Banisteria, Number 13, 1999

Amphibians and Reptiles of the Shenandoah Valley Sinkhole Pond System in Virginia

Joseph C. Mitchell

Department of Biology
University of Richmond
Richmond, Virginia 23173

and

Kurt A. Buhlmann

Savannah River Ecology Laboratory
Drawer E
Aiken, South Carolina 29802

INTRODUCTION

Seasonal ponds are used extensively for breeding and larval development and as foraging habitat by amphibians and reptiles. Complexes of ponds or freshwater wetlands free of fish are critical habitats for some species in eastern North America. Ephemeral or vernal pools, such as those created by sinkhole pond formation, offer a dynamic habitat for these animals because of variation in hydrological regimes and timing of water gain or loss. However, levels of herpetofaunal diversity and population dynamics in local regions are tied directly to the dynamics of these habitats. Landscape features such as temporary breeding ponds have been called keystone habitats because they can determine species presence or absence (Primack, 1998).

Natural sinkhole ponds in the Shenandoah Valley in the Big Levels area of Augusta County, Virginia, provide a dynamic mosaic of wetland habitats used by a diversity of amphibians for breeding. They may in fact be keystone habitats in this region. Some reptiles use these ponds temporarily. The ponds exhibit a wide range of variation in size, depth, and vegetation characteristics, occur over a relatively narrow range of elevations, and dry at different times of the year (Buhlmann et al., 1999). Some of them seldom dry at all or only during prolonged drought. Others dry frequently. Species of frogs and salamanders that use these habitats must be able to withstand the many uncertainties of breeding in ephemeral pools. Individuals of these species are long lived and are able to tolerate some years of complete reproductive failure. Others are explosive breeders and their population numbers fluctuate dramatically. And still others move between wetlands as the ponds dry. Some species use the ponds annually or over a period of several years, whereas others occur there for only brief periods of time.

The Shenandoah Valley Sinkhole Ponds (SVSP) system in the Big Levels region of the George Washington National Forest offers a dynamic landscape that supports a unique assemblage of amphibians and reptiles. The composition of the fauna is tied directly to the unique habitats provided by sinkhole ponds. Some of these populations have apparently been here since at least the Pleistocene Epoch (Guilday, 1962). These ancient lineages and the presence of boreal and coastal plain disjunct populations of diverse floral and faunal species (Rawlinson & Carr, 1931; Carr, 1937; Fleming & Van Alstine, 1999; Roble, 1999) make the Shenandoah Valley sinkhole ponds area a biologically unique environment.

We have been studying amphibians and reptiles of this area since 1986 and have accumulated numerous observations on many species. Our objectives in this paper are to summarize our natural history observations on the local herpetofauna and to discuss conservation and management issues pertinent to these animals.

MATERIALS AND METHODS

Descriptions and locations of the ponds in the SVSP system are found in Buhlmann et al. (1999). One of us (JCM) first visited the SVSP system on 18 July 1986 during which several natural history observations were made and specimens collected; these were donated to the National Museum of Natural History. KAB began a systematic inventory in late 1987 and, with the exception of 1991 and 1993, both of us accumulated information on all of the amphibians and reptiles in most months of the year (January-October) through 1998. On 3 and 8 March 1988, we installed four isolated drift fences with pitfall traps following designs in Gibbons and Semlitsch (1982) adjacent to Ponds 2, 16, and 17, and between Ponds 12 and 13. We used single lengths of 7.5 x 0.6 m aluminum flashing erected upright and buried in the ground about 10 cm. We buried a 19 l (5 gallon) plastic bucket flush to the ground at each end of each fence. We placed water and leaves in each pitfall to reduce animal mortality and provide cover. Drift fence/pitfall arrays were in operation 1988 and 1989 from January until April during which we checked the arrays every 1-2 days.

During each field trip to the SVSP system, we systematically surveyed several ponds visually and searched for larval and adult amphibians, often using aquatic dip nets to capture individuals. We measured many of the animals caught (straight-line snout-vent length [SVL] for frogs, salamanders, and snakes; carapace [CL] and plastron length [PL] for turtles) to the nearest mm and weighed many individuals with Pesola® scales to the nearest gram. We also took notes on phenotypic variation, abnormalities, injuries, and parasites. We marked turtles by filing notches in the margin of the carapace using the 1-2-4-7 system described in Mitchell (1988). Tadpole developmental stages follow the classification of Gosner (1960).

RESULTS

We obtained information on 20 species of amphibians (11 frogs and toads, 9 salamanders) and 10 species of reptiles (4 turtles, 6 snakes). One of the salamander species is listed as endangered by the Virginia Department of Game and Inland Fisheries and one turtle is considered to be sensitive to habitat alteration and commercial harvest (Ernst et al., 1994).

Annotated species list

In the following species accounts, we summarize observations and data accumulated over a 12-year period on aspects of seasonal occurrence, ponds inhabited, breeding dates, number of egg masses, larval presence and growth, dates of metamorphosis, body size, and sexual dimorphism. We also note effects of pond drying on selected species. Pond names and numbers follow Buhlmann et al. (1999). Common and scientific names follow Crother (in press).

Frogs

1. *Acris crepitans crepitans* (Northern Cricket Frog) (Ponds 2, 10, 13, 16, 17, 20, 23, 24, 33, Maple Flats North and South, Spring Pond)

This small frog was abundant in many of the sinkhole ponds in the SVSP system. The first specimens collected from this area were on 4, 11, and 18 July 1986 (USNM 347846-57, 347878-82). Dates of earliest and latest observations of active individuals were 2 February and 27 September, respectively. We recorded calling males between 18 May and 13 July. We observed adults in amplexus on 28 June and metamorphs on 18 July, 1, 8, & 14 August, and 12 & 21 September. The smallest female with yolked follicles was 20.6 mm SVL. One tadpole was observed being eaten by a giant water bug (*Lethocerus americanus*) on 1 August 1996. Of 40 frogs caught on 23 June 1997 at Pond 13, dorsal stripe color varied from red (2.5%) to green (35%) to brown (62.5%). Females (23.4±0.7 mm SVL, range = 22-25, n = 12; 1.3±0.2 g body mass, 1.1-1.4, n = 6) averaged slightly larger than males (21.0±1.4 mm SVL, 19-24, n = 43; 0.8±0.1 g, 0.7-0.9, n = 3). Only one abnormal individual was caught, a female with a missing left rear foot found at Quarles Pond on 27 April 1988.

2. *Bufo americanus americanus* (Eastern American Toad) (Ponds 2, 11, 12, 13, 14, 16)

We recorded breeding American toads from five ponds. Dates of observation of adults were between 2 March and 8 May. Males were heard calling between 14 April and 8 May. We found a gravid female on 30 March 1988. We noted tadpoles in Pond 14 on 23 March 1995. Three males measured 63, 68, and 78 mm SVL; the latter two weighed 35 and 45 g, respectively.

3. *Bufo fowleri* (Fowler's Toad) (Pond 2)

Fowler's toads apparently seldom use the sinkhole ponds for breeding. Only in Pond 2 did we find tadpoles and this was in shallow water that had been added to the pond by rain after it had dried completely a month before. Two adults were collected on 18 July 1986 on the trail near Pond 11 (USNM 347862-63). Others were observed on trails and in a shallow pool at the eastern end of the Coal Road. Dates of observation were between 17 May and 28 June. The largest male of the small sample, found on the trail near Oak Pond, was 60 mm SVL and weighed 20.5 g; the largest female was 70 mm SVL and 37.5 g.

4. *Hyla versicolor* (Gray Treefrog) (Ponds 2, 11, 12, 13, 16, 17)

Gray treefrogs appear to be limited to a small number of ponds in the area. We heard males calling between 17 May and 21 September. Only one adult was observed outside this period, on 21 April 1989. We observed tadpoles between 6 July and 2 August. We found one recent metamorph on 17 September. Eight males measured 43-49 mm SVL (mean = 45.4±2.1).

5. *Pseudacris crucifer crucifer* (Northern Spring Peeper) (Ponds 2, 3, 4, 8, 10, 11, 12, 13, 16, 17, 21, 23, 25, 27, 29, Kennedy Mountain Meadow, Maple Flats North and South, Spring Pond).

This was a common anuran in the SVSP system. Six specimens were collected along the main trail between the gate and Pond 12 on 18 July 1986 (USNM 347864-69). Dates of calling were 2 February to 6 July and 17 September to 15 October. We observed amplexus on 29 April, 10 May, and 12 June. Tadpoles collected in June and July were in widely different stages of development, indicating multiple dates of egg deposition and variation in rates of larval development. A sample of 30 tadpoles caught on 17 May 1988 in Kennedy Mountain Meadow were in Gosner (1960) developmental stages 29-38 (limb bud to nearly full hind limb development). A sample of 14 tadpoles caught on 21 June 1988 in Pond 2 were in stages 29-44 (limb bud to nearly complete metamorphosis). We observed other metamorphs on 28 June and 6 July. Male vocalizations in fall months were not associated with breeding.

6. *Pseudacris feriarum feriarum* (Upland Chorus Frog) (Pond 10)

We heard one individual calling in Pond 10 on 25 March 1988 when it contained shallow water. Several localities are known for this species in adjacent Rockingham County but this is the only observation for Augusta County (Mitchell & Reay, in press).

7. *Rana catesbeiana* (American Bullfrog) (Pond 2, 11, 12, 13, 16, 17, Maple Flats North and South, Spring Pond)

Bullfrogs breed only in ponds with nearly permanent hydroperiods because tadpoles may take as long as two years to reach metamorphosis. Juveniles and occasionally adults inhabit ponds with highly dynamic hydrologies for short periods of time but do not reproduce in them. The first specimens collected were adults, one each from Pond 11 and Spring pond (USNM 3347870-71). We heard males calling between 28 May and 13 July. Active individuals were observed between 20 January and 7 October. We observed tadpoles in each month we visited the ponds (January - October) and metamorphs on 6 July, 1 August, and 14 October. The largest tadpole we measured was 132 mm total length. Ten juveniles averaged 57.2±11.3 mm SVL (43-74). The only adult we measured was a 146 mm SVL male. We found dead adults twice, once in the bottom of Pond 16 on 20 January 1990, possibly the result of freezing, and one on the main trail near Maple Flats North on 19 September 1992 from unknown causes.

8. *Rana clamitans melanota* (Northern Green Frog) (Ponds 1, 2, 4, 11, 12, 13, 16, 17, 35, Maple Flats North and South, Spring Pond)

Green frogs reproduce in sinkhole ponds that contain water for most months of the year because tadpoles require about a year to complete development. Pond drying can cause massive mortality of tadpoles; many tadpoles were found dead in the bottom of Pond 11 on 17 October 1998. Numerous metamorphs were present at Pond 5 on 4 October 1987 but were all gone ten days later. The first specimen from the area was a tadpole collected from Maple Flats North on 18 July 1986. Calling dates were between 10 May and 8 August; this is presumably the breeding period. Dates of earliest and latest active individuals were 29 January and 27 September, respectively. We found tadpoles in multiple growth stages, representing multiple bouts of reproduction, on 13 January 1995 in Pond 11, and we collected a series of tadpoles from Pond 17 on 2 February 1990 that represented Gosner growth stages 25-36. We observed tadpoles in Gosner stages 34 (n = 1), 35 (1), and 38 (3) on 17-18 May 1988. The largest tadpole we measured was 88 mm total length. We found metamorphic individuals on 28 June and 6 July; one with a tail bud weighed 6.9 g. Juveniles were observed in all months May through October. Three juveniles averaged 36.9 mm SVL (33-40).

9. *Rana palustris* (Pickerel Frog) (Ponds 2, 11, 12, 13, 17, 32, Maple Flats North and South, Spring Pond)

Pickerel frogs are probably more abundant in the SVSP system than observation records indicate. Almost half of our records were derived from the drift fence/pitfall arrays. One adult was collected at Spring Pond and three tadpoles were obtained from Maple Flats North on 11 July 1986 (USNM 347873, 347890-92). Males were heard calling from 8 April to 6 June. We found one egg mass on 6 March 1996. We observed recently metamorphosed juveniles on 14 August (26 mm SVL) and 19 September. Two adult males were 50 and 53 mm SVL and two adult females measured 62-66 mm SVL. Juveniles and adults undoubtedly disperse through the SVSP complex on a regular basis because they have been found in several ephemeral ponds.

10. *Rana sylvatica* (Wood Frog) (Ponds 2, 11, 12, 13, 16, 17, 18, 23, 27)

Wood frogs breed earlier than any other anuran in the SVSP system. Inclusive dates of calling males are 2 February and 6 March. We found a gravid female on 14 March 1988 and pairs in amplexus on 27 February and 8 March. We observed egg masses between 24 February and 21 April and predation by marbled salamanders (*Ambystoma opacum*) larvae on the former date. Egg masses accumulate heat during the day and are often warmer than the surrounding open water (Waldman & Ryan, 1983). Temperatures 2 cm deep in two egg masses taken on a sunny 24 March 1995 were 24.2° C and 26.8° C and those of the adjacent water were 16.0° C and 21.8° C, respectively, at Pond 27. However, we found egg masses frozen above the waterline on 3 March 1988 in Pond 2, indicating the risks associated with breeding in seasonally fluctuating ponds (Fig. 1). We found two tadpoles (Gosner stages 37 and 39) on 21 June 1988. Adult males (mean = 55.0±3.2 mm SVL, range = 49-61, n = 12; 14.5±1.9 g body mass, 13.7-17.0, n = 12) were smaller than adult females (mean = 63.5, 61-66, n = 2; 24.4 g, 21.5-27.3, n = 2; both females were gravid).

11. *Scaphiopus holbrookii* (Eastern Spadefoot)

Only one individual of this fossorial species has been observed in the SVSP system. We collected an adult female (45 mm SVL) on 12 June 1987 on the main trail between Ponds 3 and 13. S.M. Roble (personal communication) confirmed the identification of a juvenile captured and released on the trail near Twin Ponds during a heavy rain on 10 June 1996.

Salamanders

12. *Ambystoma maculatum* (Spotted Salamander) (Ponds 2, 4, 5, 8, 9, 10, 13, 18, Elusive Pond, Kennedy Mountain Meadow, Maple Flats North)

Spotted salamanders, like all species in the genus *Ambystoma*, are terrestrial as adults, but return to sinkhole ponds to breed. Spotted salamanders entered sinkhole ponds later than tiger salamanders (*Ambystoma tigrinum*) (see below), and the larvae were sympatric with them and *A. opacum* larvae in several ponds. We found three adults under leaf litter at the edge of Pond 2 on 3 March 1988. The earliest date we observed adults in the ponds was 2 February 1990. We observed fresh eggs in February and early March. One egg mass had not hatched when observed on 21 April 1989. We measured individuals undergoing metamorphosis during late June through September in years when ponds retained water. Adults may be abundant in some ponds but we have never found many larvae. This may be due to the abundance of earlier fall-breeding marbled salamander whose larvae are large enough to eat hatchling spotted salamander larvae. High dragonfly densities have been shown to induce changes in coloration in tadpole tails (Caldwell, 1982; McCollum & Leimberger, 1997). Two spotted salamander larvae captured on 2 June 1998 in Pond 13 had diffuse black tail tips, suggesting that *A. maculatum* may also exhibit predator-induced polyphenism. The number of spots on the dorsum of the body and head of adults varied from 8-31 (mean = 18.4±4.1, n = 78).

13. *Ambystoma opacum* (Marbled Salamander) (Ponds 2, 3, 4, 5, 6, 11, 12, 13, 14, 16, 17, 23, 27, 32, Spring Pond)

Like other ambystomatids, marbled salamanders use many of the SVSP ponds for breeding. Adults leave their terrestrial, underground retreats in mid-September to move to breeding ponds that are usually dry at this time. Males deposit spermatophores in moist areas where they are picked up by females for internal fertilization (Noble & Brady, 1933). We found spermatophore stalks on 17 September. Females lay eggs under debris and moist logs along the edges of the ponds and remain with them until fall and winter rains. Water levels rise at varying rates but ultimately inundate the eggs. This can be as late as January in some years when the ground surrounding the eggs appears frozen (e.g., winter of 1987-1988, KAB, personal observation). Females then leave the ponds and return to underground retreats. Emersion in water causes eggs to hatch in <1 wk to 2.5 months (Noble & Brady, 1933). We have observed larvae in ponds January through mid-June. These larvae grow from about 11 mm SVL at hatching to about 30-35 mm SVL at metamorphosis. They often cannibalize each other and are important predators of other ambystomatid larvae in several ponds. Known predators of marbled salamander larvae in some ponds are larger *A. tigrinum* larvae and northern watersnakes (*Nerodia sipedon*). Eggs of this species in this area are

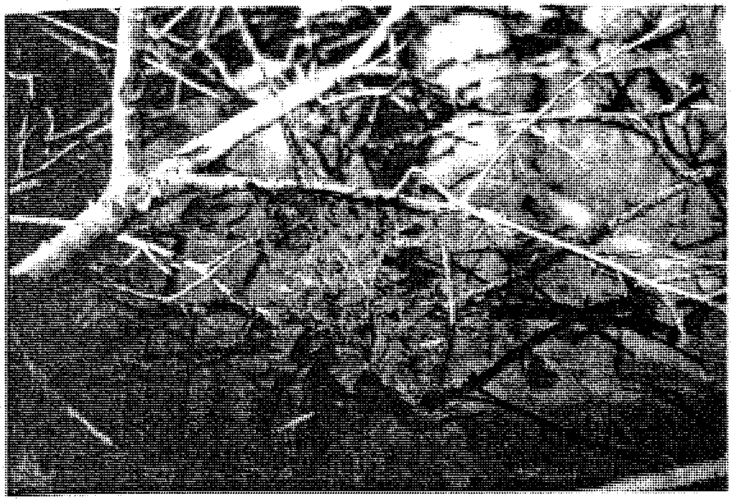

Fig. 1. Wood frog eggs exposed by pond drying, illustrating the potential variation of reproductive success due to changing environmental conditions. (Photo by KAB.)

Fig. 2. The first *Ambystoma tigrinum* (a recent metamorph) known from the SVSP system, Augusta County, Virginia. (Photo by JCM.)

Fig. 3. *Ambystoma tigrinum* larva from the Shenandoah Valley sinkhole pond system, Augusta County, Virginia. (Photo by KAB.)

apparently eaten occasionally by carnivorous millipeds, *Uroblaniulus jerseyi* (Mitchell et al., 1996). We observed successful reproduction in most years in ponds used for breeding. However, when ponds dry before late-May, as in 1997, all or most of the larvae die before reaching metamorphosis. Of 31 individuals for which we have phenotype data, 10 had a complete set of dorsal crossbars, 18 had 1-2 broken crossbars, 2 had parallel stripes instead of crossbars, and 1 had a combination of parallel stripes and crossbars.

14. *Ambystoma tigrinum tigrinum* (Eastern Tiger Salamander)

Specific locations for this species are not provided because *A. tigrinum* is listed as Endangered in Virginia (Mitchell, 1991; Pague & Buhlmann, 1991). The first specimen known to us was a recent metamorph caught on 18 July 1986 by H.P. Whidden (Fig. 2). This salamander was not preserved and subsequently lost. Buhlmann & Hoffman (1990) reported the first voucher specimen (CM 118612) collected from a shallow sinkhole pond on 12 May 1987 in the SVSP system. Tiger salamanders use several of the sinkhole ponds for breeding. We have counted egg masses in up to six ponds in most years between 1988 and 1998. Adults enter the ponds in January and February, mate, lay eggs, and then return to their underground retreats in adjacent hardwood forests where they spend most of their adult lives. Eggs are predated upon by *Notophthalmus viridescens* and *Ambystoma opacum* larvae, as well as several species of invertebrates. Tiger salamander larvae (Fig. 3) remain in water until summer months. Metamorphosis can occur as early as mid-June if the pond dries during that time. Early pond drying can cause variation in size at metamorphosis, as metamorphs found around one dry pond on 28 June 1990 were smaller (51-54 mm SVL) than gilled larvae (55-65 mm SVL) in a nearby pond with water. If the pond dries earlier than June, larvae do not survive, as was the case in several ponds in the SVSP system in 1995 and 1997. Seasonal variation in pond hydrology, as illustrated in Fig. 4, can cause some ponds used by salamanders for reproduction to be unproductive in some years, while others in the area with water produce population recruits annually or nearly so. Tiger salamanders in the SVSP system should be viewed as a metapopulation with the ponds being the complex of sources and sinks (sensu, Pulliam, 1988; Weins, 1996) imbedded in the forest ecosystem.

Adults and successful metamorphs move away from breeding ponds as far as 162 m in South Carolina (Semlitsch, 1983) and 286 m (mean = 60.5) in New York (Madison & Ferrand, 1998). We do not know how far adults and juveniles move from breeding ponds in this area but if distances are within these published values, then the entire area encompassing the entire sinkhole pond complex may be used. The entire sinkhole pond complex, ponds and forest, should be protected by another buffer of substantial size, visitors to the area should be prevented from riding off-road-vehicles in the ponds and forest, and protection of individual salamanders from poaching should be strictly enforced. Thus, conservation efforts on behalf of this salamander should focus on maintenance of the natural hydrology of the sinkhole ponds and protection of the entire hardwood forest ecosystem encompassing the SVSP system.

15. *Gyrinophilus porphyriticus porphyriticus* (Northern Spring Salamander) (Spring Pond)

A single larva of this salamander was collected in Spring Pond on 11 July 1986 by H.P. Whidden (USNM 347895).

16. *Hemidactylium scutatum* (Four-toed Salamander) (Ponds 2, 18)

Single individuals have been found near two separate ponds under logs on 7 May 1995 (Hayslett, 1995) and 21 September 1997 (30 mm SVL, 59 mm total length, 0.6 g). This species is usually associated with sphagnum moss and may be more widespread within the SVSP system.

17. *Notophthalmus viridescens viridescens* (Red-spotted Newt) (Ponds 2, 3, 8, 11, 12, 13, 16, 17, 21, 23, 24, 25, 27, 32, 33, 35, Maple Flats North and South, Quarles, Spring Pond)

Newts are commonly encountered in many of the sinkhole ponds. The first adults and larvae from the area were collected from Maple Flats North & South ponds, Spring Pond, and Ponds 11 & 12 on 11 and 18 July 1986 (USNM 347875-77, 347896-900). Adults have been observed in ponds January - October. We observed mating on 6 and 22 February and 6, 23, and 24 March. Larvae were recorded between 17 May and 27 September. Four larvae averaged 19.3±1.9 mm SVL (16-21) on 17 May, 28 larvae averaged 14.4±2.0 mm SVL (11-18) on 14 August, and 9 larvae averaged 15.2±1.3 mm SVL (14-17) on 7 October. One large larva was observed in Pond 12 and one from Pond 13 measured 28 mm SVL on 27 April 1988. These data suggest that some individuals may overwinter in some ponds and reach metamorphosis the year following hatching. Three other larvae caught the same day measured 11-16 mm SVL (mean = 14.3 mm). We found terrestrial efts on 19-21 September. Eight efts measured

27-40 mm SVL (mean 34.6±3.9) and three weighed 1.4-2.1 g (mean 1.7±0.4) on 21 September. We found an adult male under a sphagnum mat on 28 June 1990 at a dry pond. In October 1997 and 1998, we found recently metamorphosed larvae and mature adults under logs and rocks on the dry, exposed rim of ponds that had nearly dried. On 28 May 1997, one adult 44 mm SVL female had a leech attached to her venter (probably the blood leech *Batrachobdella picta* Verrill, Gill, 1978a,b) that left a 4x6 mm lesion when it was removed. Males averaged slightly larger than females: male SVL mean = 43.7±3.6 mm, 34-50, n = 46, female SVL mean = 41.5±5.5 mm, 35-54, n = 41; male mass mean = 2.7±0.4 g, 2.2-3.5, n = 27, non-gravid female mass mean = 1.9±0.6 g, 1.1-2.6, n = 11). Gravid female body mass averaged 3.7±1.1 g (2.5-5.2, n = 5).

18. *Plethodon cinereus* (Red-backed Salamander) (Ponds 2, 11, 12, near 13, 26, 27, 29)

We found most individuals of this terrestrial salamander at several terrestrial locations in the SVSP system between 13 April and 15 October. One was found under a log at Pond 13 on 19 February 1997. Adults have been uncovered under logs in the dry basins of Ponds 27 and 29 on 24 March 1995 and Pond 29 on 27 April 1988.

19. *Plethodon cylindraceus* (White-spotted Slimy Salamander) (Pond 29)

This species was uncommon in the forest in SVSP system. Most of the six individuals were caught in drift fence/pitfall arrays in spring 1988. Other dates of observation were in May and September following rains. Several individuals were found under rocks in the basin of Pond 29 on 27 April 1988. One 87 mm SVL female contained a carabid beetle in her stomach.

20. *Pseudotriton ruber ruber* (Northern Red Salamander) (near Ponds 2, 3, 13)

Several individuals were found under logs and in drift fence/pitfall arrays near some of the sinkhole ponds, although this species is not known to breed in the sinkhole ponds. Dates of observation were recorded in May, September, and October following rains. Five individuals measured 51-71 mm SVL (mean = 62.1±8.7); body mass was 3.2-8.6 g.

Turtles

21. *Chelydra serpentina serpentina* (Eastern Snapping Turtle) (Ponds 2, 8, 10, 13, 14, 33, Maple Flats North and South, Spring Pond)

This large omnivorous turtle has been observed in several ponds but only as an infrequent visitor. Ponds may serve as occasional foraging areas. The two individuals found in Pond 14 may have originated in nearby Spring pond, as this is the only pond in the area that could support a permanent population. Dates of observations are 25 March, 8 & 21 April, 12 May, and 3 & 12 June. The earliest observation was of an active individual in a pond with partial ice cover. The largest individual measured was 297 mm carapace length and the smallest was 196 mm. One nest cavity was discovered between the two Maple Flats ponds on 3 June 1994. It had been opened and the eggs eaten by an unknown mammalian predator.

22. *Chrysemys picta picta* (Eastern Painted Turtle) (Ponds 2, 11, 12, 13, 14, 20, 21, 32, 33, 34, 35, Kennedy Mountain Meadow, Maple Flats North and South, Spring Pond)

Adult painted turtles (n = 16) were observed occasionally in several ponds, especially during night surveys for salamanders. Only Quarles and Spring Ponds may support permanent populations. We have observed several painted turtles sitting on the bottom of ponds in winter. One female caught on 20 January 1990 had a body temperature of 6.7° C, equal to that of the water. One female was found as she was constructing a nest between the two Maple Flats ponds on 3 June 1994. This female was subsequently recaptured in Pond 2 on 6 March 1996 at the same body size. Adult males are smaller than adult females in carapace length, plastron length, and body mass (Table 1).

23. *Clemmys guttata* (Spotted Turtle)

Locations for this species are not provided because of its special concern status. We have found this semiaquatic turtle in several ponds in the SVSP system between late March and early July. All were mature adults (Table 1). Number of yellow spots on the carapace averaged 40.1±14.6 (7-60, n = 17). We have observed movement of individuals between two complexes of ponds, a distance of 2.5 km, and we suspect that most individuals move overland extensively when ponds dry seasonally. Spotted turtle populations are apparently rare in the Shenandoah Valley (Mitchell, 1994; Mitchell & Reay, in press). Because they are so closely tied to shallow, natural, freshwater wetlands, they are threatened range wide by habitat loss, and because they are popular in the pet trade, they are threatened by commercial collection (Ernst et al., 1994). Thus, as with many of the amphibians and reptiles,

Table 1. Body size measurements and pond locations for marked snapping turtles (*Chelydra serpentina*), painted turtles (*Chrysemys picta*), and spotted turtles (*Clemmys guttata*) in the SVSP system, Augusta County, Virginia. Location is pond name or number. Abbreviations: CL = carapace, PL = plastron length, MFN = Maple Flats North Pond, and Spr = Spring Pond. Date is day/month/year. Averages do not include juveniles or recaptures. Measurements are in mm and mass is in grams. Pond locations for *C. guttata* are not provided due to the conservation status of this species.

No.	Date	Pond	Sex	CL	PL	Mass	Notes
				Chelydra serpentina			
1	25/03/88	8	male	287.0			
2	25/03/88	10	male	297.0			
3	08/04/88	8	male	196.0			
4	08/04/88	Spr	male	252.0			
5	12/05/88	10	--				
Male average				258.0			
				Chrysemys picta			
1	12/06/87	14	male	110.0	98.8	152	
2	08/03/88	2	male	104.6	96.7	141	
3	31/03/88	11	male	133.1	117.6	264	
4	31/03/88	11	male	114.9	104.9	182	yellow plastron
unmk	27/04/88	13	female	149.0	139.2		high domed shell
40	20/01/90	13	female	134.0	120.0		missing R forefoot
41	20/01/90	13	male	130.0	118.0		
42	20/01/90	13	female	147.0	130.0		
50	02/02/90	13	male	115.6	105.4	190	
50	21/03/90	13	female	141.4	126.8	350	
10	03/06/94	MFN	female	136.8	125.0	379	nesting
10	06/03/96	2	female	136.8	124.3	355	recapture
10	22/02/95	13	male	135.2	123.5	248	missing L rear ft
101	06/03/96	11	female	90.0	84.1	98	3 year old
102	06/03/96	11	female	150.3	137.5	398	red plastron
24	25/06/96	2	male	131.4	123.0	284	
1100	06/02/97	13	female	131.7	123.0	305	
Male average				121.8	111.0	208.7	
Female average				140.0	128.8	357.4	

Table 1. Continued.

No.	Date	Sex	CL	PL	Mass	Notes
			Clemmys guttata			
1	25/03/88	female	100.6	91.6	140	55 spots
2	25/03/88	male	99.8	87.8	128	48 spots
3	25/03/88	juvenile?	86.2	78.9	87	32 spots
4	29/03/88	male	106.0	92.3	158	31 spots
5	29/03/88	female	101.1	92.3	151	43 spots
6	30/03/88	female	109.1	98.9	166	40 spots
7	30/03/88	female	105.0	96.0	152	34 spots
8	30/03/88	male	104.7	89.6	136	15 spots
9	30/03/88	female	110.7	99.9	189	55 spots
10	31/03/88	male	105.2	91.0	145	45 spots
11	12/05/88	male	113.9	99.3	169	7 spots
12	12/05/88	male	115.6	97.5	165	58 spots
13	12/05/88	male	99.0	81.1	110	41 spots
14	07/06/88	female	106.0	–	–	41 spots
15	07/88	–	109.0	96.0	–	50 spots
100	23/03/95	male	101.2	85.0	139	27 spots
101	23/03/95	female	116.6	106.4	222	60 spots
Male average			105.6	90.5	143.8	34.0
Female average			107.0	97.5	170.0	40.1

the entire SVSP complex is an important area for the conservation of this species in the Shenandoah Valley.

24. *Terrapene carolina carolina* (Eastern Box Turtle)

Shells of this terrestrial species have been found near Twin Pond and Pond 10. On 19 September 1994 between Ponds 2 and 16, we observed two males that had apparently been engaged in combat. One was on its back in a small area in which the leaves had been scattered and trampled. The second, upright, male was about a 0.5 m away. No females could be found. Male aggression has been observed in other areas (Stickel, 1989; Ernst et al., 1994) but this is the first report of one male being overturned during the conflict.

Snakes

25. *Carphophis amoenus amoenus* (Eastern Wormsnake)

A single adult was found on 17 May 1988 at the parking area along the Coal Road adjacent to Maple Flats complex.

26. *Coluber constrictor constrictor* (Northern Black Racer)

One adult black racer was observed swimming across Pond 13 on 21 April 1989. It disappeared under water after swimming to the center of the pond.

27. *Crotalus horridus* (Timber Rattlesnake)

One adult male was caught by Bob Glasgow (Wildlife Biologist, GWNF) in a small field near Spring Pond on 7 June 1987. No others have been seen in the SVSP system.

28. *Diadophis punctatus edwardsii* (Northern Ring-necked Snake)

Several ring-necked snakes have been found under bark or in stumps around the edge of sinkhole ponds. Observations include an unsexed adult (255 mm SVL, 5.1 g) caught on 27 April 1988, a gravid female (264 mm SVL) containing three eggs under tree bark on 28 May 1997, and a juvenile (135 mm SVL, 1.6 g) collected under a log on 14 June 1994. Five adults (2 females, 3 males) were found under bark of standing dead pine and oak trees on 6 July 1998. Adult female snakes (275.5±18.8 mm SVL, n = 4; 6.4±1.3 g body mass, n = 3) averaged slightly larger in length than male snakes (247.7±10.0 mm SVL, 6.7±0.2 g, n = 3). All individuals caught had complete yellow/orange collars, immaculate yellow venters, and uniform gray dorsal regions.

29. *Nerodia sipedon sipedon* (Northern Watersnake) (Ponds 2, 11, 12, 13, 26, 32, 33, 34, Maple Flats North and South)

Northern watersnakes were the most common snake encountered in the SVSP system. Individuals were observed in all months from 13 April to 12 September. Northern water snakes are occasional visitors to sinkhole ponds where they forage on seasonally abundant prey. They seem to appear at times when some prey are especially vulnerable. Several individuals were found preying on *Ambystoma tigrinum* larvae when water levels were very low and the salamanders were concentrated in a small area. One immature male watersnake (117 mm SVL, 13.3 g) disgorged a female *Acris crepitans* (25 mm SVL, 1.45 g). Another juvenile (172 mm SVL, 5.8 g) ate a metamorphic *A. opacum*. The largest adult we measured was a female (670 mm SVL, 276 g).

30. *Thamnophis sauritus sauritus* (Eastern Ribbonsnake) (Ponds 3, 11, 13)

Four individuals have been recorded from three ponds. We captured a juvenile on a dry algal mat at Pond 11 on 20 September 1992. Others include a female (23 g) in a grassy area of Pond 3 on 19 September 1995, a juvenile (189 mm SVL, 3.0 g) under a sphagnum mat on 14 October 1995, and a juvenile (229 mm, 4.0 g) found on the trail adjacent to the Maple Flats North Pond on 2 June 1998.

DISCUSSION

The modern herpetofauna of the Shenandoah Valley sinkhole ponds system is comprised primarily of species distributed widely in eastern North America, however, it also includes a small number of habitat specialists and one apparent relic from Pleistocene times. All of the amphibians and reptiles recorded for this area are known to occur in other locations in the mid-Atlantic region (Tobey, 1985; Mitchell, 1994; Conant & Collins, 1998; Mitchell & Reay, in press). Most frogs that occur in the SVSP system breed early in the season or have short larval periods (*Acris*, *Bufo*, *Hyla*, *Pseudacris*, *Scaphiopus*, *Rana sylvatica*). Pond-breeding salamanders include three species in the genus *Ambystoma*, one *Hemidactylium*, and one *Notophthalmus*. Other salamanders in the area include two streamside species (*Gyrinophilus porphyriticus*, *Pseudotriton ruber*) and two terrestrial species (*Plethodon cinereus*, *P. cylindraceus*). Thus, the total salamander fauna that actually use the sinkhole ponds include three genera and five species. Of the four freshwater turtles known for the area, one is terrestrial (*Terrapene*) and two (*Chelydra* and *Chrysemys*) are occasional users of the seasonal pond habitat. The spotted turtle is the only turtle that appears to be dependent on the seasonal pond habitat for its persistence in this landscape. Only one of the six snake species (*Nerodia*) uses the pond environment on a regular basis and no lizards have been seen here. If the sinkhole ponds did not exist on the alluvial plains in this portion of the Shenandoah Valley, the herpetofauna would probably consist of the recorded two species of toads (*Bufo*), two stream-breeding frogs (*R. clamitans*, *R. palustris*), two terrestrial salamanders (*P. cinereus*, *P. cylindraceus*), two streamside salamanders (*Gyrinophilus*, *Pseudotriton*), one turtle (*Terrapene*), and five species of terrestrial snakes. Thus, the sinkhole ponds themselves represent a critical habitat for a substantial portion of the area's known herpetofauna.

The largest data sets on the herpetofauna of the area exist for several of the ponds in the Maple Flats sinkhole pond complex. The rest of the ponds in this complex and all of the ponds in the other two complexes have been visited only a limited number of times (Buhlmann et al., 1999). Much additional work remains to be done before the inventory of the herpetofauna of the SVSP system can be considered complete. Buhlmann et al. (1999) discussed how amphibians and reptiles that inhabit the SVSP system interact with the surrounding landscape. However, the ecology, life histories, and population dynamics of all species need further study before we will understand how they respond to changes in the landscape. We have some information on life history attributes of the ambystomatid salamanders and the spotted turtle (JCM and KAB, unpublished), but we need more data on movement patterns of individuals between ponds. Such information would allow a better understanding of what types of terrestrial habitats are critical to the survival of these animals in this system and how much of the surrounding landscape needs to be included in management and conservation efforts.

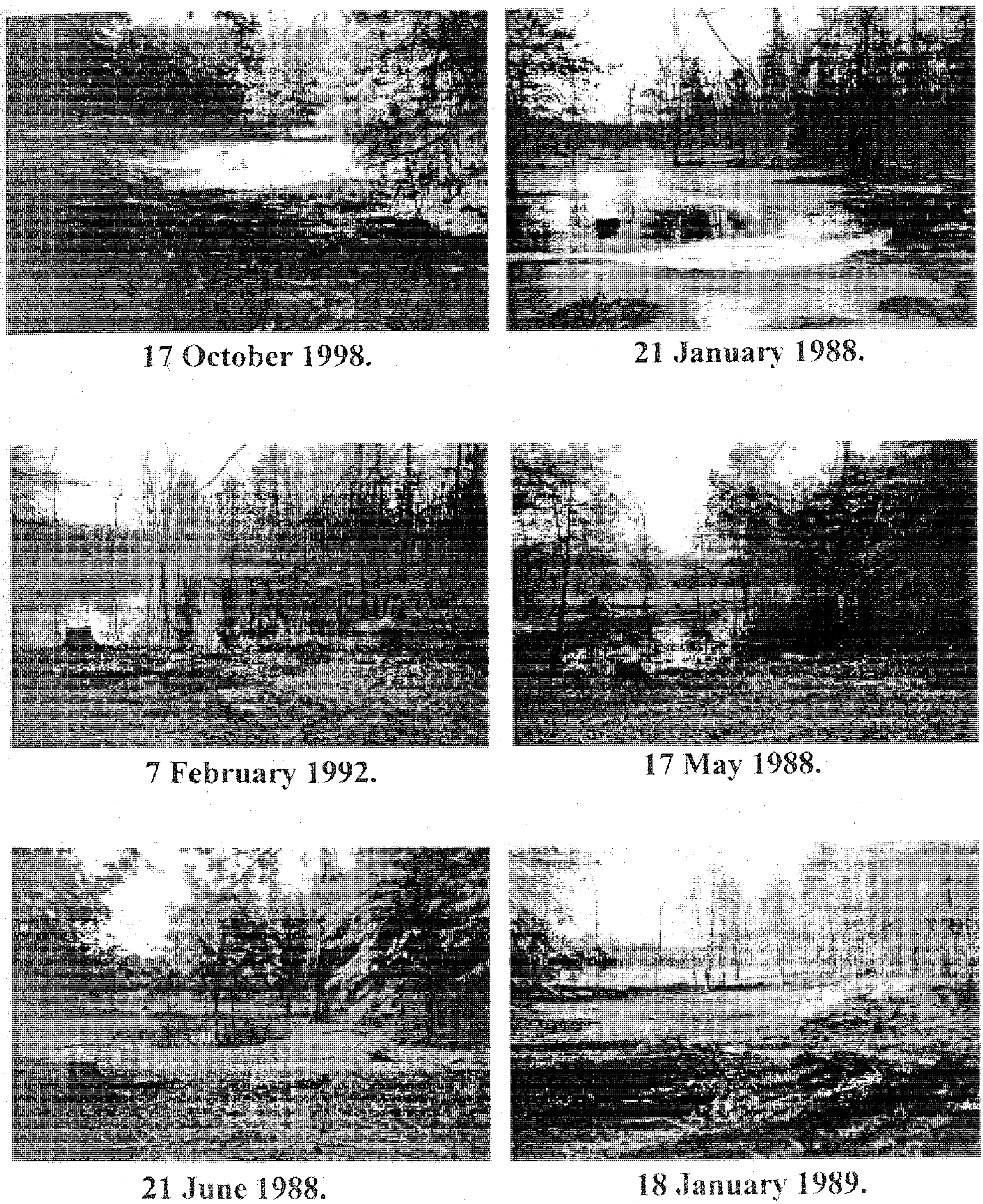

Fig. 4. Annual and seasonal variation in standing water levels in one of the Shenandoah Valley sinkhole ponds, Augusta County, Virginia. (Upper left by T.D. Tuberville. Other photos by KAB.)

Survival of the wetland dependent amphibians and reptiles in the SVSP region cannot occur without the entire complex of ponds. No single pond supports any one species fully. Some ponds are highly seasonal and hold water only in late winter to mid- or late-spring in most years (e.g., Ponds 3 & 14), while others may hold water throughout the summer in wet years (Ponds 2, 17), and still others seldom dry (e.g., Pond 13). Variation in amount and timing of annual rainfall (especially in winter and spring) induces dramatic variation in pond hydrologies. Elevation may play a role because the height of the water table in the alluvial plain varies seasonally with rainfall amounts. Some ponds higher in elevation (Ponds 2, 16) dry earlier than ponds lower in elevation (Ponds 11, 12, 13) (JCM, personal observation). Amphibian species that breed in several ponds simultaneously risk mortality in some but not all of them, whereas those that limit reproduction to a small number of ponds risk low survivorship in all but the wettest years. Several species of amphibians, especially salamanders in the genus *Ambystoma*, have experienced reproductive success in some ponds and reproductive failure in others during the years we have worked in this area (Buhlmann et al., 1999). Loss of individual ponds in the complex would place most species at risk. Adult tiger salamanders may live less than a decade in this area (Buhlmann & Mitchell, unpublished) and repeated unsuccessful reproduction in some ponds due to early drying could cause population decline or loss. Annual variation in rainfall and patterns of pond drying influence population persistence and stability for the pond-dependent amphibians.

Metapopulations consist of distinct units (subpopulations) that may be separated geographically but are connected by dispersal of individuals (Pulliam, 1988; Pulliam & Danielson, 1991). Several of the pond-dependent species in the SVSP system may exist as metapopulations, although the necessary mark-recapture data needed to demonstrate movements are lacking. Pulliam (1988) described the source/sink hypothesis in which some habitats (e.g., ponds), termed sources, produce a surplus of individuals that result in population growth. Other habitats may be sinks that produce no population recruits in bad years. Subpopulations in these sink habitats would become extirpated if immigration from source populations ceased to occur. However, in years of favorable conditions (e.g., adequate hydroperiods) sink habitats may act as source habitats. In the Maple Flats complex, we consider Pond 13 a source habitat and Ponds 2, 3, 5, 14, and 16 sink habitats. Taken together, all ponds in each of the complexes and the entire SVSP system itself act as a dynamic source/sink system. It is clear that protection of the entire complex is required for long-term persistence of a large component of the herpetofauna, including the two rare species.

Acid precipitation is a potential complicating factor for amphibians using the sinkhole ponds for reproduction. Most of the Shenandoah Valley sinkhole ponds are acidic and some have pH values that reach critical levels (Downey et al., 1999). Pond-dwelling amphibians exhibit behavioral, feeding, and altered predator responses and mortality when pH reaches 4.5 or below (Freda & Dunson, 1985, 1986; Dunson et al., 1992; Kutka, 1994). Persistent acid levels below pH 4.5 in ponds during periods in which amphibian eggs and larvae are present would cause severe mortality and result in unsuccessful reproduction. If such conditions lasted for several consecutive years exceeding the life spans of mature adults, then amphibian populations in the SVSP system could decline severely or become extirpated. Downey et al. (1999) demonstrated that pH levels in some ponds with tiger salamanders dip below 5.0 in January and February during which time egg laying and hatching occur. Tiger salamanders and other species of amphibians may be at risk from anthropogenic sources of acid precipitation. Clearly, ponds in the SVSP system need to be monitored on a regular basis and management plans need to be developed to minimize the effects of this threat.

The herpetofauna of the SVSP system in the Big Levels area would not be as rich without the sinkhole pond wetlands. Nor would it be as rich if the landscape in which these ponds are imbedded did not support a forest habitat suitable for these animals. The future of the amphibian and reptile populations in this area, especially the state endangered tiger salamander, depends on the long-term persistence, protection, and management of both habitat types.

ACKNOWLEDGMENTS

We are grateful to the many people who we have enjoyed working with in the SVSP system over the past decade: Rodney Bartgis, Dave Bowne, Sue Bruenderman, Don Church, Donna Clifton, Doug Coleman, Michael Crossland, Steve Croy, Mike Donahue, Dan Downey, Allen Gelden, Todd Georgel, Robert Glasgow, Carola Haas, Lisa Hamilton, Doug Harpole, Ed Haverlack, Mike Hayslett, Nug Hickman, Chris Hobson, Richard Hoffman, Fred & Cindy Huber, Robin Hughes, Judy Jacobs, Dawn Kirk, Scott Klinger, Melissa Larson, Chris Leary, Mike Lipford, Chris Ludwig, Sharon Mahoney, Rob McGarvey, Wendy Mitchell, Andy Moser, Marilyn and Irby Nash, James O'Hear, Chris Pague, Katie Perry, Mike Pinder, Rick Reynolds, Patricia Rich, Lynda Richardson, Steve Roble, Megan Rollins, Larry Smith, Steve Snested, Dirk Stephenson, Tracey Tuberville, Nancy Van Alstine, Pete Warny, Tamara Willis, Deb Wohl, Tim Wright, and participants in the Wintergreen Natural History Weekend Sunday field trips. We especially thank Bob Glasgow for his initial support of our field research. Partial funding was provided by several Challenge Cost Share grants from the George Washington and Jefferson National Forests. Manuscript preparation was supported by Financial Assistance Award Number DE-FC09-96SR18546 from the U.S. Department of Energy to the University of Georgia Research Foundation.

LITERATURE CITED

Buhlmann, K.A., & R.L. Hoffman. 1990. *Ambystoma tigrinum tigrinum*. Herpetological Review 21:36.

Buhlmann, K.A., J.C. Mitchell, & L.R. Smith. 1999. Descriptive ecology of the Shenandoah Valley sinkhole pond system in Virginia. Banisteria 13:23-51.

Carr, L.G. 1938. Coastal Plain plants in southeastern Augusta County, Virginia, in the Valley and Blue Ridge provinces. Virginia Academy of Science Proceedings 1937-38:1-6.

Caldwell, J.P. 1982. Disruptive selection: a tail color polymorphism in *Acris* tadpoles in response to differential predation. Canadian Journal of Zoology 60:2818-2827.

Conant, R., & J.T. Collins. 1998. A Field Guide to Reptiles and Amphibians Eastern and Central North America. Third, expanded edition. Houghton Mifflin Co., Boston, MA. 616 pp.

Crother, B.I. (ed.). in press. Standard English and scientific names of amphibians and reptiles of North America north of Mexico. Society for the Study of Amphibians and Reptiles. Herpetological Circular.

Downey, D.M., S. Wirtz, K.R. Kruer, & S.P. Douglas. 1999. Water chemistry assessment of the Shenandoah Valley sinkhole ponds in Virginia. Banisteria 13:53-65.

Dunson, W.A., R.L. Wyman, & E.S. Corbett. 1992. A symposium on amphibian declines and habitat acidification. Journal of Herpetology 26:349-352.

Ernst, C.H., J.E. Lovich, & R.W. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington, DC. 578 pp.

Fleming, G.P., & N.E. Van Alstine. 1999. Plant communities and floristic features of sinkhole ponds and seepage wetlands in southeastern Augusta County, Virginia. Banisteria 13:67-94.

Freda, J., & W.A. Dunson. 1985. The effect of acid precipitation on amphibian breeding in temporary ponds in Pennsylvania. US Fish & Wildlife Service, Eastern Energy and Land Use Team, Biological Report 80 (40.22). 85 pp.

Freda, J., & W.A. Dunson. 1986. Effects of low pH and other chemical variables on the larval distributions of amphibians. Copeia 1986:454-466.

Gibbons, J.W., & R.D. Semlitsch. 1982. Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. Brimleyana 7:1-16.

Gill, D.E. 1978a. The metapopulation ecology of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque). Ecological Monographs 48:145-166.

Gill, D.E. 1978b. Occurrence of trypanosomiasis in the red eft stage of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque). Journal of Parasitology 64:930-931.

Gosner, K.L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16:183-190.

Guilday, J.E. 1962. The Pleistocene local fauna of the Natural Chimneys, Augusta County, Virginia. Annals of Carnegie Museum 36:87-122.

Hayslett, M.S. 1995. Field notes: *Hemidactylium scutatum*. Catesbeiana 15:51.

Kutka, F.J. 1994. Low pH effects on swimming activity of *Ambystoma*salamander larvae. Environmental Toxicology and Chemistry 13:1821-1824.

Madison, D.M., & L. Ferrand, III. 1998. Habitat use during breeding and emigration in radio-implanted tiger salamanders, *Ambystoma tigrinum*. Copeia 1998:402-410.

McCollum, S.A., & J.D. Leimberger. 1997. Predator-induced morphological changes in an amphibian: predation by dragonflies affects tadpole shape and color. Oecologia 109:615-621.

Mitchell, J.C. 1988. Population ecology and life histories of the freshwater turtles *Chrysemys picta* and *Sternotherus odoratus* in an urban lake. Herpetological Monographs 2:40-61.

Mitchell, J.C. 1991. Amphibians and reptiles. Pp. 411-423 *In* K. Terwilliger (coordinator), Virginia's Endangered Species. McDonald & Woodward Publishing Co., Blacksburg, VA.

Mitchell, J.C. 1994. The Reptiles of Virginia. Smithsonian Institution Press, Washington, DC. 352 pp.

Mitchell, J.C., K.A. Buhlmann, & R.L. Hoffman. 1996. Predation of marbled salamander (*Ambystoma opacum* Gravenhorst) eggs by the milliped *Urobianiulus jerseyi* (Causey). Banisteria 8:55-56.

Mitchell, J.C., & K.K. Reay. In press. Atlas of Virginia's Amphibians and Reptiles. Special Publication Number 1, Virginia Department of Game and Inland Fisheries, Richmond, VA.

Noble, G.K., & M.K. Brady. 1933. Observations on the life history of the marbled salamander, *Ambystoma opacum* Gravenhorst. Zoologica 11:89-132.

Pague, C.A., & K.A. Buhlmann. 1991. Eastern tiger salamander, *Ambystoma tigrinum tigrinum*. Pp. 431-433 *In* K. Terwilliger (coordinator), Virginia's Endangered Species. McDonald & Woodward Publishing Co., Blacksburg, VA.

Primack, R.B. 1998. Essentials of Conservation Biology. Second Edition, Sinauer Associates, Sunderland, MA. 660 pp.

Pulliam, H.R. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Pulliam, H.R., and B.J. Danielson. 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. American Naturalist 137:S50-S66.

Roble, S.M. 1999. Dragonflies and damselflies (Odonata) of the Shenandoah Valley sinkhole pond system and vicinity, Augusta County, Virginia. Banisteria 13:101-127.

Rawlinson, E.S., & L.G. Carr. 1931. Plants of Spring pond, Augusta County, Virginia. Claytonia 3:36-40.

Semlitsch, R.D. 1983. Burrowing ability and behavior of salamanders of the genus *Ambystoma*. Canadian Journal of Zoology 61:616-620.

Stickel, L.F. 1989. Home range behavior among box turtles (*Terrapene c. carolina*) of a bottomland forest in Maryland. Journal of Herpetology 23:40-44.

Tobey, F.J. 1985. Virginia's amphibians and reptiles, a distributional survey. Virginia Herpetological Survey, Purcellville, VA. 114 pp.

Waldman, B., & M.J. Ryan. 1983. Thermal advantages of communal egg mass deposition in wood frogs (*Rana sylvatica*). Journal of Herpetology 17:70-72.

Weins, J.A. 1996. Wildlife in patchy environments: metapopulations, mosaics, and management. Pp. 53-84 *In* D.R. McCullough (ed.), Metapopulations and Wildlife Conservation. Island Press, Washington, DC.