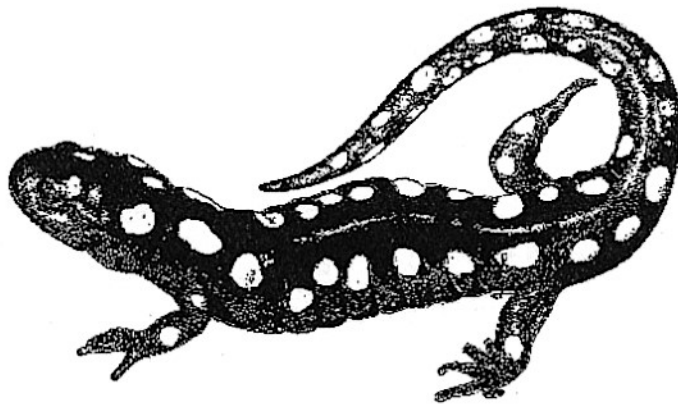




The Breeding Migration of
Marbled Salamanders (*Ambystoma opacum*)
and Spotted Salamanders (*A. maculatum*) at
the Jug Bay Wetlands Sanctuary on
Maryland's Coastal Plain

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INTRODUCTION

Salamanders are increasingly in the news because of the widespread concern among scientists and conservationists that the populations of many species are declining (Tying 1995; Wake 1991). Herpetologists agree that environmental degradation caused by water and air pollution, ozone layer thinning and habitat loss are some of the ultimate causes for these declines (Blaustein 1994; Blaustein and Wake 1995; Capone 1995; Knight 1995; Tangle 1995). Even seemingly pristine areas have suffered losses and, in the past decade, species in some habitats and national parks that are fully protected have disappeared (Lips 1998). National and international efforts have been initiated in order to gather information in order to better understand the causes and magnitude of this global problem (Pechmann et al. 1991).

Species in the family Ambystomidae are known as the mole salamanders because they spend most of each year underground (Conant and Collins 1991). During the relatively brief reproductive period they can become conspicuous when mature males and females travel along traditional routes to suitable breeding locations. Salamanders in the genus *Ambystoma* are the primary migratory salamanders found throughout the United States and four species are found in Maryland: Marbled Salamander (*Ambystoma opacum*), Spotted Salamander (*A. maculatum*), Jefferson Salamander (*A. jeffersonianum*), and Tiger Salamander (*A. tigrinum tigrinum*). Many researchers have investigated various aspects of the life history of mole salamanders, especially the Spotted and Tiger Salamanders (Harris 1980; Husting 1965; Semlitsch and Pechmann 1985; Semlitsch et al. 1993; Semlitsch 1981).

Marbled Salamanders and Spotted Salamanders are common at the Sanctuary. These salamanders spend most of the year in the well-drained, upland forest. In early fall, Marbled Salamanders migrate to ponds and wet woods to breed. Spotted Salamanders perform a similar migration in the spring. Males enter breeding areas to deposit their spermatophores and do not tend the females or eggs masses to any significant degree. Female Spotted Salamanders lay eggs in pools and temporary ponds (Husting 1965). Marbled Salamander females lay their eggs under leaves and logs along the edges of breeding ponds. They may leave immediately after laying the eggs or they may remain at the nest with the egg masses until they get covered by rising pond water (Nobel and Brady 1933).

Very little has been published about *Ambystoma opacum*. Prior to 1936 only eight papers or notes described the biology of *A. opacum* (Brimley 1920; Deckert 1916; Dunn 1917; King 1935; Lantz 1930; Mann 1855; McAtee 1933; Noble and Brady 1933). One of the most thorough studies of *A. opacum*, by Noble and Brady in 1936, has been the basis of almost all knowledge of the *A. opacum* lifestyle. *A. opacum* are often found in the same sites as *A. maculatum*, a more thoroughly studied species, but due to breeding in the fall season and over-wintering as eggs or larva, *A. opacum* are often overlooked. Noble and Brady described the female's behaviors of depositing eggs on land, usually under the leaf litter in shallow depressions. She guards them until the nest is inundated with water, when she then returns to the woods. Since 1936, much emphasis has been placed on larval development (Anderson and Graham 1967; Hassinger et al. 1970; Scott 1994; Stenhouse et al. 1983; Stenhouse 1984, 1985a, 1985b) with a flurry of activity in the 1980s on the evolution of nest-site selection (Jackson et al. 1989; Kaplan and Crump 1978; Petranka and Petranka 1981; Petranka 1990; Semlitsch et al. 1993).

In 1988, several long-term studies were initiated by Sanctuary naturalists to document and monitor the herpetofauna at the Jug Bay Wetlands Sanctuary. The aim of this work was to determine overall species diversity and relative abundance and to monitor any trends in herpetofauna population size. Field work was carried out largely by trained volunteers. A summary of this project was prepared by Smithberger and Swarth (1993).

A notable outcome of this fieldwork was the determination that several salamanders, chiefly the Marbled Salamander (*Ambystoma opacum*) and the Spotted Salamander (*A. maculatum*) were quite conspicuous and abundant in suitable habitats during the periods when adults were migrating to breeding locales. These observations led us to devote more effort to these two salamanders in recent years.

Over the eleven-year period between 1987 and 1998, volunteers and staff have been able to gather a significant amount of information about Marbled and Spotted Salamanders. This report summarizes information about these salamanders and is based almost entirely on data we have collected from pitfall traps and drift fences that were set to intercept and capture migrating salamanders. Initial years of this study produced fewer captures than later years, but early efforts were crucial for allowing us to develop standardized methods and for enabling us to locate productive trapping locations.

The questions we seek to answer through this research project, are:

- When do the salamanders begin their migration to breeding locations?
- How does the annual summer drought affect the timing of the fall *A. opacum* migration?
- How do weather conditions influence salamander movement?
- How does the migration period for males and females differ?
- How long do females remain at the breeding ponds?

ACKNOWLEDGMENTS

This study would have been impossible without the help of a large corps of dedicated volunteers. The increased success of the study, especially between 1994 and 1998, is the result of the commitment of some volunteers who were each able to check traps one morning per week. (These volunteers are indicated by an asterisk). Note: a few volunteers listed here helped with our annual herp survey but may not have participated in the migration study. Many thanks to the following:

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STUDY AREA

Jug Bay Wetlands Sanctuary is a 240 hectare (620 acre) ecological research station and wetland learning center located on the Patuxent River in southwest Anne Arundel County, Maryland, about 29 km (18 miles) south of Annapolis. The Sanctuary is operated by the County Department of Recreation and Parks, and a portion of the Sanctuary is within Maryland's Chesapeake Bay National Estuarine Research Reserve. Major habitats within the Sanctuary are fresh water tidal wetlands, non-tidal wetlands, upland hardwoods forests and agricultural fields. Two permanent creeks (Two Run Creek and Pindell Creek) drain the uplands and flow into Jug Bay, a shallow embayment on the Patuxent River. Several small, man-made ponds (old borrow pits) fill with water seasonally and are important habitats used by amphibians. These ponds, which vary in size from 5 to 25 m², were created when a railroad levee was built in the 1890s.

METHODS

Drift Fences and Pitfall Traps

Permanent drift fences with pitfall traps were the primary method that we used to monitor *Ambystoma* salamander populations. The fences served as a barrier to movement. When amphibians encountered a fence they were forced to turn either right or left. When they did this they encountered deep buckets set along the fence and salamanders fell in. Once in the buckets, salamanders were unable to climb out. Fences were placed in five habitats (see Figure 1):

- upland seasonally-flooded forest
- seasonal pond
- upland dry forest
- wet ravine-marsh edge
- permanent pond

Fences were made of 1/2 inch-mesh hardware cloth, aluminum flashing, or plastic mesh. The fences extended about one meter above the ground and approximately 10 cm below ground. The top of the fence was bent at a right angle to make it difficult for animals to travel over the top.

The pitfall traps were either two or five gallon buckets and were buried flush with the surface of the ground. A smooth transition from the ground surrounding the bucket to the lip of the bucket was critical for making it easier for animals to fall into the bucket. Therefore, care was taken by to make certain that the lip of a bucket did not protrude above the ground and also that there was no depression between the bucket and the soil.

Funnel traps made of hardware cloth approximately 1 m long with a 30 cm diameter funnel on either end were used at the Temporary Pond and the Forest Bluff sites beginning in the fall of 1996 and at Mark's Pond.

A damp sponge was placed in the trap to provide moisture and prevent the trapped animals from becoming desiccated. Foam floats were placed in buckets which provided refugia for trapped animals when the buckets filled with water. Buckets were covered with lids, funnel traps either placed in an upright position or removed, when not in use. During non-trapping periods, small gates in the fence were opened in order to permit salamanders and other animals easy access through the fence. All traps were numbered so we could record differences in trapping efficiency among traps.

The status of each bucket trap was always recorded as either "functioning" or "non-functioning." Non-functional traps resulted from several causes: saturated groundwater caused trap lips to pop above ground level; flooding may have provided some animals an avenue for escape; funnel traps were not flush against drift fences; or lids were not removed from a bucket. Data from traps that were judged to be "non-functional" were excluded from our analysis.

Description of Study Site Trap Arrays (Figure 1)

Upland Seasonally Flooded Forest (Wet Forest Site)

These traps, erected in 1988, were along a gentle wooded slope above a seasonally-flooded forest. The low-lying forest below the traps was dry most of the year but was periodically flooded in late winter and early spring. In dry springs almost no standing water was present, but in 1994, 1997, and 1998 the flooded area exceeded 3 Ha. Initially the traps were in a "cross" shape with six traps erected in the low flooded area. Due to occasional flooding and saturated groundwater the fence and traps were relocated approximately ten meters uphill in 1994. At this time a new set of eleven pitfall traps were arranged along two 50 m long fences perpendicular to the slope of the hillside. In 1996 one trap was removed so that each fence had five pitfall traps.

Seasonal Pond (Temporary Pond Site)

This fence-trap array was erected in 1988 and consisted of an aluminum flashing fence that entirely encircled a small vernal pond. This pond was adjacent to an old railroad levee and was created by the force of water that flowed through a concrete pipe during high rainfall events. The pond was dry for much of the year, but filled in late winter and spring. It measured roughly 6 x 8 meters when filled to its maximum extent. We placed four five-gallon buckets along the outside perimeter of the fence and four two-gallon buckets along the inside perimeter. In 1996, the fencing was extended with fiberglass screening to enclose the drainage stream at the outflow end of the pond. Two buckets were eventually

removed because they were continuously pushed up by groundwater pressure. Because traps flooded frequently, we added four funnel traps along the new fence in 1996. Snapping Turtles (*Chelydra serpentina*) and mudminnows (*Umbra pygmaea*) were observed in the pond and a number of small snapping turtles were captured in the pitfall traps.

Upland Dry Forest (Forest Bluff Site)

This trapping site along the top edge of a 10 m high bluff above the Two Run Creek floodplain was selected in 1996. The aluminum flashing fences were arranged in a 'Y' configuration, each arm measuring ten meters. At each end of an arm we set a single five-gallon bucket, with a fourth five-gallon pitfall trap set at the center intersection of the arms. Two funnel traps were positioned along the side of each fence (six funnel traps total). A gully leading from the top of the bluff to the floodplain intersected one arm of the array. Directly below the site several seasonal ponds harbored the egg masses and larvae of Wood Frog (*Rana sylvatica*) and Spotted Salamander (*Ambystoma maculatum*) and the larvae of Marbled Salamander (*A. opacum*).

Wet Ravine-Marsh Edge (Marsh Edge Site)

This site was selected in 1988 and initially consisted of six pitfalls and a single fence located at the upper edge of a tidal wetland, beneath Red Maples (*Acer rubra*) and adjacent to a stand of Common Reed (*Phragmites australis*). This set of traps was not productive because the array was frequently flooded by tidal waters and saturated soil often forced the buckets out of the ground. Therefore in 1991 the fences and traps were moved to a drier location 35 m inland in the old railroad bed ravine just above the point where it intersected the Otter Point Trail. This location was well above the reach of high tide waters. The new array included three fences with three buckets each, arranged parallel to the long axis of the ravine. In spring, rain runoff filled depressions at the bottom of the ravine below the traps. This site was abandoned in 1996 due to low captures.

Permanent Pond (Mark's Pond Site)

In the Spring of 1998, traps were erected above a large permanent pond, locally known as Mark's Pond, located on the Upper Railroad Bed Trail. This was the largest and most permanent of our ponds, reaching almost 30 m in diameter. There were two sets of traps. One array, located on the southwest portion of the pond, was in a Y configuration, with each arm measuring 10 m, made of fiberglass screening approximately 60 cm tall, buried 10 cm into the ground. There were 4 pitfall traps: one located at each end of the arms and one bucket in the center where all three arms converged. Six funnel traps were located along the arms on either side of the fencing. This area was bordered by a Virginia pine forest (*Pinus virginiana*). A second fence was erected on the southeast edge of the pond. It was a 10 m fence made of plastic mesh, as used for sediment control along construction sites, set at the confluence of a seasonal stream and the pond. The fence was buried 10 cm into the ground, and was approximately 80 cm tall. There were pitfall traps at either end of the fence with two funnel traps on either side of the fence.

Measurements

Salamanders were removed from the buckets, placed in a plastic bag containing a damp paper towel and weighed to the nearest 0.5 gram with a hand-held Pesola brand scale. Total body length was measured to the nearest millimeter using a metric ruler. Salamanders were measured in two increments: first from the tip of the snout to the anterior end of vent; then from the anterior end of the vent to the tip of tail.

Sex Identification

We attempted to determine the sex of every animal captured. Because animals were captured during the breeding season, individuals with swollen vents were sexed as males; swollen abdomens indicated gravid females. Often animals were captured with neither swollen vent nor abdomen. These were left unsexed for Spotted Salamanders. Marbled Salamander females often have a more grey pattern, compared to white banding in the males, so sex could be determined using color in some individuals. All animals were released shortly after capture.

Identification of Known Spotted Salamanders

We have not marked any salamanders by toe clipping, subcutaneous dies, PIT tags or by any other invasive techniques. However, we have been able to identify individual Spotted Salamanders by taking advantage of their unique dorsal spot patterns (Loafman 1991). Beginning in 1995, we began recording individual Spotted Salamanders by sketching their unique pattern of yellow spots.

The spot location and size were recorded as accurately as possible on a drawing of a salamander. The body was divided into several regions to facilitate classification. Within each region, the number of spots were counted. The head, from tip of the nose to the gular folds was the primary unit of classification for the salamanders. The neck region, from the gular folds to the origin of the front legs, was the second spot-count classification. On the body (origin of front legs to posterior end of vent), the tail (posterior of vent to tip of tail) and the legs spots were drawn and counted. Salamanders were classified into groups that had similar head and neck spots. When a Spotted Salamander was captured, we searched through the pattern drawings for individuals with identical markings. We did not use this technique with Marbled Salamanders.

Weather

The timing of salamander migration is related to immediate weather conditions. Therefore, every morning between 8:30 - 9:30 a.m., we measured current weather conditions and cloud cover at the Jug Bay weather station, located several hundred meters from the study sites. We recorded maximum and minimum air temperature ($^{\circ}\text{F}$), and we measured precipitation, in inches, during the previous 24-hour period.

Trapping Schedule

Prior to 1994 we opened the traps for two to three nights per week. Beginning in 1994 the traps were opened much more frequently. The fall trapping season began around 1 September, although field work often started in August in order to provide training for volunteers. The spring trapping season began in mid to late February. Traps were opened in the early evening and checked the following day between 8:00 and 10:00 a.m. Traps remained open for as many consecutive nights as possible, dependent on the availability of staff and volunteers to check the traps in the morning as well as the predicted rainfall. In the fall the trapping season continued through the end of November. In spring the trapping season continued until mid-April. Table 1 summarizes the 1994-1998 trapping seasons.

	1994	1994	1995	1995	1996	1996	1997	1997	1998	1998
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
First Trapping Day of Season	5-Mar	20-Aug	23-Feb	24-Aug	23-Feb	28-Aug	6-Feb	4-Sep	4-Feb	29-Aug
Last Trapping Day of Season	3-Apr	20-Nov	9-Apr	4-Nov	18-Apr	6-Dec	13-Apr	30-Nov	5-Apr	1-Nov
Number of Trapping Days	10	32	14	51	55	79	54	82	61	65
Number of Trapnights	89	715	363	1306	1106	2242	1598	2233	1960	2059

Table 1. Summary of seasonal trapping duration, number of trapping nights and number of trap- nights for years 1994 - 1997. One trapnight is the equivalent of one functional trap open for one night.

Several terms used throughout this paper are defined as follows:

capture: one animal caught in a trap. Over a season, captures do not represent individuals because some animals might be re-captured.

capture rate: the total number of animals caught per trapnight. At Wet Forest a capture rate of 1.0 represents ten salamanders caught.

trapnight: one functional trap open for one night

RESULTS

Marbled Salamanders

	1988	1989	1990	1991	1992	1993
First Trapping Day	12-Sep.	11-Aug.	21-Sep.	21-Sep.	3-Sep.	21-Aug.
Last Trapping Day	2-Nov.	28-Oct.	28-Oct.	7-Oct.	8-Nov.	31-Oct.
First Capture	12-Sep.	18-Aug.	21-Sep.	7-Oct.	3-Sep.	25-Sep.
Capture Rate	0.09	0.04	0.04	0.07	0.15	0.10
Maximum Capture Date	4-Oct.	17-Sep.	12-Oct.	7-Oct.	20-Sep.	26-Sep.
Maximum Capture Rate	0.55	0.33	0.20	0.07	0.50	0.40
Number Of Trapping Days	12	23	10	6	28	22
Number of Trapnights	226	470	176	78	340	273
Total Captures	25	18	11	1	24	12
	1994	1995	1996	1997	1998	
First Trapping Day	20-Aug.	24-Aug.	28-Aug.	4-Sep.	29-Aug.	
Last Trapping Day	20-Nov.	4-Nov.	6-Dec.	30-Nov.	1-Nov.	
First Capture	10-Sep.	10-Sep.	7-Sep.	9-Sep.	29-Aug.	
Capture Rate	0.04	0.07	0.23	0.80	0.05	
Maximum Capture Date	18-Sep.	17-Sep.	17-Sep.	13-Sep.	8-Sep.	
Maximum Capture Rate	1.28	4.21	4.36	1.79	1.29	
Number Of Trapping Days	32	51	79	82	65	
Number Of Trapnights	715	1306	2242	2233	2059	
Total Captures	37	215	432	247	180	

Table 2. Summary of the capture rates of marbled salamanders from 1988-1998 from all trapping sites. Capture rate is the number of individuals captured per trapnight for the night indicated. One trapnight is the equivalent of one functional trap open for one night. Total captures are the sum of captures for all trapping-days within a season.

Since 1988 we have had 1212 captures of Marbled Salamanders, of which 973 (80.3%) were captured during the years 1994-1998. Because we do not mark the animals, we could not estimate how many individuals we captured. The earliest an animal was found in the traps was 18 August (in 1989) and the latest date was 6 December (in 1996). Generally, there were few or no salamanders caught in early September. The maximum capture rate within a season was typically during a relatively brief period near the middle of September. 1991 was an aberrant year; only one Marbled Salamander was caught all season and it was caught on the last day of trapping. Table 2 summarizes yearly trapping effort and maximum capture rates of Marbled Salamanders.

Abundance of Marbled Salamanders

Over the eleven years under review, trapping sites have been located near five breeding areas (see Table 3). As shown in Figure 2a, the Wet Forest Site produced 77.9% of all captures. Because of varying trapping efforts at the five sites, we standardized the trapping effort by computing the "trapping site capture rate" — the total number of captures at a site for the site's total trapnights over all the years the site was in use (Figure 2b). After standardization, Wet Forest was responsible for 56% of the total capture rate. The maximum number captured at the Wet Forest site was 116 on 17 September 1996. The two arrays at Mark's Pond provided 27.1% of the relative capture rate (n=97 captures), although fall 1998 was its first season of use, and the only season it contributed the data under review. Maximum numbers captured in one day at Mark's Pond was 35 on 8 September 1998 and 35 on 16 September 1999. Until 1999 (when 28 individuals were captured on 16 September 1999) the maximum number captured at the Forest Bluff site was 7 on September 8 (1998) and 13 (1997). Temporary Pond, with 98 captures over ten seasons was a distant third, with only 8.7% of the relative capture rate. The maximum number captured at this site was 10 individuals on 17 September 1995.

Site	Years	Total Number of captures	Total Trapnights
Wet Forest	1988-1998	944	3853
Temporary Pond	1988-1997	98	2564
Marsh Edge	1988-1995	1	974
Forest Bluff	1996-1998	72	2078
Mark's Pond	1998	97	817
Total	1988-1998	1212	10,286

Table 3. Summary of captures of Marbled Salamanders at the five sites. Number of captures and trapnights are the combined total for all years indicated per site. One trapnight is the equivalent of one functional trap open for one night.

Interestingly, at Wet Forest there was a difference in capture rates between the two sections of the site. Since 1994, when the trap array was moved from the center of the pond, the Wet Forest trapping array consisted of two 50 m lengths of fence, separated by about 50 m of forest as well as a hiking trail (refer to Figure 1). The fence with pitfall traps #1-6 provided more captures than the side with traps #7-11 (679 and 259 captures respectively, $X^2 p < 0.001$).

Searches under logs and in leaf litter have produced no egg-nests or brooding females at Wet Forest, although larvae were found in abundance during the spring of 1998. At Temporary Pond and Mark's Pond both nesting females and larvae have been found.

Relationship Between Marbled Salamander Migration and Rainfall

Figure 3 illustrates the relationship between rainfall and capture rate of Marbled Salamanders at Wet Forest. We divided the 1994-1996 trapping days into days with or without rain during the previous twenty-four hours. Then we segregated these into days with captures and days without captures. In general, if there was no rain, there were no salamanders in the traps. However, rainfall did not guarantee captures; salamanders were captured only 55% of the time when rain fell during the previous 24 hours. There was no correlation ($r^2=0.16$; 1994-1996) between rainfall quantity and the magnitude of capture rate.

Although salamanders were caught after it rained, the magnitude of the capture rates could not be predicted by the amount of rain. Only 14.9% (29 of 195 days) of the trapping dates that had less than 0.75 mm (0.03") of rain had captures (Figure 4). In comparison, 80.8% of trapping dates with rainfall greater or equal to 0.75 mm had captures (59 of 73 days). Captures occurred even when only a small amount of rain fell. Salamanders were caught regularly when rainfall was greater than 0.75 mm, whether the rain fell in September, October, or November.

To determine the 'seasonal-migration response,' that is, how capture rate changed as the season progressed, we analyzed the within-season trapping success at the Wet Forest in 1994-1998 (Figure 5a-e). In four of the five years capture rates declined as the season progressed. In three of these years, the date of maximum capture rate was between 13 September and 18 September. October and November capture rates were always lower than the September capture rates within each respective year. Only 1998 Wet Forest capture rates did not follow this trend. In that year, the maximum capture rate was on 1 October. Yet for all 1998 sites combined, a pattern emerged where the maximum capture rate was on 8 September, and October rates were lower than September. (Figure 6)

We did not fully analyze the effect of minimum or maximum temperature, it appeared to have no correlation. In fact, on several mornings following sub-freezing weather we caught Marbled Salamanders. Deviation of rainfall from normal was also not an indicator of capture rates. Only about 50% of the time was capture rate low when monthly rainfall was below normal. Table 4 summarizes the monthly rainfall.

Rainfall	30 year Average (in)	1998 (in)	1997 (in)	1996 (in)	1995 (in)	1994 (in)
August	3.96	2.19	6.00	3.29	0.96	5.01
September	3.60	0.91	2.29	5.87	2.73	4.48
October	3.46	1.28	3.21	5.07	7.59	1.01
November	3.26	1.06	6.91	2.37	5.35	1.83

Table 4. Monthly rainfall at the Jug Bay Wetlands Sanctuary

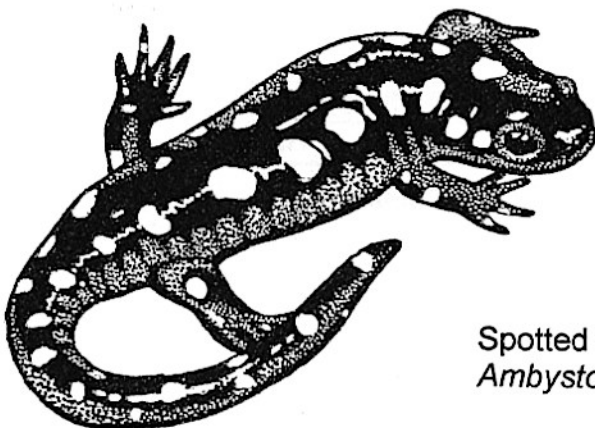
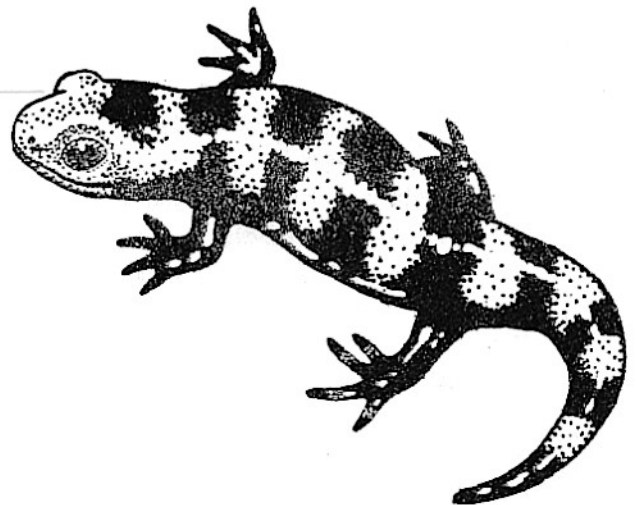
Sex-related Differences in Size of Marbled Salamanders

Females tended to be heavier than males throughout the season. About 50% of all males were between 6 - 9 grams, while approximately 50% of females were 7 - 12 grams. The snout-to-vent length of the Marbled Salamanders were adult size. Female weights declined significantly between September and October (Figure 7a; $\log r^2 = 0.52$). Male weights, summarized in Figure 7b, did not vary significantly over the season ($\log r^2 = 0.21$). Males and females were about the same length and, over the season, there was no trend in changes of length. See Table 5.

	13-Sep	17-Sep	8-Oct	19-Oct	9-Nov	2-Dec
Males	5.7 (± 0.5) (4.8-6.5) n=7	5.5 (± 0.6) (4.5-6.9) n=24	5.9 (± 0.3) (5.4-6.3) n=8	6.1 (± 0.6) (5.3-6.7) n=5	5.5 (± 0.4) (5.0-6.0) n=4	5.6 (± 1.0) (4.0-6.5) n=5
Females	5.6 (± 0.6) (4.8-6.5) n=7	5.7 (± 0.3) (5.2-6.2) n=24	5.6 (± 0.6) (5.2-6.2) n=4	6.7 (± 0.5) (5.4-7.2) n=16	5.7 (± 0.5) (4.5-7.0) n =50	6.2 (± 0.4) (5.4-6.8) n=15

Table 5. Snout-to-vent length of Marbled Salamanders captured on six days in 1996. Measurements were made from the tip of the snout to the anterior end of the vent in centimeters. Standard deviation and the range of measurements are given.

Marbled Salamander
Ambystoma opacum



Spotted Salamander
Ambystoma maculatum

RESULTS

Spotted Salamanders

Table 6 summarizes the spring trapping seasons. Spotted Salamanders were captured in small numbers throughout the year, although captures were highest in the spring. The earliest capture date during the eleven years of trapping was on 18 February (1998). The latest spring capture was 8 May (1992). One Spotted Salamander was captured on 9 November 1996.

	1988	1989	1990	1991	1992	1993
First Trapping Day	11-Feb.	13-Feb.	16-Feb.	1-Mar	23-Feb.	10-Feb.
Last Trapping Day	30-Apr.	23-Apr.	6-Apr.	20-May	24-May	16-May
Maximum Capture Date	11-Mar.	6-Mar.	30-Mar.	23-Mar.	6-Mar.	24-Mar.
Maximum Capture Rate	0.35	0.27	0.08	0.09	0.75	1.25
Number Of Trapping Days	45	32	18	31	35	26
Number Of Trapnights	636	282	209	278	265	79
Total Captured	37	13	3	4	17	15
	1994	1995	1996	1997	1998	
First Trapping Day	5-Mar	23-Feb.	23-Feb.	6-Feb.	4-Feb.	
Last Trapping Day	3-Apr.	9-Apr.	18-Apr.	13-Apr.	5-Apr.	
Maximum Capture Date	na	21-Mar.	23-Feb.	6-Mar.	18-Feb.	
Maximum Capture Rate	0.00	0.08	0.42	0.20	0.12	
Number Of Trapping Days	10	14	55	54	61	
Number Of Trapnights	89	363	1106	1598	1960	
Total Captured	0	2	12	17	7	

Table 6. Capture summary of Spotted Salamanders for spring trapping seasons.

Peak Migration of Spotted Salamanders

Over the 10 years of our study, the maximum numbers of individuals occurred in March. 50% of the maximum capture dates were within two days after the first capture. 40% were between 14 and 20 days after the first capture. One maximum capture date was 7 days after the first capture.

The largest number of captures (N = 93; 74% of total) occurred at Temporary Pond. In the traps located at Mark's Pond only one individual was captured. The three other sites had about equal numbers of captures (see Figure 8). Our first year of trapping produced the largest number of total captures (N= 34); in other years we captured less than half this total.

Differences between sexes (using marked animals only)

Using individual salamanders identified by their spot patterns, we summarized general size statistics. Female Spotted Salamanders were slightly larger in snout to vent length, total length, and weight. Table 7 summarizes their weights and lengths.

Females N = 12	Length (cm) [Snout to anterior tip of vent]	Length (cm) [Anterior tip of vent to tip of tail]	Total Length (cm)	Weight (grams)	Mean weight :length ratio of Individuals
Mean	8.9 ± 0.6	8.6 ± 1.2	17.4 ± 1.4	22.6 ± 4.4	1.30 ± 0.21
Range	8.0-10.0	6.8-11.3	15.2-19.8	17.0-30.5	
Males N = 15	Length (cm) [Snout to anterior tip of vent]	Length (cm) [Anterior tip of vent to tip of tail]	Total Length (cm)	Weight (grams)	Mean weight :length ratio of Individuals
Mean	8.1 ± 0.7	8.7 ± 1.4	16.9 ± 1.6	17.8 ± 5.2	1.21 ± 0.25
Range	7.0-9.3	7.0-12.0	14.7-20.4	9.0-24.0	

Table 7. Length and weight data of individual female and male Spotted Salamanders. (Individuals were identified by unique dorsal spot patterns).

Recaptures of Recognizable Individuals

We recaptured five individuals that we had recognized previously and identified by characteristic dorsal spot patterns. Two of those recaptures occurred in the same year as the original captures. The captures of marked animals is presented in Table 8.

Forest Bluff	Total Captured	Total New	Total Recap	New Patterns	Wet Forest	Total Captured	Total New	Total Recap	New Patterns ^a
1995	NT				1995	3	3		2
1996	2	2		2	1996	5	5		5
1997	8	8		8	1997	3	2	1	0
1998	3	2	1	2	1998	1	1		1
Temporary Pond	Total Captured	Total New	Total Recap	New Patterns ^a	Not in traps	Total Captured	Total New	Total Recap	New Patterns
1995	4	4		3	1995	0			
1996	8	7	1 ^b	7	1996	1	1		1
1997	9	8	1	8	1997	2	2		2
1998	NT				1998	2	1	1 ^c	1
Mark's Pond	Total Captured	Total New	Total Recap	New Patterns					
1998	1	1		1					

Table 8. Captures of Spotted Salamanders during spring and fall seasons at four sampling sites. Notes: a. For two animals no pattern was sketched; b. Initial capture occurred one day before it was recaptured; c. Initial capture occurred two days before it was recaptured; NT: Not trapping that year.

DISCUSSION

Marbled Salamanders

We found that rainfall stimulated Marbled Salamanders movement to and from the breeding ponds. Neither the occurrence of rain nor the amount of rainfall, however, was a predictor of the abundance of salamanders caught. During minimal amounts of rain (0.25 mm) we had capture rates over 2.0, while on some dates with over 4 cm of rain we caught only one or two salamanders (0.1 capture rate).

A determining factor for triggering the first movement of breeding salamanders appears to be the timing of rainfall in the season. Apparently, the Marbled Salamanders' breeding migration is timed to begin in mid-September when rain occurs in the evening. While rainfalls of over 0.75 mm are still likely to encourage migration, as the season progresses, the number of salamanders migrating to or from the breeding sites decreases.

Even though we began more intensive trapping in 1994, the increase in captures at Wet Forest more likely occurred because of the new location. When we moved the Wet Forest fence uphill, it was now along the edge of the vernal pond, not in the middle. Other studies have shown that Marbled Salamanders do not enter the pond to breed but lay their egg-nests at the edge of the pond in a soon-to-be flooded region (Petranka 1990; Petranka and Petranka 1981). Therefore, the deeper parts of the pond would not be a likely place to capture Marbled Salamanders.

To accurately correlate capture rate and within-season variations we must determine when salamanders are migrating to the breeding ponds, when they are at the breeding ponds and when they are migrating back to the upland forest. Knowing which direction the salamanders are moving is not possible with the current configuration of the traps, since most of the buckets are straddled by the drift fence. Buckets would have to be exclusively on one side of the fence or the other to determine direction of travel.

Determining direction of travel could also provide us with additional insight into the factors triggering movements. If we could isolate the salamanders that are heading to the ponds from those that are leaving the ponds, we may find that a different trend would emerge. For example, in one scenario migration to the pond peaks in mid-September and quickly drops to no inward migration by early October. Animals leaving the pond, begin in late September, slowly increase in mid-October and peak in early November. The migrations' overlap could explain the lull in October and the spikes of activity found in November. Alternatively, the capture rates, timing of migration, and 'seasonal-migration response' may be different for males and females. Future efforts should attempt to distinguish the migration direction of the two sexes.

We have found that early captures are predominately males, but salamanders captured on the peak migration day have a mixed sex ratio. Individuals caught later in the season tend to be females. Females captured in late October are assumed to be leaving the breeding grounds due to the lack of swollen abdomen and their lighter weights. Because the salamanders' lengths are relatively constant, we attribute the decline of female weight between September and October to egg-deposition at the pond. Males presumably leave the breeding sites before the females once mating has occurred. It is assumed that the female are remaining with their egg-nests for an indeterminate amount of time.

Capture rate must also be viewed as a relative number within each year, and should not be compared season to season. The large numbers of salamanders that were captured on 9 November 1996 does not appear unusual when you consider that over 200 salamander were trapped in September (not individuals, but they could be individuals if we could assume that they all were moving to the breeding site and had been released downhill of the fence). The September peak was followed by very little rain for almost three weeks. Between October 1 and November 8 two significant rains (Oct. 9 and Oct. 19) produced 80% of the rain that fell during those three weeks. Apparently, the salamanders were waiting for rain to occur to begin leaving the ponds. Therefore, the number of animals that migrate during the peak period will also determine future capture rates as well as the duration of the migration. If more salamanders have migrated to the ponds in September, more salamanders will have to leave the pond. Use of a 'relative capture rate' is necessary to accurately reflect differences or similarities between seasons.

One factor, which we are unable to determine is the actual time when the rain falls. If the time of rainfall was included in the analysis, we might find that rains occurring in the evening prompt more salamander activity than rain that occurs during the late morning. Until more sophisticated measuring equipment is installed, this relationship will continue to be a mystery.

In 1998, we held a series of "salamander sleepovers," where volunteers checked the traps every two to three hours over night. We found that the salamanders moved after 1 a.m. When volunteers noted the timing of rainfall, we found that the rain also fell after midnight on those nights. Unfortunately, because 1998 was extremely dry, not enough dates were sampled. In 1999 we continued the efforts to document the diel patterns of migration.

Another type of review would be to analyze the influence of multiple factors on the daily capture rate including: capture rate relative to the maximum capture rate; cumulative rainfall; number of consecutive days rain occurs; relative coolness or warmth of the season; days from the start of migration.

Marbled Salamander Migration

From the data accumulated we have created a diagram of Marbled Salamander migration which illustrates seasonal movement and different migration of males and females. Figure 9 illustrates this seasonal movements. In early September, males begin moving into breeding areas. Peak migration occurs in mid-September when both males and females move towards the breeding sites. In late September males begin leaving the breeding areas, although some females and males may still be migrating into the vernal pools. Throughout October, some females remain at the egg-nests, some females leave the breeding sites, and most males have left the breeding area. By November only females remain at the breeding sites, and they will leave as the pools fills with water.

DISCUSSION

Spotted Salamanders

In the ten years that we have studied Spotted Salamanders we have not observed the mass migrations that have been reported by other researchers. Our study sites appear to have a small population compared with nearby Flag Ponds Nature Park in Calvert County (48 km away). Researchers at Flag Ponds (John Zyla pers. comm.) reported over 200 individual Spotted Salamanders captured on a day when we captured only 4 individuals.

The decrease in captures at Temporary Pond over the years was more than likely due to the environmental degradation around the trapping site. The drift fence was often at the edge of the pond and much of the soil on the inside of the fence was eroding. For the last several years of trapping at the site, continual effort was made to re-bury the fence and close any gaps between the fence and the ground. Four of the buckets were only 2 liter and were often filled with water. The larger buckets were frequently pushed out of the ground by groundwater pressure. The downstream portion of the fence eventually degraded and was not in contact with the substrate of the pond. After removal of the fence in 1998, a 0.5 m difference existed between the uphill and downhill side of the fence. Within a month, rains and erosion smoothed out the contours of the pond.

Surprisingly, only one individual was caught at Mark's Pond. Low captures may be due to the large turtle population (approximately 26 Painted Turtles and at least three Snapping Turtles) which could prey on salamanders. At Wet Forest three of the twelve captures were in the fall. One of the recaptures was caught in the fall both times in late October in 1995 and 1997.

The Forest Bluff site was originally chosen because several egg masses were found in a small vernal pool below the site. This site provided a surprising number of captures, given its small area of trapping and dry upland forest site. Obviously, this site is in the migratory pathway of the salamanders.

Estimating Spotted Salamander Population Size

An estimate of the Spotted Salamander population size was made using the Fisher-Ford Method (Heyer et al. 1993). This method assumes that recruitment of new adults does not take place and that there are no juveniles returning as adults. The formula for this method is $N = [(n_i + 1) / (m_i + 1)] \times M$ where N = Total Population Estimate; m_i = marked individuals caught in a sample; n_i = total numbers of individuals caught in a sample; and M = total number of marked animals in population. Using data from Table 8, population size was estimated for three sites, summarized in Table 9

- Temporary Pond had the largest estimated population of 50 salamanders.
- Forest Bluff had an estimated population of 20 using the site as a migration corridor.
- A population of 14 Spotted Salamanders may breed in the Wet Forest pond.

Table 9. Population Estimate of Spotted Salamanders. Using recapture data from Table 8, a population estimate was made using the Fisher-Ford Method $N = [(ni+1)/(mi+1)] \times M$ (from Heyer et al. 1993).

	Temporary Pond	Forest Bluff	Wet Forest
Year of Estimate	1997	1998	1997
Marked individuals caught in a sample: <i>mi</i>	1	1	1
Total individuals caught in a sample: <i>ni</i>	9	3	3
Total marked animals in population: <i>M</i>	10	10	7
Total Population Estimate: <i>N</i>	50	20	14

SUMMARY

Marbled Salamanders and Spotted Salamanders attracted our interest because of their abundance in the Sanctuary, because of their conspicuous migration, and because of their dependence on two distinct habitats: vernal pools and upland forests. These closely related, congeneric species inhabit dry upland forests during the non-breeding season and move to shallow seasonal or permanent pools for breeding. Although they overlap completely in their use of these habitats, they are mutually exclusive in this use. Spotted Salamanders breed in pools in the spring whereas Marbled Salamanders breed in these same pools in the fall. As a result, these species avoid competition for limited breeding areas and the breeding habitat is able to support more salamanders than if both species bred at the same time.

The magnitude of the Marbled migration was almost always much greater and more dramatic than that of Spotted Salamanders. Based on trapping and other observations it appeared that Marbleds were clearly the more abundant species. Unfortunately it was not possible to estimate overall population size of Marbled Salamanders, but we were able to quantify relative abundance in different areas based on trapping data. Within the different vernal pools, there was great variation in numbers captured. The Wet Forest, a seasonally flooded forest, had the largest population. The highest number of individual Marbleds captured on one day were 116 at the Wet Forest site on September 17, 1996. Mark's Pond, a large permanent pond, also had a large number of breeding Marbleds. The highest number captured at Mark's Pond was 35 on September 8, 1998 and, most recently, 35 individuals on September 16, 1999. Between 1996-1998, the most captured on any one day at Forest Bluff was 7 salamanders, always in mid-September. In 1999 (data not included in this report) 28 individuals were captured on September 16 at Forest Bluff. Temporary Pond was not a significant site; the largest number captured was 10 individuals on September 17, 1995.

The maximum number of Spotted Salamanders captured at Temporary Pond was 9 on 24 March 1992. The most ever captured at the Forest Bluff site was 3 on 6 March 1997. In 1995 we began an effort to estimate the number of individual Spotted Salamanders in areas where we trapped, we captured and identified 43 individuals by using their unique dorsal spot patterns as an identifying tool. We were able to identify with certainty only three of these known individuals in the following years.

In general, male Marbled Salamanders began their migration in early September; females started later, during the two-week period starting in mid-September. Once migration was underway, their movement (as determined by pitfall captures) depended on rainfall. However, the amount of rainfall alone was not a useful predictor of the numbers of Marbled Salamanders that entered pitfall traps. Our results suggested that within-season variation in the number of animals migrating was independent of rainfall amount and was more likely related to time of year.

Heavy, gravid females migrated towards breeding ponds in mid-September to deposit their eggs. Beginning in mid-October, they migrated from the ponds back to upland non-breeding habitats. As the season progressed, the weights of captured female Marbled Salamanders declined significantly, no doubt reflecting weight loss following egg laying.

Typically, seasonal wetlands in eastern North America are wet in the spring and dry in the fall. The use of seasonal wetlands by Marbled Salamanders emphasizes the critical habitat value of "vernal" pools during the fall when they may contain little or no water. Forested wetlands are the most threatened of Maryland's wetlands. Most are seasonal and their existence and extent are dependent on surface flow and precipitation, rather than groundwater recharge. Loss of these habitats is often inadvertent because they may not be as readily recognized by wetland delineators and developers as other "wetter" wetlands. How many more forests in the mid-Atlantic region harbor similar, yet unknown, populations of *Ambystoma* salamanders? As we learn more about the occurrence of inconspicuous amphibians, we hope to be able to preserve more of their habitat for both their survival and for our own enjoyment.

Another important outcome of our study is that we introduced more than fifty volunteers and thousands of other visitors, including many school children, to the natural history of amphibians and to the field methods used to study these animals. Many of these volunteers helped over multiple years and several now work on amphibian studies elsewhere. Finally, it is our hope that the information gathered in this study is useful to other researchers and resource managers who seek to understand the lives of our amphibians and who work to protect the habitats that are crucial to their survival.

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APPENDIX OF FIGURES

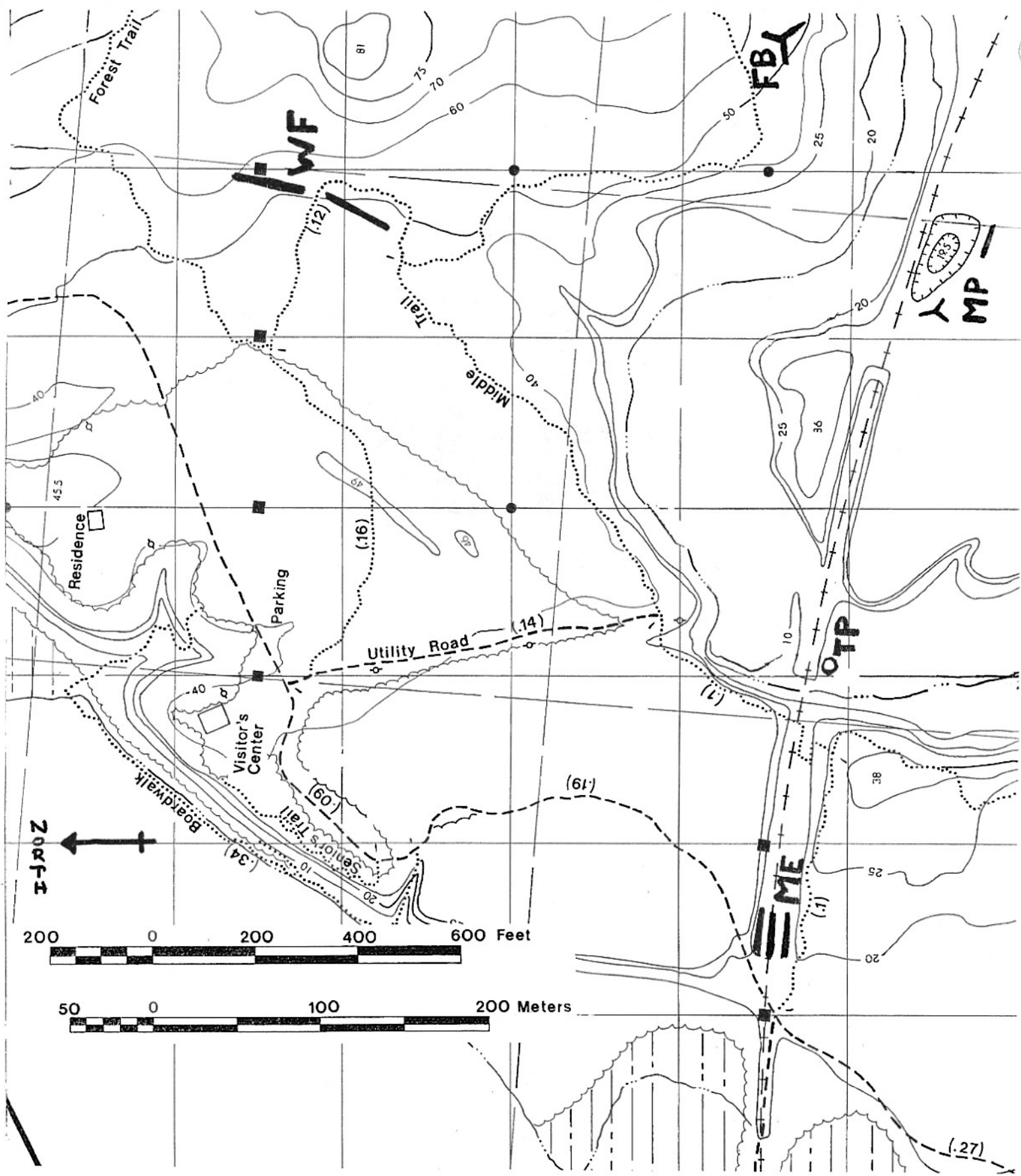


Figure 1. Location of amphibian traps showing the approximate orientation of the sites: WF (Wet Forest); FB (Forest Bluff); TP (Temporary Pond); MP (Mark's Pond) and ME (Marsh Edge).

- | | | |
|---------------------------|---------------------------|---------------------------|
| (.19) Distances, in miles | Contour elevation in feet | ----- wetlands |
| ■ Concrete monument | □ Building | ● Grid marker pole |
| Hiking trail | --- Utility road | -o- Electric utility pole |
| | - - - - Two Run Creek | + Abandoned railroad |

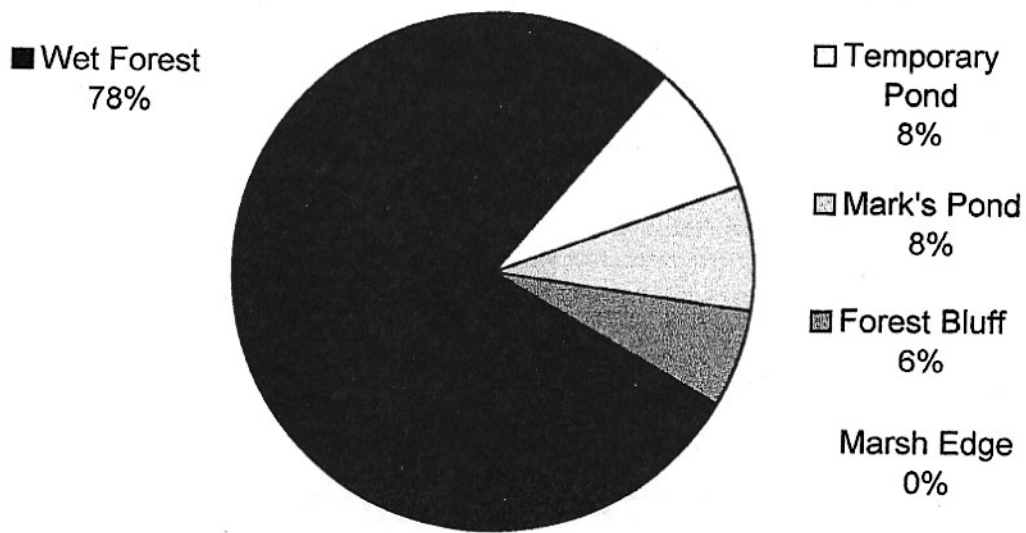


Figure 2a. Proportion of Captures of Marbled Salamanders from Five Sites From 1988-1998 (N=1212 captures)

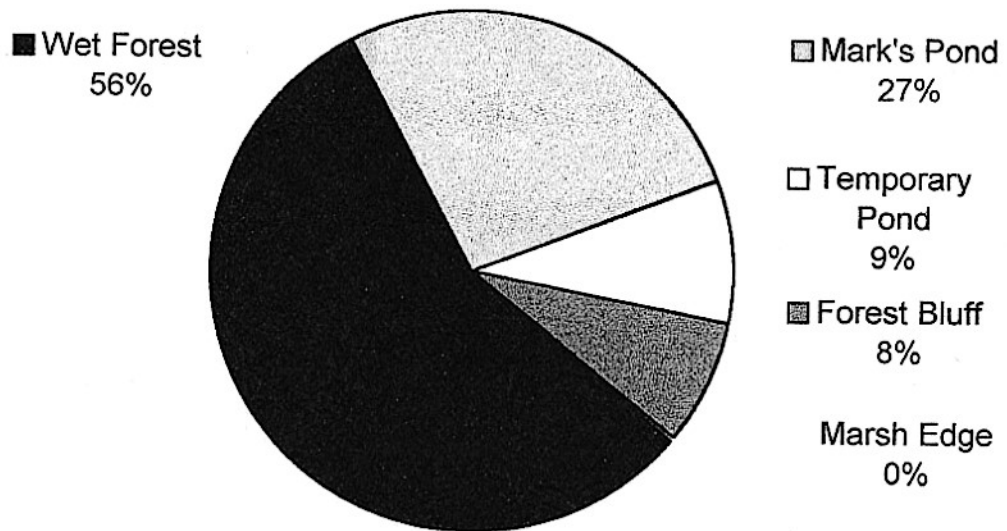


Figure 2b. The Percentage of Relative Capture Rate of Marbled Salamanders from 1988-1998 (N=1212 captures; 10,286 total trap-nights)

The relative capture rate is the ratio $(n/N)/(t/T)$ where n =number of captures at one site over all years; N =total number of captures at all sites over all years; t =number of trapnights at one site over all years; and T =total number of trapnights at all sites over all years. See text for more information. Table 3 summarizes captures and trapnights for each site.

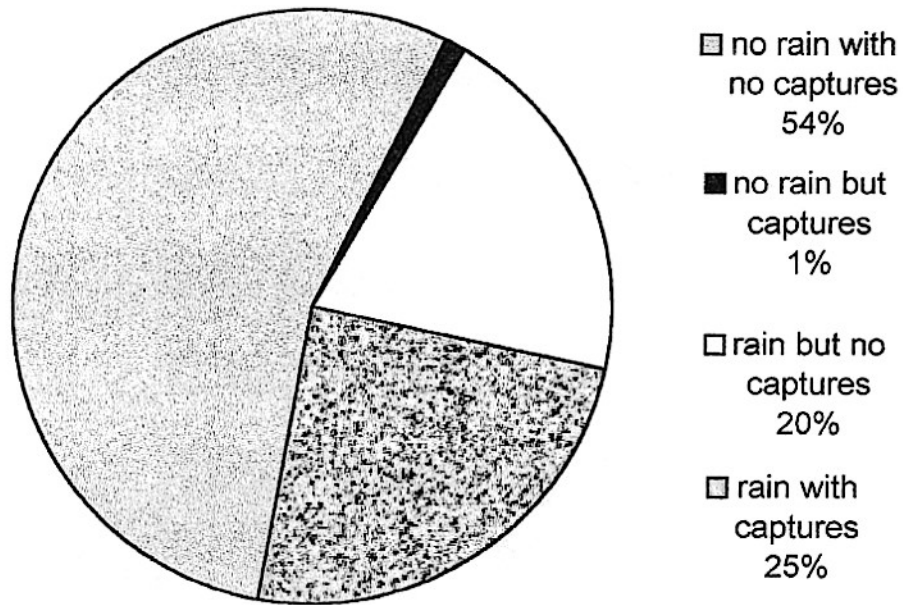


Figure 3. Percentage of Captures of Marbled Salamanders in the Wet Forest in Relation to Occurrence of Rainfall during Fall Trapping Seasons, 1994-1996 (n=167 trapping days; 684 captures)

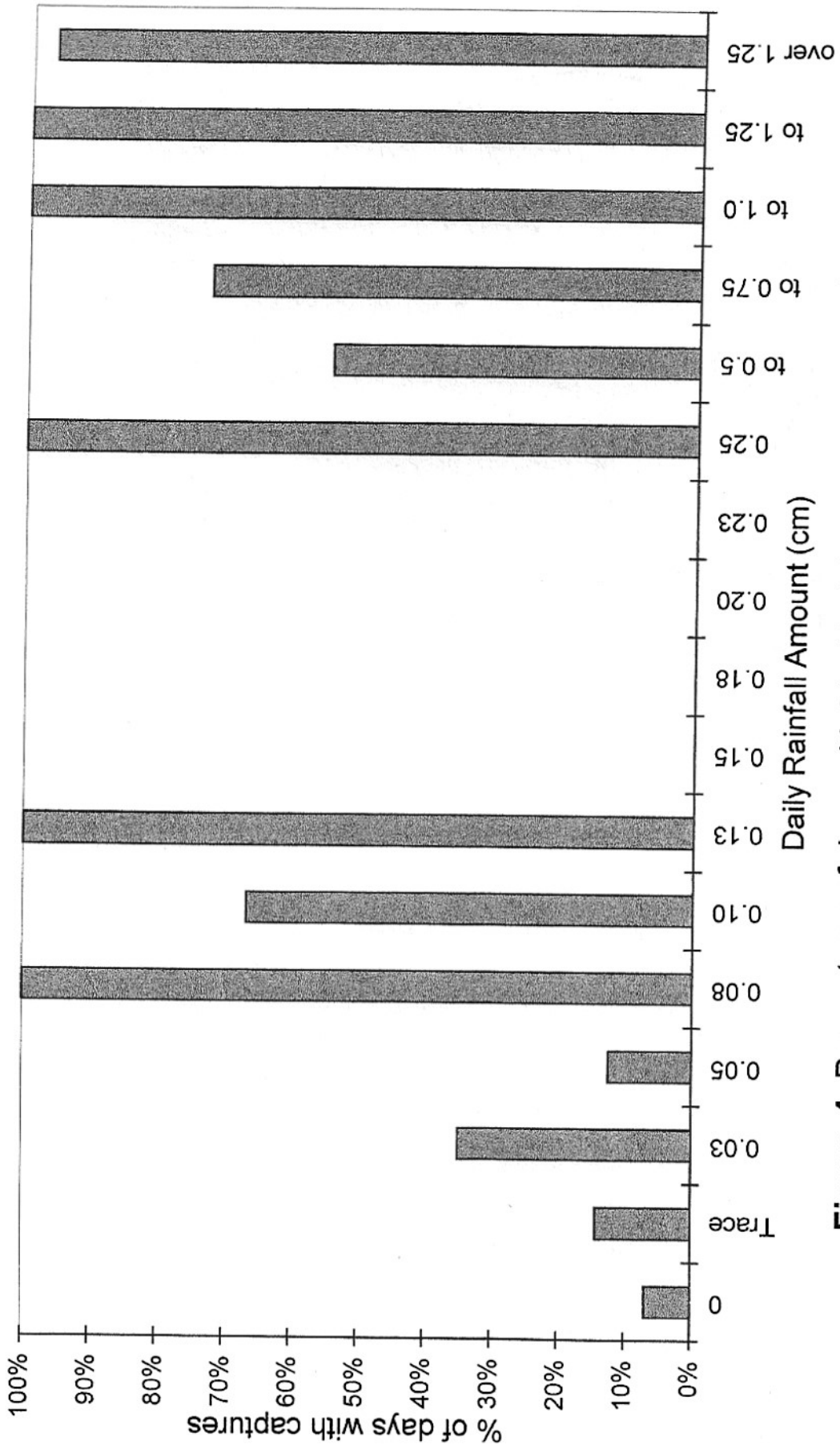


Figure 4. Percentage of days with Marbled Salamander captures from all sites (1994-1998) N=268 trapping days; 1111 captures.

Trapping days were grouped by daily rainfall amount. The y-axis represents the percentage of days within each daily rainfall amount category that had captures.

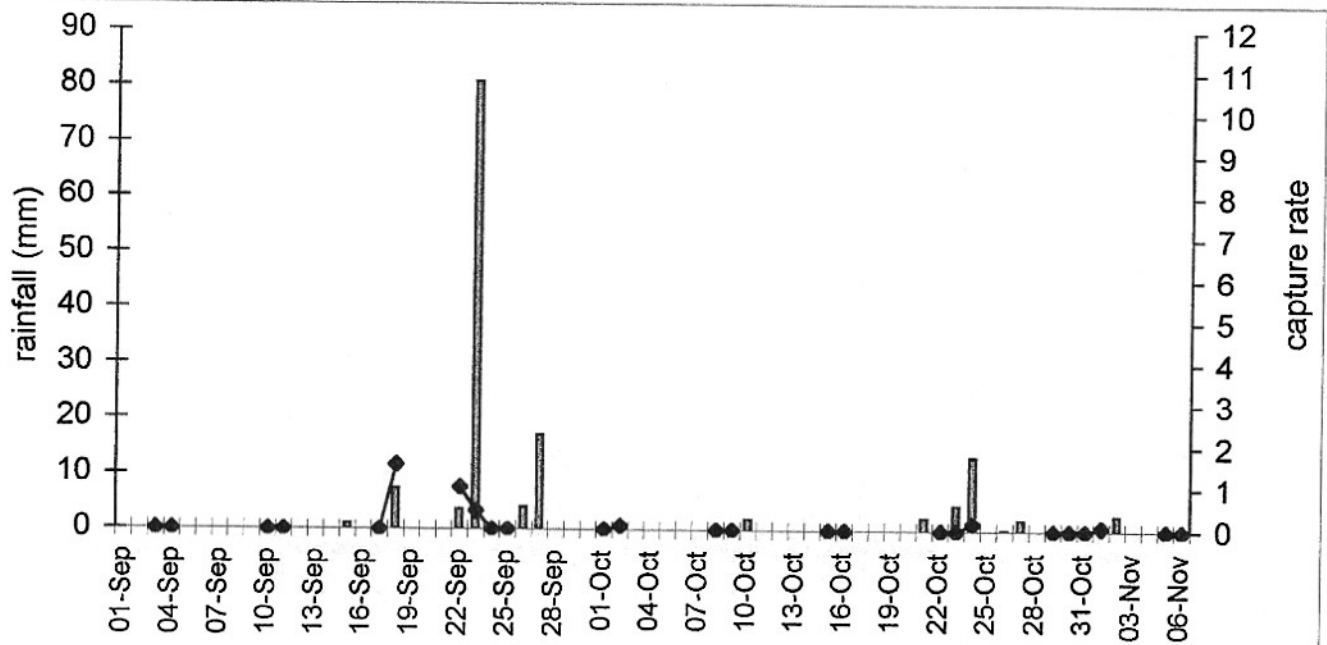


Figure 5a. 1994 Marbled Salamander Capture Rate in the Wet Forest and Daily Rainfall

Figures 5a-e. Capture Rates of Marbled Salamanders at Wet Forest Trapping Site (—◆—) and Daily Rainfall Amounts (bars). When traps were closed, no diamond is shown. A Wet Forest capture rate of 1.0 is equivalent to one Marbled Salamander caught in each trap.

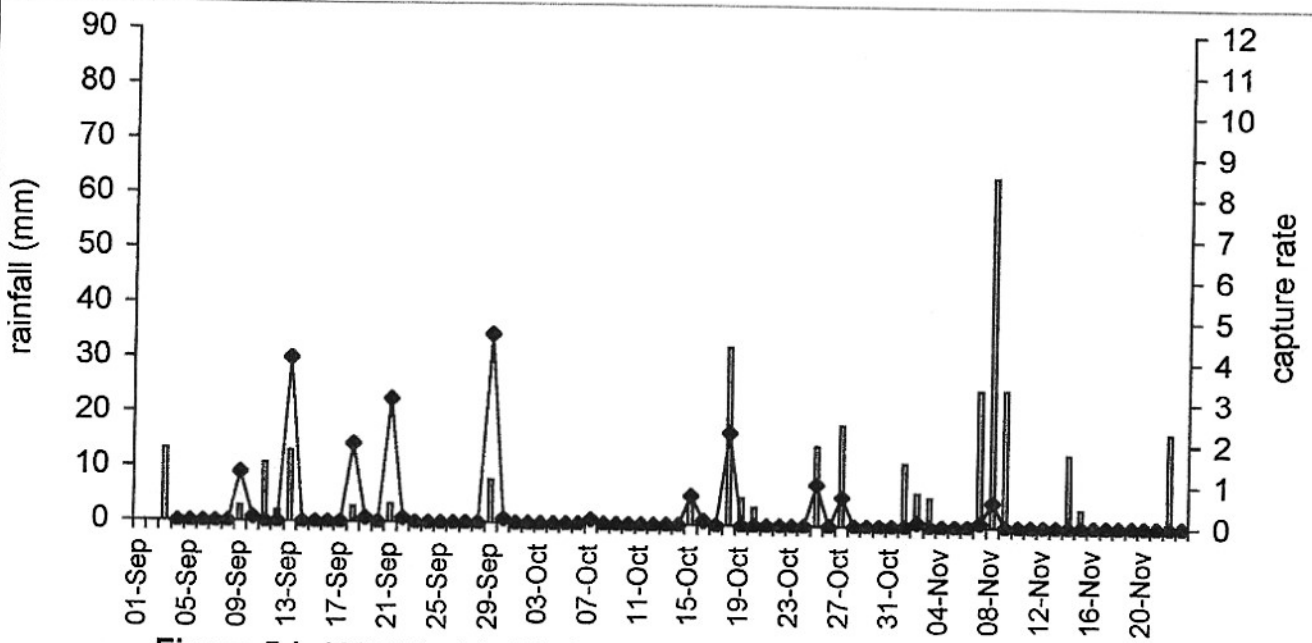


Figure 5d. 1997 Marbled Salamander Capture Rate in the Wet Forest and Daily Rainfall

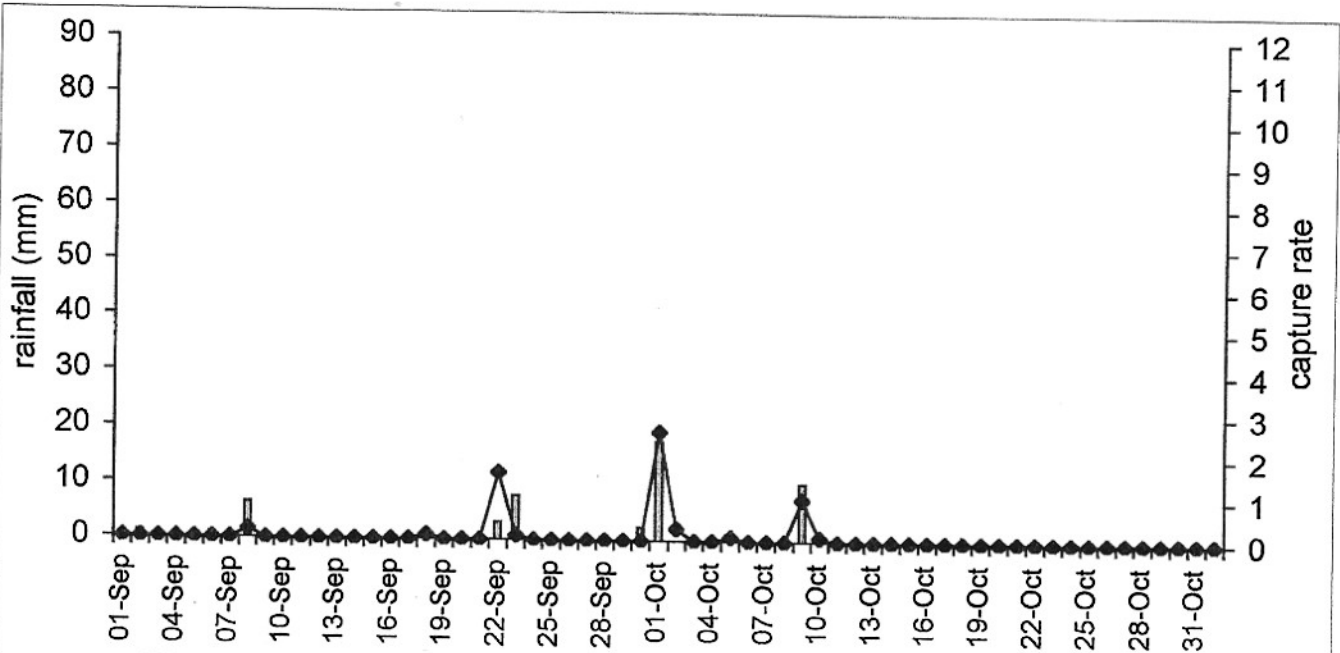


Figure 5e. 1998 Marbled Salamander Capture Rate in the Wet Forest and Daily Rainfall

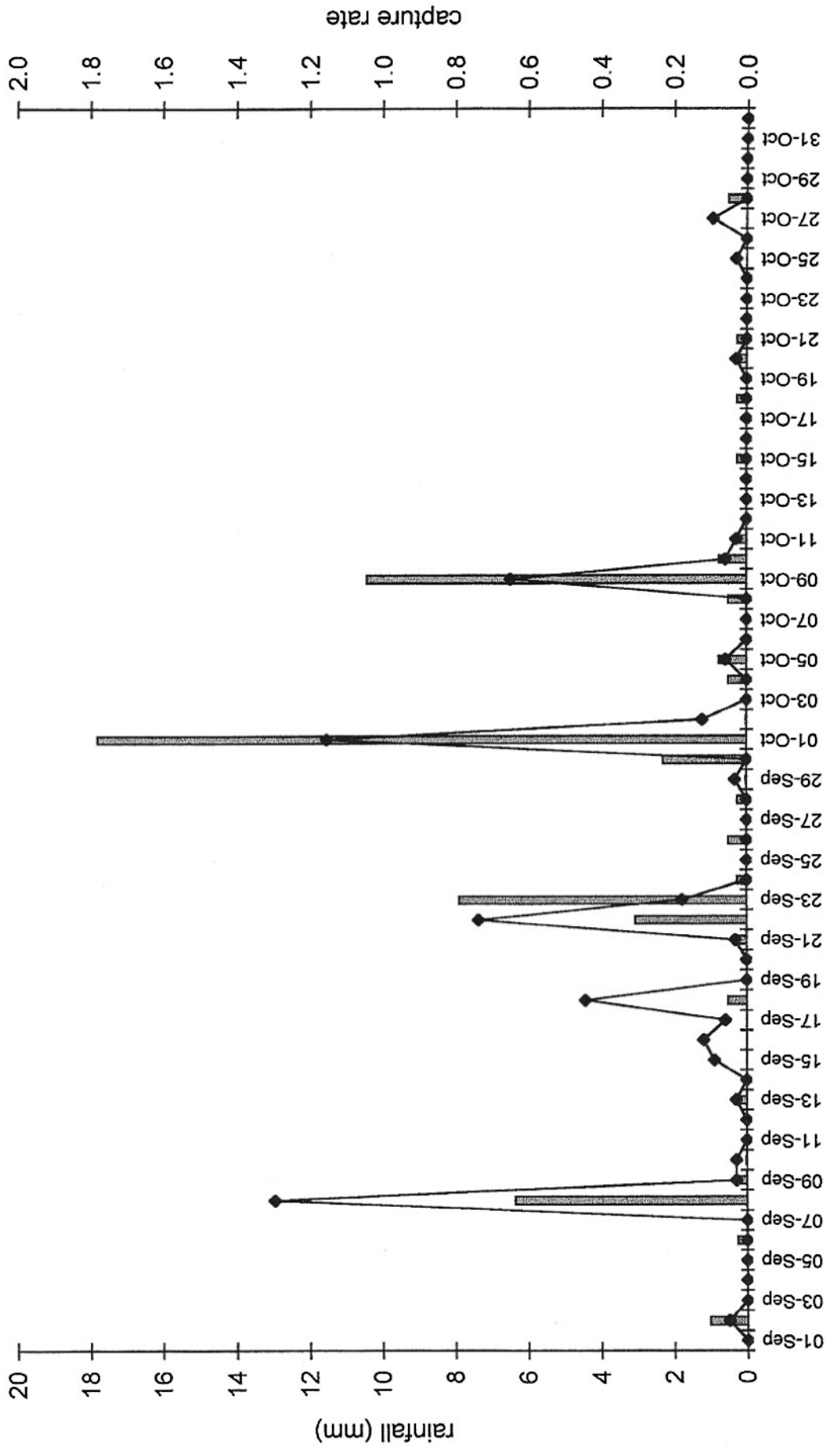


Figure 6. 1998 Marbled Salamander Capture Rate at All Trapping Sites and Daily Rainfall Amounts

mm rain
 capture rate, all sites

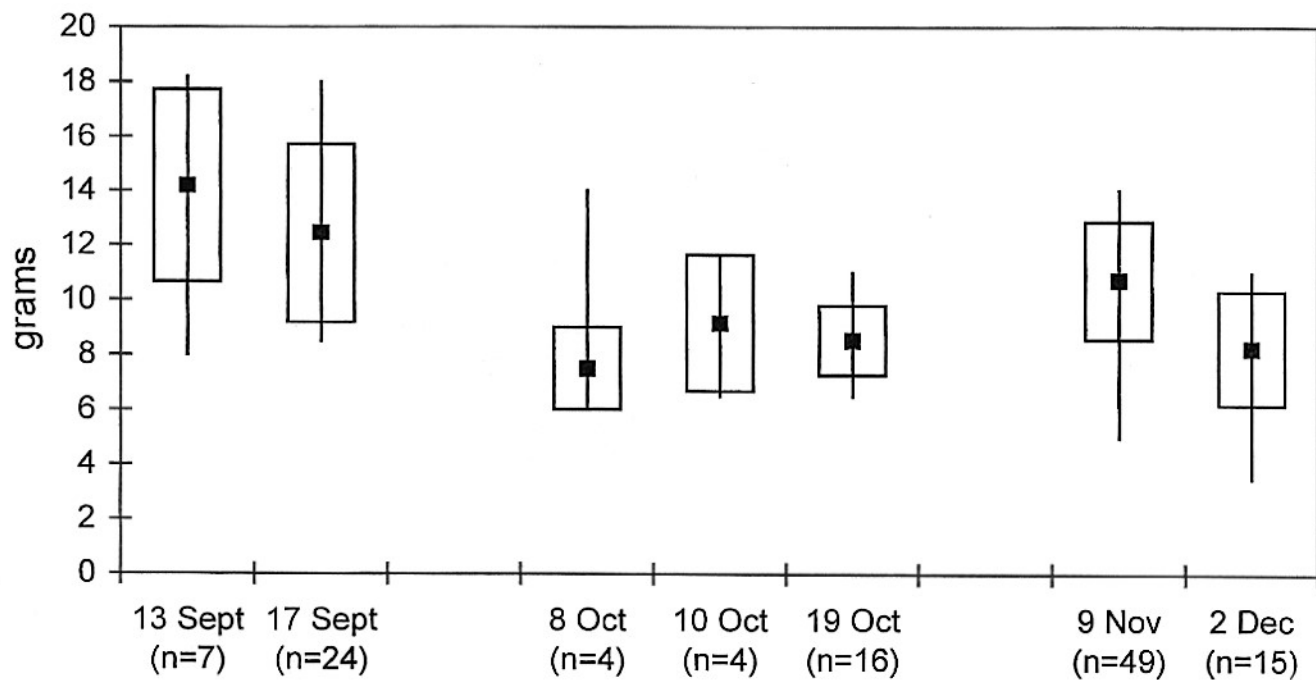


Figure 7a. 1996 Female Marbled Salamander Weight

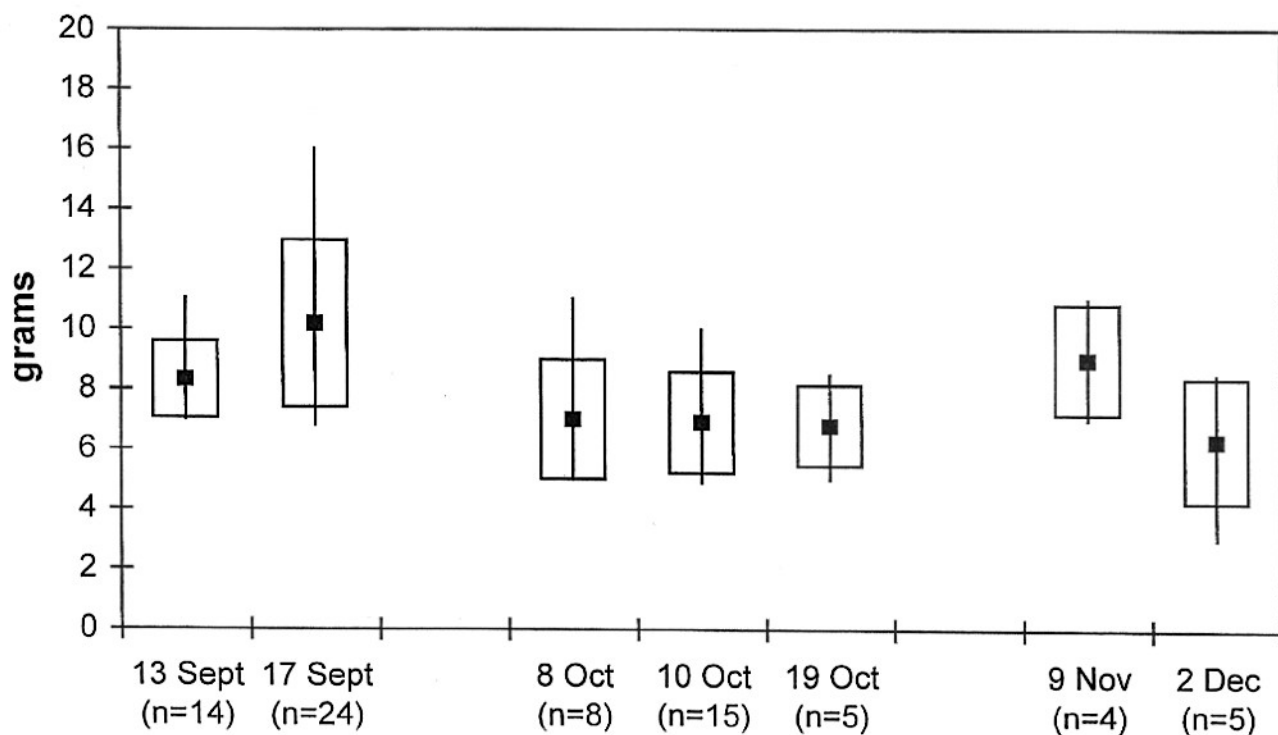


Figure 7b. 1996 Male Marbled Salamander Weight

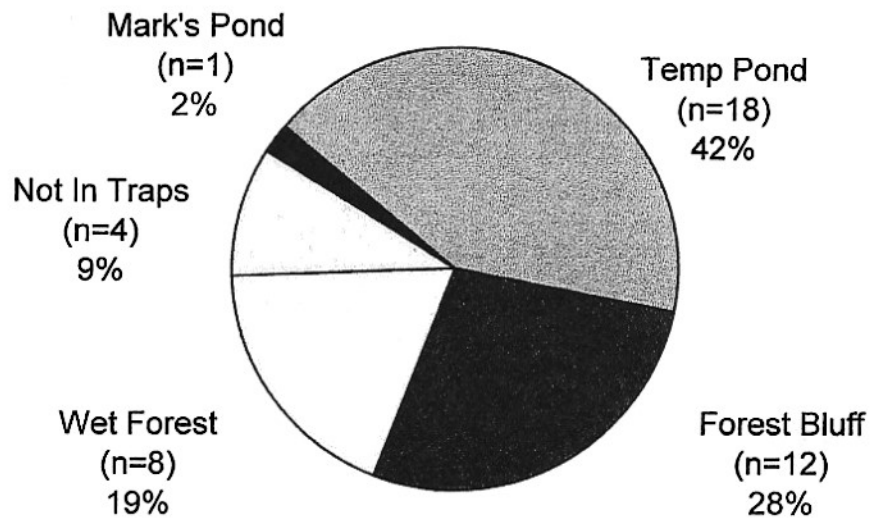


Figure 8. Number of Spotted Salamanders Captured at the Five Different Trapping Sites During Spring and Fall Trapping Seasons 1995-1998

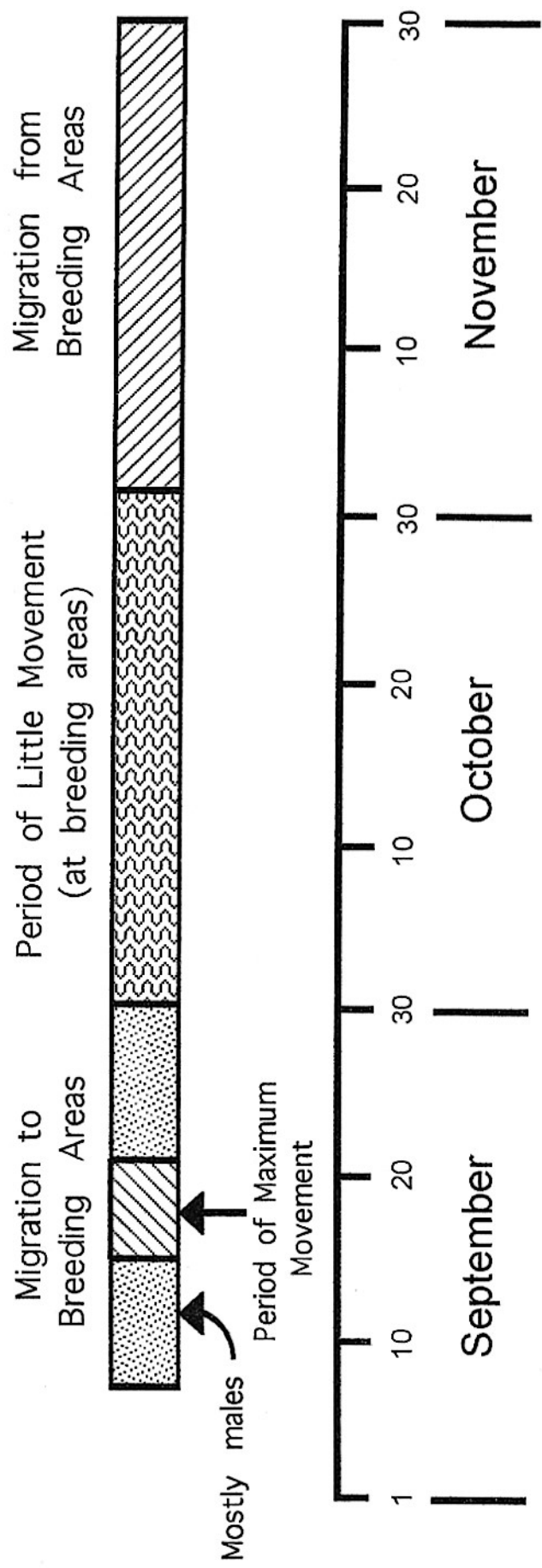


Figure 9. Periods of migration and breeding in Marbled Salamanders