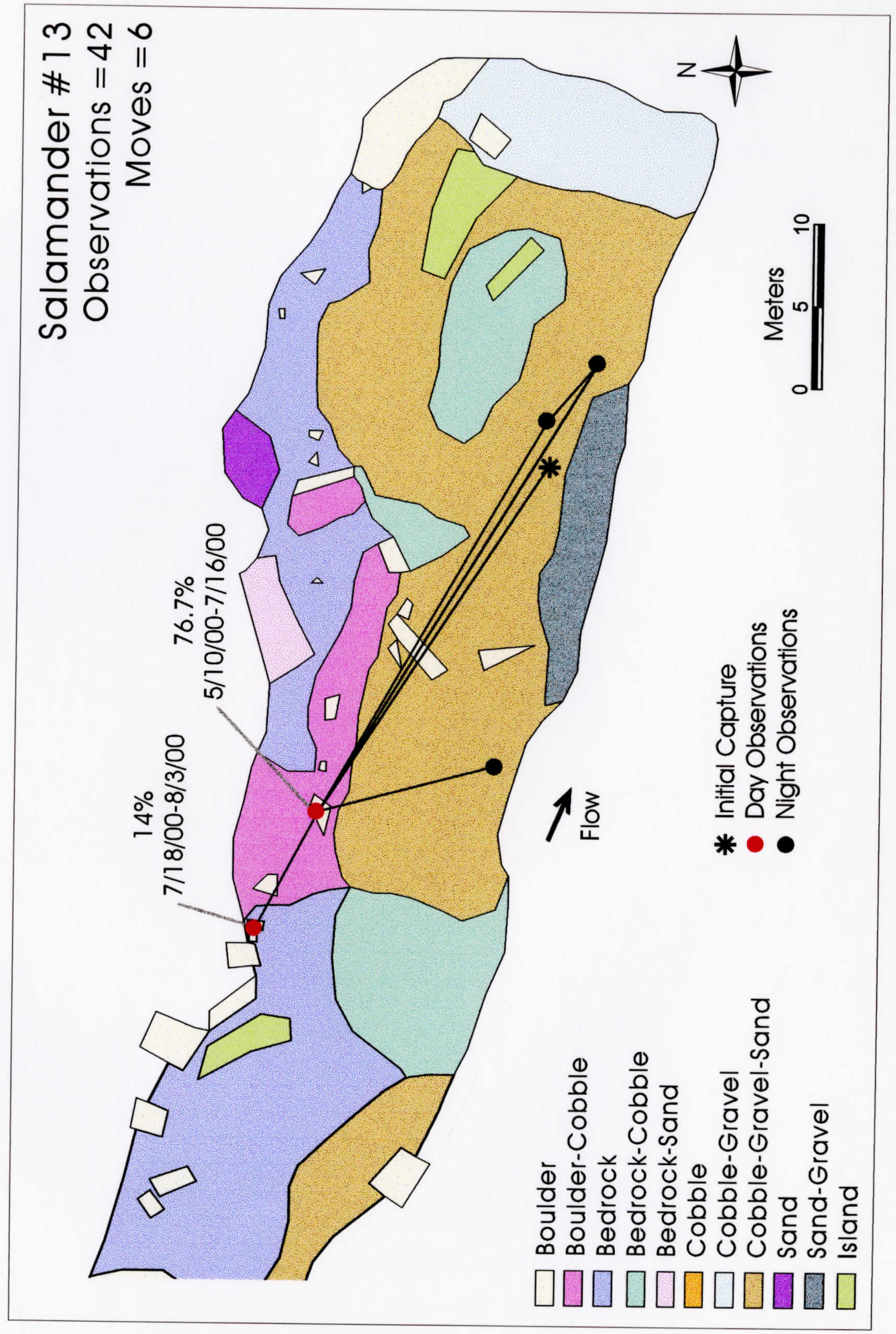


Fig. 14. Movements of Salamander #13. A black star represents site of initial capture, a red dot indicates daytime observations, a black dot indicates nighttime observations. Observation sites and lines of travel may represent multiple observations. Small boulders may be covered by symbols. Dates and percent observation at major locations are presented marginally.



<u>Analysis of Combined Movements</u>

Analysis of movements of hellbenders in the Watauga River was complicated because most observations (880 out of 999) showed the animals in the same place as during the previous visit (Table 5). When all data were included, hellbenders moved significantly further at night (Fig. 15, ANOVA, $F_{1,985}=57.23$, $P<<0.001$). There was no significant effect of sex on distance moved and the sex * photoperiod interaction was not significant.

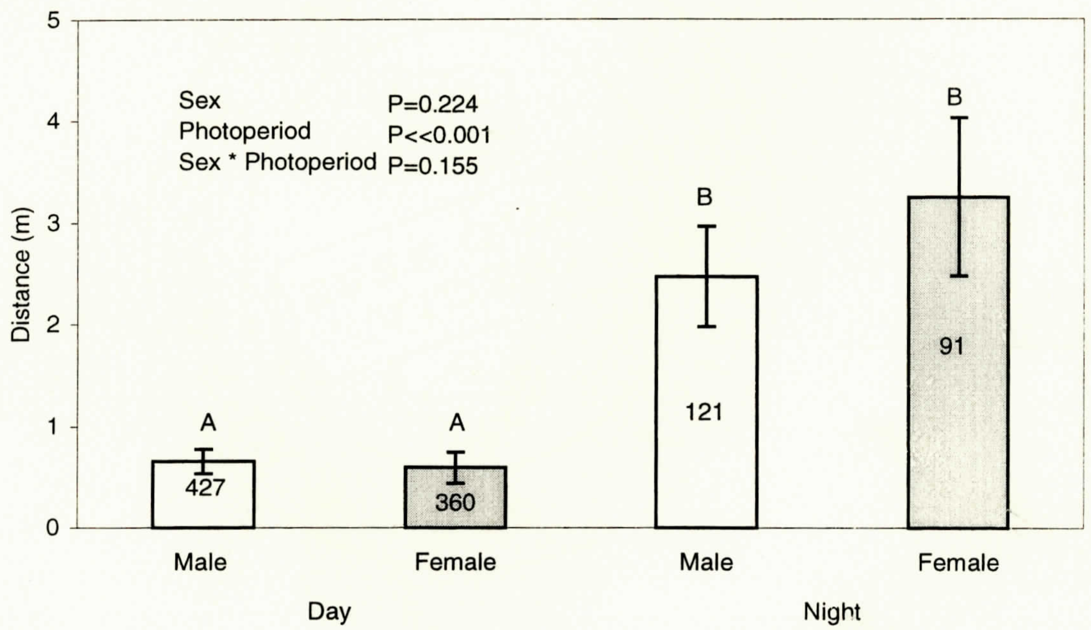


Fig. 15. Movements of hellbenders. Data were separated by sex and photoperiod. Columns with the same letter above them are not significantly different. Error bars represent +/- one standard error.

When zeros were excluded, males moved significantly less than females (Fig. 16, ANOVA, $F_{1,115}=7.94$, $P=0.006$). There was no significant effect of photoperiod on movement and sex * photoperiod interaction was not significant.

Table 5. Summary of movements of implanted *Cryptobranchus alleganiensis*. Length of movements was calculated using ArcView®.

Specimen #	Sex	Zeros #	Moves #	Minimum (m)	Maximum (m)	Average Move (zeros excluded)	Average Move (zeros included)
1	F	140	14	11.20	23.44	15.41	1.49
2	M	171	23	5.74	22.11	14.59	1.80
5	M	114	10	6.66	13.07	9.23	0.81
6	F	144	2	6.52	16.30	13.04	0.27
7	M	76	35	1.39	21.81	5.54	1.78
8	F	59	3	7.56	13.19	10.82	0.69
9	F	30	13	1.53	25.73	14.60	4.75
10	M	70	3	12.55	37.01	21.44	1.16
11	M	41	0	0	0	0	0
13	F	35	6	4.60	31.73	16.89	2.82
All Day		713	74	1.31	37.00	10.88	0.63
All Night		167	35	2.05	32.32	13.27	2.81
Males		472	71	1.10	37.20	10.14	1.06
Females		408	38	2.67	32.04	14.67	1.13

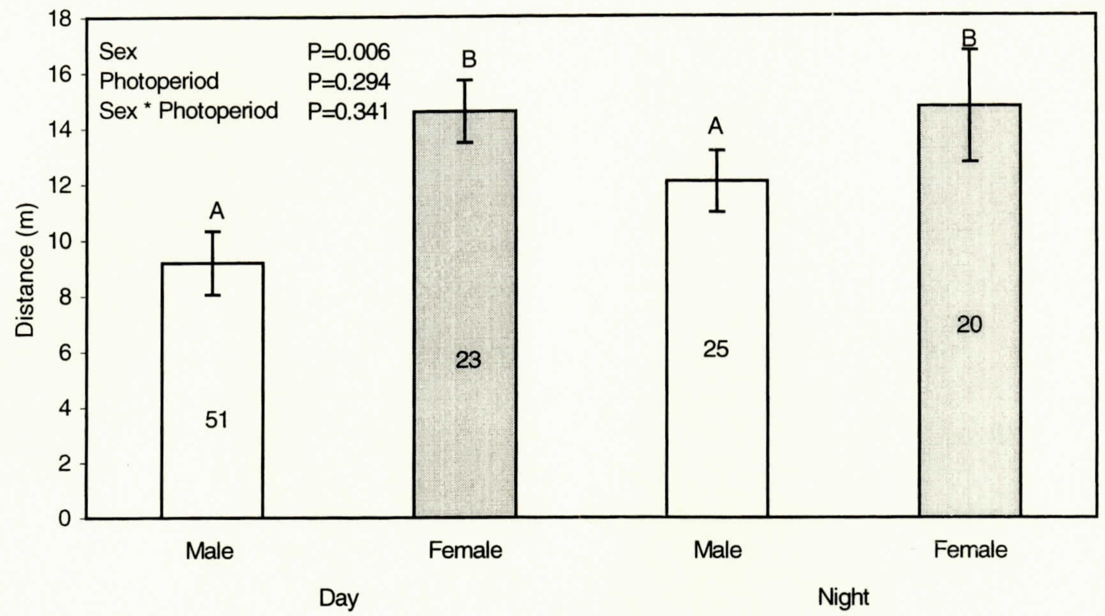


Fig. 16. Movements of hellbenders when zeros were excluded. Data was separated by sex and photoperiod. Columns with the same letter above them are not significantly different. Error bars represent +/- one standard error.

Examination of frequency of moves was complicated by variation in both number of moves and number of observations per salamander. When # moves/# observations was sorted by sex and photoperiod, males seemed to move more between successive daytime observations than did females (9.8% vs. 2.9%, respectively). The opposite was true at night (16.3% vs. 47.4%, respectively). When these proportions were transformed (arcsine) for statistical analysis, only photoperiod had a significant effect on movement frequency (Fig. 17, ANOVA, $F_{1,16}$=5.32, P=0.035).

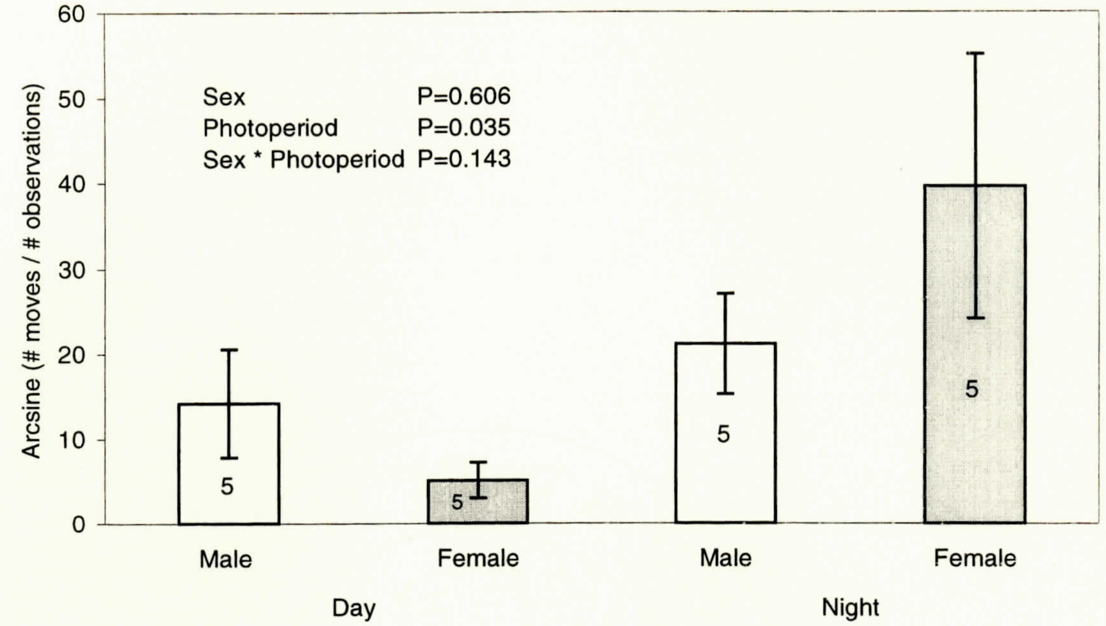


Fig. 17. Frequency of moves by hellbenders. Each column is the average for five individuals. Error bars represent +/- one standard error. Number of moves per individual was quite variable (Table 5).

When all observations were sorted by distance moved, there was no difference between males and females (Table 6, test for independence, χ^2=9.395, df=4, P>0.05).

Table 6. Contingency table for movements of male and female hellbenders. Movements were sorted into 5 m increments (χ^2=9.395, df=4, NS).

Distance moved (m)	Female	Male	Total
0-5.0	413	496	909
5.1-10.0	5	20	25
10.1-15.0	16	18	34
15.1-20.0	7	3	10
>20.1	11	10	21
Total	452	547	999

Hellbender activity was almost completely nocturnal. Hellbenders were "out" on the substrate on only 43 of the 1009 observations and only one of these was during the day. This difference between day and night activity is highly significant for both sexes (Table 7 for males, test for independence, χ^2=72.42, df=1, P<<0.001; Table 8 for females, test for independence, χ^2=78.44, df=1, P<<0.001). Male and female hellbenders were much more likely to be away from shelter at night than in the daytime. In addition, males and females were equally likely to be "out" for both day and night observations (Table 9 for daytime, test for independence, χ^2=0.8442, df=1, NS; Table 10 for nighttime, test for independence, χ^2=0.4041, df=1, NS 909). In fact, only one animal was observed "out" in the daytime. Both sexes emerged infrequently in the day and emerged at the same rate at night.

Hellbenders were not equally active in all seasons when all observations were included in the analysis (Fig. 18, ANOVA, $F_{3,995}$=5.70, P=0.001). Tukey's post-hoc pairwise comparison revealed movements in summer and winter were intermediate between the fall (sedentary) and spring (active) and were not significantly different from either in. Distances moved in spring ($\bar{X}$=2.115 m) were significantly greater than in fall ($\bar{X}$=0.435 m).

Table 7. Daily activity patterns of male hellbenders (χ^2=72.42, df=1, P<<0.001).

Hellbender activity	Day	Night	Total
In (hidden under shelter)	426	104	530
Out (exposed on substrate)	1	22	23
Total	427	126	553

Table 8. Daily activity patterns of female hellbenders (χ^2=78.44, df=1, P<<0.001).

Hellbender activity	Day	Night	Total
In (hidden under shelter)	360	76	436
Out (exposed on substrate)	0	20	20
Total	360	96	456

Table 9. Daytime activity of hellbenders (χ^2=0.8442 df=1, NS).

Hellbender activity	Male	Female	Total
In (hidden under shelter)	426	360	786
Out (exposed on substrate)	1	0	1
Total	427	360	787

Table 10. Nighttime activity of hellbenders (χ^2=0.4041, df=1, NS).

Hellbender activity	Male	Female	Total
In (hidden under shelter)	104	76	180
Out (exposed on substrate)	22	20	42
Total	126	96	222

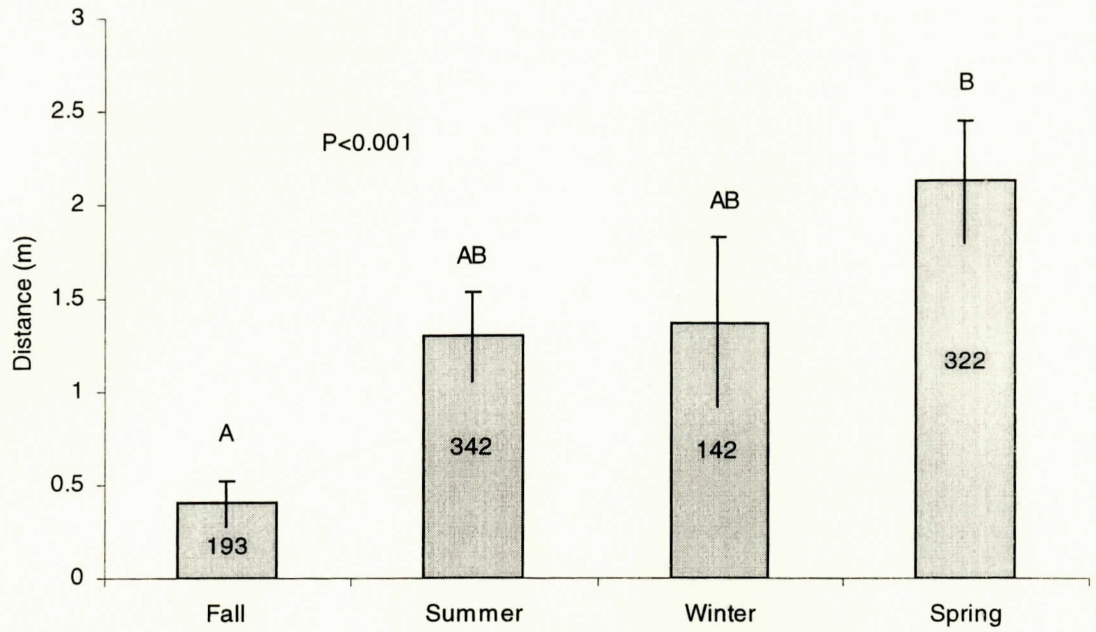


Fig. 18. Seasonal differences in hellbender movements, including zeros (ANOVA, $F_{3,995}$=5.70, P=0.001). Columns with different letters above them are significantly different. Error bars represent +/- one standard error.

Hellbender activity could be divided into two seasonal patterns when zeros were excluded (Fig. 19, ANOVA, $F_{3,115}$=12.63, P<<0.001). They were relatively inactive in summer and fall ($\bar{X}$=9.229 m and $\bar{X}$=6.000 m, respectively, Tukey's post-hoc pairwise comparison, NS) and active in winter and spring ($\bar{X}$=19.4 m and $\bar{X}$=14.5 m, respectively, Tukey's post-hoc pairwise comparison, NS). All of the movements in winter were relatively long and very late in that season and might be viewed as spring movements. In fact, removal of these movements leaves no movements during winter, which is exactly opposite from what this analysis suggests.

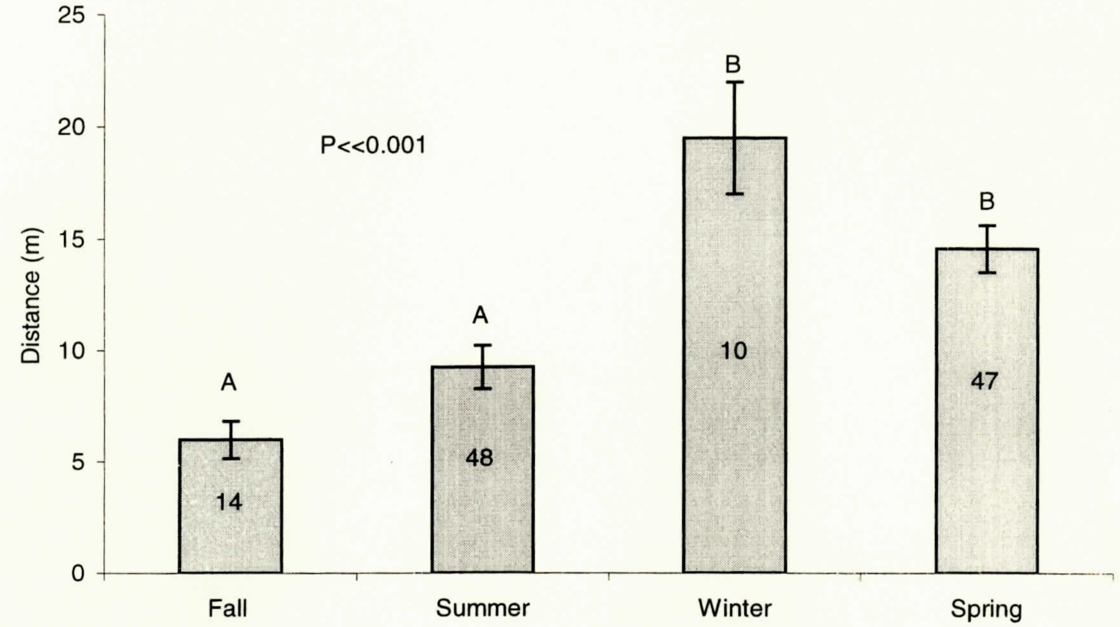


Fig. 19. Seasonal differences in hellbender movements, with non-movements excluded (ANOVA, $F_{3,115}$=12.63, P<<0.001). Columns with different letters above them are significantly different. Error bars represent +/- one standard error.

Seasonal differences in hellbender movement were also evident in non-parametric Chi-square (χ^2) tests. In addition, the contingency table comparable to the ANOVA for seasonal movements, with zeros included, was significant (Table 11, test for independence, χ^2=29.348, df=9, P<0.001). Major deviations from expected values were too many spring movement of 10.1-15.0 m and >15 m and too few fall movements of the same distances.

The other measure of hellbender activity, frequency of emergences from refugia was also significantly influenced by season (Table 12, test for independence, χ^2=12.54, df=3, P<0.01). Over 90 % of "out" observations were in spring and summer when only 66 % of observations were made. The contingency table for actual movements, zeros excluded, could not be evaluated because of the low number of moves in fall and winter (Table 13).

Table 11. Seasonal movement contingency table (χ^2=29.348, df=9, P<0.001). Movements were distance between salamander locations on consecutive site visits. Movements were sorted into 5 m increments.

Distance moved (m)	Spring	Summer	Fall	Winter	Total
0-5.0	280	313	184	132	909
5.1-10.0	5	12	7	1	25
10.1-15.0	19	8	2	4	33
>15.1	18	9	0	5	32
Total	322	342	193	142	999

Table 12. Seasonal activity of hellbenders (χ^2=12.54, df=3, P<0.01).

Hellbender activity	Spring	Summer	Fall	Winter	Total
In (hidden under shelter)	304	330	193	139	966
Out (exposed on substrate)	18	12	0	3	33
Total	322	342	193	142	999

Table 13. Seasonal movement contingency table, zeros excluded. Movements were distance between salamander locations on consecutive site visits. Movements were sorted into 5 m increments. Due to low number of moves in fall and winter no analysis was performed on this contingency table.

Distance moved (m)	Spring	Summer	Fall	Winter	Total
<5.0	5	19	5	0	29
5.1-10.0	5	12	7	1	25
10.1-15.0	19	8	2	4	33
>15.1	18	9	0	5	32
Total	47	48	14	10	119

Habitat Use

Substrate Use

Hellbenders did not utilize substrates randomly (Fig. 20, goodness of fit, χ^2=6470.3, df=9, P<<0.001). Hellbenders spent most of their time (92%) under boulders, which occupied only 11.3% of the site and were never observed in five of ten habitat classifications (cobble-gravel, boulder-cobble, sand-gravel, bedrock-sand, and sand). When hellbenders were "out" and active at night, they moved to the C-G-S and C habitats, which were avoided in the daytime (Fig. 21, goodness of fit, χ^2=49.8, df=9, P<0.001).

Hellbenders did not select daytime retreats in the same habitats throughout the year (Table 14, test for independence, χ^2=92.0, df=12, P<<0.001). During fall and winter, hellbenders selected boulders almost exclusively. In summer and spring the salamanders used a greater diversity of habitats, and bedrock-cobble was used only in spring. Mixed cobble habitats were used in all seasons except for fall. In addition, bedrock-cobble habitats were only used during spring. Shelter boulders used during colder times were significantly larger than boulders used in warmer times (Fig. 22, ANOVA, $F_{3,742}$=22.21, P<0.001). Hellbenders moved to larger boulders in fall and winter ($\bar{X}$=5.190 m^2 and $\bar{X}$=4.992 m^2, respectively) and used smaller boulders in spring and summer ($\bar{X}$=1.997 m^2 and $\bar{X}$=2.763 m^2, respectively).

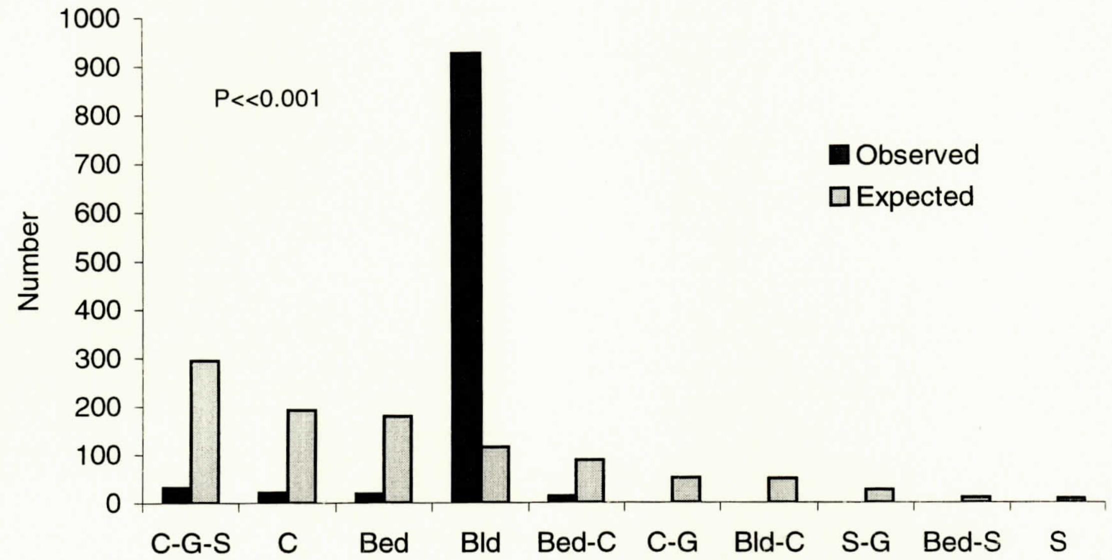


Fig. 20. Substrate utilization of hellbenders (χ^2=6470.3, df=9, P<<0.001). Substrate type for each salamander location was compared with values expected if substrate use were random.

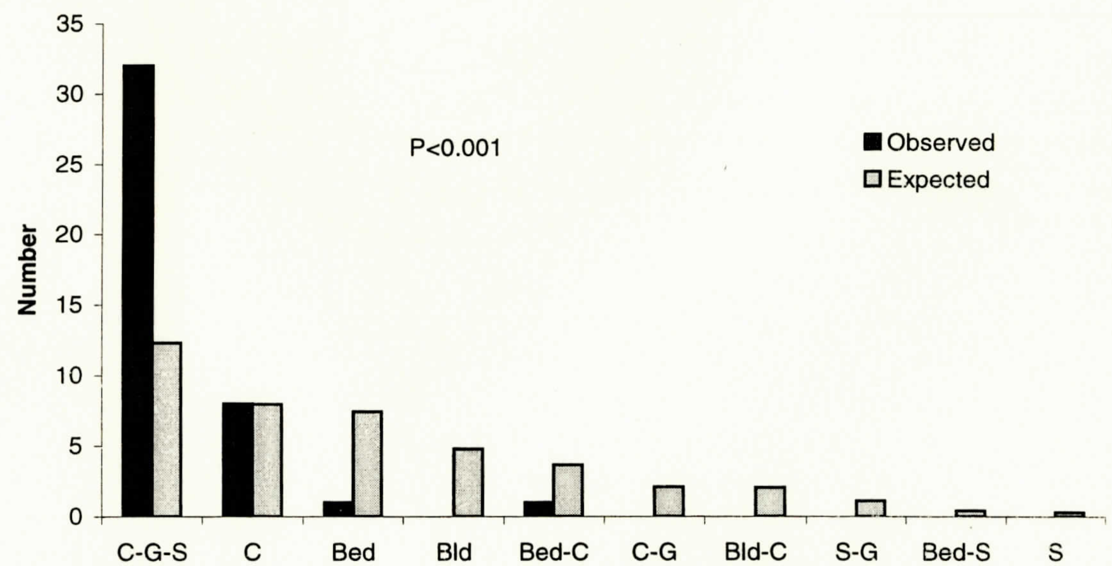


Fig. 21. Substrate utilization of hellbenders during "out" observations (χ^2=49.8, df=9, P<0.001). Expected values reflect availability of each substrate category in the study site (n=1009).

Table 14. Seasonal substrate utilization for daytime observations (χ^2=92.0, df=12, P<<0.001).

Substrate Type	Spring	Summer	Fall	Winter	Total
Cobble-Gravel-Sand	21	6	0	5	32
Cobble	2	18	0	1	21
Bedrock	14	3	1	0	18
Boulder	278	316	192	139	925
Bedrock-Cobble	13	0	0	0	13
Total	328	343	193	145	1009

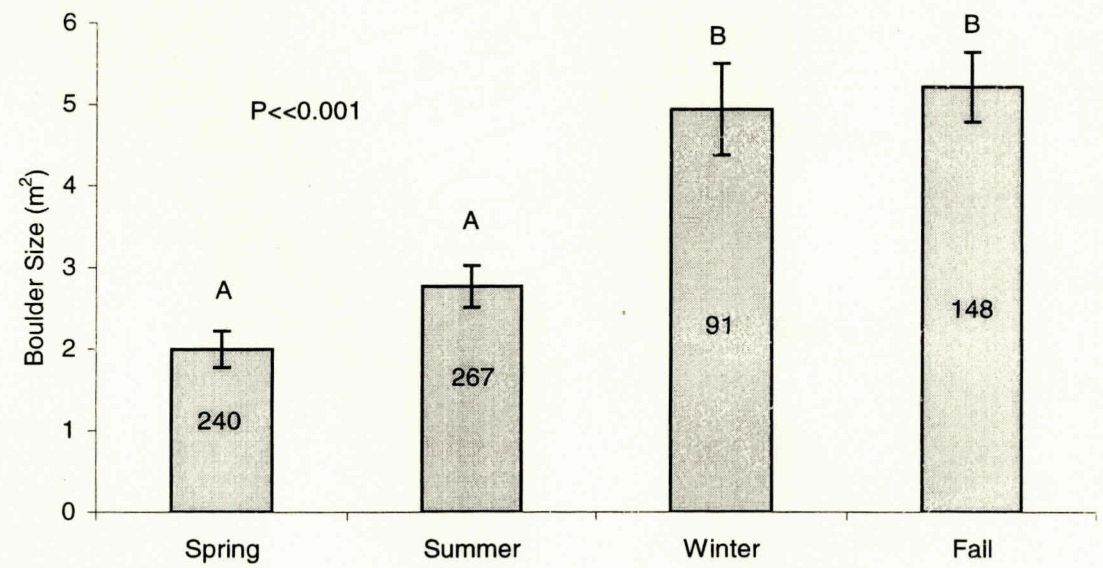


Fig. 22. Size of daytime retreats used by hellbenders (ANOVA, $F_{3,742}$=22.21, P<0.001). Boulder size was determined by ArcView®. Seasonal differences were highly significant and were correlated with the two seasonal (spring-summer and fall-winter) use patterns. Error bars represent +/- one standard error.

Water Depth Use

Hellbenders were found in water depths ranging from 30 to >120 cm in the deepest parts of the study site. The salamanders did not use the study area randomly according to water depth (Fig. 23, goodness of fit, χ^2=7039.61, df=12, P<<0.001). Four deeper categories (0.7-0.8, 0.9-1.0, 1.0-1.1, and >1.2 m) were used more often than expected and all categories <0.7 m were used less than expected. Since several depth categories included expected values less than five observations, the depth profile was collapsed to four categories for an additional test; the salamanders still preferred deeper water (Fig. 24, goodness of fit, χ^2=2253.89, df=3, P<<0.001). Depths less than 0.7 m were used much less than expected, while habitats deeper than 0.7 m were used more than expected.

Hellbenders used deeper water in the colder fall and winter periods and shallower water in spring and summer (Fig. 25, ANOVA, $F_{3,783}$=67.73, P<<0.001). A Chi square test for independence also showed that water depths used by salamanders differed by season (Table 15, test for independence, χ^2=313.45, df=27, P<<0.001).

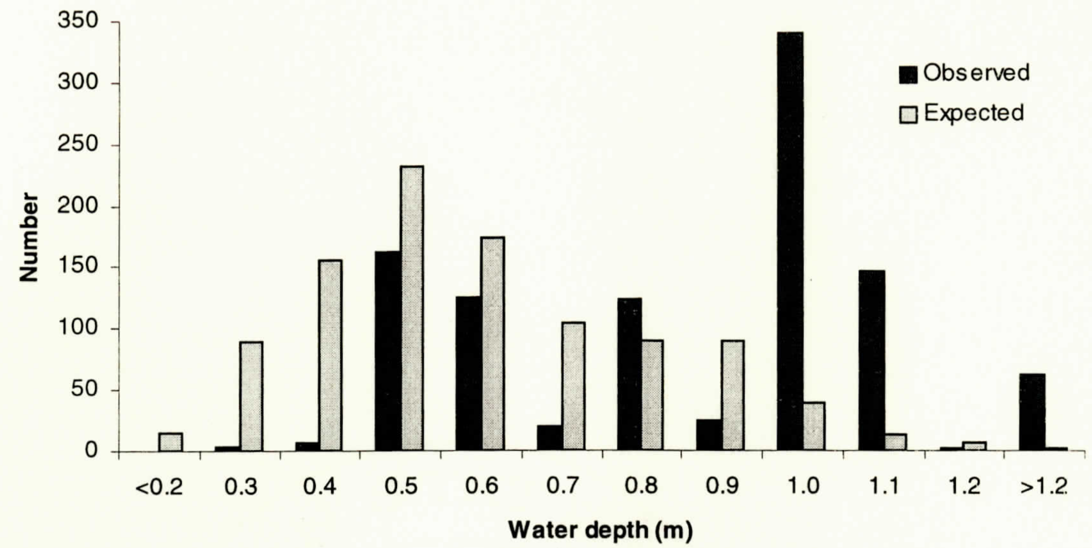


Fig. 23. Water depth utilization for all salamander observations (χ^2=7039.6, df=11, P<<0.001). Fine grain separation of water depth resulted in several expected values less than five. Expected values reflect availability of each depth category in the study site (n=1009).

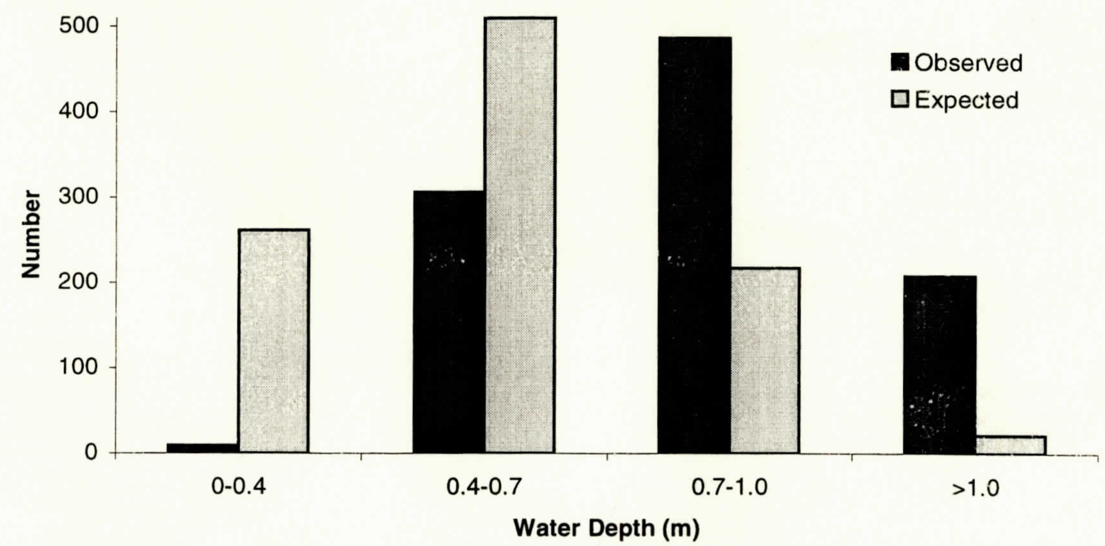


Fig. 24. Water depth utilization for all salamander observations (χ^2=2253.9, df=3, P<<0.001). Coarse grain separation of water depth resulted in no expected values less than five. Expected values reflect availability of each depth category in the study site (n=1009).

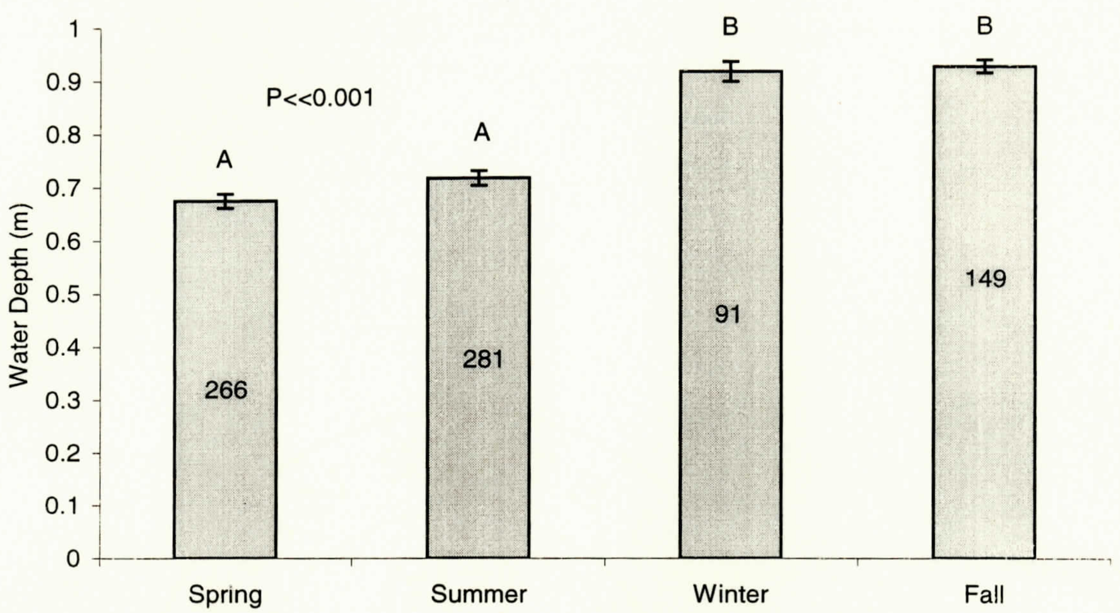


Fig. 25. Depth of water used seasonally by hellbenders for daytime observations (ANOVA, $F_{3,783}$=67.73, P<<0.001). Columns with different letters above them are significantly different. Error bars represent +/- one standard error.

Table 15. Seasonal water depth utilization (χ^2=205.71, df=9, P<<0.001).

Depth (m)	Spring	Summer	Fall	Winter	Total
0-0.4	35	24	0	3	62
0.4-0.7	167	149	38	20	374
0.7-1.0	126	165	125	95	511
>1.0	0	5	30	27	62
Total	328	343	193	145	1009

Temperature

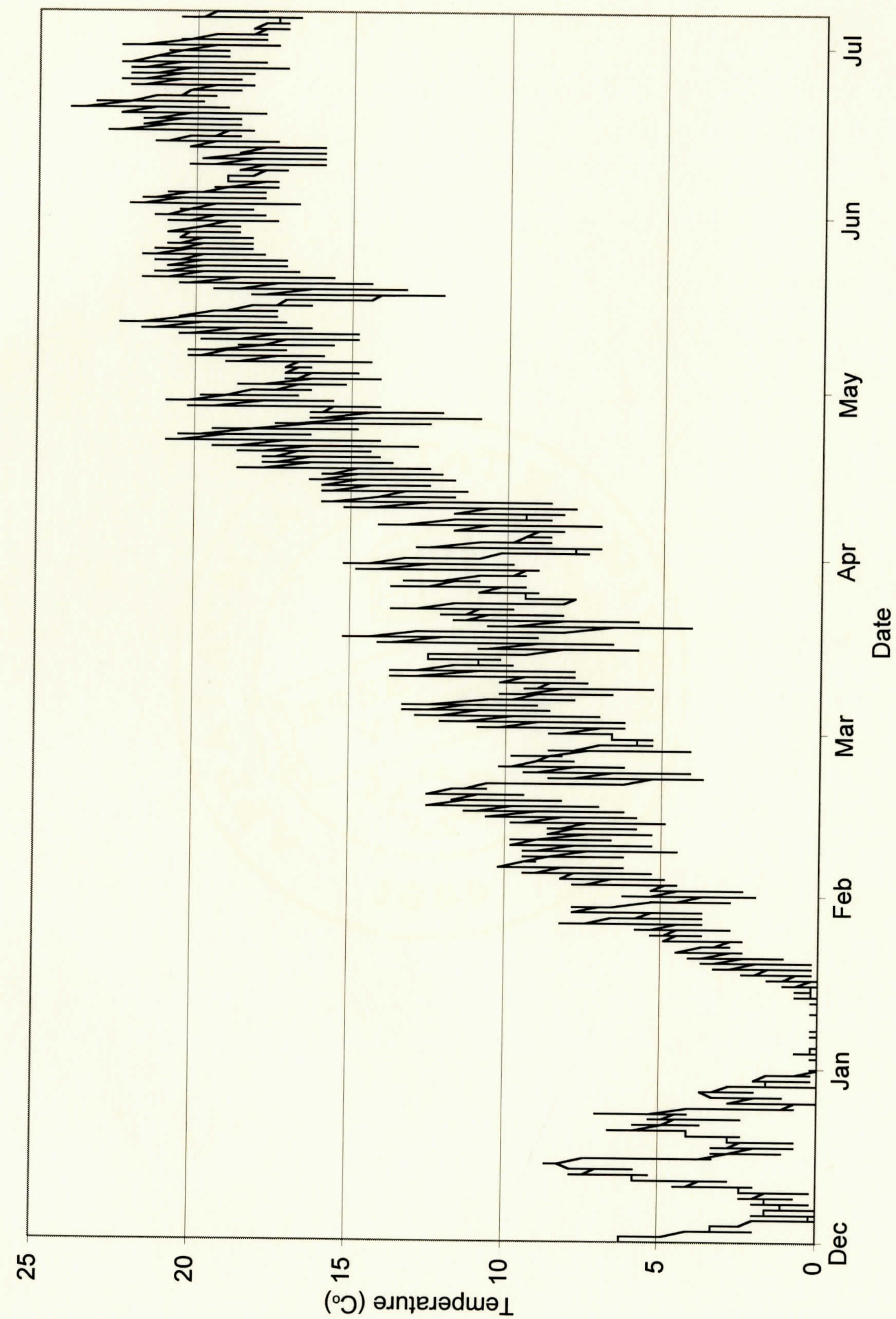
Water temperature averaged 10.58° C (ranging from -0.1 to 24.0° C) over 1756 temperature recordings from 21 December 1999 to 27 July 2000 (Fig. 26,

Table 16). Water temperature fluctuated an average of 3.16° C daily, 7.55° C weekly, and 8.00° C seasonally. Water temperature remained >1° C from 20 January 2000 to 6 February 2000. No movements were recorded until average daily water temperature was >5° C.

Table 16. Monthly and seasonal variation in water temperatures at 70 cm depth in the Watauga River. Dates included in seasons were: winter (December 21-March 19), spring (March 20-June 20), and summer (June 21-July 27). Temperatures were collected using a HOBO data logger.

Month	Minimum (°C)	Maximum (°C)	Average (°C)	Average Daily Change (°C)
December	-0.1	6.2	2.33	1.69
January	-0.1	8.6	2.19	1.60
February	-0.1	10.2	3.86	2.51
March	3.7	13.7	8.20	3.75
April	4.1	15.2	10.01	3.91
May	8.6	20.9	15.92	4.26
June	12.1	22.4	18.54	3.46
July	15.9	24.0	19.34	3.17
Winter	-0.1	12.5	3.95	2.33
Spring	4.1	22.4	13.62	3.99
Summer	15.9	24.0	19.18	3.09

Fig. 26. Temperature data collected by Hobo data logger. The data logger was started 17 December 1999 and collected 27 July 2000.



DISCUSSION

The radiotelemetry work with hellbenders living in the Watauga River provided a number of insights into their basic natural history and raises several new questions. Some of these results seem to be in conflict with previously published work on hellbenders and warrant discussion in the larger context of hellbenders across their range. How are Watauga River hellbenders similar to other populations and how are they different? Are hellbenders in the Watauga River really in need of protection? How can we use the movement data of adult hellbenders to delineate habitat requirements? What additional data would be needed to make recommendations about conservation of hellbenders? Finally, the Special Concern legal status of hellbenders in North Carolina requires effort to integrate the new hellbender data with future conservation plans.

Watauga River Hellbenders

General Observations

Hellbenders in the Watauga River appear to be relatively sedentary and remain hidden the vast majority of time. Boulders are preferred for shelter. One or two primary shelters are used throughout the year and may be used in successive years. All specimens in this study moved to large boulders in deep

water during cold periods. Movement to areas not likely to freeze would reduce their chance of freezing during occasional bitterly cold periods (Blais 1996). As temperatures increase, some individuals remained stationary; but others moved into alternate shelters in shallower waters. During warmer months some hellbenders emerged at night and moved to cobble-gravel-sand habitat, presumably to feed, for social interactions, or to move to a new retreat.

Hellbenders almost certainly use many more criteria in selecting their retreats than were evaluated in my study. Some criteria might include: current flow around their shelter rocks, number and position of entrances/exits, local prey densities, movement patterns of prey species, and proximity to hunting grounds. Collectively, these criteria probably determine the quality of each potential retreat and the activity of any hellbender using it. In addition, the quality of a hellbenders's retreat probably influences how often the animal moves.

There was considerable variation in movement frequency of these hellbenders. Some individuals moved relatively often, but others used the same shelter for up to a year. A hellbender might remain sedentary for several reasons, including high prey availability and/or control of a preferred nest site. If food regularly comes to a salamander in its retreat, it could remain stationary for long periods. If the shelter does not offer adequate food, hellbenders using these sites would need to actively forage away from their shelters and might move more often.

In addition to individual variation in frequency of moves, movement patterns differed significantly between sexes and photoperiods, and among seasons. Males and females were equally likely to move throughout the year but females moved farther each time. This difference is probably related to differing sexual strategies. Males select and defend nest sites where females later deposit their eggs (Bishop 1943). Since good nest sites are a valuable (and possibly limiting) resource, males may guard them for a large part of the year (Nickerson and Mays 1973a). Males with good nest sites probably limit both frequency and distances they move beginning well before the actual breeding season in August. Remaining stationary would reduce their chance of losing the site, but may also reduce food availability. "Decisions" to move probably represent a balance of costs associated with potential loss of favorable shelter and benefits associated with feeding.

These salamanders were primarily nocturnal and daytime movements were rare. At night some salamanders move out on the preferred substrate (mixed cobble), possibly to forage. Mixed cobble substrates offer increased interstitial space (hiding places for prey) and may hold greater densities of the preferred prey, which are crayfish (Bishop 1943).

Data Limitations

The primary emphasis of this study was hellbenders' use of daytime retreats, but night surveys also provided information on salamander movements. If time and energy were available the design of this experiment could be expanded to address additional issues:

1) With the small number of marked animals used in this study, there were suggestions that both habitat use and movements vary with both sex and size. Increasing number of salamanders would allow more robust comparisons between sexes and among size classes.
2) Since most salamanders were not located every day, there is some doubt about the actual frequency with which they changed shelter rocks. Daily or hourly visits to the site would reveal short term sheltering among sites if it occurs. Intervals of daily observations in each season would clarify this detail about hellbender movement.
3) There are several questions about nocturnal emergences and movements of hellbenders which could be answered if time allowed more and longer nighttime surveys. Do all hellbenders emerge on "perfect nights"? What weather criteria stimulate nocturnal moves?
4) One major but inevitable weakness of this study was that it focused on only one site on one stream. There is no way to determine the generality of these results to the Watauga River or to other watersheds. Simultaneous work at more sites per stream and more streams would allow me to determine if the behavior of the Watauga River hellbenders is typical of other populations.
5) No efforts were made to monitor the availability of hellbender food, particularly crayfish. Simultaneous trapping of crayfish in the multiple sites suggested in #4 would allow analysis of the relationship between

hellbender activity and prey availability.

Seasonal Differences in Activity of Hellbenders

Most hellbenders were extremely sedentary throughout the winter and remained in deep water under large boulders. They did not emerge even at night. As water temperatures rose in late winter (early March), frequency of movement increased. In the spring animals moved more often and farther. Hellbenders probably move for a variety of reasons. Some animals probably move to better foraging areas. Since deeper areas at the study site have very little of the preferred mixed cobble substrate, some animals might move to get away from larger conspecifics and other predators.

Movements became less frequent and shorter with warmer summer temperatures. The individuals which occasionally emerged were probably feeding or males searching for nest sites. Most animals captured did have crayfish in their stomachs. Breeding activity peaks in late August when females are full of eggs and search for the best nest sites (Nickerson and Mays 1973a). Successful males guard their nest site and clutch(es) from predators, including other hellbenders, and do not move (Petranka 1998). Males without nest sites move and gather upstream from occupied nest sites. Since hellbenders have external fertilization sperm released by these males could fertilize some eggs in the nest downstream (Blais 1996). This satellite male strategy probably explains why two to four animals gathered just upstream from salamander #2 (a large sedentary male) from August 27 to September 2, 1999. Females and

unsuccessful males move back to deep water in early fall (late September to early October) where they remain until the spring. Males with nests remain with their nests throughout the winter. Movements of all individuals were rare during fall and winter.

Threats To Local Hellbenders

Among many threats to the hellbender population in the Watauga River three seem most important: 1) increased siltation, 2) trout and trout fisherman, and 3) collectors. Increased sediment loads are blamed for decreases in hellbender populations across their range (Conant and Collins 1998). Silt fills the interstitial space in substrate where hellbenders, especially small ones, and their prey shelter and nest. Although the Watauga River is considered High Quality Water (HQW), siltation rates are increasing in several sections of river (Anonymous 1997). Siltation is unlikely to decrease in coming years, since the rate of development in the Watauga River corridor is increasing rapidly.

The heavy fishing pressure this section of river receives throughout the year probably has a negative effects on hellbenders. As many as twelve fishermen were observed fishing within the study site (100 m) at a single time. The constant movement of fishermen across the substrate cannot benefit hellbenders. Salamanders may also be hurt or killed when shelter boulders shift beneath the feet of anglers. Some fishermen also kill every hellbender they catch. Reasons offered for these deeds include hellbenders eat trout, they are believed to be poisonous, and they are considered “too ugly to live”.

Trout, themselves may threaten hellbenders through both direct and indirect interactions. In a normal stream adult hellbenders and trout probably compete for many food resources such as crayfish, smaller fish, and smaller hellbenders, so increases in adult trout density should have a negative impact on both adult and juvenile hellbenders. Increase in juvenile trout might enhance the food base for hellbenders and have a positive impact on hellbenders. Trout and hellbenders should also interact indirectly, through competition for food resources, especially crayfish and smaller fish. While several variations are possible, the most likely effects of trout on crayfish and their hellbender predators are negative. However, it is unclear how these interactions will change when stream communities are grossly modified by stocking.

Since trout fishing plays a significant role in the economy of Watauga County, the North Carolina Wildlife Resources Commission stocks many of the local streams. Stocking seems to fall into three basic strategies: 1) Streams not stocked, 2) streams stocked to mimic natural densities, and 3) streams stocked with large fish and above natural densities ("delayed harvest"). In areas designated "delayed harvest" waters, including the study site, large numbers of trout are stocked in small areas to increase anglers' chances of catching trout. In summer, these waters convert to normal hatchery supported regulations and trout can be harvested. "Delayed harvest" waters receive up to a five fold increase in fishing pressure (North Carolina Wildlife Resource Commission 2001), which cannot benefit hellbender populations.

Heavy stocking, such as that at the Watauga River site, will have all the negative impacts discussed above and a few positive ones. Quite a few trout are damaged during stocking and subsequent fishing. If these fish become injured or they die, they become a food source for bigger fish, hellbenders, and crayfish. Also, the multiple capture and release of individual fish in "delayed harvest" waters could weaken healthy fish, so availability of carrion would be extended to much of the year. Both hellbenders and crayfish chould benefit from this increase in food supply.

The study site is well known to herpetologists as a good spot for hellbenders. Besides the obvious fact that collectors remove individuals from the population, they may significantly damage habitat as well. The preferred method of finding hellbenders is by flipping large rocks (Soule and Lindberg 1994). Hellbenders in this study and others seem extremely attached to specific shelters. Displaced individuals often return to their initial site of capture (Hillis and Bellis 1971). Once a boulder is flipped, its "quality" could be altered and might even become unusable by hellbenders. Most changes in rock position are probably for the worse. Collectors and/or researchers using "standard collecting techniques" probably damage hellbender habitat and populations in many more ways than simply collecting animals.

Hellbenders Throughout Their Range

Previous Studies Using Radiotelemetry

Two previous investigators have studied hellbender movements using radiotelemetry. Coatney (1982) observed nocturnal movements of seven Ozark hellbenders over a 14 day period during the breeding period in August and calculated elliptical home ranges. While Coatney's (1982) females had slightly larger home ranges (range=25.4-194.3 m^2, $\bar{X}$=99.48 m^2, n=3) than did males (range=18.8-253.2 m^2, $\bar{X}$=82.92 m^2, n=4), the difference was not significantly different. These animals moved (# moves/ # observations) often but it was unclear if this was due to breeding or feeding activities.

Blais (1996) obtained somewhat different results for 16 hellbenders in New York. He studied these animals for 12 months and calculated linear home ranges by season. These animals used (moved along) from 0 m to 407.3 meters of the stream. New York hellbenders were larger on average than those studied in the Ozarks. Hellbender density was estimated to be 29.4 animals in a 900 meter stretch of stream, a considerably lower density than in the Ozarks (Blais 1996). He observed a low number of movements (29 moves/484 observations) and concluded these salamanders were sit and wait predators, unlike Ozark hellbenders. He conducted seven night surveys and observed no salamanders "out" on the substrate.

Activity of hellbenders in the Ozarks and in New York appears different from each other and from those in Watauga River. Hellbender density (although

no formal estimate was conducted) in Watauga River appears intermediate between those in the Ozarks and New York, but most similar to the latter. Individual salamanders in the Watauga River population displayed great variations in movement pattern. Movements of several salamanders' were similar to those in New York; however, others were similar to those in the Ozarks (e.g. salamander #11 had no observed movements while salamander #7 had 35 observed movements).

Several researchers have reported long distance movements (>100 m) in marked hellbenders (Nickerson and Mays 1973b, Wiggs 1977, Peterson 1987, Coatney 1982, Blais 1996), but no such moves were seen in the Watauga River. Since long distance movements would tie together subpopulations along a river, it is important to understand the differences seen in the various studies. The most obvious difference in these studies is that Watauga River hellbenders were collected at night without habitat disturbance. In all previous studies animals were collected by flipping rocks. Since hellbenders appear to prefer one or two shelter rocks (Nickerson and Mays 1973a), it seems almost certain that rock flipping changes hellbender habitat. Turning over a rock sheltering a hellbender will completely alter the rock's hydrology and its likelihood of becoming silted. Whatever made that rock a favorable retreat would be changed dramatically. Similarly, flipping all those other rocks without hellbenders would affect overall habitat stability for local hellbenders. Effects of rock flipping can be both immediate and delayed. For example, several hellbenders in the Watauga River move between one shelter for warm times and another for cold times. If a shelter used during cold times is flipped in July, it may be three months before a salamander returns to its winter home. If that shelter is no longer usable, the salamander must find another, less desirable shelter. Hellbenders displaced from their preferred rocks may have to travel long distances to find undisturbed, usable shelters.

The study by Blais (1996) showed that hellbenders behaved dramatically different after both capture and disturbance (i.e. rock flipping). He observed a total of 29 movements in 484 observations. Most movements (62%) occurred within one week of a disturbance and only 21% of movements occurred more than two weeks after a disturbance. In addition, 75% of 17 movements >30 m were observed within one week of a disturbance. An astonishing seven long distance movements occurred within a day of a disturbance.

Hellbenders and the North Carolina Law

Hellbenders are considered a species “of special concern” by the State of North Carolina (Anonymous 1997). Hellbenders can serve as indicators of water quality because of their sensitivity to pollution and siltation (Anonymous 1997). Small changes in either may have dramatic effects on local populations. Currently, these salamanders are relatively uncommon in local streams and seem to be rarer now than in recent history (R. W. Van Devender, pers. comm.). However, there are few data supporting either this statement or the contrary one

that hellbenders are at natural densities. It seems that the real needs today are more information about hellbenders and the various factors controlling their populations.

One purpose of the present study was to increase our knowledge of hellbenders in North Carolina as a prelude to re-evaluating their current status. Several results and observations from this study should be important in evaluating the status of hellbenders in North Carolina. The most obvious finding relevant to conservation is that adult hellbenders do not move very often and/or very far. Individuals may live most of their life within a small area using boulders as shelters and foraging on mixed cobble substrates. While there are small sexual and seasonal differences in hellbender behavior in the Watauga River, none of these seem important to the larger scale issues related to “health” of hellbender populations throughout this drainage or the whole range in North Carolina. While these limited results cannot answer all the questions about hellbender conservation, experience gained during this work can identify the most pressing questions to be answered about hellbenders and suggest ways of getting answers to these questions. To insure the survival of Eastern Hellbenders in North Carolina it is essential that further studies be conducted. If we can answer the six questions posed below, we will be able to make meaningful decisions about hellbender conservation.

Proposed Management Plan for Hellbenders in North Carolina

In order to protect hellbender populations in North Carolina, we must have a variety of additional information. Outlined below are my suggestions for the State of North Carolina, including questions we need to answer and the analytical methods needed to answer these questions. Obtaining the answers to these questions should be considered high priority and need to be addressed. The State of North Carolina should commit resources immediately to answer these questions.

I. How can we rank habitat quality for hellbenders?
   A. Use availability of preferred substrates for shelter (boulders) and feeding (mixed cobble) to rank habitats according to habitat quality index (HQI).
   B. Evaluate HQI in many sites, both within streams and across drainages.
   C. Create nocturnal hellbender index (NHI) using nocturnal searches.
   D. Statistically compare #2 and #3, to validate HQI model.

II. How does trout stocking influence hellbenders?
   A. Evaluate hellbender population (both HQI and NHI) in numerous reaches of individual streams with different stocking regimes.
   B. Evaluate prey density in numerous reaches of individual streams with different stocking regimes.
   C. Statistically compare prey density in stocked and unstocked streams and across the HQI gradient.

III. What roles do reproduction and juveniles play in population dynamics?
   A. Evaluate breeding success by locating successful nest sites during all other surveys.
   B. Conduct field surveys to determine substrate use of juvenile hellbenders.
   C. Statistically compare #1 and #2 with hellbender index.

IV. Where can hellbenders be found today?
   A. Evaluate hellbender populations across their range in North Carolina using the hellbender index. Use historical data, museum specimen localities, and personal communication with locals to determine survey sites.

V. What effects does siltation have on hellbenders?
   A. Conduct controlled field experiments testing the effects of siltation on hellbenders, especially juveniles.
   B. Statistically compare habitat quality and hellbender density at sites above and below a sediment source.

VI. Are hellbender subpopulations genetically isolated?
   A. Collect tissue samples for DNA sequencing and protein electrophoresis as part of normal surveys.
   B. Use some sort of clustering algorithm to compare genetic variations within streams, within drainages, and across drainages to determine if subpopulations are genetically isolated.

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