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Monograph

Forty-Years of Field Notes The Cheat Mountain Salamander (*Plethodon nettingi*)

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Abstract: In the following pages, I describe 40 years of field observations on the Cheat Mountain Salamander (*Plethodon nettingi*), a federally threatened species. This is not a research paper in that I do not attempt to analyze data, but rather it is a means to share information I have collected during my time in the field with this species. Cheat Mountain Salamanders are found in just five counties in the high elevations of the Allegheny Mountains in eastern West Virginia. I have searched over 1,300 sites in these five counties and determined that its range extends from Blackwater River Canyon (Tucker County) in the north to Thorny Flat (Pocahontas County) in the south, a linear distance of about 92 km. Within this range, I observed over 2,000 Cheat Mountain Salamanders in 81 populations. Data collected in these 81 populations include habitat characteristics, elevational ranges, mountain aspects, cover objects, food items, sympatric species, syntopic events, phenology, reproduction, conservation issues, and status of populations. It is my hope that information presented herein will be useful to biologists who will be studying this species in future years.

Keywords: *Plethodon*; salamanders; habitat; interactions

Introduction

I first became aware of the Cheat Mountain Salamander (*Plethodon nettingi*) when I was a graduate student at Marshall University in the mid-1960s. My thesis advisor was Dr. N. Bayard Green, who described and named the Cheat Mountain Salamander (CMS) in 1938. After studying under Dr. Green for two years, I began my college teaching career in 1966 at Salem College in Harrison County, West Virginia. During the early years of my career, I began searching for amphibians and reptiles throughout the area near the college, but I did not observe CMS until 1969 when I enrolled in a PhD program at West Virginia University (WVU). My first class, herpetology, was at the WVU Biological Station at Terra Alta (aka TABS) in Preston County West Virginia. Dr. Green taught this course, and he took the class on a field trip to search for CMS at Gaudineer and Barton knobs in Pocahontas and Randolph counties, respectively. This was my first look at a species that would become the focus of a large part of my life's work and professional career.

Discovery of the Cheat Mountain Salamander

Human history of CMS began on 25 June 1935 when Edward Raney and students from the Oglebay Nature Training School conducted the first recorded study of salamanders on Barton Knob in Randolph County (Netting 1937). Graham Netting (1937) reported that they found 10 Wehrle's Salamanders (*P. wehrlei*) but did not mention any other species. Several days later, Graham Netting, Leonard Llewellyn, and students from the Oglebay Nature Training School searched for salamanders on Barton Knob for about one hour in the morning and found five Allegheny Mountain Dusky Salamanders (*Desmognathus ochrophaeus*), eight Wehrle's Salamanders, 29 Eastern Red-backed Salamanders (*P. cinereus*), and one unknown species (*Plethodon* sp.), which was likely CMS (Netting 1937; Brooks 1948). In 1938, N. Bayard Green collected eleven specimens of this unknown salamander on Barton

Knob and subsequently described it as a new species. The specific epithet *nettingi* honors Green's friend and colleague Graham Netting (Green 1938).

Green's (1938) original description of CMS is as follows: "A small *Plethodon* with an elongate body; costal grooves 18-19, usually 18; vomerine teeth 4-8 in row extending to outer edge of nares; belly uniformly dark with throat lighter than belly; back with many fine gold flecks extending to base of tail, not evident in preserved specimens." Green listed three species associated with CMS: Eastern Red-backed Salamander, Wehrle's Salamander, and Allegheny Mountain Dusky Salamander.

Green (1938) originally described CMS as a full species. Subsequently, Highton and Grobman (1956) recognized CMS as a subspecies of the Ravine Salamander (*P. richmondi*). Thurow (1957, 1968), Highton (1971), and Highton and Larson (1979) elevated CMS to full species status.

Grobman (1949) compared the number of costal grooves and pigmentation of CMS to a salamander in Virginia (then known as *P. huldae*), which was later identified as a lead-backed phase of the Eastern Red-backed Salamander (Muchmore 1955). Thurow (1955) compared what was thought to be CMS at "Peaks of Otter" in Bedford and Botetourt counties in Virginia with CMS from Gaudineer Knob, West Virginia. Subsequently, the Peaks of Otter Salamander was determined to be a different species and given the name *P. hubrichti* (Thurow 1957). When Highton (1962) considered CMS a subspecies of the Ravine Salamander, he described the external morphological characteristics of CMS including the number of trunk vertebrae. Thurow (1968) compared the costal groove counts and body somites, osteology of the skull and limbs, pigmentation, dentition, and secondary sexual characters of small black plethodon salamanders, (including CMS). He concluded there were two eastern small plethodon groups: a more primitive relict group (including CMS) and a more progressive group (including the Eastern Red-backed Salamander).

In comprehensive works on the genus *Plethodon* of the Southern Appalachians, Highton (1971; 1995) and Highton and Larson (1979) discussed the genetic relationships of CMS with other species of eastern small *Plethodon*. They considered CMS along with the Eastern Red-backed Salamander, Ravine Salamander, Peaks of Otter Salamander, Valley and Ridge Salamander (*P. hoffmani*), Shenandoah Salamander (*P. shenandoah*), and Southern Red-backed Salamander (*P. serratus*) related and allocated them to the *cinereus* group. Highton (1986) provided an excellent morphological description along with the synonymy of CMS.

The U.S. Forest Service listed CMS in the "undetermined category" in the United States Fish and Wildlife Service's (USFWS) 1973 edition of "Threatened Wildlife of the United States." Between 1976 and the time CMS was listed by the USFWS, the Monongahela National Forest (MNF) administration protected the species within the Forest boundaries, and it was at this time that the MNF had me survey many areas within the Forest for CMS. With data collected during this time, the USFWS listed CMS as a federally threatened species on September 28, 1989 (Federal Register 1989).

Where was CMS first discovered?

Previously, I wrote CMS were first found on White Top in Randolph County, east of Barton Knob (Pauley 2005). However, after searching Green's and Maurice Brooks' (West Virginia University professor) writings, they do not mention CMS at White Top. I was fortunate to have known Drs. Green and Brooks and spoke with them on several occasions. Because I did not "make up" the occurrence of CMS on White Top, could one of them have told me the salamander was found on White Top? Brooks (1948) stated in 1936 that Green and Richmond collected eight specimens east of Barton Knob near Cheat Bridge. Could this refer to White Top? We may never know. For now, I assume I was in error by stating White Top was the original site for CMS. Nevertheless, several known populations exist within 5 km of White Top. One site is below the elevation of White Top.

I searched White Top for salamanders in 1989 and 1994, but found only one Red Eft, a juvenile, terrestrial phase of the Eastern Newt (*Notophthalmus viridescens*) and ten Eastern Red-backed Salamanders. Since the time of Brooks, Green, Richmond, and Netting, White Top has been strip mined leaving an arid "island" at the summit of what once was most likely a mesic Red Spruce forest. Nevertheless, with this many populations of CMS close to White Top, CMS surely occurred there in the past.

Natural history research

The beginning

In 1975, I received a package with a letter from Mr. Arnold Shultz, Monongahela National Forest (MNF) Wildlife Biologist, asking me to identify an enclosed preserved salamander. The specimen was a Cheat Mountain Salamander. With that identification and subsequent discussions with the staff of the MNF, they offered me a small grant to study CMS within the Forest property. Because MNF staff requested a plant community analysis of CMS habitat as part of this study, I asked Dr. Jesse Clovis of WVU to join me in this study. In 1976, Dr. Clovis and I began a four-year study of CMS and its habitat within the MNF. For me, this work was a springboard for a 40-year study of the species.

To begin the study of CMS, Dr. Clovis and I selected four CMS populations and three control sites. The control sites were areas that had the proper habitat and were within the known CMS elevational range and geographic distribution but lacked CMS populations. Dr. Clovis examined the vegetation characteristics of these seven study sites, and I studied the range of CMS within the MNF as well as habitat characteristics.

In 1980, Dr. Clovis and I presented a 167-page report to the MNF that described the CMS habitat, range, environmental characteristics, and interactions with two major competitors, Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders (Pauley and Clovis 1980). In this report, Dr. Clovis described vegetation aspects of the habitat, and I discussed other habitat characteristics such as soil temperature, moisture, and pH and relative humidity as well as the elevational distribution of CMS. I reported other natural history data including cover objects, nesting time, and sympatric salamander species. Additionally, I conducted laboratory studies to establish critical thermal maximum tolerances, dehydration rates, light/dark preferences, substrate pH and moisture preferences, and food items of each salamander species. I also conducted salamander surveys on 19 mountains in an attempt to determine the range and distribution of CMS. Because of the lack of knowledge of the total range of CMS in 1976-1979, I surveyed mountains I now know are outside of the range. During these four years, I observed 2,391 salamanders of which 458 (19.2%) were CMS (**Table 1**).

Table 1. Salamander species and numbers observed during the initial four years (1976-1979) of my studies of the Cheat Mountain Salamander on the Monongahela National Forest (Pauley and Clovis 1980).

Species Observed	Number Observed
Eastern Red-backed Salamander (*Plethodon cinereus*)	1,024
Allegheny Mountain Dusky Salamander *(Desmognathus ochrophaeus*)	622
Cheat Mountain Salamander (*P. nettingi*)	458
Wehrle's Salamander (*P. wehrlei*)	137
Northern Slimy Salamander (*P. glutinosus*)	107
Eastern Newt (*Notophthalmus viridescens*)	17
Northern Two-lined Salamander (*Eurycea bislineata*)	6
Valley and Ridge Salamander (*P. hoffmani*)	5
Spotted Salamander (*Ambystoma maculatum*)	4
Northern Dusky Salamander (*D. fuscus*)	3
Seal Salamander (*D. monticola*)	3
Northern Spring Salamander (*Gyrinophilus p. porphyriticus*)	3
Four-toed Salamander (*Hemidactylium scutatum*)	2

During most surveys to determine the range and distribution of CMS and studies of selected populations, I collected the following data – date, location on USGS topographic quadrangle maps, county, salamander species, number of each species observed, life stage, sex, reproductive status, dominant plant species in the canopy, understory, and on the ground, elevation, aspect, cover object, and coordinates. I used these data to define various features of CMS' natural history, including habitat characteristics, food items, sympatric species, syntopic events, phenology, and reproduction.

Distribution

Prior to our four-year study and subsequent publications from this study, several published papers discussed the taxonomic status and natural history of CMS. After Green's (1938) original description of CMS, Richmond and Boggess (1941) wrote a key to the reptiles and amphibians of West Virginia in which they stated CMS (under the common name of Netting's Salamander) was known only from the mountains around Cheat Bridge in Randolph County. Green (1943) also used the common name "Netting's Salamander" and stated CMS occurred in Randolph and Pocahontas counties, which is the first mention of CMS occurring in Pocahontas County. Grobman (1944) assumed CMS was restricted to the Cheat Mountain Range in Randolph and Pocahontas counties.

Professor Maurice Brooks began studying the natural history of CMS in 1939 and continued his studies through 1947 (Brooks 1948). He described the known range of CMS at that time to include an area from the headwaters of Condon Run near Bickle Knob (Randolph County) south to the southern end of Cheat Mountain at Thorny Flat (Pocahontas County), a linear distance of approximately 72 km (**Figure 1**). Within the range Brooks described, he found CMS at four localities – Gaudineer Knob, Barton Knob, and Bickle Knob (probably Stuart Knob) in Randolph County, and Thorny Flat in Pocahontas County. Brooks (1948) also determined the elevational range of CMS was between 1084 m at Cheat Bridge (Randolph County) and 1476 m atop Bald Knob (Pocahontas County), the highest point in the Cheat Mountain system. In a treatise on amphibians in West Virginia, Green (1976) provided a description of CMS and stated it was found only in the Cheat Mountain area at high elevations.

Data I collected during the four-year study of CMS for the MNF resulted in several short publications and presentations as well as established the foundation for future studies of CMS. In these published papers, I described the elevational distribution of amphibians and reptiles above 975 m in five counties in the Allegheny Mountains of West Virginia (Pauley 1980). I also described the range and distribution of CMS from data collected in the initial study (Pauley 1981). At that time (1980-1981), the known elevational range of CMS extended from approximately 1052 m to 1402 m, and the total range extended east from McGowan Mountain (Tucker County) to Dolly Sods (Tucker County), south to Spruce Knob (Pendleton County), southwest to Thorny Flat (Pocahontas County), and north through Barton Knob (Randolph County) to McGowan Mountain (**Figure 2**).

From 1982 to 1990, I continued to search for new populations within and outside the known CMS range. After analyzing data collected during these studies, I determined there were 54 disjunct populations of CMS. I discovered the northern edge of the range extended to the north side of Blackwater Canyon (Tucker County) (Pauley 1986; 1987a; 1990). Additional studies from 1990 to 2000 increased the number of populations to 59 and extended the lowest elevational site to 805 m at Blackwater Canyon (Pauley and Pauley 1997).

I continued to conduct surveys for state and federal agencies and private entities through the 1990s and 2000s. In 2007, I published a note that provided an update of the range and distribution of CMS (Pauley 2007a). In this paper, I defined the range as extending from Blackwater Canyon in Tucker County south to Thorny Flat in Pocahontas County. I concluded there were approximately 80 disjunct populations of CMS throughout its range and 60 of these were on federal or state-owned lands.

Between 1980 and 2016, I conducted over 70 surveys in seven counties (Grant, Greenbrier, Pendleton, Pocahontas, Randolph, Tucker, and Webster) (**Appendix A**). I found CMS at the most western edge of Grant County at the top of Allegheny Front, as well as throughout Pendleton, Pocahontas, Randolph, and Tucker counties, but I did not find them in Greenbrier and Webster counties. I also conducted 14 research studies that targeted CMS throughout its known range (**Appendix B**). These studies allowed me to provide additional salamander occurrence data to the MNF, USFWS, and West Virginia Division of Natural Resources (WVDNR). These studies also increased our knowledge of the ecology and natural history of CMS.

During my 40 years of searching for CMS, I have examined over 1,300 sites and have found them in approximately 135 locations. In addition, I have conducted areal extent studies to delineate specific population areas at 14 locations and determined several of these 135 sites were part of a single population (**Appendix C**). Currently, it appears there are 81 disjunct populations within the overall range of CMS.

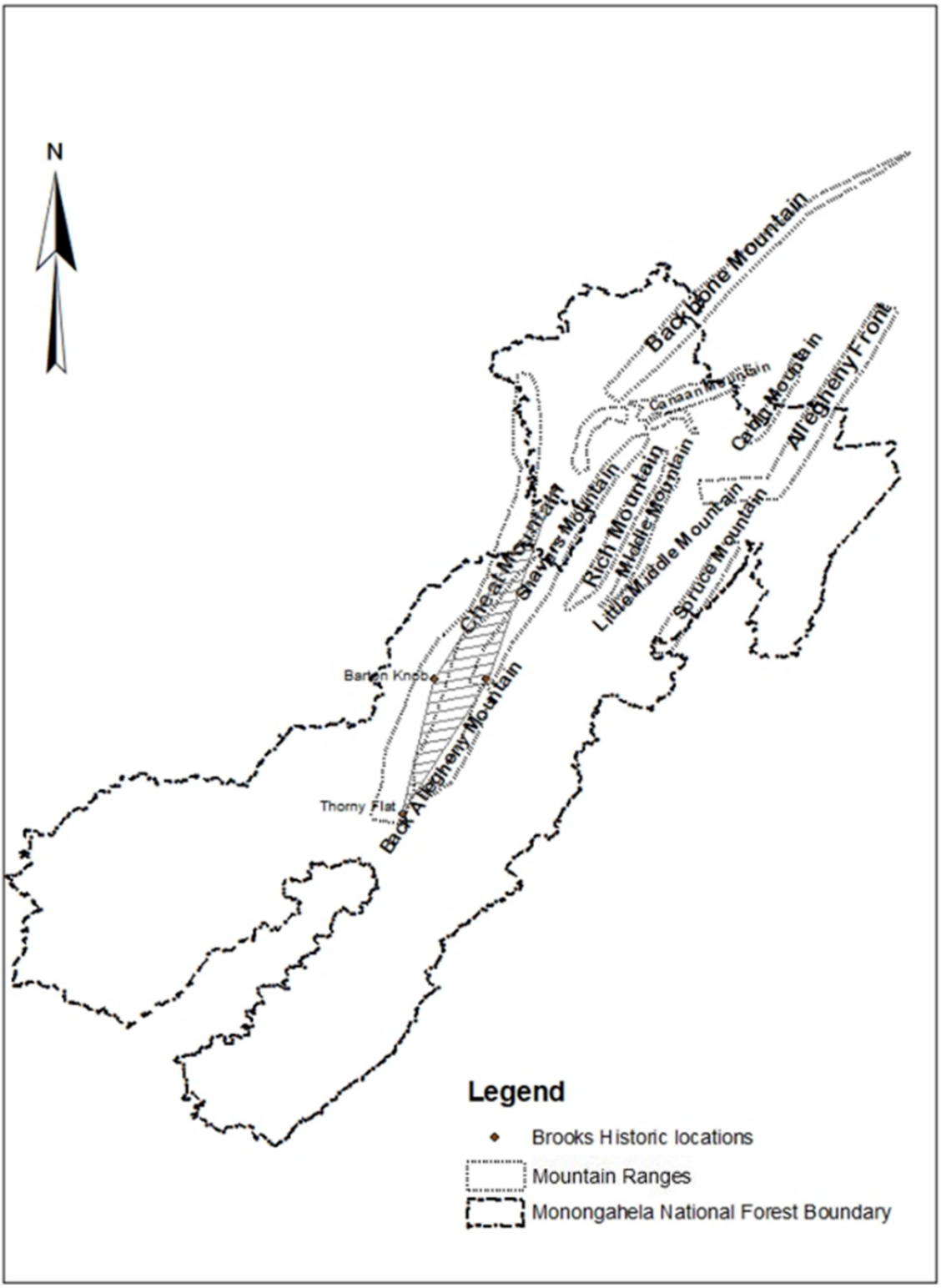

Figure 1. Maurice Brooks Historic CMS Range.

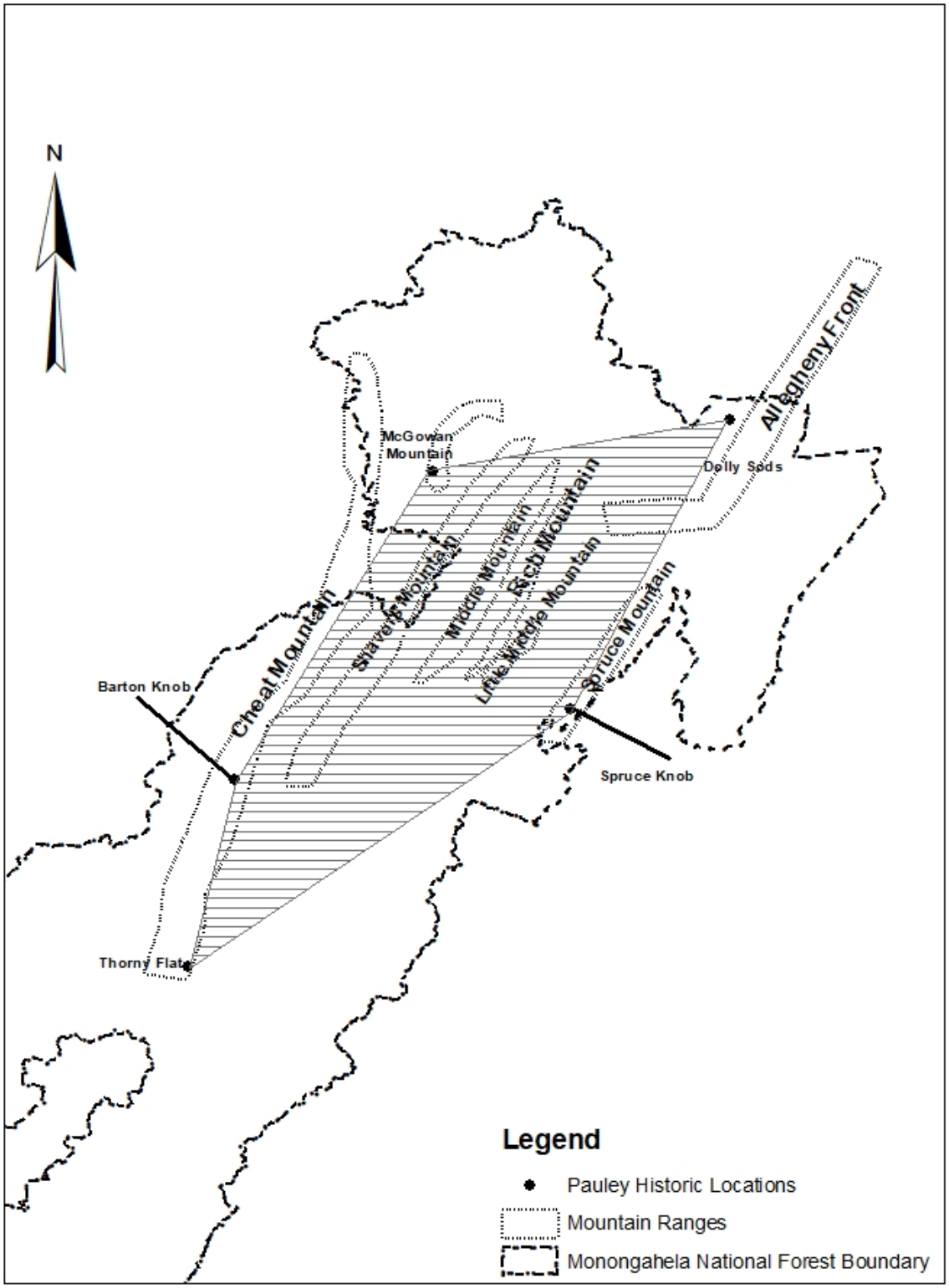

Figure 2. 1980s Historic CMS Range.

Habitat

Green (1938) described the habitat of CMS as cool shady ravines where they are found in moist decaying logs and under rocks, especially where one rock rests upon another. Brooks (1948) conducted field surveys and reported natural history observations. He found CMS associated only with Red Spruce (*Picea rubens*) and Yellow Birch (*Betula alleghaniensis*) forests throughout its known range at that time. He stated CMS appeared limited to nearly pure stands of Red Spruce, or to forests where Red Spruce was a prominent species. He reported finding more CMS in younger timber than in mature stands. He further described the habitat to include moss-covered boulders and small rocks typically on the surface of the soil or just below it.

Brooks also described the seasonal and daily activities, reproduction, and other salamander species associated with CMS. Sixty years after Brooks' published work, I compared my field notes with his (Pauley 2008b) and discovered important differences. For example, Brooks found CMS only in Red Spruce and Yellow Birch forests. I found them in deciduous and Eastern Hemlock (*Tsuga canadensis*) forests as well. I also found differences in salamander species associated with CMS. I found Northern Slimy Salamanders more common throughout the range of CMS than did Brooks and Eastern Red-backed Salamanders common in the Bickle Knob area, a species he reported absent there.

After examining the first 20 years of my CMS data in 1996, it became apparent most CMS occurrences were associated with rock outcrops, emergent rocks, or numerous ground rocks (Pauley and Pauley 1998; Pauley et al. 2005; Pauley 2005; 2008a). B.A. Pauley (1998) investigated the association of CMS, Eastern Red-backed Salamanders, and Allegheny Mountain Dusky Salamanders with emergent rocks. She found CMS appeared to be associated with these large rocks due to greater moisture and cooler temperatures near the rocks. She also determined litter mass was an important microhabitat component for CMS. Santiago (1999) concurred with our (B.A. Pauley [1998] and T.K. Pauley [2005]) findings that relative humidity, soil and litter moisture, and soil and air temperatures are important components of the microhabitat of CMS. Approximately 87% of CMS populations I found were in areas with large emergent rocks or an abundance of ground rocks (Pauley 2008a). This percentage may be higher because I did not record the presence/absence of rocks during my early studies of CMS. I believe CMS are found in these rocky areas because those that occupied such areas survived heavy logging and forest fires during the late 1800s and early 1990s (Pauley 2008a).

In an attempt to predict occurrences of CMS, Dillard et al. (2008) collected data on 13 explanatory macrohabitat variables at CMS occupied and random sites. They found the probability of finding CMS increased at higher elevations and areas underlain by sandstone geology.

Vegetation

I recorded the dominant tree species in the canopy at 430 CMS locations within the 81 known populations. Based on the proximity of these locations, I combined them into 195 CMS collection sites. A CMS collection site is a location where one or more individuals of this species were observed. These collection sites are not distinctive populations because several collection sites may be within a large single population. Of the 195 collection sites, 108 (55.4%) were in Red Spruce stands, 27 (13.8%) in mixed deciduous tree species stands, 19 (9.7%) in mixed Red Spruce and deciduous tree stands, 19 (9.7%) in Eastern Hemlock stands, 10 (5.1%) in mixed Red Spruce and Eastern Hemlock stands, eight (4.1%) in mixed Red Spruce, Eastern Hemlock, and deciduous stands, and four (2.1%) in mixed Eastern Hemlock and deciduous stands.

While these data indicate the original habitat of CMS was a Red Spruce forest, CMS can survive in Eastern Hemlock and deciduous tree stands. The low percentages of CMS found in mixed tree species forests of Red Spruce-deciduous trees (9.7%) and in Red Spruce-Eastern Hemlock (5.1%) may indicate these areas were once part of a contiguous Red Spruce forest. If the original habitat of CMS was a Red Spruce forest, then the 13.8% of these collection sites in deciduous stands, 9.7% in Eastern Hemlock, and 2.1% in Eastern Hemlock and deciduous stands are most likely in areas that were also part of a large historical Red Spruce forest. Lumber harvesting and subsequent fires during the late 1800s and early 1900s (West Virginia Conservation Commission 1908) destroyed the Red Spruce seedbed and altered soil conditions and the microclimate, which allowed

northern hardwoods to dominate areas once occupied by Red Spruce forests (Thomas-Van Gundy and Sturtevant 2014). Loss of the Red Spruce seedbed, slow maturity of Red Spruce, and limited dispersal distance of Red Spruce seeds impeded the natural restoration of Red Spruce forests (Pielke 1981). Where Red Spruce forests had been logged, the soil dried out and northern hardwoods replaced Red Spruce. Where Red Spruce forests burned, the damage is much longer lasting. Red Spruce is a fire-sensitive species, and the seedbed is vulnerable to burning. Fires after initial logging burned the humus and soil down to underlying rocks destroying the Red Spruce seedbed. Red Spruce forests that burned after logging (1880-1920) have not yet returned (personal communication, Elizabeth Byers). Because CMS was initially associated with Red Spruce, the removal of the original Red Spruce forest most likely had a detrimental effect on the survival of some populations as well as the CMS distribution. In a paper published in 2008, I hypothesized that when the original forest was cut and burned in the late 1800s and early to mid-1900s, only CMS in rocky areas survived the inferno (Pauley 2008a). These survivors represent the populations found today.

Similarly, I recorded the presence and absence of Three-lobed Bazzania (*Bazzania trilobata*) at 96 CMS collection sites. Of these, 69 (71.9%) contained some Three-lobed Bazzania and 27 (28.1%) did not contain any. In addition to Red Spruce as the probable tree canopy species in historical CMS sites, Three-lobed Bazzania was probably the dominant ground cover species in CMS habitat until Red Spruce forests were clearcut and burned. Three-lobed Bazzania is found on humus or peaty soil, decaying logs, tree bases, and sandstone rocks, usually under moist coniferous forests. It is generally found in areas with soil that has developed from siliceous rocks, such as sandstone (personal communication, Elizabeth Byers).

Elevation and aspect

Elevational range of known CMS populations is approximately 610 m in Blackwater Canyon to 1482 m at Spruce Knob, the highest elevation in West Virginia. Based on personal observations of occurrences throughout the known range of CMS, I believe they could occur in appropriate habitat at elevations above 610 m in the extreme northern limit of the range, 914 m in the middle of the range, and 1067 m in the southern areas of the range.

CMS are found on hillsides of all aspects. Of the known CMS populations, 61.4% have a northern aspect when considering both cardinal and ordinal directions. Of the remaining 38.6%, 3.0% faced south, 13.7% southeast, 5.7% southwest, 9.5% west, 5.0% east, and 1.7% flat areas (generally on ridges).

Use of cover objects

Of all CMS (n=2,133) observed under cover objects during day searches, 1,021 (47.9%) were under logs, 778 (36.5%) under rocks, 161 (7.5%) under bark, and 173 (8.1%) under leaf litter.

Cover objects by sex

Adult males are recognized by occurrence of squared snouts and swollen cloacae during the breeding season (fall and spring). Adult individuals observed during the breeding season without these characteristics are considered females. Cover objects of sexes included: logs - 335 (49.3%) females and 345 (50.7%) males; rocks - 298 (50.1%) females and 297 (49.9%) males; bark - 56 (47.9%) females and 61 (52.1%) males; litter - 28 (73.7%) females and 10 (26.3%) males. Of adults found on the surface, mostly during night surveys, 97 (53.3%) were females and 85 (46.7%) males. It appears males and females do not select different cover objects; rather both sexes use what is available.

Cover objectives by size class

I categorized CMS in approximate size classes (juveniles <30 mm SVL [snout-to-vent length], subadults 31 to 39 mm, and adults 40 to 48 mm) roughly based on Takahashi's (2002) sizes of Eastern Red-backed Salamanders that occupy the same geographical range as CMS. Of all CMS found under logs (n=1,021), 786 (77.0%) were adults, 179 (17.5%) subadults, and 56 (5.5%) juveniles. Other cover objects by CMS size class included: rocks (n=778), of which 675 (86.8%) were used by adults, 91(11.7%) by subadults, 12 (1.5%) by juveniles; bark (n=161) concealed 133 (82.6%) adults, 19 (11.8%) subadults, and 9 (5.6%) juveniles; litter searches (n=173) revealed 43 (24.9%) adults, 41 (23.7%) subadults, 89 (51.4%) juveniles. A greater number of adults and subadults were under rocks and logs rather than under bark and litter. This may be

because logs and rocks are more abundant on the forest floor than bark, and I spent less time searching in litter than under rocks, logs, and bark. A greater number of juveniles found in litter than under cover objects agrees with the observations Jaeger et al. (1995) reported regarding Eastern Red-backed Salamanders.

Cover objects by season

CMS generally emerge on the forest floor surface in April or May. In April, 13 (52.0%) CMS were under rocks, 11 (44.0%) under logs, one (4.0%) under bark, and 0 under litter. In May, 134 (50.6%) were under rocks, 128 (48.3%) under logs, two (0.7%) under bark, and one (0.4%) under litter. In June, 176 (45.2%) were under rocks, 173 (44.5%) under logs, 39 (10.0%) under bark, and one (0.26%) under litter. In July, 188 (35.3%) were under rocks, 283 (53.1%) under logs, 46 (8.6%) under bark, and 16 (3.0%) under litter. In August, 52 (25.1%) were under rocks, 115 (55.6%) under logs, 16 (7.7%) under bark, and 24 (11.6%) under litter. In September, 171 (37.9%) were under rocks, 234 (51.9%) under logs, 39 (8.6%) under bark, and seven (1.6%) under litter. In October, 43 were under rocks (40.9%), 47 under logs (44.8%), five under bark (4.8%), and 10 under litter (9.5%).

There appears to be a trend in the use of cover objects by season. More CMS were found under rocks in the spring after exiting winter refugia, with a similar peak in use of cover objects in September and October before entering winter refugia. This seasonal use of cover objects could be because there are more openings (holes) to enter and exit winter refugia beneath rocks than logs (Pauley and Keller 1993). Salamanders move to rocks before retreating to underground refugia in mid to late autumn and emerge from these refugia via rock cover the ensuing spring. As soil temperatures increase and soil moisture decreases in summer and early autumn, CMS tend to shift cover object use to moist logs. Anecdotally, I found fewer CMS under Yellow Birch logs than Red Spruce and other species of tree logs. I believe this is because the wood of Yellow Birch logs rots faster than the bark allowing air to enter the log which results in a drier microhabitat.

Food

Like all species of *Plethodon*, CMS feed on invertebrates. I examined 42 specimens in 1980 for food items and found the following in order of occurrence: mites 42.1%; springtails 17.8%; beetles 16.4%; flies 9.3%; ants 4.3%; others 10.1% (Pauley and Clovis 1980; Green and Pauley 1987). Eastern Red-backed Salamanders consume similar food items (Pauley 1978c).

Sympatric species of salamanders

Today, CMS are confined to rocky areas, likely due to competition with two other species of salamanders, Eastern Red-backed Salamander and Allegheny Mountain Dusky Salamander. CMS are in competition for moist spots with Allegheny Mountain Dusky Salamanders and for food and nesting sites with Eastern Red-backed Salamanders (Pauley and Clovis 1980; B.A. Pauley 1998; T.K. Pauley 2005).

Other woodland species of salamanders found in sympatry with CMS, include two eastern large *Plethodon*, Northern Slimy Salamanders and Wehrle's Salamanders. Wehrle's Salamanders are generally more common within the CMS range than Northern Slimy Salamanders (Pauley 1980). I have found Eastern Red-backed Salamanders in 89% of the CMS populations, Allegheny Mountain Dusky Salamanders in 79%, Wehrle's Salamanders in 64%, and Northern Slimy Salamanders in 56% (Pauley 2008b). Brooks (1945) noted the same sympatric species with CMS I observed, but he found Northern Slimy Salamanders in high elevation deciduous forests but not in Red Spruce forests. I found them in over half of the known CMS sites (Pauley 2008b). Brooks (1945) also commented on the absence of Eastern Red-backed Salamanders in the Bickle Knob area, a species that commonly occurs in this area today. In addition to CMS, Brooks (1945) found one Eastern Long-tailed Salamander (*Eurycea l. longicauda*) at the Bickle Knob site, and my wife and I found one at Dolly Sods in 2013. Brooks (1945) noted that Graham Netting found one at 1067 m but did not disclose the location. To my knowledge, these are the only reported records of Eastern Long-tailed Salamanders in CMS habitat. Brooks (1948) reported Allegheny Mountain Dusky Salamanders, Eastern Red-backed Salamanders, and Wehrle's Salamanders on mountain ridges with remnant stands of spruce outside the known CMS range at that time. These species remain in these areas today.

Syntopic events

A syntopic event occurs when more than one individual occurs in the same microhabitat, i.e., under the same cover object. I did not record multiple individuals under a single cover object until 1991. Since then, I have recorded 37 CMS syntopic events. I suspect more than one individual using the same cover object is more common than my data represents because I have often witnessed syntopic events with other species of salamanders, especially Allegheny Mountain Dusky Salamanders. I have observed the following salamander combinations under a single cover object: two events with two CMS males; 14 male and nongravid female CMS events; one CMS male and one gravid female event; one male and one juvenile CMS event; five female and female CMS events; one female and subadult CMS event; two events of male with female CMS were on nests; and two female CMS with nests under the same cover object. I also observed one event with a male CMS and a male Eastern Red-backed Salamander, two events with male CMS and male Allegheny Mountain Dusky Salamanders, two events with female CMS and female Eastern Red-backed Salamanders, one event with a CMS female and an unknown sex of an adult Eastern Red-backed Salamander, two events with CMS females and Allegheny Mountain dusky females, and one event with a CMS female and a subadult Allegheny Mountain Dusky Salamander.

Phenology

Brooks (1948) reported April 10 as the earliest date and October 19 as the latest date he found CMS on the surface of the forest floor. The earliest date I have observed CMS on the forest floor (under a cover object) was March 24, 1979 (n=2) at Stuart Knob. The next earliest dates were April 17, 1991 at Cabin Mountain (n=5), April 17, 1992 at Stuart Knob (n=2) and April 26, 2013 at Gaudineer Knob (n=2). I have found CMS in early May (3^{rd}-9^{th}) at Snowshoe Mountain (n=2), Gaudineer Knob (n=33), and Condon Run near Stuart Knob (n=12). Unfortunately, I did not measure soil temperatures at the time of these observations.

In 2015, I conducted a phenological study of CMS populations at Stuart Knob, Blackwater Falls State Park, Dolly Sods, and Gaudineer Knob (Pauley 2015a). My objective was to determine what soil temperatures CMS emerge in the spring from underground winter refugia. Due to a late snow cover in 2015, the earliest date I could get to all four sites was April 16. Soil temperatures at sites where I observed CMS under cover objects ranged from a low of 3.0° C at Gaudineer Knob on April 16 to a high of 17.7° C on May 12 at Gaudineer Knob. CMS became most abundant in the spring under cover objects on the forest floor when soil temperatures reached 8.0° - 10.0° C. These soil temperatures were generally reached in early to mid-May. Soil temperatures varied among sites depending on the elevation of the site and percentage of leaf cover in the canopy. Soil temperatures at higher elevation sites remained cooler longer than soil temperatures at lower elevations, and sites with a thin tree canopy tended to warm sooner compared to sites with a thicker canopy. Salamander species observed and soil temperatures recorded at the time of observance during spring surveys in 2015 are presented in **Table 2**.

The latest date I have observed CMS under surface cover objects was October 25, 1986 at Dolly Sods and at Spruce Knob. At Dolly Sods, I found four CMS at a soil temperature of 8.0° C. At Spruce Knob, I found just one CMS at a soil temperature of 7.0° C. Through the years, I have observed CMS throughout its range from the 1^{st} to the 25^{th} of October. To help determine when CMS reduces activity before hibernation in the fall, I resumed the phenological study in September of 2015 at the same four study sites previously described. I also collected salamander and soil temperature data at the BWFSP site during the first week of October. In addition, I recorded the soil temperature and searched for CMS at the BWFSP and Stuart Knob sites on November 19, 2015.

Based on the number of CMS I have observed through the years and temperature data collected in 1986 and 2015, CMS likely remain active on the forest floor until about mid-October. By then, the soil temperature decreases to 10° C or less at which time most members of a population move to subterranean refugia. Salamander species observed and soil temperatures recorded at the time of observance during fall surveys in 2015 are presented in **Table 3**.

Table 2. Phenological spring activities and soil temperatures observed during April and May 2015.

Date/Species	Numbers	Site	Soil Temperature
April 16			
CMS	2	Dolly Sods	Range: 4.4º – 5.5º C
Eastern Red-backed	7		Average: 5.0º C
Wehrle's	1		
April 16			
CMS	5	Stuart Knob	Range: 6.8º – 7.7º C
Eastern Red-backed	5		Average: 7.1º C
April 21			
CMS	2	Gaudineer Knob	Range: 4.4º – 6.9º C
Eastern Red-backed	0		Average: 5.7º C
April 21			
CMS	5	Blackwater Falls	Range: 7.1º – 8.7º C
Eastern Red-backed	1	State Park	Average: 7.9º C
April 28			
CMS	1	Gaudineer Knob	Range: 3.0º – 6.3º C
Eastern Red-backed	0		Average: 4.5º C
April 28			
CMS	2	Stuart Knob	Range: 3.0º – 6.3º C
Eastern Red-backed	2		Average: 4.5º C
Allegheny Mountain Dusky	1		
April 29			
CMS	1	Dolly Sods	Range: 4.0º – 5.6º C
Eastern Red-backed	6		Average: 4.9º C
Northern Slimy	1		
April 29			
CMS	5	Blackwater Falls	Range: 4.8º – 6.1º C
Eastern Red-backed	1	State Park	Average: 5.5º C
May 5			
CMS	7	Gaudineer Knob	Range: 8.6º – 12.2º C
Eastern Red-backed	0		Average: 10.6º C
May 6			
CMS	0	Dolly Sods	Range: 10.3º – 12.0º C
Eastern Red-backed	4		Average: 10.8º C
Northern Slimy	3		
May 6			
CMS	4	Blackwater Falls	Range: 9.5º – 13.4º C
Eastern Red-backed	0	State Park	Average: 11.8º C

Table 2 (*Continued*).

Date/Species	Numbers	Site	Soil Temperature
May 6			
CMS	4	Stuart Knob	Range: 8.3° – 14.7° C
Eastern Red-backed	3		Average: 11.5° C
May 12			
CMS	4	Stuart Knob	Range: 14.7° – 16.4° C
Eastern Red-backed	0		Average: 14.7° C
Wehrle's	1		
May 12			
CMS	5	Gaudineer Knob	Range:11.4° – 17.7° C
Eastern Red-backed	3		Average:17.4° C
May 13			
CMS	0	Dolly Sods	Range: 8.2° – 9.7° C
Eastern Red-backed	0		Average: 8.8° C
May 13			
CMS	4	Blackwater Falls	Range: 8.6° – 11.0° C
Eastern Red-backed	0	State Park	Average: 9.9° C
May 20			
CMS	10	Gaudineer Knob	Range: 7.3° – 9.4° C
Eastern Red-backed	1		Average: 8.0° C
May 20			
CMS	3	Stuart Knob	Range: 9.8° – 11.8° C
Eastern Red-backed	2		Average: 10.6° C
May 20			
CMS	9	Blackwater Falls	Range: 9.5° – 12.9° C
Eastern Red-backed	1	State Park	Average: 10.7° C
Wehrle's	1		
May 20			
CMS	1	Dolly Sods	Range: 11.7° – 15.5° C
Eastern Red-backed	2		Average: 13.2° C
Northern Slimy	1		

Table 3. Phenological fall activities and soil temperatures observed during September, October, and November 2015.

Date/Species	Numbers	Site	Soil Temperature
September 16			
CMS	3	Dolly Sods	Range: 12.9° – 14.2° C
Eastern Red-backed	7		Average: 13.4° C
September 16			
CMS	4	Stuart Knob	Range: 14.4° – 15.5° C
Eastern Red-backed	8		Average: 14.6° C
Northern Slimy	1		
Wehrle's	1		

Table 3 (*Continued*).

Date/Species	Numbers	Site	Soil Temperature
September 16			
CMS	3	Gaudineer Knob	Range: 13.4° – 16.2° C
Eastern Red-backed	5		Average: 12.9° C
September 16			
CMS	3	Blackwater Falls	Range: 11.9° – 13.5° C
Eastern Red-backed	0	State Park	Average: 12.5° C
Northern slimy	1		
September 29			
CMS	2	Dolly Sods	Range: 13.6° – 14.5° C
Eastern Red-backed	9		Average: 13.9° C
September 29			
CMS	2	Stuart Knob	Range: 14.3° – 15.4° C
Eastern Red-backed	4		Average: 14.9° C
Northern Slimy	1		
Wehrle's	2		
Allegheny Mountain Dusky	1		
September 29			
CMS	2	Blackwater Falls	Range: 14.8° – 16.3° C
Eastern Red-backed	1	State Park	Average: 15.8° C
September 30			
CMS	6	Gaudineer Knob	Range: 12.8° – 15.6° C
Eastern Red-backed	2		Average: 14.1° C
October 6			
CMS	5	Blackwater Falls	Range: 10.4° – 11.7° C
Eastern Red-backed	2	State Park	Average: 11.2° C
November 19			
CMS	0	Stuart Knob	Range: 7.1° – 9.7° C
Eastern Red-backed	7		Average: 8.6° C
November 19			
CMS	2	*Blackwater Falls	Range: 9.3° – 11.5° C
Eastern Red-backed	1	State Park	Average: 10° C

*Dr. Cathy Johnson (MNF) found one CMS at Blackwater Falls State Park on December 13, 2015.

Reproduction

Although I began collecting field data in 1976, I did not record the sexes of individual salamanders until 1992. To reduce the possibility of errors, I used only data for specimens I examined for reproductive characteristics, not those examined by field assistants.

During these 24 years, I examined 85 specimens of CMS I deemed males based on snout and cloaca characteristics. While there is a paucity of published data regarding the reproduction biology of CMS, there are several published studies that describe the reproduction of Eastern Red-backed Salamanders. These two species are similar in size and life history traits. Because Eastern Red-backed Salamanders occur throughout the CMS range, I used published work that describes the reproductive characteristics of Eastern Red-backed Salamanders to augment my

data on the reproduction of CMS. As described above, I based CMS size classes on Takahashi's data (2002).

During the breeding season, sexually mature male Eastern Red-backed Salamanders have swollen (squared) snouts and enlarged premaxillary teeth, and papillae in the cloacal vents (Dunn 1926; Blanchard 1928; Bishop 1941, 1943; Sever 1975; Anthony et al. 2008; Anthony and Pfingsten 2013). Conversely, females have rounded snouts. Cloacal glands of male Eastern Red-backed Salamanders enlarge during the breeding season (Thurow 1957; Sever 1978) and surface tissue around the vent is lighter in coloration (Thurow 1957; Kniowshi 2006). The cloacal vent of females is a narrow slit and not lighter in coloration. In male CMS, snouts begin to square off in late July and early August and cloacae start to swell (indicated by lighter coloration) in late August or early September. By mid-September, both characteristics are obvious, and these traits continue to be observable until late May or early June of the ensuing year.

Ovarian eggs begin to become visible through the abdominal wall of mature female CMS in late summer or early fall and eggs continue to develop until deposition the following spring. The earliest I have found a gravid female is August 9 and the latest date in the spring/summer is June 10. Because mature ovarian eggs are visible through the body wall of sexually mature females in September, October, and November or until they submerge into winter subterraneous refugia, they are easy to distinguish from nongravid mature females. Gravid females continue to be easily recognized the ensuing spring after emergence from winter refugia (March or April) to early June. By early June, gravid females have deposited their eggs and are tending them in nests in subterranean cavities, under rocks or logs, or in decaying logs. I have observed nests with eggs and tending females from May 15 to July 26. I have found neonates in nests with females in early September, indicating eggs hatch in late August or early September (Pauley 2008c).

Eastern Red-backed Salamanders in northern latitudes of the northeastern United States exhibit biennial egg deposition (Test and Bingham 1948; Sayer 1966; Werner 1971; Anthony and Pfingsten 2013). Because the growing season in these northern latitudes is similar to the high elevations of West Virginia where CMS occurs, and because a percentage of mature CMS females are not gravid when other females are gravid, biennial egg laying in CMS is plausible. Further, female Eastern Red-backed Salamanders deposit eggs biennially in the high elevations of West Virginia (Takahashi 2002), areas where they are sympatric with CMS.

Sayler (1966) estimated 50% of mature females in a population of Eastern Red-backed Salamanders in Maryland were on nests during the egg-deposition period and 50% were in a non-breeding condition. Conversely, Werner (1971) found 8% of the adult female Eastern Red-backed Salamander population in Michigan were in a non-breeding condition during the egg-deposition period. I examined 107 sexually mature CMS females between August 9 and June 10 for presence of visible ovarian eggs through the abdominal wall. Of these 107 specimens, 73 (68.2%) were gravid and 34 (31.7%) were non-gravid. The proportion of nearly 32% of mature female CMS I observed in the non-breeding condition suggests biennial egg deposition does occur in CMS.

Deposited CMS eggs are in small grape-like clusters suspended from the underside of a rock or log or in log cavities or subterranean cavities. I have observed 25 CMS nests, 23 with eggs between May 15 and July 26, and two with neonates on September 4th and 12th. Egg clutch sizes varied from 5 to 11 (Pauley 2008b). Brooks (1948) reported 29 nests from May 28 to August 25 with 4 to 17 eggs. All nests Brooks found were in well-decayed spruce logs. Neil Richmond found one nest with 8 eggs on July 15, 1936. The nest contained eight eggs, each 4 mm. in diameter and with a well-developed embryo (Green 1938).

In all nests I observed, females were in attendance. As with CMS, female Eastern Red-backed Salamanders guard the eggs during development (Bishop 1941; Highton and Savage 1961). Sayler (1966) concluded that spent Eastern Red-backed females, i.e., those that have deposited their eggs and have guarded their nest during embryo development, leave the nest approximately 6 to 8 weeks (August) after egg deposition. My nesting data suggest CMS deposit eggs about June 1 and the eggs hatch around September 1, approximately 90 days instead of the 40 to 60 days Sayler (1966) predicted for Eastern Red-backed Salamanders. This explains why in the phenological study of CMS in 2015, I found 6 of 13 females in early spring were emaciated, i.e., spent. These six spent females (approximately 50% of those observed) spent the previous summer (2014) guarding their nest. It

appears the long nesting period of CMS (a time the female eats little or nothing) gives nesting salamanders little time to accumulate enough fat to survive the winter, a period of 150 to 180 days. Early winters and late springs could result in an increased mortality of spent females.

CONSERVATION

Introduction

Most known populations of CMS are within the boundaries of the MNF which provides them protection from some disturbances (Pauley et al. 2005). Nevertheless, the future of CMS is somewhat uncertain because of climatic changes and competition with other species such as the Eastern Red-backed Salamander and the Allegheny Mountain Dusky Salamander (Kroschel et al. 2014). Further, most CMS populations are impacted by human-induced habitat alterations such as forest clear cuts, roads, hiking trails, and ski slopes (Pauley 1994; 2005; Mitchell et al. 1999). Such perturbations can alter crucial environmental factors that help stabilize habitats. For example, Waldron and Pauley (2012) found low soil temperature, low precipitation, low relative humidity, reduced litter depth, reduced duff depth, and reduced moss cover were factors that affected movement, survival, and abundance of CMS when associated with trails and gated roads.

These habitat alterations also allow entrance of potential predators into forests where CMS reside. Bradshaw (2010) examined the distance snakes (predators on salamanders) move into forests within known CMS populations from areas of disturbance such as roads and ski slopes. While Bradshaw did not find snakes within forests occupied by CMS, she did find two species, Northern Ring-necked Snake (*Diadophis punctatus edwardsii*) and Eastern Garter Snakes (*Thamnophis s. sirtalis*), known salamander predators, present at the edges of forested areas adjacent to CMS populations. Messenger et al. (2011) captured an Eastern Garter Snake in one of Bradshaw's study sites that regurgitated a partially digested CMS. Below I discuss five studies I conducted that dealt with different conservation issues that could affect the status of CMS.

Ski slope

In 1977, I unsuccessfully searched for CMS on MNF land adjacent to a forested area that would become a ski slope in Tucker County. Eight years later (in 1985) the ski slope owners applied for a special use permit from the MNF to build a ski slope. The proposed ski slope would pass through MNF land. The MNF staff asked me to survey the Forest Service land for CMS, and I found a population where the proposed ski slope was to be constructed. I flagged what I thought was the edge of the CMS population prior to construction. The summer after the ski slope path was constructed I began a 31-year study of the impacts of the ski slope on this population of CMS.

The ski slope comes within a few meters of the population on two sides and curves around the population as it goes downhill. I established 43 monitoring sites along four transects between the upper and lower sections of the ski slope. I considered ten monitoring sites adjacent to the slope as impact sites and 33 sites farther into the forest (i.e., away from the ski slope) as non-impact sites. Over these 31 years, I conducted salamander surveys once or twice each year. For the first 26 years, I also recorded relative humidity and soil temperature at ground level and collected soil and litter moisture samples at every other nonimpact site and at every impact site. I weighed and dried the samples in the laboratory to determine percent moisture. I did not collect environmental data the last five years because the MNF staff decided I had collected enough baseline data to allow biologists in the future to detect negative changes in environmental conditions. At present, all parties agreed the population status would be checked at least once each year for the duration of the special use permit.

Analyses of the data collected over these 31 years indicate that increased solar radiation due to the open canopy created by the ski slope and possibly reduced competition from CMS has benefited other species of salamanders, particularly the Eastern Red-backed Salamander (Rucker 2021).

Buffer zone size

Human-induced disruptions of habitats may lead to fragmentation or dissection of single large populations into smaller subunits. Habitat fragmentation results in barriers to salamander dispersal and gene flow as well as altering environmental conditions in and around openings (Ash 1988; Petranka et al. 1993). In addition, fragmentation creates isolated patches of species that

may be vulnerable to local extinctions (Vos and Chardon 1998).

In addition to dividing populations, habitat disturbances can move the edge of a forest closer to the forest interior and potentially a CMS population. With the edge of the forest pushed to the interior of the forest, relative humidity generally decreases, and the forest floor is drier due to exposure to wind currents and sunlight (Pauley and Watson 2003). Under normal conditions, CMS microsites are moister than microsites occupied by Eastern Red-backed Salamanders, a main competitor of CMS (Pauley and Clovis 1980; Pauley 2005). Dehydration tests in the laboratory concur with the moisture data collected in the field in that CMS loses body moisture faster than Eastern Red-backed Salamanders (Pauley and Clovis 1980; Pauley 2005). Thus, drier conditions caused by habitat alterations such as open corridors may give the competitive edge to Eastern Red-backed Salamanders when in sympatry with CMS. Further, Adams et al. (2007) hypothesized that Eastern Red-backed Salamanders have enhanced morphological flexibility and ecological tolerance that allows them to adapt more rapidly to local environmental conditions.

The CMS Recovery Plan (USDI 1991) recommends an approximately 90-m buffer around habitat disturbances or alterations that could negatively affect CMS populations. Buffer zones are transition areas between two different habitat types that mitigate the effects of one habitat on another (Phillips et al. 2000). Appropriate size and effectiveness of buffer zones can vary according to topography, aspect of mountain slopes, elevation, vegetation types, and the sensitivity of species threatened by habitat alterations. Welsh and Droege (2001) suggested that lungless salamanders like CMS make excellent models to study ecosystem stresses because of their small size and sensitivity to environmental conditions.

In 2001 - 2002, Dr. Mark Watson (University of Charleston) and I examined the effects of three environmentally disturbed areas, a ski slope, gravel road, and clearcut, on adjacent forests with known CMS populations (Pauley and Watson 2003). The ski slope is located on Cabin Mountain (Tucker County) (elevation approximately 1280 m). The forest composition of the study site is Red Spruce interspersed with Yellow Birch. The gravel road site is on McGowan Mountain in Randolph County (elevation approximately 1110 m). The forest consists of Eastern Hemlock and mixed hardwoods with a western aspect. The clearcut is also on McGowan Mountain in Randolph County (elevation approximately 1060 m). The canopy is composed of mixed hardwood species interspersed with large Eastern Hemlocks. This site has a southwest aspect. The clearcut was approximately 10 years old at the time of our study.

At each study site, five 50-m transects were arranged parallel to the habitat disturbance. The first transect started at the edge of the road, ski slope, or clearcut and subsequent transects were arranged at 10-m intervals into the forest. Coverboard arrays were placed every 10 m along each transect to create a 50-m by 50-m grid design. Coverboard arrays consisted of 16 boards (8”x 4”x1”) positioned side-by-side in a rectangular design with about one inch space between each board to allow rainwater to flow between the boards to prevent dry spots (Pauley 1995).

Salamander and environmental data were collected once a month from May through October (2001-2002). Soil surface temperatures were measured with Reotemp© soil thermometers inserted three cm into the substrate. Air temperature and relative humidity values were recorded at soil surface with a thermohygrometer. A 10-cm by 10-cm Plexiglas© template was randomly placed by blind toss in the immediate vicinity of each coverboard array. A knife was used to cut a 10-cm x10-cm area of litter sample beneath the template. The first three cm of soil beneath the litter was removed to determine soil moisture. A dry soil surface, indicated by the moisture content in the first three cm, can limit the horizontal and vertical movements of woodland salamanders. Litter and soil samples were dehydrated in the laboratory to determine the percentage of moisture by comparing wet vs dry weights. Soil pH at each study site was measured by making a slurry of soil (10% soil and 90% distilled water) and determined with a portable pH meter.

We observed five species of woodland salamanders during this study. Of these, CMS Eastern Red-backed Salamanders, and Allegheny Mountain Dusky Salamanders were the most common and thus used as study species. Of the three salamander species, CMS decreased in number near the edge of the forest. Eastern Red-backed Salamanders varied in response to the edges of the three treatments and Allegheny Mountain Dusky Salamanders increased slightly in numbers away

from the edge (**Figure 3**). Allegheny Mountain Dusky Salamanders were close to seeps, thus microhabitat might have influenced its distribution more than the habitat disturbances.

Change in environmental factors because of these disturbances combined with interspecific competition could affect the microdistribution of salamanders. In a study of environmental requirements and interspecific interactions, I described a three-way interaction among these species that influences their microdistribution (Pauley and Clovis 1980; Pauley 2005). I determined CMS and Allegheny Mountain Dusky Salamanders require microsites with greater soil moisture compared to Eastern Red-backed Salamanders, and therefore compete for moist spots, whereas CMS and Eastern Red-backed Salamanders deposit eggs at the same time of the year, and therefore compete for nesting sites. Further, CMS and Eastern Red-backed Salamanders are similar in body size which allows them to compete for the same primary and secondary prey items.

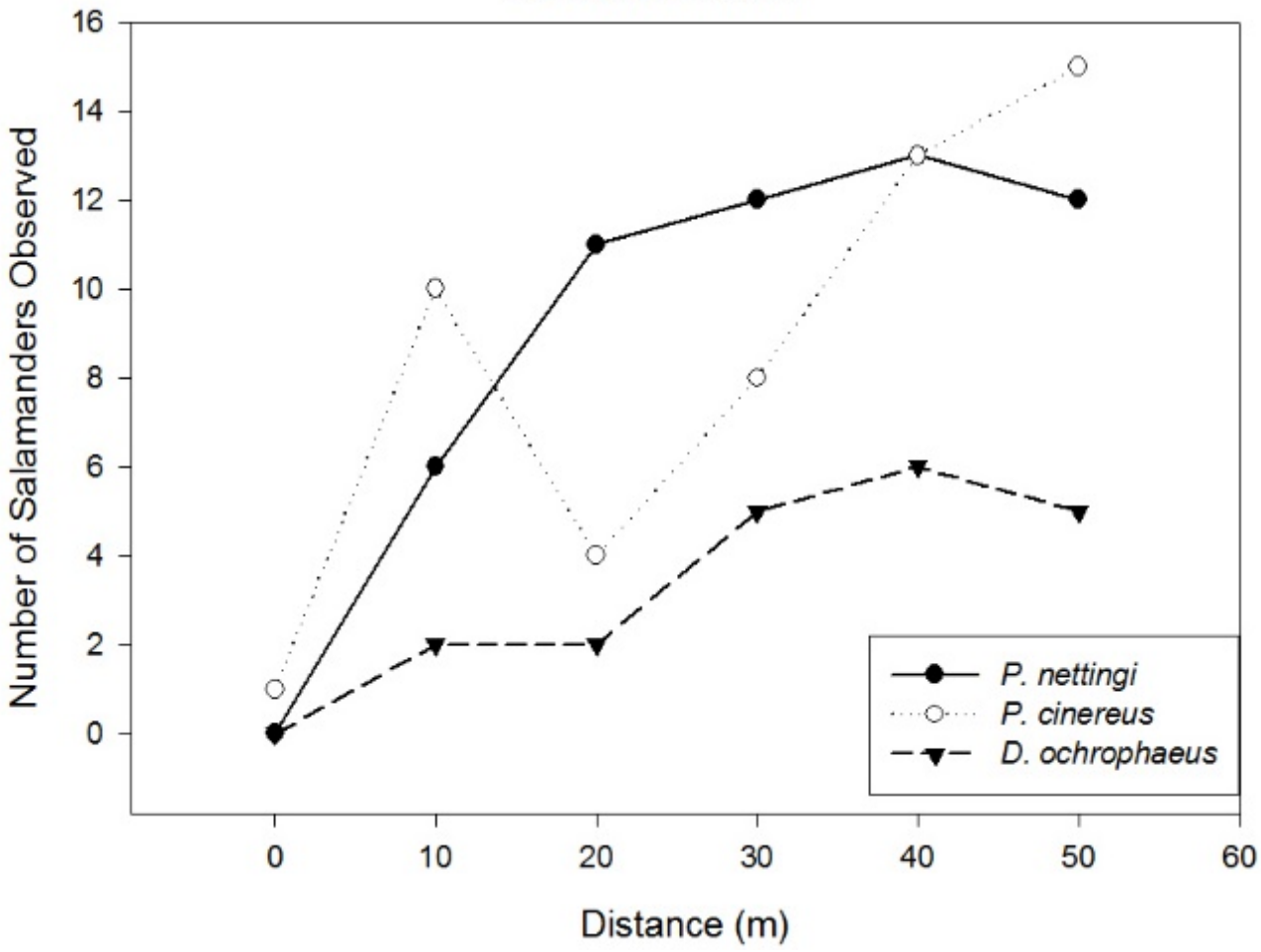

Figure 3. Distances of salamanders from the edges of disturbances at all sites.

Gradients of environmental factors from the edge into the forest could alter interspecific interactions. Terrestrial salamanders depend on litter for foraging (Ash 1995), and their surface abundance is positively correlated with the amount of litter on the forest floor (Pough et al. 1987). Because woodland salamanders are lungless and ectothermic, they depend on moist habitats for dermal respiration (Pauley 1978a; Ash 1995) and cool temperatures for optimal thermal regulation (Pauley 1978b). Loss of soil and litter moisture and high soil temperatures observed at the edges of some disturbances may contribute to the decline or loss of salamanders as demonstrated in this current study by Pauley and Watson (2003).

Different kinds of disturbances, aspect, elevation, and legacy of an area can influence both salamander abundance and richness. The number of CMS was less on the ski slope area than either the clearcut or the road site. The low numbers associated with the ski slope are probably because CMS is a montane species, and the center of populations is generally located on or near mountain tops. Numbers of CMS tend to decrease downslope in favor of Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders (Pauley and Clovis 1980). The site at the ski slope was downslope which may have been at the lower edge of the areal extent of the CMS population. The number of CMS at the ski slope site did not vary with distance from the slope when compared to the road and the clearcut. This may be due to the cooler and moister north-facing slope. Generally, north-facing slopes are not subject to direct insolation and maintain cooler temperatures and greater soil moisture compared to west, south, and east-facing slopes, respectively (Smith 1990).

Direct influence of the gravel road on salamander abundance extended 30 m into the forest and at least 50 m at the clearcut site. This may be due to the aspect and layout of the sites. The clearcut site is southwest facing and the clearcut was below the study area, such that insolation may have been more direct in this area. Lower relative humidity, higher soil temperature, and lower soil moisture suggests the clearcut site was drier than the road and the ski slope sites. The road site had more moderate environmental regimes than the clearcut. This was probably because the width of the disturbance (road) resulted in a narrow gap in the canopy whereas the clearcut caused a large break in the canopy.

Another abiotic factor that may alter salamander species composition is limestone dust from road surfaces. Soil pH was greater near the forest service road in our study than at the ski slope or clearcut sites. Limestone dust from this infrequently traveled road apparently raised soil pH of the adjacent forest. More heavily traveled roads that produce greater amounts of limestone dust may influence soil pH at greater distances. Limestone dust may influence plant communities (Brown 2009; Mortensen et al. 2009; Rauschert and Nord 2010; Nord and Mortensen 2010). Weathers et al. (2001) found edges of fragmented forests contain concentrated wind-born pollutants. It is unknown what influence wind-born pollutants may have on forest salamanders.

A potential factor that may alter salamander distributions in high mountains of West Virginia is historical land use (Pauley 2015b). Herbeck and Larsen (1998) found past timber harvests influenced salamander abundance. They observed five times more salamanders in old-growth timber stands than in second growth and 20 times more salamanders in second growth than in recently regenerated stands. Past land-use practices could influence the status of salamander habitat. Fewer salamanders occur in young or recently cut forest due to detrimental impacts on habitat. Petranka et al. (1993) stated that it might take up to 100 years before salamanders can return to stable densities in some areas. After disturbances, it is possible the original salamander assemblages will not return to their previous condition.

In this study, we found the edge effect varied according to exposure of the edge to insolation and wind, which influences temperature and moisture regimes important for the survival of lungless salamanders. Edge effect was also related to height of the canopy and width of corridor or disturbance. Based on our findings, a 30-m buffer zone appears to work where the disturbance is small, such as the one-lane gravel road where the canopy is nearly full above the road. Conversely, the large corridor of the clearcut negatively affected CMS numbers throughout the 50 m extent of our study. The original 90-m buffer recommended in the Recovery Plan appears necessary for larger disturbances such as clearcuts, housing developments, ski slopes, and rights-of-way

Translocation of CMS

In 1981 (prior to the federal listing of CMS), a mining company proposed to construct a deep coal mine portal on Shavers Mountain east of the confluence of Yokum Run and Shavers Fork. While this area was within the boundaries of the MNF, the mining company owned the mineral rights. At the request of the MNF staff, I surveyed this area for CMS and found a population where the portal was to be constructed. After discussions with the administrative staff of MNF, WVDNR, Office of Surface Mining, Sierra Club, Highlands Conservancy, and Enviro Energy, Inc., it was agreed I would attempt to relocate as many CMS as possible to a site within the known range of CMS but where they had not been observed in previous surveys.

In preparation for the relocation effort, I examined six potential sites. Based on a habitat of mostly Red Spruce with Three-lobed Bazzania and a location well within the known range of CMS, I selected a site on Cheat Mountain. I had surveyed this site in October 1980 as part of my efforts to determine the range and distribution of CMS. Prior to relocating CMS from the mine portal site, I again surveyed the relocation site for CMS during the day of June 24, 1981 and during a rainfall the night of June 25, 1981. To reduce potential competition with other species of salamanders (Eastern Red-backed, Allegheny Mountain Dusky, and Wehrle's Salamanders) at the relocation site, I moved those found during a night search to a location approximately 0.16 km southeast.

I, with the aid of employees of Enviro Energy, collected 47 CMS at the mine portal site during the days of June 23 and 25, 1981 and during the night of June 26, 1981. I released the captured salamanders at 10 separate locations in the relocation site during a rainfall on the night of June 26, 1981. I released them in groups of five at nine sites and one group of two at the tenth site. All releases were at the bases of trees where the stem flow would provide the greatest soil moisture. Snout-to-vent lengths of released CMS ranged from 20.8 - 47.5 mm (mean = 41.2 mm). Other species of salamanders observed at the mine portal site that were not moved included 39 Eastern Red-backed Salamanders, 16 Wehrle's Salamanders, 12 Northern Slimy Salamanders, 38 Allegheny Mountain Dusky Salamanders, and two Northern Spring Salamanders (*Gyrinophilus p. porphyriticus*) (Pauley 1982).

I searched for CMS on six occasions after I relocated them. The results of these surveys are as follows: 1982 – nine Eastern Red-backed Salamanders and nine Wehrle's Salamanders; 1983 – six Eastern Red-backed Salamanders and seven Wehrle's Salamanders; 1984 – two Eastern Red-backed Salamanders and one Wehrle's Salamander; 1985 – two Eastern Red-backed Salamanders and three Wehrle's Salamanders; 1994 – ten Eastern Red-backed Salamanders and three Wehrle's Salamanders; 2013 – seven Eastern Red-backed Salamanders, one Northern Slimy Salamander, and two Wehrle's Salamanders. I did not find CMS after the relocation event on June 26, 1981. Apparently, released CMS did not survive at the relocation site.

Mark Watson and I resurveyed the coalmine portal site in 2013 and did not find CMS. We did find seven Eastern Red-backed Salamanders, two Wehrle's Salamanders, and one Northern Slimy Salamander.

Barton Knob, the type locality of CMS

As stated above under "Discovery of the Cheat Mountain Salamander," Barton Knob (Randolph County) is where CMS was first discovered, and the place N.B. Green collected the holotypes used to describe the species in1938. Except for fragmented areas, the original forest here has been cut since 1900 (Brooks 1948). By the mid-to-late 1930s, Red Spruce at Barton Knob was restricted to the summit and a few feet downslope (Netting 1937; Green 1938). Green (1938) noted Eastern Hemlock, Yellow Birch and Rhododendron (*Rhododendron maximum*) replaced Red Spruce on the lower slopes and in ravines. The west, south, and north slopes of Barton Knob (below 1289 m) were strip mined prior to 1986 when MNF purchased the area from Mower Lumber, Inc.

After Graham Netting and Leonard Llewellyn reported the first CMS on Barton Knob, Maurice Brooks (1948) made repeated collecting trips during day and night at different seasons but found just a few additional specimens (he did not provide an exact number). He also searched below the spruce stand (below 1219 m) in a dense forest of mixed Eastern Hemlock and Yellow Birch without success. He concluded CMS only occurred in substantial numbers in young spruce stands above 1219 m.

I conducted daytime surveys for CMS at Barton Knob by turning over cover objects such as rocks, logs, bark, and litter in 1977, 1989, 1993, 1994, 1997, 2009, and 2015. I found CMS in all years except in 2009. Species and numbers observed each year are listed in **Table 4**.

Salamander species I found at Barton Knob are similar to historical reports by Netting (1937), Green (1938), and Brooks (1948). In 11 surveys during 40 years, I found 110 Eastern Red-backed Salamanders, 47 Wehrle's Salamanders, and 29 CMS. The most obvious difference between these historical surveys and my more recent surveys is the low numbers of Wehrle's Salamanders and CMS. While Green (1937; 1938) was studying CMS (soon after its description), he reported commonly finding Eastern Red-backed and Wehrle's Salamanders at Barton Knob. The decline of Wehrle's Salamanders over these 61 years might shed some light on the paucity of CMS found in the most recent surveys. All CMS and Wehrle's Salamanders I observed at Barton Knob were on the northeast side, the side that was not strip-mined. The absence of Wehrle's Salamanders and particularly CMS on the southern side and top of Barton Knob could be due to the drying effect of the strip mine. Ground water flows out of the exposed rocks of the strip-mined areas on the west, southwest, and south sides resulting in a xeric habitat on the upslope hillsides and ridge. The loss of groundwater via the strip mine and the south and western aspects may have rendered this area of Barton Knob too dry to support these two species. Conversely, Eastern Red-backed Salamanders can inhabit a variety of habitats making it the most common woodland salamander in northeastern forests (Burton and Likens 1975). One reason for the wide distribution and abundance of Eastern Red-backed Salamanders throughout its range is its tolerance of dry conditions (Pauley 2005).

My salamander searches on Barton Knob from 1977 to 2015 show a decline in CMS numbers and an increase in Eastern Red-backed Salamander abundance. Comparison of Eastern Red-backed Salamander and CMS abundance from 1977 – 1997 with 2009 – 2015, Eastern Red-backed Salamanders increased from 61.7 % to 92.4% whereas CMS decreased from 38.3% to 7.6%. These data indicate CMS may be declining at Barton Knob, the type locality, and it could possibly become extirpated in the near future. Systematic studies are needed to determine the status of CMS at Barton Knob.

Table 4. Salamanders observed at Barton Knob in 1977, 1989, 1993, 1994, 1997, 2009, and 2015.

Collection Date	Numbers Observed
1977 (September 18)	
Eastern Red-backed Salamander	2
Cheat Mountain Salamander	**2**
Wehrle's Salamander	1
TOTAL SALAMANDERS OBSERVED	5
1989 (June 7)	
Eastern Red-backed Salamander	11
Cheat Mountain Salamander	**16**
Wehrle's Salamander	5
Allegheny Mountain Dusky Salamander	4
Eastern Newt (Red Eft)	1
TOTAL SALAMANDERS OBSERVED	37
1993 (August 20)	
Eastern Red-backed Salamander	1
Cheat Mountain Salamander	**1**
TOTAL SALAMANDERS OBSERVED	2
1994 (June 25)	
Eastern Red-backed Salamander	21
Cheat Mountain Salamander	**1**
Wehrle's Salamander	5
Allegheny Mountain Dusky Salamander	13
Eastern Newt (Red Eft)	1
TOTAL SALAMANDERS OBSERVED	40
1997 (September 18)	
Eastern Red-backed Salamander	2
Cheat Mountain Salamander	**3**
Wehrle's Salamander	1
TOTAL SALAMANDERS OBSERVED	6
2009 (June 17 and September 11)	
Eastern Red-backed Salamander	55
Northern Slimy Salamander	2
Cheat Mountain Salamander	**0**
Wehrle's Salamander	6
Allegheny Mountain Dusky Salamander	4
Spotted Salamander	3
Eastern Newt (Red Eft)	2
TOTAL SALAMANDERS OBSERVED	72
2010 (May 30)	
Eastern Red-backed Salamander	9
Cheat Mountain Salamander	**5**
Wehrle's Salamander	17
Allegheny Mountain Dusky Salamander	2
Spotted Salamander	3
TOTAL SALAMANDERS OBSERVED	36
2015 (July 31, August 3, and August 5)	
Eastern Red-backed Salamander	9
Cheat Mountain Salamander	**1**
Wehrle's Salamander	12
Allegheny Mountain Dusky Salamander	12
TOTAL SALAMANDERS OBSERVED	34

In addition to being the type locality of the CMS and one of the 81 known disjunct populations, Barton Knob is important to the species for other reasons. It is one of the most western CMS populations known. The closest CMS population to Barton Knob is near Cheat Bridge. Shavers Fork and strip mines separate this population and the Barton Knob population thus isolating the Barton Knob population. The distance between these two populations and the barriers that Shavers Fork and the strip mines present assures the Barton Knob population will be a separate gene pool for many generations.

Effects of hiking trails and gated roads on the movement of CMS

In the early years of my work with CMS, I was surprised to find many of the known CMS populations contained many old railroad grades and haul roads as well as currently used hiking trails. As I continued to search the high Alleghenies, I learned many CMS populations have been disturbed by hiking trails, recreation areas, ski slopes, gravel roads, haul roads, strip mines, deep mines, and other types of human activities (Pauley 1987b; 2005). Some hiking trails followed defunct railroad grades, and it appeared they could fragment some CMS populations. It is not known if creosote or other chemicals used to preserve railroad ties affected the occurrence of CMS. Future studies should consider an analysis of soil samples.

I observed that use of some hiking trails was so intense, that there was very little leaf cover on these trails. In 1991, I started a two-year study to determine if hiking trails could potentially fragment and prevent movement among CMS populations. I examined one trail with heavy foot traffic and few leaves on the tread, one trail with moderate foot travel and a thin layer of leaves, and one trail with light foot travel and a relatively thick leaf cover.

I took random samples of leaf litter from each trail in a 10 cm x 10 cm square and dried them in the laboratory to compare the dry weights of leaves on each trail. The heavily traveled trail had significantly less leaf litter during the summer months than did the moderately or lightly traveled trails. For salamander data, I measured snout-to-vent length, recorded the sex, and toe-clipped each individual for future recognition The most common species observed were the CMS (n=167), Wehrle's Salamander (n=82), and Eastern Red-backed Salamander (n=24).

I did not observe CMS or Eastern Red-backed Salamanders on the heavily traveled trail, nor did I find either species to cross the trail. I did not observe Wehrle's Salamander on the heavily traveled trail but found four individuals on the opposite side of the trail from where they were originally captured demonstrating they crossed the trail. I did not find any of these species on the moderately traveled trail or evidence they crossed the trail. I found all three species on the lightly traveled trail (Pauley 2005).

Dr. Jayme Waldron, Marshall University graduate students, and I conducted a two-year study (2008-2009) on the effects of trails and gated roads on the movement of CMS. We found that relatively low soil temperature, low precipitation and relative humidity, and reduced litter depth, duff depth, and moss cover were major factors that affected movement, survival, and abundance of CMS (Waldron and Pauley 2012). These results supported the preliminary data presented above (Pauley 2005), that heavily traveled trails can impede the movement of CMS, at least during the summer months.

I collected data on trails during the summer and early autumn months before leaf fall. Through the years of searching for woodland salamanders during and after autumn leaf fall, I have observed many beneath newly fallen leaf cover. While this is anecdotal information, I have seen this phenomenon frequently and suspect woodland salamanders move under leaves and possibly do so during the day when I found them to be very active. Thus, salamanders may cross heavily traveled trails during heavy leaf cover in the autumn.

While trails, roads, rights-of-way, and ski slopes may prevent salamanders from crossing the surface, they may move beneath the surface. I observed woodland salamanders underground in a wide-open corridor during the spring months but not in the summer months after soil temperatures increase. This suggests while woodland salamanders may not traverse the surface of hiking trails, ski slopes, rights-of-way, etc., they might move underground and thus cross these barriers. More research is necessary to confirm the validity of this important phenomenon.

Evaluation of historical populations

A major concern of the future existence of CMS is the stability of known populations. To shed some light on this, I examined the vertical or elevational distribution status at four historical sites in 2007. In addition, I surveyed for the presence of CMS at 15 historical sites in 2008 and 24 sites in 2013.

Vertical range

During my initial study of CMS from 1976 to 1980, I ascertained that Eastern Red-backed, Northern Slimy, Wehrle's, and Allegheny Mountain Dusky Salamanders were the major species associated with CMS. Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders were the most abundant within the total range as well as within the elevational or vertical range (914 to 1463 m) of CMS (Pauley and Clovis 1980). As part of this initial five-year study, I examined the vertical range of CMS at four sites, Spruce Knob, Stuart Knob, Gaudineer Knob, and Dolly Sods in 1978-1979. In a study for the USFWS in 2007, I repeated the vertical range study (Pauley 2007b). Here I compare data collected during these two study dates in an effort to determine changes in the vertical range of CMS and its two main competitors. I also report changes of soil temperature, soil moisture, and relative humidity along a vertical gradient at each site.

At each of the four sites, I established 10-m x 20-m study quadrats at 12.2 m intervals that extended from the highest elevation point where CMS occurred to 24.4 m, or two quadrats, below the point where I last observed CMS. Forty-foot (12.2 m) intervals were selected because (1) elevation contour lines are in 40-ft. intervals on topographic maps of these sites, which provides an easy means of locating each transect, and (2) I concluded 12.2-m intervals were distant enough to determine any change in vegetation, microclimate, or salamander community composition. After determining the highest point where CMS occurred at each site, I established locations of quadrats by walking downslope 12.2 m in elevation as determined by a hand-held altimeter.

The number of quadrats at each site depended on the length of the vertical range of CMS. Spruce Knob had the greatest vertical range with 13 quadrats followed by eight at Stuart Knob, eight at Dolly Sods, and seven at Gaudineer Knob. I examined each quadrat carefully for salamanders on two different occasions when soil and litter were damp.

I searched for salamanders during the day by turning over rocks and logs in each quadrat. I recorded soil temperature and relative humidity in each quadrat with Reotemp© thermometers and portable hygrometers. I determined soil moisture by collecting soil samples and drying them in the laboratory to provide percent moisture of each soil sample.

Data collected at the four study sites from 1978-79 and in 2007 showed CMS, Eastern Red-backed Salamanders, and Allegheny Mountain Dusky Salamanders have predictable vertical ranges. CMS was the dominant species at or at near the summits of each study site, Eastern Red-backed Salamanders were in sympatry with CMS from the highest elevation to near the middle of the CMS vertical range, and Allegheny Mountain Dusky Salamanders were the dominant species below the CMS range. The greatest variation of this pattern was at Spruce Knob where Allegheny Mountain Dusky Salamanders were in sympatry with CMS throughout the vertical range, and Eastern Red-backed Salamanders occurred in the lower half of the vertical range.

With exception of Stuart Knob, vertical ranges of the three study species showed variations between the two study dates (1978-79 and 2007). Vertical range of CMS at Spruce Knob and Gaudineer Knob remained the same, but the vertical range of Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders showed some changes. Both of these species may be expanding their vertical ranges at these sites and, as major competitors of CMS, this could be to the detriment of CMS. Only additional research and time can determine this.

The vertical range of CMS at Dolly Sods was 12.2 m less in 2007 than in 1978-79. I state this with caution because it is possible that I missed finding CMS at the lower elevation in 2007. If the vertical range of CMS has decreased at Dolly Sods, and if the vertical ranges of Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders have increased at Spruce Knob, Dolly Sods, and Gaudineer Knob, then there might be some subtle but significant changes in the status of CMS at these sites.

This possible shift in salamander distributions might intensify the competitive stress on CMS from Eastern Red-backed and Allegheny Mountain Dusky

Salamanders. If additional research at Dolly Sods confirms the vertical range of CMS is declining while the vertical ranges of Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders are expanding, then CMS may be in jeopardy there.

In 1978-79, the mean soil temperature in all CMS quadrats was 14.7° C and in the non-CMS areas 14.8° C. In 2007, the mean soil temperature was 17.3° C at both CMS and non-CMS areas. While it appears soil temperature is not a limiting factor in the vertical distribution of CMS (Pauley and Clovis 1980), this possible increase in temperature since 1978-79 may be indicative of a warming trend in the higher elevations that could result in a less than optimal temperature regime for CMS. However, soil temperature data were collected on August 3, 4, and 14 at all sites in 2007 and in 1978-79 on July 31 and September 8 at Gaudineer Knob, September 8 and October 3 at Spruce Knob, July 25 and October 20 at Stuart Knob, and July 21 and October 20 at Dolly Sods. Lower temperatures in 1978-79 may be attributed to data being collected at different dates than in 2007. The exceptionally hot and dry season in 2007 may also be a contributing factor to the disparity of soil temperatures between the two data collection periods.

Daytime temperatures and the dew point decease with an increase in elevation resulting in greater relative humidity (Smith 1990) within the CMS vertical range than below it. I found this to be the case in 1978-79 at Stuart Knob and Dolly Sods but not at Gaudineer Knob and Spruce Knob. This trend, for the most part, was not the case in 2007. In addition to relative humidity being lower at all sites in 2007 than in 1978-79, relative humidity at Stuart Knob, Gaudineer Knob, and Dolly Sods was higher at lower elevations. Whether these data suggest higher elevations are drier is yet to be determined. If soil temperature and relative humidity are indicative of a warmer and drier climate for the high elevations, conditions may be less favorable for CMS compared to Eastern Red-backed and Allegheny Mountain Dusky Salamanders, which have much larger total ranges that include areas with warmer temperatures, and drier conditions in the case of Eastern Red-backed Salamanders. As with soil temperature data, I collected relative humidity data during the hot, dry summer of 2007, and this might be the reason for the disparity in the relative humidity percentages between the two collection periods.

The most salient aspect of the soil moisture data is the disparity between the percent of soil moisture found in 1978-79 and 2007. As stated above, 2007 was a hot, dry summer and this might have contributed to the higher soil temperatures and lower relative humidities. These hot, dry conditions in 2007 were not reflected in the soil moisture, which was considerably higher at all populations in 2007 than in 1978-79. Soil moisture was determined in both study periods by calculating the percent of moisture after samples were dried (moist soil weight-dry soil weight/moist soil weight). Regardless of the possible discrepancy of the percent of soil moisture between the two collection dates, there remains a similar trend between CMS and non-CMS quadrats. Soil moisture was nearly the same in CMS quadrats and non-CMS quadrats for both collecting periods at all sites except non-CMS quadrats at Stuart Knob. The non-CMS sites at Stuart Knob are located in an area with several seeps and at the head of a small stream. Such moist conditions most likely altered the soil moisture and relative humidity in these quadrats.

Anecdotally, it appeared fern was more abundant at Dolly Sods in 2007 than in 1978-79. If the vegetation of the forest floor has changed during these 28 years, this could be an indication of a change in climatic conditions which could affect salamander distributions. Another indication plant communities might be changing in the higher elevations is the presence of Poison Ivy (*Toxicodendron radicans*) at Gaudineer Knob. This (2007) is the first time in 30 years I have found this plant in the Red Spruce forest in West Virginia. More research will be necessary to determine if vegetation patterns have changed at Gaudineer Knob as well as the other study sites. Calise (1978), Clovis (1979), and Pauley and Clovis (1980) conducted vegetation analyses of these four study sites, and their work could serve as baseline data to determine changes in plant composition. Changes in plant communities could be an indicator of impending changes in the salamander communities.

To help clarify the status of these four populations, Whitney Kroschel, one of my former graduate students, compared the status of CMS in 2011 with data I collected at these four sites in 1978-79 (Kroschel 2012; Kroschel et al. 2014). Her data suggested CMS populations have declined and Eastern Red-backed Salamanders have possibly expanded their vertical distribution negatively

affecting mid- and high-elevation populations of CMS. She concluded that it appears CMS are declining due to environmental changes and colonization of Eastern Red-backed Salamanders in sites previously occupied by CMS.

Re-surveys of historical sites (1978 – 2008)

In 2008, I continued my quest to examine possible changes in salamander species composition in known CMS populations. I re-surveyed 15 historical sites, three at Dolly Sods and 12 on Back Allegheny Mountain including Bald Knob.

Dolly Sods (Tucker County)

I first found CMS in the Rohrbaugh Plains area of Dolly Sods in 1978. In 2008, I located the population again in two small Red Spruce stands. These may be two small separate populations because I could not find a connection between them. In addition to CMS, I found Eastern Red-backed, Northern Slimy, Wehrle's, and Allegheny Mountain Dusky Salamanders. I located a population on the lip of the Allegheny Front and at the eastern edge of the CMS range in 1989 and 1990 and again in 2008. There are many areas at Dolly Sods where I did not find CMS after numerous attempts. One such area is Blackbird Knob. I first surveyed the area in 1978. Thirty years later, in 2008, a graduate student and I spent two days searching this area without success. In 1978, I did not find any salamanders; in 2008, we found just one subadult Eastern Red-backed Salamander. This area of Dolly Sods experienced wildfires in the past (Turner 2001). Fires may have destroyed the original habitat along with salamanders that may have been present. Blackbird Knob today is a deciduous forest with an open floor, a habitat not conducive for CMS.

Back Allegheny Mountain (Randolph County)

In 1989, I found CMS at two high points on a ridge of Back Allegheny Mountain that runs between Fish Hatchery Run and Watertank Hollow at the northern end and Watertank Hollow and Greathouse Hollow at the southern end. I searched for salamanders between the two high points but did not locate CMS. It appears even though both the northern and southern populations are on the same ridge they are disjunct. In the 1980s, the northern site had been clearcut which allowed easy access for surveys. In 2008, a thick stand of Red Spruce prevented surveys. While I did not find CMS there in 2008, I returned to the northern site in 2013 and found one CMS. In future years, when Red Spruce have thinned out, surveys at the northern end of the ridge could reveal more CMS.

In 1985, I found CMS associated with emergent rocks on a ridge northeast of the two sites mention above. The area had also recently been clearcut. I surveyed this area again in 1997, 2004, and 2008 and located CMS there as well as downslope to 1204 m.

Locations where I found CMS on Back Allegheny Mountain from the Randolph/Pocahontas County line to Odey Run were marked with accuracy as much as possible in 1980. Since 1980, timbering and mining activities have compromised habitat throughout the area. Nevertheless, I was able to locate four small, disjunct CMS sites within this area in 2008 and two additional small sites in 2015. Now that this area is within the MNF, the CMS habitat and locations are protected allowing CMS populations to survive and perhaps overtime expand in size. However, because mining activities heavily affected some locations within this area it may take generations before the land returns to optimal CMS habitat.

One CMS location of particular interest in this area is located east of the headwaters of Odey Run (Pocahontas County). In the 1970s and 1980s, I believe I found CMS at a high point between the headwaters of Odey Run and Roaring Springs. In 2008, I did not find them at the high point, but rather found them downslope. Red Spruce growth was too thick for me to survey the summit, but CMS could certainly be there. I hope future researchers will check this site again when the Red Spruce stand matures and thins out enough to allow surveys

Maurice Brooks found CMS at Bald Knob (Pocahontas County) in 1940. I searched the summit without success in 1979 and 1989. Clarkson (1990) reported clearcuts on Bald Knob in 1950 and 1958, an event that might have eliminated the species on the summit. Today the knob has a thick growth of Red Spruce trees which makes conducting surveys difficult. Nevertheless, Mark Watson and I searched this area for the third time in 2008. After hours of searching, we located one CMS east and downslope of the knob. As far as I know, this is the first CMS found at Bald Knob since the 1950s. From what I can ascertain from my attempts to find CMS on the summit, they were absent there between 1979 and

2008. However, with the thick Red Spruce stand on the summit, they could certainly return in the future. When I visited the summit in 1980, the Red Spruce were approximately one to two feet in height. In 2008, the trees had grown to 20 or more feet in height. I hope future researchers will search for CMS at this site. If researchers find CMS on the summit, it could be evidence they can reestablish in Red Spruce restoration projects in other areas of the MNF.

Re-surveys of historical sites (1978 – 2013)

In the spring, summer, and fall of 2013, I surveyed 24 sites where I found CMS 12 to 35 years previously. The objective of this study was to compare presence/absence of CMS in 2013 at sites I visited initially between 1978 and 2001. Mark Watson joined me in this effort. We used the same survey methods in 2013 I used to survey these sites initially. We searched for salamanders beneath rocks, logs, and litter during daylight for one-person hour. Because GPS technology was not available during my early years in the field, I used a compass and altimeter to record locations of CMS sites. For this reason, it was not always possible to determine exact locations where I conducted the initial surveys. Nevertheless, I believe we were close to, if not at, the same sites of my initial surveys.

The 24 sites listed below are in order since the original survey, i.e., the oldest or first sites surveyed are described first and the most recent sites discovered described last. I surveyed some sites between the initial date (1978) and 2013. In these cases, the salamander data for those intermittent dates are included.

Mozark Mountain (Tucker County)

I surveyed the Mozark Mountain site on August 3, 1978 and found one CMS and eight Allegheny Mountain Dusky Salamanders. The habitat had not changed over the 24 years between the visits. The forest consisted of a mix of deciduous species in the canopy and understory and there were several large emergent rocks. Mark Watson and I searched extensively in 2002 around several emergent rocks in the same area I surveyed in 1978. We observed four Eastern Red-backed Salamanders and one Allegheny Mountain Dusky Salamander. Given the xeric habitat of this site, it is not surprising I found only one CMS in 1978 and none in 2002. The surveys in 1978 and 2002 were at the summit of Mozark Mountain (elevation 1171 m). In 2002, we made additional searches from the summit downslope to about 1128 m on the east and west sides of the mountain. We found five Eastern Red-backed Salamanders, two Northern Slimy Salamanders, and two Allegheny Mountain Dusky Salamanders on the east side and one Allegheny Mountain Dusky Salamander on the west side. The habitat on the eastern side of the mountain was dry but consisted of a Red Spruce canopy with an understory of Rhododendron and Mountain Laurel (*Kalmia latifolia*). There were areas of Pincushion Moss (*Leucobryum glaucum*) with scattered patches of Three-lobed Bazzania on the forest floor. The forest floor was approximately 80-90% open with buried rocks and had about 5-10% course woody debris. Except for the arid conditions on the eastern side of the mountain, this area was more typical CMS habitat than the west side. We attempted to visit the site again in 2013 but the number of downed trees after Super Storm Sandy inhibited access to the site.

Allegheny Front (Randolph County)

The habitat at this site changed little during the 35 years between visits. I first visited Red Creek Plains on August 1, 1978 when I observed five CMS, two Eastern Red-backed Salamanders, and one Northern Slimy Salamander. On July 30, 2013, we found just two Eastern Red-backed Salamanders. We observed areas with typical CMS habitat in 1978 and 2013. I did not record ground cover in 1978, but mosses and lichens dominated the forest floor in 2013, a cover not conducive to CMS. Nevertheless, I would not conclude CMS are not present.

Little Middle Mountain (Randolph County)

In 1979, I found four CMS and one Allegheny Mountain Dusky Salamander on Little Middle Mountain. Because of cold temperatures in early October in 2013, salamanders were not on the surface; we did not find any species. However, the habitat appeared to be the same as observed 34 years prior rendering a good possibility CMS are still present. Plant species remained the same with a Red Spruce and Yellow Birch canopy and scattered Three-lobed Bazzania on the forest floor.

McGowan Mountain south of Turkey Run (Tucker County)

In 1979, CMS were in a forest of small Red Spruce and Yellow Birch. In 2013, we found them in an Eastern Hemlock, Yellow Birch, Red Maple (*Acer rubrum*), and a few Red Spruce. Many of the trees were large and there were areas with thick Rhododendron. The difference in the tree species, particularly Red Spruce in 1979 and Eastern Hemlock in 2013 raises a question about the locations surveyed. Were we in the same location in 2013 as we were in 1979? Some of the Eastern Hemlock and Red Spruce were large, so we were most likely not at the exact location but certainly in the same general area. Regardless of the exact location during these two sampling dates, the CMS population in this area appears to be stable and healthy. For example, I found five CMS along with six Eastern Red-backed Salamanders, two Northern Slimy Salamanders, and one Allegheny Mountain Dusky Salamander in 1979. In 2013, we located six CMS and one Allegheny Mountain Dusky Salamander.

Allegheny Front, Flat Rock Plains and Red Creek Plains (Randolph County)

Apparently, during these 34 years (1979-2013) numerous Red Spruce trees have grown in open areas at this site producing an extremely thick growth. The spruce trees were so thick it was impossible to conduct a salamander survey in 2013. Three-lobed Bazzania was scattered on the forest floor in 1979 and 2013. In 1979, two CMS were the only salamanders I observed. In 2013, we did not observe any salamanders. This was partly due to the thick Red Spruce growth.

Back Allegheny Mountain east of Oats Run (Pocahontas County)

There appeared to be no change in the habitat at this site, which consisted of Red Spruce and Yellow Birch canopy with Three-lobed Bazzania and mosses on the forest floor. I found four CMS in 1979 and no Eastern Red-backed Salamanders. In 2013, we observed two CMS and six Eastern Red-backed Salamanders.

Shavers Mountain east of Shavers Fork (Randolph County)

In 1981, before the CMS was federally listed, I was asked by Enviro Energy (on behalf of Mower Lumber Co.) to move a population of CMS in order to allow the construction of a deep mine. With approval of the U.S. Forest Service, I moved 47 CMS to a site on Cheat Mountain (for details, see the section above on the Translocation of CMS). The purpose of the survey in 2013 was to search for remnants of this original population. We did not find CMS at this site in 2013.

In 1981, the site where the mine portal was to be constructed, American Beech (*Fagus grandifolia*) and Yellow Birch were the dominant canopy species and Red Spruce comprised the understory. Spinulose Shield Fern (*Dryopteris carthusiana*) and Three-lobed Bazzania were on the forest floor. In 2013, the forest was composed of Red Spruce and Yellow Birch with Three-lobed Bazzania and mosses on the forest floor.

Gaudineer Knob area (Randolph County)

We examined three sites north and northwest of Gaudineer Knob on Shavers Mountain that I surveyed in 1980, 1981, and 1983. These sites are about 0.5 km apart. The first site was on a high point where I observed one CMS, two Eastern Red-backed Salamanders, and two Allegheny Mountain Dusky Salamanders in 1980. In 2013, we only found Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders. The vegetation was about the same except there appeared to be larger Red Spruce in 2013 than in 1980, possibly the result of 33 years of tree growth.

In 1981, I located one juvenile CMS at a site near Shavers Fork. In 1981 and 2013, the forest canopy was composed of Red Spruce and Yellow Birch. Conversely, vegetation on the forest floor changed from Spinulose Shield Fern and White Wood Sorrel (*Oxalis montana*) to Three-lobed Bazzania and mosses on ground rocks. The area was dry with several large emergent rocks. Although the habitat appears to be somewhat typical for CMS, only finding one small specimen in 1981 and no salamanders in 2013 reflects a site that may no longer support CMS.

The third site was between the first two described above. I found one CMS in 1983 but not

in 2013. Eastern Red-backed Salamanders were prevalent in 1983 and Allegheny Mountain Dusky Salamanders dominated in 2013. Vegetation observed in 2013 was different from what I observed in 1983. In 1983, the forest canopy and understory were Red Spruce and Yellow Birch, and the forest floor was mostly Spinulose Shield Fern. In 2013, the canopy was mainly Yellow Birch, Black Cherry (*Prunus serotina*), and Red Maple and the understory Red Spruce and American Beech. The dominant herbaceous growth remained the same, Spinulose Shield Fern.

In 2013, we found a population of CMS approximately halfway between the CMS site at the high elevation and the site I found downslope (the second site north of Gaudineer Knob described above). I believe two scenarios might explain the lack of CMS at the two original sites. I might have been at the two edges of this current known population in 1980 and 1983 or this current population may have extended the distance between the original sites and changes in the habitat have reduced it to a small area between them. The habitat where we found the CMS in 2013 consisted of a Red Spruce canopy with Three-lobed Bazzania on the floor, which is classic CMS habitat.

Cheat Mountain south of Stalnaker Run (Randolph County)

I found CMS at this site in 1983 and in 1996. Vegetation composition was about the same in 1983 and 1996, but not in 2013. Along with Red Spruce, I recorded Eastern Hemlock in the canopy in 1983 and 1996. In 2013, we observed Yellow Birch in the canopy rather than Eastern Hemlock. We also found scattered Three-lobed Bazzania in 2013 instead of Hay-scented Fern (*Dennstaedtia punctilobula*) recorded in 1983. I did not record Three-lobed Bazzania in 1993 and 1996. Further, we did not find CMS in areas with Eastern Hemlock and Red Spruce in 2013 as I did in 1983 and 1996. In 2013, we found the area with Red Spruce and Eastern Hemlock as I described in 1983 and 1996, but we did not find CMS there. We found them only in a Red Spruce forest. Salamander species numbers ranged from one CMS in 1983 to five CMS, 24 Eastern Red-backed Salamanders, two Northern Slimy Salamanders, two Wehrle's Salamanders, and five Allegheny Mountain Dusky Salamanders in 1996 to two CMS, 10 Eastern Red-backed Salamanders, four Wehrle's Salamanders, and one Allegheny Mountain Dusky Salamander in 2013.

Shavers Mountain north of Stuart Knob (Randolph County)

In 1985, I recorded 11 CMS, one Northern Slimy Salamander, two Wehrle's Salamanders, and seven Allegheny Mountain Dusky Salamanders. In 2013, we found two CMS, seven Eastern Red-backed Salamanders, three Wehrle's Salamanders, and seven Allegheny Mountain Dusky Salamanders. The greater number of Eastern Red-backed Salamanders observed in 2013 could indicate a population shift between Eastern Red-backed Salamanders and CMS. While we found fewer CMS in 2013 compared to 1985, there were many downed trees from the aftermath of Super Storm Sandy, which impeded the survey. Forest plant species did not vary between survey dates. Red Spruce, Yellow Birch and Three-lobed Bazzania remained the dominant plant species.

Canaan Mountain north of Pointy Knob (Tucker County)

The only salamander I recorded at this site in 1985 was one CMS at a high point. In 2013, we found five CMS and one Eastern Red-backed Salamander downslope and north of the high point. Without GPS technology in 1985, we might not have been in the precise place in 2013 where I was in 1985, but we were in the same vicinity. Plant species remained the same, Red Spruce, Eastern Hemlock, and scattered mosses.

Spruce Mountain (Pendleton County)

In both survey years, the forest canopy of Red Spruce and forest floor of Three-lobed Bazzania remained but the understory varied with Red Spruce and Rhododendron in 1985 and Mountain Holly (*Ilex montana*) in 2013. I recorded five CMS and 14 Eastern Red-backed Salamanders in 1985 and 10 CMS and three Eastern Red-backed Salamanders in 2013. The lower number of Eastern Red-backed Salamanders and greater number of CMS in 2013 relative to 1985 may be a result of staggered vertical movements of salamanders, i.e., not all salamanders in an area are at the surface at the same time.

Backbone Mountain (Tucker County)

I searched for CMS along a trail in 1985, 1986, 1995, and 2013. The habitat at this site changed through the years. In 2013, Rhododendron and Mountain Laurel almost obliterated the trail and the areas where I found CMS in 1985, 1986, and 1995. We were unable to find CMS in 2013, but they are most likely in the area. The area is extremely rugged with rock cliffs and steep hillsides that extend down to Blackwater River. Such rugged terrain makes searches for salamanders difficult. It is interesting we found just three salamanders in 2013 compared to 27 in 1985, six in 1986, and 38 in 1995. Of the 27 in 1985, four were CMS, two Eastern Red-backed Salamanders, eight Northern Slimy Salamanders, and 13 Wehrle's Salamanders. Of the six in 1986, two were CMS, two Eastern Red-backed Salamanders, and two Wehrle's Salamanders. In 1995, four were CMS, 24 Eastern Red-backed Salamanders, seven Northern Slimy Salamanders, and three Wehrle's Salamanders. We found just three Eastern Red-backed Salamanders in 2013.

Shavers Mountain east of Harpers Run (Randolph County)

The results of the 2013 survey are similar to what I observed in 1985 in one of two sites in this area. The first population is located at a high point and appears to be stable. I recorded three CMS in 1985 and two Eastern Red-backed Salamanders, one Northern Slimy Salamander, four Wehrle's Salamanders, and two Allegheny Mountain Dusky Salamanders. In 2013, we located two CMS and one Northern Slimy Salamander.

The second population is located south and downslope of the high point. The forest habitat here appears to have changed over the 28 years between the two surveys. I observed small Red Maple trees in the herbaceous layer in 1985 that apparently became part of the canopy in 2013. I found Red Spruce trees in the canopy in 1985, but not in 2013. Without GPS data in 1985, the mapped location might not have been accurate, and we may have not been in the same site in 2013, but certainly in the same vicinity. We found considerably fewer CMS in 2013 compared to 1985. The weather conditions were ideal for salamander surveys in 2013 so the difference in CMS observations between the two survey dates could be a result of not being in the exact location. Nevertheless, finding one CMS in 2013 does provide some confidence a population of CMS still exists in this area. In 1985, I recorded 13 CMS, one Northern Slimy Salamander, and three Wehrle's Salamanders compared to one CMS, three Eastern Red-backed Salamanders, and three Northern Slimy Salamanders in 2013. I could not find a connection between these two populations in 1985 or 2013.

Shavers Mountain, Stuart Knob (Randolph County)

Forest here consists of a mix of deciduous tree species with scattered Red Spruce in the understory and Hay-scented Fern and mosses on the forest floor, not an optimal habitat for CMS. Based on numbers found during surveys over the last 28 years, CMS may be declining in this marginal habitat. Only additional surveys will confirm the status of this population. In 1985, I observed seven CMS, nine Eastern Red-backed Salamanders, one Northern Slimy Salamander, one Wehrle's Salamander, and 13 Allegheny Mountain Dusky Salamanders. In 1990, I recorded two CMS, three Eastern Red-backed Salamanders, and one Allegheny Mountain Dusky Salamander, and in 2013, one CMS, three Eastern Red-backed Salamanders, one Northern Slimy Salamander, two Wehrle's Salamanders, and three Allegheny Mountain Dusky Salamanders.

Red Creek Plains at the Allegheny Front (Randolph County)

While there are some differences in the tree species recorded between the two surveys, the species of salamanders appear to have remained about the same. The canopy in 1988 consisted of Red Spruce and Yellow Birch and in 2013, the canopy consisted of Mountain Holly. Likewise, the understory varied from Rhododendron in 1988 to Red Spruce in 2013. Mosses were on the forest floor in 1988 and 2013. One CMS and one Eastern Red-backed Salamander were observed in 1988 and one CMS, four Eastern Red-backed Salamanders, and two Northern Slimy Salamanders in 2013. Again, without GPS technology during the initial survey, we may have been in the same vicinity but not the exact site

Back Allegheny Mountain south of Fish Hatchery Run (Randolph County)

When I surveyed this area in 1989, it had been recently clearcut. I found one CMS on the ridge in the clearcut area. In 2008, I searched what I believed to be the same area where I found the single specimen in 1989, but only found one Wehrle's Salamander and one Allegheny Mountain Dusky Salamander. We searched the area again in 2013 but only found one Eastern Red-backed Salamander. However, when we surveyed downslope (north), we found a single CMS at an elevation of approximately 1347 m. This appears to be a fragile population. Plant life remained the same with a canopy and understory of Red Spruce and Three-lobed Bazzania on the forest floor.

Shavers Mountain, summit of Stuart Knob (Randolph County)

In 1990, I recorded five CMS, one Northern Slimy Salamander, one Wehrle's Salamander, and eight Allegheny Mountain Dusky Salamanders. We did not find CMS at this site in 2013 but did find five Eastern Red-backed Salamanders and three Northern Slimy Salamanders. The habitat is dry and there are several large rocks where CMS could take refuge. I recommend that this site be searched again during or shortly after a rain event. The forest trees were Yellow Birch, Black Cherry, and scattered Red Spruce with mosses on the forest floor in 1990. I found similar species in 2013 but with the addition of Red Maple and Hay-scented Fern.

Canaan Mountain (Tucker County)

This study was conducted along a trail at Blackwater Falls State Park. Because of its location and easy access, it is one of the most walked trails in the eastern United States. The WVDNR held a Nongame Weekend for the public at the park from 1984 to 2004. Several hundred people attended each year. Except for the first couple of years, activities included a night salamander walk on this trail for participants of the nongame weekend. I also used this trail between 1991 and 1993 as part of a study to determine potential effects of trails on salamander movements. I noticed a decline in the occurrences of CMS toward the end of my trail study and by the 2002 nongame weekend. After 2002, I walked the trail one night each in 2011, 2013, 2014, 2017, and 2018. In 2011, I observed one CMS, two in 2013, one in 2014, and none in 2017 and 2018. There is an obvious decline in this species along this trail that may be the result of human traffic.

Spruce Mountain radio tower area (Pendleton County)

In 1991, I recorded two CMS and two Eastern Red-backed Salamanders at this site. We returned in 2013 and only located five Eastern Red-backed Salamanders. While this site has tree species (Red Spruce and Yellow Birch) typically associated with CMS, it is a dry habitat, which could reduce the occurrence of CMS. I noted scattered Three-lobed Bazzania in 1991 but not in 2013. Because we did not find CMS during the summer of 2013, when ample rainfall had occurred, the species may no longer be present at this site.

McGowan Mountain west of Forest Service Road 324 (Randolph County)

I found eight Cheat Mountain Salamanders in 1993, and we found five in 2013 at this location. In addition, I recorded two Eastern Red-backed Salamanders, two Wehrle's Salamanders, and six Allegheny Mountain Dusky Salamanders in 1993, and we found six Allegheny Mountain Dusky Salamanders in 2013. Even though this is a fragment (isolated by a gravel road) of a larger CMS population on McGowan Mountain, it appears to be healthy. It is in a precarious location because there is a gated road below this population, thus isolating it between two roads. In addition, it is at the lower limits of the CMS elevational range at McGowan Mountain. The habitat remained the same, Red Spruce, Yellow Birch with scattered Three-lobed Bazzania.

Canaan Mountain, Gentle Falls area of Blackwater Falls State Park (Tucker County)

I found just one CMS here in 1991 and none in 2013. Other species of salamanders observed included six Eastern Red-backed Salamanders (one in 1994 and five in 2013), two Wehrle's Salamanders, and one Allegheny Mountain Dusky Salamander (both species found in 2013). The plant composition remained the same, Eastern Hemlock and Yellow Birch canopy with an understory of Rhododendron. Because of the Rhododendron, the

forest floor had few herbaceous plants. CMS may no longer be present at this site.

Canaan Mountain, southern slope (Tucker County)

I surveyed along a trail three times from 1994 to 2013. In 1994, I recorded one CMS and two Eastern Red-backed Salamanders. In 1999, I reported nine CMS, five Eastern Red-backed Salamanders, 13 Northern Slimy Salamanders, and two Allegheny Mountain Dusky Salamanders. In 2013, we found nine CMS, one Eastern Red-backed Salamander, and two Allegheny Mountain Dusky Salamanders. This population of CMS appears to be healthy. The number of salamander occurrences has remained about the same since 1994. The plant community remained the same with a canopy of Eastern Hemlock and Yellow Birch, an understory of scattered Rhododendron, and a forest floor with scattered mosses.

McGowan Mountain, Yellow Creek area (Randolph County)

Even though this population is adjacent to a clearcut that has become a field, it appears to be stable. We used this site to study the buffer zone requirements for CMS in 2002 (for details see the section on Buffer Zone Size). We found the same number of CMS (6) in 2013 as I found during each of two surveys in 2002. The plant community also remained the same with a canopy of Eastern Hemlock, Red Spruce, and a mix of deciduous species, an understory of American Beech, and an herbaceous layer of mixed species.

Summary and conclusions

I am hopeful that forty years of searching the high Allegheny Mountains in eastern West Virginia for Cheat Mountain Salamanders will be an impetus for future studies and protection of this endemic federally protected species. Today there are 81 known disjunct populations, but surely, other isolated populations exist within the 92 km north-to-south range. Although Red Spruce forest with a *Bazzania* covered floor was most likely the habitat of CMS before the original forest was cut and burned in the late 1800s and early 1900s, some populations occur today in deciduous forests at elevations over 610 m in the northern part of the range and over 1067 m in the southern part of the range.

Field studies throughout the total range of CMS during these 40 years provided some basic information about its natural history. Most populations are in habitats with northern aspects. During day searches, most individuals observed were under logs, followed by rocks. The most common species observed with CMS were Eastern Red-backed Salamanders and Allegheny Mountain Dusky Salamanders. CMS retreats underground when soil temperature drops below 10º C in mid-October and surface when springtime soil temperatures rise above 10º C. CMS mate in April and May; however, there may be some mating in late September and early October. Females deposited eggs in late May or early June and remain with them until they hatch in late August or early September.

Conservation studies during these 40 years on the effects of habitat disturbances and status of populations provide the following data:

1) A 90-m buffer appears appropriate to prevent leaf litter and the top layer of soil from drying in areas with large disturbances such as clearcuts.
2) An attempt to move a population was not successful. Six searches over a span of 31 years did not yield one of the 47 CMS moved from a site to be disturbed to a location with typical CMS habitat characteristics.
3) Heavy-traveled foot trails and roads appear to limit and, in some cases, prevent surface movement of CMS.
4) Connectivity of populations is broken by natural barriers such as streams and low elevations and by anthropomorphic disturbances such as highways, rights-of-way, and other forest disturbances.
5) A study of four CMS sites in 1976 to 1980 and again in 2007 showed that CMS and two common sympatric species, Eastern Red-backed Salamander and Allegheny Mountain Dusky Salamander, have predictable vertical ranges. During the span of these 27-31 years, the vertical range of these two competitor sympatric species might be expanding, which could be detrimental to CMS.

6) Twenty-four sites surveyed in 1978 to 1993 for CMS were surveyed again in 2013. Seventeen of these historical sites showed a decline in CMS, four remained the same, and three had an increase. Because of the low number of CMS found at some sites, it is difficult to state with certainty that these declines are real.

So it goes, 40 years, a huge part of a human's life on earth, spent to study one species was time well spent. Now in my 80th year I start the process of handing the Cheat Mountain Salamander "torch" to other biologists. I hope those who follow me will continue to study and protect all our Allegheny Mountain native species for generations to come.

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Literature Cited

Adams, D.C., West, M.E. and Collyer, M.L. 2007. *Location-specific sympatric morphological divergence as a possible response to species interactions in West Virginia Plethodon salamander communities*. Journal of Animal Ecology **76**:289-295.

Anthony, C.D., Venesky, M.D., and Hickerson, C.A.M. 2008. *Ecological separation in a polymorphic terrestrial salamander*. Journal of Animal Ecology **77**:646-653.

Anthony, C.D. and Pfingsten, R.A. 2013. *Eastern Red-backed Salamander, Plethodon cinereus (Green 1818)* in Amphibians of Ohio. pp 335-360. Ohio Biological Survey, Columbus, Ohio.

Ash, A. 1988. *Disappearance of salamanders from clearcut plots*. Journal of the Elisha Mitchell Scientific Society **104**:116-122.

Ash, A. 1995. *Effects of clear-cutting on litter parameters in the southern Blue Ridge Mountains*. Castanea **60**(2):89-97.

Bishop, S.C. 1941. *The Salamanders of New York.* New York State Museum Bulletin. 365pp.

Bishop, S.C. 1943. *Handbook of Salamanders*. Comstock Publishing. Ithaca, New York. 555 pp.

Blanchard, F.N. 1928. *Topics from the life history and habits of the red-backed salamander in southern Michigan.* The American Naturalist **62**:156-164.

Bradshaw, C.R. 2010. *Effect of snake populations on salamanders as a result of forest fragmentation*. M.S. thesis, Marshall University, Huntington, WV. 96 pp.

Brooks, M. 1945. *Notes on amphibians from Bickle's Knob, West Virginia*. Copeia **4**:231.

Brooks, M. 1948. *Notes on the Cheat Mountain Salamander*. Copeia. **4**:239-244.

Brown, W.E. 2009. *Impacts of dirt and gravel road dust on roadside organic forest soils and roadside vegetation*. M.S. thesis. The Pennsylvania State University School of Forest Resources, State College, Pennsylvania. 82 pp.

Burton, T.M. and Likens, G.E. 1975. *Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire*. Copeia **1975**:541-546.

Calise, C.B. 1978. *Bryophyte ecology in high elevation forests of West Virginia*. M.S. Thesis, West Virginia University, Morgantown, West Virginia.

Clarkson, R.B. 1990. *On beyond Leatherbark: the Cass saga*. McClain Printing Company. Parsons, WV. 625 pp.

Clovis, J.F. 1979. *Tree importance values in West Virginia red spruce forests inhabited by the Cheat Mountain Salamander*. Proceedings of the West Virginia Academy of Science. **51**(1):58 – 64.

Dillard, L.O., Russell, K.R., and Ford, W.M. 2008. *Macrohabitat models of occurrence for the threatened Cheat Mountain Salamander, Plethodon nettingi*. Applied Herpetology **5**(3):201-224.

Dunn, E.R. 1926. *The Salamander of the Family Plethodontidae*. Smith College 50th Anniversary Publication, Northhampton, Massachusetts. 441 pp.

Federal Register. 1989. *Endangered and threatened wildlife and plants: Determination of threatened status for the Cheat Mountain Salamander and endangered status for the Shenandoah Salamander*. **54**:34464-34486.

Green, N.B. 1937. *The amphibians and reptiles of Randolph County, West Virginia*. Herpetologica **1**:113-116

Green, N.B. 1938. *A new salamander, Plethodon nettingi, from West Virginia.* Annals of the Carnegie Museum **27**:295-299.

Green, N.B. 1943. *The salamanders of West Virginia*. West Virginia Conservation **6**:16-18.

Green, N.B. 1976. *Amphibia of West Virginia*. West Virginia Heritage Encyclopedia **1**:73-85

Green, N.B. and Pauley, T.K. 1987. *Amphibians and reptiles in West Virginia*. University of Pittsburgh Press. 241 pp.

Grobman, A.B. 1944. *The distribution of the salamanders of the genus Plethodon in eastern United States and Canada*. Annals of the New York Academy of Science **45**(7):261-316.

Grobman, A.B. 1949. *Some recent collections of Plethodon from Virginia with descriptions of a new form.* Proceedings of the Biological Society of Washington **62**(135-142)

Herbeck, L.A. and Larsen, D.R. 1998. *Plethodontid salamander response to silvicultural practices in Missouri Ozark forests*. Conservation Biology **13**:623-632.

Highton, R. 1962. *Revision of North American salamanders of the genus Plethodon*. Bulletin of the Florida State Museum **6**:235-367.

Highton, R. 1971 (1972). *Distributional interactions among eastern North American salamanders of the genus Plethodon* in P.C. Holt (ed.). The Distributional History of the Biota of the Southern Appalachians, Part III, pp. 139-188. Vertebrates. Research Division Monograph Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Highton, R. 1986. *Plethodon nettingi Green*. Catalogue of American amphibians and reptiles. Society for the Study of Amphibians and Reptiles. Pp. 383.1-383.2.

Highton, R. 1995. *Speciation in eastern North American salamanders of the genus Plethodon*. Annual review of ecology and systematics **26**:579-600.

Highton, R. and Grobman, A.B. 1956. *Two new salamanders of the genus Plethodon from the southeastern United States*. Herpetologica **12**(3):185-188.

Highton, R. and Savage, T. 1961. *Functions of the brooding behavior in the female Red-backed Salamander, Plethodon cinereus*. Copeia **1961**:95-98.

Highton, R. and Larson, A. 1979. *The genetic relationships of the salamanders of the genus Plethodon*. Systematic Zoology **28**:579-599.

Jaeger, R.G., Wicknick, J.A., Griffis, M.R., and Anthony, C.D. 1995. *Socioecology of a terrestrial salamander: Juveniles enter adult territories during stressful foraging periods.* Ecology **76**(2):533-543.

Kniowshi, A.B. 2006. *The ecology of the Peaks of Otter Salamander (Plethodon hubrichti) in the contact zone with the Redback Salamander (P. cinereus)*. Senior Thesis, Liberty University, Lynchburg, VA. 40 pp.

Kroschel, W.A. 2012. *Revisiting the ecological status of the Cheat Mountain Salamander (Plethodon nettingi) after 32 years*. M.S. thesis. Marshall University, Huntington, WV. 102 pp.

Kroschel, W.A., Sutton, W.B., McClure, C.J.W., and Pauley, T.K. 2014. *Decline of the Cheat Mountain Salamander over a 32-year period and the potential influence of competition from a sympatric species*. Journal of Herpetology. **48**(3):415-422.

Messenger K., Shepard, N., and Yirka, M. 2011. *Plethodon nettingi (Cheat Mountain Salamander). Predation*. Herpetological Review **42**(4):582-583.

Mitchell, J.C., Pauley, T.K., Withers, D.I, Roble, S.M., Miller, B.T., Braswell, A.L., Cupp, P.V., Jr., and Hobson, C.S. 1999. *Conservation status of the southern Appalachian herpetofauna.* Virginia Journal of Science **50**:13-35.

Mortensen, D.A., Rauschert, S.J., Nord, A.N., and Jones, B.P. 2009. *Forest Roads Facilitate the Spread of Invasive Plants. Invasive Plant Science and Management* **2**:191-199.

Muchmore, W.B. 1955. *Brassy flecking in the salamander Plethodon c. cinereus, and the validity of Plethodon huldae*. Copeia **3**:170-173.

Netting, G.M. 1937. *Wehrle's salamander, Plethodon wehrlei Fowler and Dunn, in West Virginia*. Proceedings of the West Virginia Academy of Science **10**:89-93.

Nord, A.N. and Mortensen, D.A. 2010. *Use of limestone gravel on forest roads increases abundance of Microstegium vimineum (Japanese stiltgrass)*. 95th ESA Annual Convention. Conference Paper.

Pauley, B.A. 1998. *The Use of Rocks as Refugia for the Cheat Mountain Salamander, Plethodon nettingi Green.* M.S. thesis. Marshall University, Huntington, WV. 81pp.

Pauley, B.A. and Pauley, T.K. 1997. *Range and distribution of the Cheat Mountain Salamander, Plethodon nettingi: an update.* Proceedings of the West Virginia Academy of Science **69**(1):4.

Pauley, B.A. and T.K. Pauley, T.K. 1998. *Microdistribution of Plethodon nettingi in association with emergent rocks*. Proceedings of the West Virginia Academy of Science **70**(1):9.

Pauley, T.K. 1978a. *Moisture as a factor regulating habitat partitioning between two sympatric Plethodon (Amphibia, Urodela, Plethodontidae) species.* Journal of Herpetology **12**(4):491-493.

Pauley, T.K. 1978b. *Temperature and insolation as factors regulating the partitioning of habitats of two sympatric Plethodon species*. Proceedings of the West Virginia Academy of Science **50**(2,3,4):77-84.

Pauley, T.K. 1978c. *Food types and distribution as a Plethodon habitat partitioning factor*. Bulleting Maryland Herpetological Society **14**(2):79-82.

Pauley, T. K. 1980. *Field notes on the distribution of terrestrial amphibians and reptiles of the West Virginia mountains above 975 meters*. Proceedings of the West Virginia Academy of Science **52**(2):84-92.

Pauley, T.K. 1981. *The range and distribution of the Cheat Mountain salamander, Plethodon nettingi.* Proceedings of the West Virginia Academy of Science **53**(2):31-35.

Pauley, T.K. 1982. *A Study of a transferred population of Cheat Mountain Salamanders*. Proceedings of the West Virginia Academy of Science **54**(1):13.

Pauley, T.K. 1986. *Additional notes on the range and distribution of the Cheat Mountain Salamander, Plethodon nettingi*. Proceedings of the West Virginia Academy of Science **58** (2,3,4):56-59.

Pauley, T.K. 1987a. *Range of the Cheat Mountain Salamander*. Herpetological Review **18**(2):39.

Pauley, T.K. 1987b. *Habitat disturbances on the Cheat Mountain Salamander*. Proceedings of the West Virginia Academy of Science **59**(1):23.

Pauley, T.K. 1990. *The ecology of the Cheat Mountain Salamander, Plethodon nettingi (Green), with discussions on two sympatric species*. Association of Southeastern Biologists **37**(2):80.

Pauley, T.K. 1994. *Impact of habitat disturbances on amphibians in West Virginia*. Herpetologists League and Society for the Study of Amphibians and Reptiles Annual Meeting, Athens, Georgia (Abstract)

Pauley, T.K. 1995. *Effects of Diflubenzuron on Non-target Organisms (Salamanders) in Broadleaf Forested Watersheds in the Northeast*. National Center of Forest Health Management, Technology Transfer. USDA-Forest Service, FHM-NC-0595: Chapter 6:42-52.

Pauley, T.K. 2005. *Reflections Upon Amphibian Conservation* in M.J. Lannoo (ed), Amphibian Declines: The Conservation Status of the United States Species. Chapter 40, pp. 277-281, University of California Press, Berkeley, California

Pauley, T.K. 2007a. *Revised notes on the range of the Cheat Mountain Salamander, Plethodon nettingi, (Amphibia: Caudata)*. Proceedings of the West Virginia Academy of Science **79**(2):16-21.

Pauley, T.K. 2007b. *Status of four Plethodon nettingi populations after a 28-year hiatus*. Unpublished report to the Fish and Wildlife Service.

Pauley, T.K. 2008a. *The Appalachian Inferno: A possible reason for the disjunct distribution of a federally protected salamander species, Plethodon nettingi (Cheat Mountain Salamander)*. Northeastern Naturalist **15**(4):595-606.

Pauley, T.K. 2008b. *Status of the federally threatened Cheat Mountain Salamander, Plethodon nettingi, (Amphibia: Caudata): Sixty years later*. Proceedings of the West Virginia Academy of Science **80**(2):26-29.

Pauley, T.K. 2008c. *Life history of the Cheat Mountain Salamander, Plethodon nettingi.* Proceedings of the West Virginia Academy of Science **80** (1):4-5 (Abstract).

Pauley, T.K. 2015a. *Phenology and reproduction activities of the Cheat Mountain Salamander*. Report submitted to the West Virginia Division of Natural Resources. 8pp.

Pauley, T.K. 2015b. *Amphibians in the Canaan Valley Drainage.* Southeastern Naturalist **14** (Special Edition 7):314-322.

Pauley, T.K. and Clovis, J.F. 1980. *The ecological status of the Cheat Mountain Salamander*. U. S. Department of Agriculture, Forest Service Report 7798. 160 pp.

Pauley, T.K. and Keller, E.C., Jr. 1993. *Relationships of burrow size, soil temperature, and body size and temperature in the salamanders Plethodon wehrlei and Plethodon cinereus*. Proceedings of the West Virginia Academy of Science **65**(2,3,4):2-7.

Pauley, T.K. and Watson, M.B. 2003. *Determination of the size of buffer zones to prevent detrimental effects on the Cheat Mountain Salamander (Plethodon nettingi)*. Report submitted to the United States Fish and Wildlife Service.

Pauley, T.K., Pauley, B.A., and Watson, M.B. 2005. *Plethodon nettingi* in M.J. Lannoo (ed), Amphibian Declines: The Conservation Status of the United States Species. pp. 829-831 University of California Press, Berkeley, California

Petranka, J.W., Eldridge, M.E., and Haley, K.E. 1993. *Effects of timber harvesting on Southern Appalachian salamanders*. Conservation Biology **7**:363-370.

Phillips, M.J., Swift, L.W., Jr., and Blinn, C.R. 2000. *Best management practices for riparian areas* in E.S. Verry, J.W. Hornbeck, and C.A. Dolloff (eds). Riparian Management in Forests of the Continental Eastern United States. Chapter 16, pages 273-286. CRC Press (Lewis Publishers).

Pielke, R.A. 1981. *The distribution of spruce in west-central Virginia before lumbering*. Castanea **46**:201-216.

Pough, F.H., Smith, E.M., Rhodes, D.H., and Collazo, A. 1987. *The abundance of salamanders in forest stands with different histories of disturbance*. Forest Ecology and Management **20**:1-9.

Rauschert, E.S.J. and Nord, A.N. 2010. *Japanese Stiltgrass: An Invasive Plant on the Move*. The Ohio Woodland Journal, 17.

Richmond, N.D. and Boggess, G. 1941. *A key to the reptiles and amphibians of West Virginia*. West Virginia University Bulletin **42**:1-9.

Rucker, L.E. 2021. *Responses of common and threatened terrestrial salamanders to climate change and habitat disturbance in Central Appalachia*. Ph.D. Dissertation (In progress). West Virginia University, Morgantown, West Virginia.

Santiago, J. 1999. *Influences of relative humidity, soil and air temperatures, and lunar phase on occurrence of terrestrial plethodontid salamanders at high elevation sites*. M.S. thesis. Marshall University, Huntington, WV. 131 pp.

Sayer, A. 1966. *The reproductive ecology of the Red-backed salamander, Plethodon cinereus in Maryland*. Copeia **1966**:183-193.

Sever, D.M. 1975. *Morphology and seasonal variation of the mental glands of the dwarf salamander, Eurycea quadridigitata (Holbrook)*. Herpetologica **31**:241-151.

Sever, D.M. 1978. *Male cloacal glands of Plethodon cinereus and Plethodon dorsalis (Amphibia: Plethodontidae)*. Herpetologica **34**(1):1-20.

Smith, R.L. 1990. *Ecology and field biology*. Harper and Row Publishers, New York.

Takahashi, M. 2002. *Comparisons in morphology, reproductive status, and feeding ecology of Plethodon cinereus at high and low elevations in West Virginia*. M.S. thesis. Marshall University, Huntington, WV. 85 pp.

Test, F.H. and Bingham, B.A. 1948. *Census of a population of the red-backed Salamander (Plethodon cinereus)*. The American Midland Naturalist **39**:362-372.

Thomas-Van Gundy, M.A. and Sturtevant, B.R. 2014. *Using scenario modeling for red spruce restoration planning in West Virginia*. Journal of Forestry **112**(5):457-466.

Thurow, G. 1955. *Plethodon nettingi in Virginia*. Herpetologica **11**:102-103.

Thurow, G. 1957. *A new Plethodon from Virginia*. Herpetologica **13**:59-66.

Thurow, G. 1968. *On the small black Plethodon problem*. Western Illinois University Series in Biological Science No. **6**:1-48.

Turner, J. 2001. *Recovered Wilderness: Solitude and Human History Intertwine in the Dolly Sods. Sierra Club: Explore, Enjoy, and Protect the Planet*. The Magazine of the Sierra Club.

United States Fish and Wildlife Service. 1973. *Threatened Wildlife of the United States*. Resource Publication, Series Number 114. 289p.

USDI Fish and Wildlife Service. 1991. *Cheat Mountain Salamander Recovery Plan*. Newton Center, MA. 30 pp.

Vos, C.C. and Chardon, J.P. 1998. *Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis*. Journal of Applied Ecology **35**:44-56.

Waldron, J.L. and Pauley, T.K. 2012. *The effects of trails and gated roads on Cheat Mountain Salamander (Plethodon nettingi) movement, survival, and abundance in the Monongahela National Forest*. Unpublished report to the United State Forest Service.

Weathers, K.C., M.L. Cadenasso, and S.T.A. Pickett. 2001. *Forest edges as nutrient and pollutant concentrators: Potential synergisms between fragmentation, forest canopies, and atmosphere*. Conservation Biology **15**:1506-1514.

Welsh, H.H. Jr and Droege, S. 2001. *A case for using Plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests*. Conservation Biology **15**:558-569.

Werner, J.K. 1971. *Notes on the reproductive cycle of Plethodon cinereus in Michigan*. Copeia **1971**(1): 161-162

West Virginia Conservation Commission. 1908. *West Virginia Board of Agriculture, biennial report, 1899 and 1900.* The Tribune Printing Co., Charleston, WV.

Appendix A. Surveys by county conducted for Cheat Mountain Salamanders between 1976 and 2016. In addition to these surveys, I conducted numerous habitat assessments in which I did not find Cheat Mountain Salamander habitat and thus did not recommend surveys.

Date	County	CMS Present
1976-79	Randolph, Tucker, Pocahontas, Grant, and Pendleton	Yes
1976-79	Greenbrier, Webster	No
1980	Randolph	Yes
1981	Randolph	Yes
1983	Randolph	Yes
1984	Randolph	Yes
1984	Randolph	Yes
1988	Randolph, Pocahontas	Yes
1988	Tucker	Yes
1989	Pocahontas	No
1988-89	Randolph, Pocahontas	Yes
1989	Randolph	No
1989	Randolph	Yes
1989	Randolph	No
1991	Randolph	No
1991	Tucker	Yes
1992	Tucker	No
1993	Tucker	No
1993	Tucker	No
1993	Pocahontas	No
1993	Randolph	No
1993	Pocahontas, Randolph, Webster	No
1993	Randolph	No
1993	Pocahontas, Randolph	No
1994	Tucker	No
1994	Pocahontas	No
1994	Pocahontas	No
1994	Tucker	No
1995	Tucker	Yes
1996	Randolph	No
1995	Randolph	No
1996	Tucker	No
1996	Randolph	Yes
1996	Randolph	Yes
1996	Randolph	Yes
1996	Pocahontas	No
1997	Pocahontas	No
1998	Randolph	No
1998	Randolph	Yes
1998	Webster	No
1999	Tucker	Yes
1999	Tucker	Yes
1999	Tucker	No
1999	Tucker	Yes
2000	Randolph	Yes
2000	Pocahontas	Yes
2000	Tucker	No
2000	Pocahontas	No
2001	Pocahontas	No
2001	Pocahontas	Yes

Appendix A (*Continued*).

Date	County	CMS Present
2001	Randolph	No
2001	Randolph	No
2001	Randolph	Yes
2001	Tucker	Yes
2002	Tucker	No
2002	Tucker	No
2002	Tucker	No
2002	Pocahontas	Yes
2003	Pocahontas	Yes
2003	Pocahontas	No
2003	Tucker	Yes
2004	Tucker	No
2004	Pocahontas	Yes
2004	Tucker	No
2004	Grant	No
2004	Tucker	Yes
2005	Tucker	Yes
2005	Pocahontas	No
2010	Pocahontas	No
2010	Randolph	Yes
2015	Randolph	Yes
2015	Pocahontas	No
2015	Pendleton	Yes
2015	Tucker	No
2016	Pendleton	Yes

Appendix B. Research studies of the Cheat Mountain Salamander from 1981 to 2015.

Research Topic	Date
Relocation of CMS	1981
Effects of a ski slope on a population of CMS	1986-2016
Areal extents of CMS populations	1991
Effects of hiking trails on CMS populations	1991-1992
Determination of CMS benchmark populations	1994-1995
Areal extents of known populations	2001, 2002
Effects of buffer sizes on CMS populations	2001-2001
Status of four CMS populations after a 28-year hiatus	2007
Areal extents of known populations	2008
Status of CMS at Barton Knob, the type locality	2009
Areal extents of known CMS populations	2010
Connectivity of all known CMS populations	2011-2012
Status of 28 known CMS populations	2013
Seasonal phenology of CMS	2015

Appendix C. Areal extent studies to delineate population sizes.

Location	Date
Dolly Sods (Fisher Spring Run area)	1991
Gaudineer Knob	1991, 2011
Spruce Knob	1991, 1992
Stuart Knob	1991, 2020
Barton Knob	1994, 2009
Blackwater Canyon	1992, 1994, 2003
McGowan Mountain	1994, 2010, 2011
Shavers Mountain (High Falls area)	1996
Canaan Mountain	1998, 1999
Dolly Sods (small population south of Fisher Spring Run population)	1998, 2012
Cabin Mountain (Canaan Valley State Park)	2002
Cabin Mountain	2008
Dolly Sods (Rohrbaugh Plains)	2008
Dolly Sods (Red Creek Plains)	2010
Blackwater Falls State Park	2015
Snowshoe (2)	2000-2019