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Revisiting the Ecological Status of the Cheat Mountain Salamander (Plethodon nettingi) After 32 Years

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REVISITING THE ECOLOGICAL STATUS OF THE CHEAT MOUNTAIN SALAMANDER (*PLETHODON NETTINGI*) AFTER 32 YEARS

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the Graduate College of
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In partial fulfillment of
the requirements for the degree of
Master of Science

Biological Sciences

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

ABSTRACT

The Cheat Mountain Salamander (*Plethodon nettingi)* is endemic to the high elevations of the Allegheny Mountains in West Virginia and is listed by the U.S. Fish and Wildlife Service as a threatened species. In 1978-79 and in 2011 the vertical distribution of *P. nettingi* was measured at four sites to determine their range of occupancy in relation to elevation. During both time periods, a transect was established at each site that ran from high to low elevation. Along each transect, quadrats were placed at regular, 12.2 m elevation intervals. Quadrats were searched twice for presence/absence (i.e., occupancy) and abundance of *P. nettingi* and competitor salamander species. To determine if salamander species distribution had changed over time, occupancy modeling was used to compare species occupancy between the two time periods. I found that *Plethodon nettingi* was positively associated with higher elevations, and competitor species were negatively associated with higher elevations. *Plethodon nettingi* occupancy probability declined the most at the middle to highest elevations. There was no relationship between the change in occupancy of *P. nettingi* and *Desmognathus ochrophaeus*, but at the highest elevations the changes in occupancy of *P. nettingi* and *Plethodon cinereus* was negatively correlated. I suggest competition between these species is most intense at higher elevations and *P. nettingi* is possibly being outcompeted by *P. cinereus*. Habitat properties were also measured at each site and comparisons between the two time periods revealed varying trends in temperature, relative humidity, and moisture, but additional research is needed to draw complete conclusions on site dynamics. Summaries of forest properties suggested slightly less diversity at sites in 2011 compared to 1978-79, but incomplete data prevented testing for significance.

INTRODUCTION

Plethodon nettingi (Cheat Mountain Salamander) is a small salamander species known to occur only in the high elevations of the Allegheny Mountains, a central region of the Appalachian Mountains. *Plethodon nettingi* occurs between elevations of 792 m and 1482 m and can only be found in the state of West Virginia, in five counties: Pocahontas, Pendleton, Tucker, Randolph and the most western corner of Grant County along the Allegheny Front (Pauley, 2007a). The U.S. Fish and Wildlife Service listed *P. nettingi* as a threatened species in 1989 (Federal Register, 1989). Tree species known to commonly occur in *P. nettingi* habitat include red spruce and yellow birch. These forest types dominated the Allegheny Mountains until the late 1800s when logging operations and forest fires swept through the region. Although *P. nettingi* survived these events and now inhabits the more recent, second and third growth forests, its original habitat was permanently lost and some of its populations are currently in danger of extinction (Pauley, 1991; 2005; 2008a).

This study evaluated the vertical distribution of *P. nettingi* and its relation to the presence or absence of competitor species within the same habitat. In addition, aspects of *P. nettingi* habitat were measured and summarized. To analyze possible changes in salamander distribution and habitat over time, I compared results to a previous study conducted in 1978-79 (Pauley and Clovis, 1980). This comparison gave insight into how the *P. nettingi* status might have changed over a 32-year period.

CHAPTER I – *Plethodon nettingi*

Species Description – *Plethodon nettingi* (Cheat Mountain Salamander) is a member of the family, Plethodontidae, known as the Lungless Salamander Family for their absence of lungs. *Plethodon nettingi* is a small, terrestrial salamander, usually no longer than 11 cm head to tail-tip (Conant and Collins, 1998) and with 18 costal grooves (Highton, 1972). It is slender and black, and typically has silvery-gold flecks across its dorsum. The venter is gray and the throat is slightly lighter in color (Figure 1).

Figure 1. *Plethodon nettingi* (Cheat Mountain Salamander). Photo by author.

Plethodon nettingi is endemic to five counties in the high elevations of the Allegheny Mountains in eastern West Virginia: Pocahontas, Pendleton, Tucker, Randolph and Grant counties. The range of *P. nettingi* lies almost entirely within the boundaries of the Monongahela National Forest (Figure 2). The total range is 80 x 250 km (Pauley, 2008b), extending from Blackwater River Canyon (Tucker County) in the north to Thorny Flat on Cheat Mountain (Pocahontas County) in the south. From west to east, the range width is 3.2 km in the south and expands to about 31 km in the north (Pauley, 2007a). The *P. nettingi* vertical distribution ranges from 792 m to 1482 m (Pauley, 2008b).

Figure 2. The location of the Monongahela National Forest. Map by author, spatial data courtesy of U.S. Fish and Wildlife Service Elkins Field Office.

Plethodon nettingi was first observed in 1935 by Graham Netting and Leonard Llewellyn (Brooks, 1948; Pauley, 2008b). It was described as a new species by N.B. Green in 1938 from specimens taken from Barton Knob in Randolph County, WV (Pauley, 2008b). On September 28, 1989 *P. nettingi* was listed by the U.S. Fish and Wildlife Service as a threatened species (Federal Register, 1989).

History – The history of *P. nettingi* largely coincides with the history of Allegheny forests, or more specifically, red spruce (*Picea rubens*) forested habitat. Although prior studies did not find *P. nettingi* strongly correlated with certain species of vegetation (Calise, 1978; Clovis, 1979), Pauley (2005) described common habitats of *P. nettingi* to include red spruce stands and *Bazzania trilobata*, a type of liverwort which grows on forest floors (and often amongst red spruce). The original spruce stands grew in areas with thin, moist soils, often on steep mountain slopes. These conditions allowed them to outcompete most other tree species and as a result, red spruce stands dominated the highest elevations in the Allegheny Mountains. Here they grew among rocks covered in humus and were regularly blanketed by clouds, which created an abundance of both atmospheric and soil moisture (Clarkson, 1964). Such habitat is where *P. nettingi* evolved and survived for, possibly, hundreds of years before their existence was documented (Figure 3).

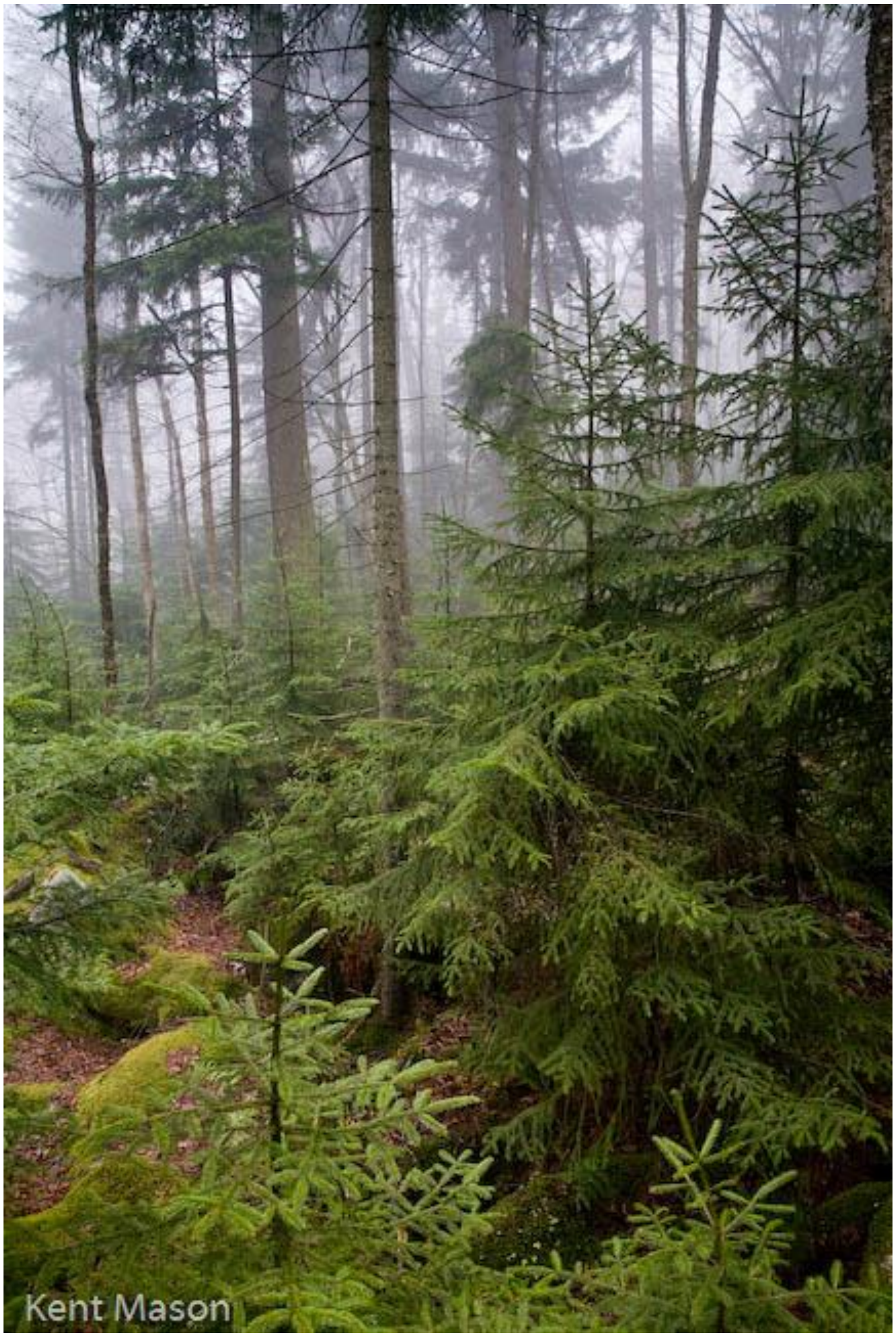


Figure 3. Old growth red spruce forest at Gaudineer Scenic Area, Monongahela National Forest, West Virginia. Photo courtesy of Kent Mason © 2008.

The most recent significant changes in red spruce forests began when Europeans first set foot in North America. At this time there were approximately 607,028 hectares of red spruce forest (Hopkins, 1908). Before the Civil War, some areas were subject to localized wildfires and small-scaled clearing. The clearing was done by landowners who desired open space to graze their animals and cultivate their crops. Within *P. nettingi* range, "hacking" (girdling trees, usually followed by cutting or burning) occurred in northern Pocahontas and southern Randolph counties (Hopkins 1908; Clarkson 1964). Wildfires added to the forest destruction. In 1863 arguably the first major fire in *P. nettingi* range broke out when a Confederate scouts' campfire lost control on the Roaring Plains area of Dolly Sods, Randolph County. The fire continued to burn through Tucker, Grant, and Pendleton counties until it reached the Greenbrier River (West Virginia Board of Agriculture, 1900). By 1865 the red spruce forests were estimated to have declined to 303,514 hectares (Hopkins, 1908). Thirty years later in 1895, destructive insects, fire, and increased lumbering operations further reduced the spruce to about 91,054 hectares (West Virginia Board of Agriculture, 1900).

The lumber industry in West Virginia accelerated around the turn of the 19th Century. Spruce was in high demand for lumber and pulp, and technologies for cutting, transporting, and manufacturing timber into pulp had greatly improved. Railroad track mileage in West Virginia doubled in the 1880s, and doubled again in the 1890s, by this time stretching well into the Allegheny Mountains (from Lewis, 1998). Around Cheat Mountain (where *P. nettingi* was first discovered) railroads were built to transport the virgin forest lumber as they were the most convenient source of pulpwood for a new paper mill in Covington, Virginia. At Spruce Knob, the highest point in the state, timber was reportedly removed at a rate of 12 to 20 hectares a day (West Virginia Board of Agriculture, 1900). When removing timber, men left the treetops and branches on the ground. The limbs, still carrying their full foliage, eventually dried and became highly vulnerable to catching fire (Clarkson, 1964).

Forest fires affected every county in West Virginia, and more than one-tenth of the surface of the entire state burned (from Lewis, 1998). One of the more massive fires in the state was noted in the *Report of the West Virginia Conservation Commission, 1908,* which stated, "…the first serious fire occurred on August 28, and from that time there was no cessation for three months" (Conservation Commission, 1909). Along the Blackwater River a 1908 fire burned 23,597 m^3 of hemlock and chestnut forest. The dried, desolate lands were ideal for spreading fires, which burned so thoroughly that even the rich topsoil in many areas was burned down to the bedrock. In 1908 A.B. Brooks, the state's leading conservationist and director of the West Virginia Geological Survey, climbed to the top of Spruce Knob and reported observing fertile farms and forests to the east, towards Virginia. But of his view to the west, he wrote, "…most of the country was a waste of brake-covered ground from which almost every trace of the original forest had been swept by fires" (West Virginia Board of Agriculture, 1900; Lewis, 1998). The pattern of clear cutting followed by widespread burning continued throughout the Alleghenies and westward. Areas such as Bald Knob and Blackwater Canyon were thoroughly clear-cut, and by 1910 wildfires swept through both areas, easily fueled by the forest remnants and the rich topsoil (from Lewis, 1998).

Exposure of the topsoil not only made rich fuel for burning, but also escalated erosion and soil degradation. With no vegetation to cover it and provide structure, the soil quickly dried out and washed away in many areas. A survey conducted in 1930 reported that about 4 million West Virginia hectares had lost between 25 and 75 percent of their topsoil, and 90 percent of the state's 6.2 million hectares of land surface had experienced increased soil erosion (Oliverio, 1972). The destruction and subsequent burning of the original forest further damaged and delayed its ability to become reestablished.

One of the other major side effects of timbering was the pollution and degradation of many of the state's waterways. In an effort to save the Ohio and Potomac watersheds, the federal government established the 647,000 hectare

Monongahela National Forest in 1920 (Kahn, 1974), which today encompasses nearly the full known range of *P. nettingi.* The forest eventually regenerated during the following years and by 1960 forests at both ends of *P. nettingi* range had grown into nearly mature stands.

Most of the original forest within *P. nettingi* range has been completely cut, and in many cases burned, within the past 100 years. Altogether, the areas presently regarded a *P. nettingi* habitat have a history littered with heavy disturbances.

With such thorough destruction of the old growth forests, many species likely experienced catastrophic damage to their populations. Some locations, such as Dolly Sods and Spruce Knob, have large areas of exposed rock where the soil completely burned away. Needless to say, it would have been difficult for soil-dwelling animals, such as salamanders, to survive the heat and destruction of rapid moving flames. Yet, they unquestionably did persist and now *P. nettingi* make up at least 80 disjunct populations. Pauley (2007b; 2008a) hypothesized *P. nettingi* survived logging and forest fires by taking refuge in deep cracks and crevices of large, emergent rocks where they could escape the timber harvest operations and high temperatures of the flames. Boulder fields, rock talus, and rhododendron (*Rhododendron maximum*) patches growing in narrow ravines could have also served as refugia for *P. nettingi* (Pauley, 2007b). Today, the 82 recognized *P. nettingi* population locations together form a discontinuous distribution (Pauley, 2008a).

Habitat – Clovis (1979; Pauley and Clovis 1980) and Calise (1978) found *P. nettingi* was not significantly associated with particular types of vegetation or bryophytes. However, the habitat of *P. nettingi* is most often described as forests dominated by red spruce (*Picea rubens*) and/or yellow birch (*Betula alleghaniensis*; Pauley, 2005), and they have also been found in eastern hemlock (*Tsuga canadensis*) stands and other mixed deciduous forests at elevations above 610 m (Pauley, 2007b; 2008b). A type of liverwort, *Bazzania trilobata*, which grows on forest floors is also commonly used to describe *P. nettingi* habitat (Pauley, 2005; Pauley, 2008a).

Plethodon nettingi generally require cool, moist environmental conditions compared to other Plethodontid salamanders. They occur at higher elevations, between 792 m and 1482 m (Pauley, 2007a). *Plethodon nettingi* are usually associated with boulder fields, rock outcrops, emergent rocks, or steep ravines with rhododendron (Pauley, 2005).

Sympatric Species – There are generally four other species that tend to overlap with the *P. nettingi* vertical distribution (*Plethodon cinereus, Plethdon glutinosus,* *Plethodon wehrlei*, and *Desmognathus ochrophaeus)*. But primarily two species, *P. cinereus* and *D. ochrophaeus*, compete with *P. nettingi* for habitat (Pauley, 2005); hence their relationships with *P. nettingi* have been studied more closely.

Plethodon cinereus (Eastern Red-backed Salamander) is also a member of the genus, *Plethodon*, which includes the terrestrial, woodland salamander species (Figure 4). The size and shape of the body are similar to that of *P. nettingi;* it is slender, has 18 costal grooves (Highton, 1972), and adults are often 7 to 10 cm in length. Unlike *P. nettingi,* this species has two distinct color phases: the redback and the leadback phases (Conant and Collins, 1998). In the redback phase, the dorsum is dark gray with a red stripe (which can vary in shade) that runs down the back. The venter has a “salt and pepper” mottling pattern. The leadback phase can easily be confused with *P. nettingi* because the dorsum is dark with a gray/white speckled pattern. Thus, the venter pattern can be a defining characteristic to distinguish between the two species, since *P. nettingi* has a uniform gray venter. *Plethodon cinereus* is one of the most widely distributed species in West Virginia, and has a large range extendding from southern Ontario and southern Quebec to Illinois and North Carolina (Conant and Collins, 1998).

Figure 4. *Plethodon cinereus* (Eastern Red-backed Salamander). Photo by author.

Desmognathus ochrophaues (Allegheny Mountain Dusky Salamander) is of the genus, *Desmognathus*, which includes the more aquatic dusky salamander species found near streams, springs, or seeps (Green and Pauley, 1987; Figure 5). *Desmognathus ochrophaeus* is unique in its genus in that it is the most terrestrial of the dusky salamanders in West Virginia and is often found far from a water source. *Desmognathus ochrophaeus* is similar to *P. nettingi* and *P. cinereus* in terms of its overall length, but this species is not as slender as the other two. It has a thicker torso and has larger hind limbs in proportion to the front limbs. The neck is more muscular and the head is larger compared to *P. nettingi* and *P. cinereus.* One characteristic that distinguishes *D. ochrophaeus* from the other two species is that, like most dusky salamanders, they have a light line that runs from the eye to the angle of the jaw (Conant and Collins, 1998). The coloration of this species varies much more than the other two species. It usually has a yellow or brown dorsum with darker chevron-shaped marks running down its back. The range of *D. ochrophaeus* extends from northern New York down through Pennsylvania, West Virginia, through the western edges of Virginia, North Carolina, and South Carolina, to northern Georgia (Conant and Collins, 1998).

Figure 5. *Desmognathus ochrophaeus* (Allegheny Mountain Dusky Salamander). Photo by author.

Previous Research – The first thorough natural history report about *P. nettingi* was conducted in 1978-79 by T.K. Pauley and J.F. Clovis (1980). The study established the first major status report on *P. nettingi* populations at four locations: Spruce Knob, Dolly Sods, Stuart Knob, and Gaudineer Knob (Figure 6). Pauley and Clovis documented salamander abundance (i.e., the number of individuals encountered by searching the ground surface and turning surface cover objects), vegetation, and environmental characteristics (e.g., soil temperature, relative humidity) at these sites and established an image of 1978-79 *P. nettingi* presence, abundance, and habitat. In addition, they documented distributions of *P. cinereus* and *D. ochrophaeus* in relation to *P. nettingi* vertical distribution at each site. In general, *P. nettingi* occupied a nearly continuous distribution in the range of 1120 to 1380 m. *Plethodon cinereus* was found at the middle to lower end of the *P. nettingi* distribution, and *D. ochrophaeus* usually occupied the low end of the *P. nettingi* distribution. Thus, mapping each species' vertical distribution at each site generally revealed *D. ochrophaeus* at the lowest elevations, followed by *P. cinereus*, and *P. nettingi* inhabiting the highest elevations, with some overlap.

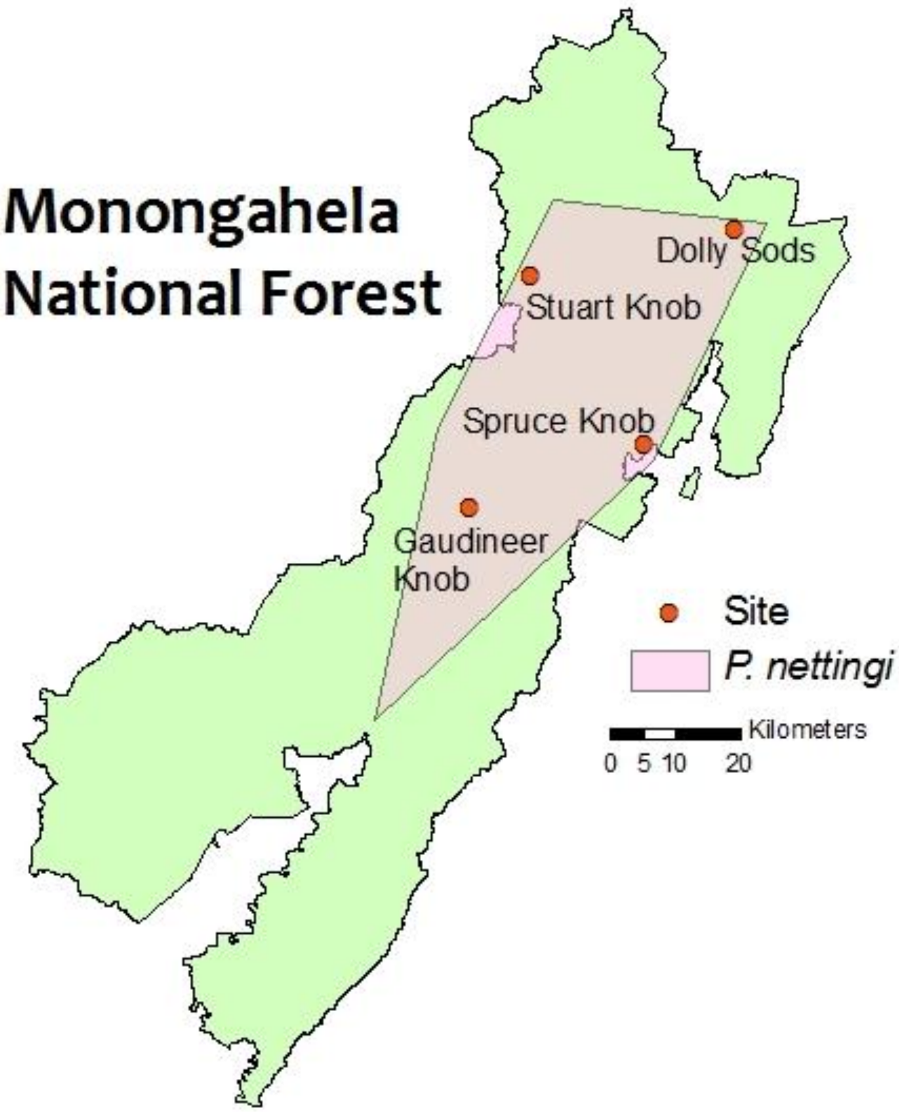


Figure 6. The range of *Plethodon nettingi* and the location of the four study sites used by Pauley and Clovis (1980). Map by author; spatial data courtesy of U.S. Fish and Wildlife Service, Elkins Field Office.

Pauley and Clovis (1980) also studied the interspecific relationship between *P. nettingi* and *P. cinereus*. *Plethodon cinereus* is probably the most common competitor encountered by *P. nettingi*. Regarding temperature, they found *P. nettingi* in microhabitats with lower temperatures compared to locations at which *P. cinereus* was found. They also found that *P. cinereus* had a lower critical thermal maximum (33.0°C) compared to *P. nettingi* (33.8°C). They hypothesized *P. nettingi* are able to inhabit warmer soils at elevations below their distribution, but competition has limited them from expanding down-slope (Pauley and Clovis, 1980). Highton (1972) also suggested *P. cinereus* is a more successful competitor than *P. nettingi* and limits the latter's expansion.

Pauley and Clovis (1980) found *P. nettingi* to occur at locations with a much higher relative humidity (81.3%) compared to *P. cinereus* (74.3%), and concluded *P. nettingi* preferred sites with greater moister compared to *P. cinereus*. Dehydration studies discovered *P. nettingi* loses moisture at a greater rate than *P. cinereus* and cannot withstand as great a loss of body moisture before death. Therefore, *P. nettingi* requires a higher standard of habitat moisture. These data supported their hypothesis that *P. nettingi* remains at higher elevations where temperature is low and relative humidity is high, because they are more successful in these conditions (Pauley and Clovis, 1980).

Pauley and Clovis (1980) suggested other forms of competition between *P. nettingi* and *P. cinereus*. Stomach content analyses concluded both species consume generally the same foods (e.g., mites, beetle and fly larvae, ants) and therefore might compete for this resource. Due to the similar body size of both species, they suggested *P. nettingi* is in competition with *P. cinereus* for burrows and nesting sites (Pauley and Clovis, 1980).

Pauley and Clovis (1980) did not conduct laboratory studies with *D. ochrophaeus*, however, they mapped their distribution at several known *P. nettingi* sites. They found *D. ochrophaeus* primarily at the lower elevations of the *P. nettingi* distributions at 13 out of 20 known *P. nettingi* population sites. They hypothesized *P. nettingi* potentially competes with *D. ochrophaeus* for moist sites, burrows, and cover objects, and this has contributed to the inability of *P. nettingi* to expand beyond its known range (Pauley and Clovis, 1980).

In 1979, Pauley and Clovis (1980) concluded *P. nettingi* competes with *P. cinereus* within its vertical distribution and competes with *D. ochrophaeus* below its vertical distribution. Both competition and the stricter environmental requirements of *P. nettingi* make it difficult for this species to expand both its distribution and range (Pauley an Clovis, 1980).

The abundance of *P. nettingi* at the four sites used in 1978-79 was not documented again until 2007. During this year Pauley replicated the original survey but excluded a vegetation analysis. He recorded salamander presence, abundance, and environmental characteristics. A general comparison between the 1978-79 salamander abundance and 2007 abundance showed a decline in salamander presence and abundance (Pauley, 2007b). The 2007 field season was especially warm and dry, and Pauley was skeptical of the possible implications of the raw data (Pauley, pers. comm., 2011). Although the 2007 data established an updated image of the *P. nettingi* distribution in the same manner used in 1978-79, it could not be determined whether differences in the data were due to actual changes in *P. nettingi* presence and abundance, or due to the unusually dry weather of 2007. Here, I present a more thorough, representative status report on the *P. nettingi* distribution.

Objectives – The goal of this study was to update the status of *P. nettingi* and compare the results to the status of *P. nettingi* in 1978-79 (Pauley and Clovis, 1980). If any changes in salamander distributions had occurred since the original study, my goal was to identify them in this report. The main objectives used in this study were to:

1. Determine the vertical distribution of *P. nettingi*, *P. cinereus,* and *D. ochrophaeus* in terms of both occupancy (i.e., presence/absence) and abundance for the year 2011.

2. Model how *P. nettingi* occupancy may have changed since 1978-79, and compare with *P. cinereus* and *D. ochrophaeus* occupancy.

3. Describe the current habitat in terms of its environmental conditions and vegetation.

Study Sites – The four sites used in this study were the same sites used by Pauley and Clovis (1980) in 1978-79. The sites were Spruce Knob, Dolly Sods, Stuart Knob, and Gaudineer Knob, all of which were located within the Monongahela National Forest in the West Virginia Allegheny Mountains.

Spruce Knob (Pendleton County) is the highest point in the state of West Virginia. It is about 88 kilometers from Elkins, WV, and accessible from U.S. highway 33 E. It is located at 38.7° N and -79.5° W and has an elevation of 1482 m. The stand age is approximately 80 years old (Clovis, 1979). The forests are mostly dominated by yellow birch with some red spruce and red maple (Clovis, 1979).

Dolly Sods is located primarily in Tucker County, near West Virginia highway 55 E, about 88 kilometers from Elkins, WV. It is a large U.S. Wilderness Area, about 70 km^2, located at approximately 38.9° N and -79.3° W (USFS, 2011). It is a mountaintop meadow and one of the highest plateaus east of the Mississippi with an elevation range of 760 to 1430 m (USFS, 2011). The stand age is about 70 years old (Clovis, 1979). Forests types are known to vary; some forest communities include oak, maple, and basswood hardwoods; maple, birch, and beech; and also stands of red spruce, hemlock, and rhododendron (Venable, 1996).

Stuart Knob (Randolph County) is located off U.S. highway 33, about 8 kilometers east of downtown Elkins, WV. Its summit has coordinates of 38.9° N and -79.7° W and an elevation of 1221 m. In previous studies Stuart Knob is referred to as Bickle Knob (Clovis, 1979; Pauley and Clovis, 1980). The stand age of the forest is close to 90 years (Clovis, 1979). It is primarily mixed deciduous forest, dominated by yellow birch and red maple, but stands of red spruce are present as well (Clovis, 1979).

Gaudineer Knob (Pocahontas/Randolph Counties) is the southern-most of all four sites, located off U.S. highway 250, about 55 kilometers south of Elkins, WV. The elevation is 1359 m and the coordinates are 38.6° N and -79.8° W. The stand age is approximately 80 years old; the last harvest occurred in 1921 (Clovis, 1979). The forest is predominantly red spruce and the ground is carpeted by the lush, mossy-looking *Bazzania trilobata*, a type of bryophyte.

CHAPTER II – Salamander occupancy: 1978-79 vs. 2011

Introduction – Over the past 25 years, major declines at the global scale have been noted for nearly one-third of extant amphibian species (Blaustein et al., 1994; Houlahan et al., 2000; Stuart et al., 2004). Among the causes of these declines are changes in natural habitat, which can be due to habitat fragmentation, deterioration (Soule 1987, Fiedler and Jain 1992), loss (Fahrig, 2003); and also changes in regional climate patterns (McMenamin et al., 2008). Understanding how these changes affect species at both local and landscape scales, in terms of multiple populations, is important for evaluating ecological and longterm conservation status (Hecnar and M'Closkey, 1996; Van Buskirk, 2005). Amphibian species most at risk include threatened and endangered species that are limited by factors that include reduced population size, reduced gene flow and genetic variability, small geographic range, and available suitable habitat (Pauley, 2008b; Byers and Norris, 2011).

Alterations of habitat and climate conditions can further lead to changes in interspecific competition dynamics (Nee and May, 1992). For example, interspecific competition can enhance the vulnerability of salamander species with relatively small distributions. Populations restricted to substandard niches by interspecific competition may become more susceptible to extirpation during extreme weather conditions (Griffis and Jaeger, 1998). Additionally, habitat alterations at small scales can create spatial and temporal variations in the environment that may influence one species more positively than another species, and thus impact species distribution and abundance (Grover and Wilbur, 2002). Evidence has shown that the indirect effects of habitat alterations can persist through species interactions even after the habitat has returned to pre-disturbance status (Grover and Wilbur, 2002). Studies have suggested that salamanders will coexist in areas where resources are abundant but will compete with one another as resources (e.g., burrows, food) become limited (Southerland, 1986a; 1986b). Such circumstances may present themselves if habitat alterations result in deterioration or loss of premium habitats. Subtle changes in habitat are sometimes difficult to determine, and therefore, evaluating the status of resident species is a means to identify possible habitat alterations and their consequences.

A variety of statistical techniques such as mark-recapture and presence/absence surveys can be used to evaluate the ecological status of focal species. However, for species with incomplete detection, it is important to account for disparate detection rates to obtain a better understanding of longterm population dynamics. Mark-recapture techniques are one of the most reliable means for estimating abundance because capture data can be corrected for errors in detection (Bailey et al., 2004). However, these methods are typically expensive and unreasonable for monitoring amphibian populations over long time periods and at large spatial scales (Bailey et al., 2004). Occupancy modeling is an analysis technique that uses detection and non-detection (i.e., presence and absence) data corrected for errors in detection to evaluate ecological factors impacting species, usually at larger spatial scales (MacKenzie et al., 2006). Analysis techniques that account for errors in detection are recommended over traditional count data because substantial fractions of terrestrial salamander populations are subterranean (Petranka, 1998), and many salamander species display seasonally dependent activity patterns (Bailey et al., 2004).

The purpose of this study was to explore ecological factors potentially impacting occupancy rates of three salamander species (i.e., *Plethodon nettingi, P. cinereus,* and *Desmognathus ochrophaeus*) in high-elevation forests of West Virginia over a 32-year period. *Plethodon nettingi* is a federally threatened salamander species (Federal Register, 1989) located in the Allegheny Mountains of West Virginia. It occurs at relatively high elevations between 792 m and 1482 m where its distribution is likely restricted by both environmental factors and competition with similar species, namely *Plethodon cinereus* and *Desmognathus ochrophaeus* (Highton, 1972; Pauley and Clovis, 1980; Pauley, 2005; Adams et al., 2007). A secondary purpose of this study was to evaluate the potential of establishing benchmark populations (Pauley, 1991; USFWS, 2009) to determine the current and longterm conservation status of *P. nettingi*. Overall, I aimed to use these data to examine population dynamics of *P. nettingi, P. cinereus* and *D. ochrophaeus* and to examine potential interactions among these species.

Materials and Methods

Study Site – My study was centered in the Allegheny Mountains geographic province of West Virginia. Average annual precipitation throughout this region is approximately 143 cm, which occurs primarily during the spring and summer seasons (Gilliam and Adams, 1996; Gilliam, 2002). Soils are characterized as Inceptisols or Spodosols, as they are sandy or loamy, slightly acidic, and generally less than 1 m in depth (Gilliam, 2002; Jenkins, 2002). Along with these relatively thin soils, the forest substrate is typically composed of rock talus or large emergent boulders. Almost all of the forests are second growth stands that regenerated after intense logging operations that occurred in West Virginia between 1880 and 1920 (Lewis, 1998). Common tree species within the study sites included red spruce (*Picea rubens*), red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). Elevation in this region ranges from approximately 295 to 1,482 meters. Four high-elevation sites (Spruce Knob, Dolly Sods, Stuart Knob, and Gaudineer Knob) within the Monongahela National Forest were selected for this study (Figure 1). These study sites were selected because they each had known *P. nettingi* populations in 1978 and were widely distributed throughout the range of *P. nettingi*.

Salamander Sampling – In 1978 a single elevational sampling transect was established at each of the four study sites extending from the point of highest elevation to 24.4 meters below the point where the last *P. nettingi* was detected in 1978-79 (Pauley and Clovis, 1980). Within each transect, a handheld altimeter was used to establish quadrats (10 x 20 m) at 12.2 m intervals. These intervals were chosen because elevation contour lines occurred in 12.2 m intervals and provided a simpler means to locate each transect. Additionally, 12.2 m intervals were believed to be an adequate distance to determine any changes in salamander composition (Pauley and Clovis, 1980). Because the vertical distribution of *P. nettingi* varied among sites in 1978-79, the lengths of each transect differed in overall altitudinal range, and consequently, the total number of quadrats (Table 1).

Each transect was originally sampled once during both 1978 and 1979, and was resampled twice during 2011. Sampling occurred during summer months (i.e. June – August). To lessen habitat disturbances, transects were surveyed a maximum of two times during sampling periods. Salamander searches were performed during daylight hours by closely inspecting the litter and turning rocks and logs within each quadrat. Salamander detection and non-detection data were recorded along with count data for all species of salamanders encountered and recorded as present (1) and absent (0) and as the number of individuals observed per species, per quadrat, respectively. All cover objects were returned to their original locations, and no salamanders were collected or removed from the study sites. To reduce errors in detection, all searches were conducted within 48 hours of a rainfall event.

Data Analysis – I used program PRESENCE (v. 4.0) to model changes in occupancy for *P. nettingi*, *P. cinereus*, and *D. ochrophaeus* over a 32-year period. I used single season models to simultaneously model occupancy (Ψ) and detection (p) for two time periods (i.e., 1978-79 and 2011). I initially attempted to use multi-season analyses to model occupancy, colonization, extinction, and detection for the three salamander species, but these models did not converge or produce reliable model outputs.

Overall, I evaluated the fit of three models (i.e., null, elevation, and squared elevation) to determine occupancy probabilities for each species. Because detection probabilities were relatively high (0.5 or greater) during each survey period for each species, I considered detection a nuisance parameter (Steen et al., 2012) and focused primarily on the impacts of elevation on occupancy rates for each species. I was particularly interested in the change in *P. nettingi* occupancy and analyzed averaged model outputs to compare potential effects of elevation and competitor occupancy rates on the changes in *P. nettingi* occupancy probabilities (Table 2).

I used Akaike's Information Criterion (AIC) to evaluate candidate models (Burnham and Anderson, 2002) that best described the contribution of elevation on salamander occupancy. When there was more than one candidate model with high support (evidence ratios < 2.7), I averaged coefficients across the models (Burnham and Anderson, 2002) and calculated standard errors and 85% confidence intervals for these coefficients (Richmond et al., 2010). I used model averaging to calculate unconditional estimates of occupancy for each species during 1978 and 2011, separately, and then used the unconditional estimates of occupancy to calculate the change in the probability of occupancy between the two time periods at each site for each species. I used multiple regression to test hypotheses that observed changes in occupancy that were related to elevation and the presence of competitors using Program R (v. 2.15.0). For *P. nettingi*, I built models to evaluate hypotheses that changes in *P. nettingi* occupancy (dependent variable) were related to elev, elev^2, (i.e., elevation and squared elevation) and changes in occupancy of *P. cinereus* and *D. ochrophaeus* (Table 3). I also modeled the changes in occupancy of *P. cinereus* and *D. ochrophaeus* based on elev and elev^2. For each species, I ranked and compared all models using AIC adjusted for small sample sizes (AIC_c).

Table 1. Number of quadrats and elevational range at each study site. Quadrats were spaced approximately 12.2 m apart in elevation along transects.

Site	Number of Quadrats	Elevation Range (m)
Spruce Knob	13	1378 - 1231
Dolly Sods	8	1207 - 1122
Stuart Knob	8	1195 - 1109
Gaudineer Knob	7	1353 – 1280

Results – The average model detection rates (p) for *P. nettingi*, *P. cinereus,* and *D. ochrophaeus* were 0.61, 0.51, and 0.70, respectively. The regression model that best described the change in *P. nettingi* occupancy from 1978 to 2011 (i.e., the model with the highest $\mathrm{AIC_c}$ weight; $\omega = 0.78$) incorporated impacts from elevation, change in *P. cinereus* occupancy, and an interaction between elevation and *P. cinereus* occupancy (Table 3). The second best model incorporated impacts from elevation and change in *P. cinereus* occupancy ($\omega = 0.08$), suggesting that elevation and *P. cinereus* occupancy may be important factors affecting *P. nettingi* occupancy at these study sites. The model that best described the change in *P. cinereus* occupancy from 1978 to 2011 incorporated only elevation ($\omega = 0.60$) (Table 3). The model that best described the change in *D. ochrophaeus* occupancy from 1978 to 2011 incorporated impacts from elevation and squared elevation (ω

= 0.92) (Table 3). The variables in the models that best explained the change in *P. nettingi* occupancy between 1978 and 2011 included the change in *P. cinereus* occupancy, elevation, and the interaction between elevation and *P. cinereus* occupancy (Table 4). When model coefficients were averaged for *P. nettingi*, the 85% confidence intervals for the change in *P. cinereus* occupancy (CI = 0.06 to 0.39), elevation (CI = 0.10 to 0.28), and the interaction of elevation and change in *P. cinereus* occupancy (CI = -0.38 to -0.11) indicate good support for this model. Confidence intervals from the highest supported *P. cinereus* model indicate that elevation was an influential factor (CI = -0.44 to -0.25) (Table 4). Elevation was also a strong variable in the top *D. ochrophaeus* models (CI = -0.31 to -0.06), as well as squared elevation (CI = -0.49 to -0.16) (Table 4). These confidence intervals indicate that elevation and/or squared elevation is an important factor for explaining the presence and absence of all three salamander species. In the case of *P. nettingi*, the occupancy of *P. cinereus* is also an important factor explaining *P. nettingi* presence and absence.

Overall, *P. nettingi* occupancy probabilities were greater at middle and higher elevations compared to lower elevations in 1978 and 2011, indicating that this species is more likely (≥ 60%) to occupy higher elevation sites, i.e., between 1229 and 1378 m (Figure 2). However, when occupancy rates were compared between 1978-79 and 2011, *P. nettingi* occupancy probabilities declined with increased elevation at a greater rate in 2011 compared to 1978 (Figure 2), suggesting *P. nettingi* has become less common at the middle and high elevation sites.

In general, occupancy of *P. cinereus* and *D. ochrophaeus* were negatively associated with elevation (Figure 3). *Plethodon cinereus* had greater occupancy at lower elevations (i.e., 1110 to 1229 m) and *D. ochrophaeus* seemed to occupy low to middle elevations (i.e., 1110 to 1289 m); but both species were less likely to inhabit higher elevation sites.

There was a positive relationship between the change in species occupancy when *P. nettingi* and *P. cinereus* were compared at the minimum (1110 m) and mean elevations (1239 m), such that occupancy of both species tended to increase and decrease at the same sites (Figure 4). But at the maximum elevation (1378 m) *P. nettingi* and *P. cinereus* became negatively associated, indicating that sites where change in *P. nettingi* occupancy decreased were sites where the change in *P. cinereus* occupancy increased between the two time periods (Figure 4). There was no significant relationship between the changes in occupancy of *P. nettingi* and *D. ochrophaeus* between 1978 and 2011.

Table 2. Highest supported models (ΔAIC < 2.0) describing salamander occupancy (Ψ) and detection (p) during 1978-79 and 2011 at alpine sites in the Monongahela National Forest, WV. The null models [$\Psi(.)$, $p(.)$] assumed constant occupancy and detection probabilities.

Species	Model	-2 log likelihood^{a}	K^{b}	AIC$_c^{c}$	ΔAIC$_c^{d}$	ω_i^{e}
Plethodon nettingi 1978-79	Ψ(elev), p(.)	85.00	3	91.00	0.00	0.69
	Ψ(elev^2), p(.)	84.66	4	92.66	1.66	0. 30
	Ψ(.), p(.)	98.76	2	102.76	11.76	0. 0019
Plethodon nettingi 2011	Ψ(elev), p(.)	76.01	3	82.01	0.00	0.53
	Ψ(elev^2), p(.)	74.29	4	82.29	0.28	0.46
	Ψ(.), p(.)	88.5	2	92.5	10.49	0.0028
Plethodon cinereus 1978-79	Ψ(elev), p(.)	76.38	3	82.38	0.00	0.71
	Ψ(elev^2), p(.)	76.38	4	84.38	2.00	0.26
	Ψ(.), p(.)	85.08	2	89.08	6.70	0.025
Plethodon cinereus 2011	Ψ(.), p(.)	95.07	2	99.07	0.00	0.43
	Ψ(elev), p(.)	93.26	3	99.26	0.19	0.39
	Ψ(elev^2), p(.)	92.89	4	100.89	1.82	0.17
Desmognathus ochrophaeus 1978-79	Ψ(elev^2), p(.)	71.08	4	79.08	0.00	0.47
	Ψ(.), p(.)	75.51	2	79.51	0.43	0.38
	Ψ(elev), p(.)	75.47	3	81.47	2.39	0.14
Desmognathus ochrophaeus 2011	Ψ(elev), p(.)	76.74	3	82.74	0.00	0.59
	Ψ(elev^2), p(.)	76.02	4	84.02	1.28	0.31
	Ψ(.), p(.)	82.35	2	86.35	3.61	0.097

[a] Value derived from regression output

[b] Number of parameters in each model

[c] Akaike' information criterion

[d] The difference between the top AIC model and each candidate model

[e] Akaike's weight denotes a relative weight value for each model; higher values indicate better supported models

Table 3. Models describing change in occupancy of *Plethodon nettingi, Plethodon cinereus,* and *Desmognathus ochrophaeus* between 1978 – 2011 at high elevation sites in the

Monongahela National Forest, West Virginia, U.S.A. Null models are those where occupancy and detection were held constant.

Models	-2 log likelihood[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	ω[e]
Δ *P. nettingi*					
Elev + Δ *P. cinereus* + Elev * Δ *P. cinereus*	-18.94	5	49.89	0.00	0.78
Elev + Δ *P. cinereus*	-22.52	4	54.33	4.44	0.08
Elev	-24.51	3	55.77	5.88	0.04
Elev + Elev^2	-23.62	4	56.54	6.65	0.03
Null	-26.13	2	56.62	6.73	0.03
Δ *D. ochrophaeus*	-25.69	3	58.13	8.24	0.01
Elev. + Δ *D. ochrophaeus*	-26.10	4	58.96	9.07	0.01
Δ *P. cinereus*	-24.32	3	60.65	10.76	0.00
Δ *P. cinereus*					
Elev	-16.05	3	38.85	0.00	0.60
Elev + Elev^2	-15.16	4	39.62	0.77	0.40
Null	-26.65	2	57.66	18.81	0.00
Δ *D. ochrophaeus*					
Elev + Elev^2	-25.78	4	60.86	0.00	0.92
Elev	-29.87	3	66.50	5.64	0.06
Null	-32.06	2	68.48	7.62	0.02

[a] Value derived from model output
[b] Number of model parameters
[c] Akaike's information criterion adjusted for small sample sizes
[d] The difference between the top AIC model and each candidate model
[e] Akaike's weight; higher values indicate models with greater support

Table 4. Model-averaged parameter estimates, standard errors, and 85% confidence intervals for variables explaining occupancy of *Plethodon nettingi*, *Plethdon cinereus*, and

Desmognathus ochrophaeus between 1978-79 and 2011 at sites within the Monongahela National Forest in West Virginia. Parameter estimates for *P. nettingi* were from the best model.

Variable	β ± S.E.	t or z	*p*-value	85% Confidence	Interval
P. nettingi					
(Intercept)	-0.28 ± 0.05	-5.21	< 0.0001	-0.35	-0.20
Δ *P. cinereus*	-0.23 ± 0.11	1.99	0.05	0.06	0.39
Elev	-0.19 ± 0.06	3.19	0.003	0.10	0.28
Elev * Δ *P. cinereus*	-0.09 ± 0.09	-2.65	0.01	-0.38	-0.11
P. cinereus					
(Intercept)	-0.001 ± 0.10	0.01	0.99	-0.14	0.14
Elev	-0.35 ± 0.07	5.08	< 0.0001	-0.44	-0.25
Elev^2	0.11 ± 0.08	1.24	0.21	-0.01	0.23
D. ochrophaeus					
(Intercept)	0.44 ± 0.16	2.68	0.007	0.21	0.67
Elev	-0.19 ± 0.09	2.04	0.04	-0.31	-0.06
Elev^2	-0.32 ± 0.11	2.79	0.005	-0.49	-0.16

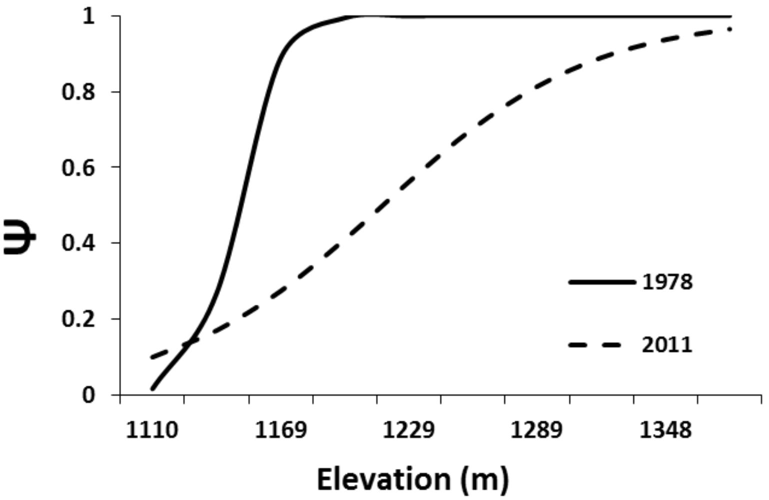


Figure 7. Occupancy rates (Ψ) of *Plethodon nettingi* in relation to elevation during two separate periods at sites in the Allegheny Mountains of West Virginia.

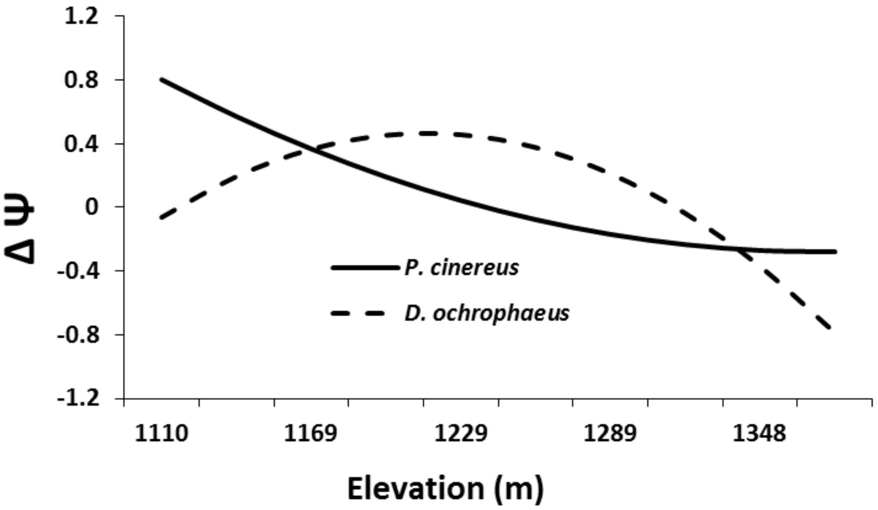


Figure 8. Change in occupancy rates (ΔΨ) of *Plethodon cinereus* and *Desmognathus ochrophaeus* in relation to elevation at sites in the Allegheny Mountains of West Virginia.

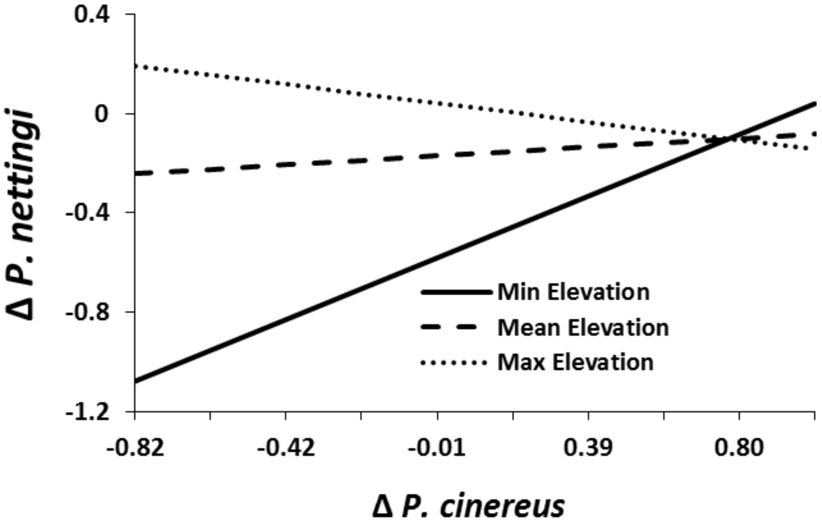


Figure 9. The relationship between the changes in occupancy of *Plethodon nettingi* and *Plethodon cinereus* at minimum, maximum, and mean elevations between 1978-79 and 2011.

Discussion – Overall, my analysis revealed that *P. nettingi* occupancy probabilities were considerably lower in 2011 compared to 1978-79 at medium and high elevations (1169 - 1378 m). My results suggest that the negative changes in *P. nettingi* occupancy at high elevation sites may be due to competitive interactions with *P. cinereus.* Although competition between *P. nettingi* and *P. cinereus* has been hypothesized as one of the main factors negatively impacting *P. nettingi* populations (Highton, 1972; Pauley and Clovis, 1980; Wicknick and Pauley, 1998; Pauley, 2005; Pauley, 2007a; Adams et al., 2007), this study represents the first effort to use long term data to evaluate potential interactions between *P. nettingi* and sympatric salamander species. My data illustrate that mid- and higher elevation populations of *P. nettingi* are declining, and also suggest that *P. cinereus* are expanding their vertical distribution farther into *P. nettingi* territory, and in doing so, are potentially having a negative impact on longterm *P. nettingi* occupancy.

Jaeger (1974) suggested that competition can occur indirectly through exploitation of a resource, directly through interference in obtaining a resource, or it can occur through a combination of both mechanisms. *Plethodon nettingi* and *P. cinereus* likely compete through both exploitation and interference due to their similarities in morphology and habitat. It is unlikely, but possible that *P. nettingi* and *P. cinereus* compete for food resources or foraging space at the higher elevations. Jaeger (1972) determined that food may be limiting during periods of dry weather; however, Fraser (1976a) concluded that competition was only relevant during these times if species shared cover objects or if all individuals emerged to forage at the same time during the first wet period following a dry period. Empirical evidence suggests that salamanders do not clump together under refugia during dry conditions, and their staggered feeding behavior prevents competition with one another during foraging (Fraser, 1976a). *Plethodon nettingi* and *P. cinereus* generally consume the same major food taxa and size of prey; however, the fact that *P. nettingi* occurs in a physiographic province that receives more rainfall than any of the surrounding provinces suggests conditions that promote food competition (i.e., dry weather) are less likely to occur within *P. nettingi* range compared to surrounding areas (Pauley and Clovis, 1980). As an alternative hypothesis, it has been suggested that competition may occur for space, specifically for favorable nesting sites and possibly territory (Fraser, 1976a).

Some evidence has suggested intraspecific competition for food occurs between *P. cinereus* individuals. However, food was found to be more limiting on warm days compared to cool, wet days (Jaeger, 1980). Furthermore, it has been suggested that some individuals may consistently occupy optimal foraging territory, implying that interference competition, not necessarily the exploitation of food, may occur between conspecifics (Jaeger, 1980).

Competition for high moisture sites is another possible, but in this case an unlikely, source of competition between *P. nettingi* and *P. cinereus* at high elevations. Laboratory studies determined that *P. nettingi* loses moisture at a greater rate compared to *P. cinereus,* and surveys found that *P. nettingi* were more often located at microsites with higher relative humidity compared to *P. cinereus* (Pauley and Clovis, 1980). The ability of *P. cinereus* to tolerate microhabitats with less moisture compared to *P. nettingi* suggests that high moisture sites are not a limiting factor. In a similar study, Jaeger (1971a) compared moisture preference and dehydrations rates between *P. cinereus* and the Shenandoah salamander (*Plethodon shenandoah*) at sympatric sites and found that *P. shenandoah* was more tolerant of body moisture loss, which partially explained its tendency to inhabit talus habitat which was too dry for *P. cinereus* to tolerate (Jaeger, 1971b). *Plethodon nettingi* is hypothesized to compete with *D. ochrophaeus* for moist sites at low elevations where temperatures tend to be warmer and drier (Pauley and Clovis, 1980; Pauley 2008a). Hypotheses regarding salamander competition for territory and nesting sites are therefore more plausible for explaining competitive interactions between *P. nettingi* and *P. cinereus.*

Observations of *P. nettingi* and *P. cinereus* nesting sites indicate that they nest in the same habitat types (i.e., under rocks, logs, and bark; Pauley, 2005). Furthermore, other studies have noted aggressive behavior of brooding *P. cinereus* females towards conspecifics (Highton and Savage, 1961; Bachmann, 1964), which suggests higher territoriality in *P. cinereus* (Fraser, 1976a). Documented evidence suggests competition for burrows might be possible between similar sized salamanders (Fraser, 1976b; Maiorana, 1978; Pauley and Clovis, 1980), and this interaction may be present between *P. nettingi* and *P. cinereus* based on body size similarities (i.e., snout-vent length; Pauley and Clovis, 1980). Cover objects may also be a source for competition between *P. nettingi* and *P. cinereus.* Two other plethodontid salamander species, the Pigeon Mountain salamander (*Plethodon petraeus*) and the northern slimy salamander (*Plethodon glutinosus*) are suspected to compete for cover objects that provide adequate moisture (Marshall et al., 2004). Evidence has shown there is no discrepancy between type or size of cover objects used by *P. nettingi* and *P. cinereus* (Pauley and Clovis, 1980), thus both species use similar cover objects and may compete for those with optimal conditions. Exploitation of all of these resources (nesting sites, burrows, and cover objects) by *P. cinereus* may be possible due to greater morphological variation between sympatric and allopatric populations of *P. cinereus* and *P. nettingi.* Adams et al. (2007)

compared head and body morphology of sympatric and allopatric *P. nettingi* and *P. cinereus* populations and were able to illustrate character displacement between sympatric populations of *P. cinereus* and *P. nettingi* in the form of variable cranial morphology. *Plethodon nettingi* individuals were significantly larger than *P. cinereus,* and larger bodies, especially larger heads, may limit the extent of burrows salamanders can occupy (Fraser, 1976b; Maiorana, 1978), which may imply more burrows are accessible to *P. cinereus* than *P. nettingi*. Adams et al. (2007) hypothesized that the flexibility in morphology of *P. cinereus*, as well as their higher tolerance to more variable habitat, allows them to adapt faster to environmental conditions compared to *P. nettingi*. Along with the hypothesis of successful resource exploitation by *P. cinereus*, this may explain the increased success and occupancy of *P. cinereus* at higher elevations in 2011 compared to 1978-79.

Although it is likely *P. nettingi* and *P. cinereus* are competing for resources, this does not fully explain why *P. cinereus* are potentially outcompeting *P. nettingi* at higher elevations, especially when *P. cinereus* occupancy appears negatively correlated with elevation. This pattern may be explained by the hypothesis that *P. cinereus* is outcompeting *P. nettingi* through interference competition, such that *P. cinereus* is a superior competitor compared to *P. nettingi*. Wicknick and Pauley (1998) suggested both *P. nettingi* and *P. cinereus* are territorial and actively defend their home ranges. But Jaeger et al. (1982) demonstrated the strength of territoriality of *P. cinereus*, finding them to expel intruders in 74% of encounters. As further evidence of territoriality, *P. cinereus* has been found to exhibit strong homing in a study that found 91% of recaptured individuals within 1 m of their original capture site (Gergits and Jaeger, 1990). It is possible that as *P. cinereus* moves into *P. nettingi* territory, the latter species is less familiar with heterospecific individuals, and are more easily outcompeted by the more aggressive *P. cinereus*. A comparison of behavior between *P. cinereus* and the northern ravine salamander (*Plethodon electromorphus*) found that *P. cinereus* individuals from allopatric populations behaved more aggressively when introduced to conspecifics, whereas allopatric individuals of *P. electromorphus* behaved more submissively in comparison to *P. cinereus* when encountering conspecifics (Deitloff et al., 2008). It was hypothesized that a first time encounter of *P. electromorphus* with *P. cinereus* in the field would result in *P. electromorphus* behaving submissively. This phenomenon may explain the success of *P. cinereus* at higher elevations if these *P. nettingi* populations are unconditioned for competition with a more aggressive species.

Other competitive relationships between *Plethodon* salamanders at high elevations have been studied in detail. Hairston (1949; 1951; 1980) analyzed competition between sympatric populations of salamanders within the Jordan's salamander species complex (hereafter *Plethodon jordani*) and salamanders within the slimy salamander species complex (hereafter *Plethodon glutinosus*). In general, species within the *P. jordani* complex inhabit higher elevations, whereas species in the *P. glutinosus* complex inhabit lower elevations. Removal experiments illustrate that individuals in the *P. glutinosus* complex could exist at higher elevations in the absence of individuals in the *P. jordani* species complex, but the latter species complex restricts the former from expanding upslope. Similarly, Pauley and Clovis (1980) hypothesized that *P. nettingi* are capable of inhabiting lower elevations, but competition with *P. cinereus* and *D. ochrophaeus* is possibly restricting them to the mountain tops. Similarly, effects of competitive interactions with *P. cinereus* appear to restrict *P. shenandoah* to isolated pockets through competition, even though the latter is physiologically capable of inhabiting habitats outside its current distribution (Jaeger, 1971a; 1971b; 1974).

Plethodon nettingi may also compete with *D. ochrophaeus* for moist spots, burrows, and cover objects, but competition between these species has historically occurred in lower elevation populations of *P. nettingi* (Pauley 2005; Pauley 2007a; Pauley and Clovis, 1980). Because evidence suggests *P. nettingi* and *D. ochrophaeus* have similar moisture level tolerances (Pauley, 2005), competition between these species possibly increases at the lower elevations as high moisture microhabitats become a limiting resource (Pauley and Clovis, 1980; Green and Pauley, 1987; Pauley, 2008a). Thus, similar moisture requirements of both species may reduce the potential of *P. nettingi* to expand its distribution into *D. ochrophaeus* territory.

There are additional opportunities to expand upon this study, especially with the use of occupancy modeling. Because occupancy modeling only requires detection and non-detection data (i.e., presence and absence), it permits more efficient use of time compared to obtaining true estimates of abundance. Additionally, occupancy modeling permits estimation of detection probabilities, whereas estimates of relative abundance are highly prone to detection errors. Thus, sampling units can be surveyed more frequently and may possibly allow for an increase in total number of sites sampled. More survey events and study sites would likely present a more accurate representation of occupancy probabilities for the three species examined in this study. A greater sample size may have provided a sufficient data set to apply the multi-season occupancy models. Future research should evaluate salamander occupancy at additional sites throughout the range of *P. nettingi*. Microhabitat covariates such as canopy cover, overstory and shrub density, cover object availability, temperature, relative humidity, soil properties, and vegetation should be included in occupancy models to evaluate the environmental covariates that regulate the vertical distribution of *P. nettingi*.

Conservation Implications – Although *P. nettingi* was granted protection under the Endangered Species Act as a federally threatened species (Federal Register, 1989), results from this study suggest that some *P. nettingi* populations are declining. Competitive interaction between sympatric species is a plausible explanation for such declines, but even this phenomenon may be facilitated by other, larger factors, such as habitat and climate change. Over the past one hundred years global surface temperatures have increased by 0.55° C, and out of those, the 11 warmest years have occurred since 1980 (IPCC, 2007). Warming temperatures could potentially impact salamander microhabitats, especially if they correlate with drier soils. In the coming decades, climate predictions estimate a global increase in temperature of about 0.2° C per decade (IPCC, 2007), and in the United States this also means increased patterns of abnormal weather, including increased drought frequency, less precipitation, and more intense storms (CCSP, 2008). The NatureServe global and subnational conservation status ranks *P. nettingi* as a G2, S2 species, meaning its status is "imperiled" and extremely vulnerable to predicted climate fluctuations (Byers and Norris, 2011).

On a smaller scale there are more direct, human-related factors that may also pose threats to conservation of *P. nettingi*. Habitat fragmentation, the creation of habitat edges, and other related activities tend to have negative impacts on woodland amphibians. Salamander abundance at forest edges have been found to be lower compared to abundance of salamanders located closer to the forest interiors (Demaynadier and Hunter, 1998; Marsh and Beckman, 2004; Marsh, 2007). It is unlikely *P. nettingi* habitat at the four sites used in this study was fragmented since 1978-79; however, maintenance activities along existing forest edges (e.g., resurfacing roads and regular trail foot traffic) near the *P. nettingi* populations may have reduced *P. nettingi* abundance in these edge areas (Pauley, 1991; 2008b). Limited road and trail usage near *P. nettingi* populations may help abate fragmentation impacts on *P. nettingi* abundance.

Determining how these potential threats are affecting *P. nettingi* populations at present and in the future is important for conserving this species. My research illustrates the importance of establishing benchmark *P. nettingi* monitoring sites. These longterm sites will help management agencies assess the longterm status of *P. nettingi* populations. A practical solution would be to use detection and non-detection (i.e., presence and absence) assessments, which would permit monitoring of a greater number of sites within relatively shorter time periods. Thus, *P. nettingi* populations could be monitored and assessed regularly (i.e., every 5-10 years).

CHAPTER III – Environment: 1978 vs. 2011

Introduction – The intimate relationship salamanders share with their environment is due to dependence on their surroundings to maintain appropriate body temperature and moisture absorbance. The three terrestrial salamanders (*Plethodon nettingi, Plethodon cinereus,* and *Desmognathus ochrophaeus*) examined in this study rely primarily on soil and leaf litter for moisture. They absorb moisture through their skin from the ground (Spight, 1968) and not from the surrounding air, which partly explains their subterranean nature. Salamanders are also dependent on their environment for coolness and warmth. They cannot regulate their own body temperature, which leads them to make behavioral adjustments according to their environment (Brattstrom, 1963). Soil and air temperature tolerations are two factors that influence salamander distribution in their environment (Hutchison, 1961; Spotila, 1972). A third factor, relative humidity, is also influential and strongly correlated to habitat temperature and moisture (Shelford, 1914). These three environmental factors — moisture, temperature (specifically of soils), and relative humidity— were examined in 1978 and again in 2011 to determine and compare the habitat conditions of the threatened species, *P. nettingi,* and competitive salamander species in their habitat in the high elevations of the Allegheny Mountains in West

Virginia.

Soils – Soil is a natural product of the abiotic environmental factors, climate, time, topography, and geologic parent material. These factors further interact with organic material and produce soil types which vary depending on the combined conditions of those factors (McBratney et al., 2000). In the Allegheny Mountains the hardwood and spruce-dominated forests at elevations over 1000 m generally grow on soils classified as Inceptisols and Spodosols (Jenkins, 2002). Inceptisols are "recent" soils with only slight profile development and their natural productivity is highly variable. They are common in montane regions because steep slopes tend to slow profile development. Spodosols are naturally poor in fertility and occur in moist conditions and in cold regions where conifers typically dominate the forests (Brady and Weil, 2008). Both of these soils are relatively well-drained, and in high elevations of the Alleghenies, rock fragments and boulders are common, resulting in a shallow root zone (Duiker, 2004).

The history of timbering and subsequent burning of these forests and soils highly influenced their formation on the landscape. For many centuries before these major disturbances occurred, the temperate forests of the Allegheny Mountains experienced relatively uninterrupted growth, allowing rich layers of soil to develop and build over time. When wildfires burned over the region they destroyed rich topsoil layers of approximately 30 to 90 cm in thickness (Brooks, 1911). In 1908, conservationist A.B. Brooks, describing areas he observed in Randolph County, wrote, "The brake land has been burned over so often that the soil is destitute of humus and is dead" (Clarkson, 1964). Evident scars remain on the surface in areas where topsoil burned down to the bedrock exposing large, emergent rocks and boulders. Red spruce forests were especially susceptible because the rich, deep humus often burned to the bedrock (Clarkson, 1964). In the years following lumbering and wildfires, erosion became a serious problem. Rain easily washed away the thin, topsoil, further reducing the land's fertility and contributing to its barren surface (Department of Agriculture, 1939). The extreme resilience of the forests has since redeveloped topsoil to an extent throughout most of the Allegheny Mountains. Today, rocky substrate covered by a thin topsoil layer is common at the sites used in this study (Figure 10). In this study, I evaluated soil conditions during the year 2011 at four sites with *P. nettingi* populations to describe the habitat in terms of percent soil moisture and soil pH, and to compare these with soil moisture and pH conditions in 1978 (Pauley and Clovis, 1980).

Figure 10. An example of habitat at Spruce Knob, located in the Monongahela National Forest in West Virginia. Photo by author.

Temperature – The significance of temperature on a habitat is measured at multiple levels. For instance, on a landscape scale the climate of the high Alleghenies can be described as cold continental with a moderate summer and without a dry season (Dfb Koppen classification) (Pidwirny, 2011). The range of precipitation can be extreme, ranging from 226 cm in Bayard, Grant County in 1926 to 25 cm in Upper Tract, Pendleton County in 1930, but the annual average precipitation is 100-115 cm (Batty, 2012). The influence of temperature on habitats at a small scale can also be significant. For example, research on red spruce saplings showed soil temperature to be a better indicator of net photosynthesis compared to air temperature (Paul et al., 1997).

Large-scale climate change is of concern in mountainous regions because of species dependence on the cool, moist habitats of the high elevations. If temperatures increase, some animals risk losing habitat, particularly those that are incapable of migrating or that are slow in moving to higher elevations (Byers and Norris, 2011). Small scale changes in temperature also threaten these habitats and are caused by various activities, including road or trail construction and maintenance, timber harvests, ski slope construction, and clearing utility right-of-way corridors. Most often these changes facilitate an increase in microsite temperatures due to canopy removal (Laurence et al., 2011). But unlike regional climate change where effects are measured over centuries, the effects from canopy removal are usually immediate and may last from a few weeks to more than a decade later. For instance, Reichenbach and Sattler (2007) compared numbers of salamanders in pre- and post-timbering plots and found the numbers one year after timbering decreased by 41 percent. Twelve years later the number of salamanders remained at 45 percent below the pre-timbering numbers. Reichenbach and Sattler attributed much of this decline to less canopy closure, opening the forest to more sun and wind, and thus causing changes in temperature.

Localized temperature extremes, natural or human-caused, can influence species distribution. For instance, salamanders may be forced to compete with one another for cover objects if temperatures get too high. Mathis (1990) determined territoriality in *P. cinereus* by documenting large individuals under large cover objects; and if abandoned, smaller individuals would invade the territory and occupy the large cover objects. Mathis further found the temperature of soils at 5 cm depth under the large cover objects to be significantly cooler than soils under smaller cover objects at equal depth. But under small cover objects soil temperatures were no different than those from random samples of soil beneath leaf litter. Mathis suggested larger cover objects provide refuge for salamanders from extreme temperatures, whereas smaller cover objects do not. Soil temperature is therefore an important determinate for individual salamander distribution. Mathis found no difference in air temperature between samples under large cover objects, small cover objects, and leaf litter, indicating air temperature is not as directly influential as soil temperature on salamander distribution. Temperature is thus an important variable in *P. nettingi* habitat. The study presented here documented both soil and air temperatures during the year 2011 at sites with *P. nettingi* populations to describe the habitat and to compare with soil and air temperatures from 1978 (Pauley and Clovis, 1980).

Relative humidity – Relative humidity (RH) is the amount of water vapor in the air in relation to the maximum amount of water vapor the air could hold. Relative humidity in the Allegheny Mountains is typically high during the summer. Blankets of clouds hiding the mountaintops at night and early morning are evidence of the high amount of water held in the air during the days. The average RH in Elkins, West Virginia (a city generally located between the four sites used in this study) in the months of June through September is 94% and 60% for morning and afternoon, respectively (NOAA, 2012). However, the average elevation of the city is only about 610 m and the peaks of the Alleghenies reach up to 1482 m at Spruce Knob, meaning the thinner air and cooler temperatures at the mountaintops tend to cause more condensation and rainfall compared to lower elevations. Even so, Elkins already receives a substantial amount of annual rainfall. The average annual precipitation received by the city is 117 cm, meaning the mountaintops receive considerably more rainfall. During the year of this study, 2011, the average precipitation in West Virginia was 137 cm, which was 18 percent above normal (NOAA, 2012). The high RH and precipitation made this a favorable study season for salamander research. Salamander activity is more dependent on precipitation and humidity than it is on air and ground temperatures due to their need to stay moist (Bogert, 1952). Salamanders expose relatively more wet body surface to the air than any other terrestrial vertebrates (Spight, 1968). An abnormally dry and warm season could easily influence surface abundance by forcing salamanders to retreat under ground to stay cool and moist. The 2011 humidity and rainfall levels were representative of a typical season in the Alleghenies, and likely supported a typical season of salamander activity. This study documented RH during the year 2011 at four sites with *P. nettingi* populations to describe the habitat and to compare with RH values recorded in 1978 (Pauley and Clovis, 1980).

Methods – I surveyed environmental variables at four sites in the West Virginia Monongahela National Forest: Spruce Knob in Pendleton County, Dolly Sods in Tucker County, Stuart Knob in Randolph County, and Gaudineer Knob in Pocahontas County. The exact survey locations at each site are identical to locations surveyed in 1978 (Pauley and Clovis, 1980).

At each site I established quadrats within the vertical range of *P. nettingi* (Pauley and Clovis, 1980). Using a handheld altimeter, quadrats of 10 x 20 m were spaced at regular elevation intervals of 12.2 m, and located linearly along the same general transect used at each site in 1978 (Pauley and Clovis, 1980). Because the vertical distribution of *P. nettingi* varied between sites in 1978, the ranges of altitudes are not identical and, consequently, the sites have different numbers of quadrats (Table 1).

Within each quadrat I determined several environmental properties. I measured soil temperature at 3 cm depth using soil temperature probes. I measured relative humidity and air temperature at ground level using hygrometers. I collected soil and leaf litter samples, and from these, I determined percent soil moisture, soil pH, and percent leaf litter moisture. I collected data from each quadrat on two separate occasions between June and September of 2011. Data were always collected within a one-hour period sometime between noon and 4 pm, and after a 48-hour absence of rainfall.

Data were averaged, first by elevation, and then by site. When possible, I compared data to the 1978 environmental data collected by Pauley and Clovis (1980). I used Student's t-test to determine statistical differences between means.

Results – Average soil moisture was roughly the same at all sites in 2011 (~45%) with the exception of Guadineer Knob, which was slightly higher (52.1%) (Table 5). Soil pH did not vary substantially between sites, staying in the range of 4.5 – 5 pH. Stuart Knob and Gaudineer Knob seemed to be the cooler two of the four sites, both in soil and air temperature. Relative humidity was highest at Gaudineer Knob (87%); the other sites RH averaged between 73% and 80%. Leaf litter moisture was more variable, ranging from 50.3% at Stuart Knob to 37.5% at Gaudineer Knob, which was inconsistent with the pattern in percent soil moisture. Environmental data from 1978 were incomplete (e.g., there was no soil moisture data from Gaudineer Knob) (Pauley and Clovis, 1980), however the data that were available were compared with the 2011 results.

Table 5. Means and standard errors of environmental variables measured during the summer of 2011 at four sites within the Monongahela National Forest in West Virginia.

	Spruce Knob	Dolly Sods	Stuart Knob	Gaudineer Knob
Soil moisture (%)	44.7 ± 1.6	44.4 ± 2.9	45.5 ± 3.8	52.1 ± 2.8
Soil pH	4.9 ± 0.2	4.6 ± 0.1	4.8 ± 0.1	4.6 ± 0.1
Soil temperature (°C)	14.4 ± 0.1	15.9 ± 0.1	12.6 ± 0.3	12.9 ± 0.4
Air temperature (°C)	20.3 ± 0.3	21.4 ± 0.2	16.5 ± 0.4	18.4 ± 0.1
Relative humidity (%)	77.3 ± 0.8	74.8 ± 1.5	77.6 ± 1.6	87.0 ± 1.6
Leaf litter moisture (%)	39.9 ± 1.8	45.2 ± 2.3	50.3 ± 2.5	37.5 ± 2.4

Both Spruce Knob and Stuart Knob had significantly higher average soil moisture in 2011 compared to 1978 ($p \leq 0.001$), ranging from 21.7% to 44.7% and from 21.9% to 45.6%, respectively. Dolly Sods had higher average percent moisture, but it was not significant (Table 6); data from 1978 were unavailable for a comparison at Gaudineer Knob. Soil pH was the most consistent environmental variable between 1978 and 2011 with no significant changes (Table 7).

Table 6. Average soil moisture (± SE) (%) from 1978 and 2011 at four sites with known *P. nettingi* populations in the Monongahela National Forest, WV.

Site	1978**	2011	Difference	P-value
Spruce Knob	21.7 ± 2.3	44.7 ± 1.2	+ 23.0	< 0.001*
Dolly Sods	36.4 ± 2.6	44.4 ± 2.9	+ 8.0	0.06
Stuart Knob	21.9 ± 3.6	45.6 ± 3.8	+ 23.7	< 0.001*
Gaudineer Knob	N/A	52.1 ± 2.8	--	--

* Significance difference

** From Pauley and Clovis (1980)

Table 7. Average soil pH (± SE) from 1978 and 2011 at four sites with known *P. nettingi* populations in the Monongahela National Forest, WV.

Site	1978*	2011	Difference	P -value
Spruce Knob	5.1 ± 0.1	4.9 ± 0.2	- 0.2	0.23
Dolly Sods	4.3 ± 0.1	4.6 ± 0.1	+ 0.3	0.12
Stuart Knob	4.5 ± 0.2	4.8 ± 0.1	+ 0.3	0.13
Gaudineer Knob	4.4 ± 0.1	4.6 ± 0.1	+ 0.2	0.16

* From Pauley and Clovis (1980)

Soil temperature was considerably different between years ($p < 0.05$). At Spruce Knob average temperature ranged from 11.9°C to 14.4°C. Dolly Sods ranged from 14.4°C to 15.9°C. Conversely, the opposite trend appeared at the other two sites ($p < 0.05$): Stuart Knob ranged from an average soil temperature of 18.1°C to 12.6°C, and Gaudineer ranged from 14.1°C to 12.9°C (Table 8).

Table 8. Average soil temperature (± SE) (°C) from 1978 and 2011 at four sites with known *P. nettingi* populations in the Monongahela National Forest, WV.

Site	1978**	2011	Difference	P-value
Spruce Knob	11.9 ± 0.2	14.4 ± 0.1	+ 2.5	< 0.001*
Dolly Sods	14.3 ± 0.2	15.9 ± 0.1	+ 1.6	< 0.001*
Stuart Knob	18.4 ± 0.4	12.6 ± 0.3	+ 5.8	< 0.001*
Gaudineer Knob	14.1 ± 0.2	12.9 ± 0.4	- 1.2	0.02*

* Significance difference

** From Pauley and Clovis (1980)

Air temperature at ground level was significantly warmer ($p < 0.05$) at both Spruce Knob and Gaudineer Knob in 2011, ranging from 14.1°C to 20.3°C at Spruce Knob and from 13.5°C to 18. 4°C at Gaudineer Knob (Table 9). Data from 1978 at Dolly Sods and Stuart Knob were unavailable for comparison.

Table 9. Average air temperature (± SE) (°C) from 1978 and 2011 at sites with known *P. nettingi* populations in the Monongahela National Forest, WV.

Site	1978**	2011	Difference	P-value
Spruce Knob	14.1 ± 0.6	20.3 ± 0.3	+ 6.2	< 0.001*
Dolly Sods	--	21.4 ± 0.2	--	--
Stuart Knob	--	16.5 ± 0.4	--	--
Gaudineer Knob	13.4 ± 0.9	18.4 ± 0.1	+ 5.0	< 0.05*

* Significance difference

** From Pauley and Clovis (1980)

Relative humidity ranged from 70.1% in 1978 to 77.3% in 2011 at Spruce Knob ($p < 0.05$). At Dolly Sods and Stuart Knob RH was lower in 2011 ($p<0.001$). At Dolly Sods the mean was 87.7% in 1978 and 74.8% in 2011. At Stuart Knob average RH ranged from 87.7% to 77.6%. There was no significant change in RH at Gaudineer Knob (Table 10).

Table 10. Average relative humidity (± SE) (%) from 1978 and 2011 at four sites with known *P. nettingi* populations in the Monongahela National Forest, WV.

Site	1978**	2011	Difference	P-value
Spruce Knob	70.1 ± 3.2	77.3 ± 0.8	+ 7.2	0.046*
Dolly Sods	87.8 ± 0.9	74.8 ± 4.3	- 13.0	< 0.001*
Stuart Knob	87.7 ± 1.7	77.6 ± 1.6	- 10.1	< 0.001*
Gaudineer Knob	86.0 ± 1.1	87.0 ± 1.2	+ 1.0	0.63

* Significance difference

** From Pauley and Clovis (1980)

Discussion – Generally, all sites represented forest floor microhabitats that experienced warm to cool air temperatures; had cooler and slightly acidic soils with high moisture content; relatively high humidity; and relatively moist leaf litter. Over the past 32 years, a uniform warming or cooling trend appears absent across all sites; however, some sites showed signs of either one of these patterns or the other. This study recognizes and acknowledges the probability of randomness and false significance due to annual variation in temperature and precipitation. As such, implications made from the data can only be speculative. Nonetheless, the study serves to summarize and describe the environmental conditions of *P. nettingi* habitat as they relate to the species status in 2011.

Spruce Knob appears to be getting warmer and wetter. In 2011, this site experienced higher percent soil moisture, higher relative humidity, and higher soil and air temperatures, which may be a sign of increased forest density and a fuller canopy. A decline in canopy cover often leads to habitat drying conditions, which suggests a dense forest would contain moisture more effectively than a thinner forest (Laurence, et al., 2011). A fuller canopy does not necessarily imply a decline in temperature, but it is interesting temperatures were not more consistent. A possible explanation is the combined effect of the low and high elevations. The five to seven sites used in this study at the highest elevations at Spruce Knob had a clear difference in substrate, which can be described as rock talus with shallow topsoil. Also at these sites the forest was blatantly more open with fewer understory trees. The lower elevation sites were denser with young trees and had noticeably thicker topsoil. Hypothetically the high elevations may be experiencing increased temperatures whereas the low elevations are retaining more moisture in 2011 compared to in the past. It is likely the high soil and air temperatures are a product of the high overall forest moisture insulating the microhabitat conditions.

Dolly Sods also appeared to exhibit a warmer, drier forest floor microhabitat in 2011 compared to 1978. Soil temperature appeared to have increased while relative humidity decreased. This pattern is more indicative of a thinning canopy (Herbeck and Larsen, 1998). Brooks and Kyker-Snowman (2008) studied timbering effects on forest floor temperature and RH and determined selective harvesting that retains canopy has a small effect on temperature (<1°C) and no effect on RH. By contrast, in their study, Reichenbach and Sattler (2007) attributed the 41 percent decline in salamander numbers to post-timbering effects— namely more opened canopy, increased wind and sun, and higher temperatures. Thus, canopy influences on microhabitat warming and drying are dependent on the extent to which canopy is reduced. If Dolly Sods has experienced a dramatic change in canopy cover since 1978, it is reasonable RH has decreased and soil temperatures have increased.

Stuart Knob displayed some irregular environmental patterns, such that it appeared to have cooler soil temperatures, and RH was lower where soil moisture content was greater in 2011 compared to 1978. Soil moisture and RH both tend to increase or decrease in response to similar effects (e.g., timber harvests or edge effects) (Laurence et al., 2011; Gehlhausen et al., 2000), which is inconsistent with what was observed. However, the mean RH at Stuart Knob in 2011 was similar to two of the other sites implying the 2011 RH was not considerably low.

In 2011 Gaudineer Knob had lower soil temperature, but higher air temperature compared to 1978. Relative humidity remained consistent between the years. This pattern is contradictory to research showing trends in soil temperatures associated with trends in air temperatures (Qian et al., 2011). However, like at Spruce Knob, variability in elevations and forest dynamics could be responsible for irregular environmental patterns. Unfortunately soil moisture data from 1978 were unavailable for a between-year comparison.

Despite the suggested trends shown by our data comparisons, I caution against using these conclusions as definitive evidence for habitat change. Because of the methods employed by Pauley and Clovis (1980) and repeated in 2011, sample sizes (n = 8 -10) were relatively low per elevation, and elevation data (n = 7 - 13) were averaged to determine site values. Thus, greater sample sizes and additional annual values of these parameters would yield more reliable conclusions. These data are meant to be used to 1) describe *P. nettingi* habitat in 2011; 2) expose potential trends that may possibly (not definitively) be occurring at each of these sites; and 3) encourage future sampling to illustrate a more complete image of how environments at each site might be changing over time.

CHAPTER IV – Vegetation: 1978 vs. 2011

Introduction - The forests of the West Virginia Allegheny Mountains have a history of significant disturbances; most of these were related to timbering operations that took place primarily between 1880 and 1920 (Lewis, 1998). This period was the peak of the timber industry in West Virginia. Due to this momentum and the relatively high value of spruce wood, the mountainous regions of the state were thoroughly clear-cut, including nearly the entire area of the present Monongahela National Forest. Many of these harvests were followed by wildfires fueled by leftover slash and rich forest topsoil (from Lewis, 1998).

The present range of *Plethodon nettingi* falls almost entirely within the Monongahela National Forest and is restricted to elevations above 610 m in the northern part of the range, and above 1067 m in the southern part (Pauley, 2005; 2007b). Thus, the original forest in which *P. nettingi* evolved and adapted to over many hundreds of years was eliminated in a matter of a few decades; it is unknown the extent to which *P. nettingi* depended on the conditions of the original forest for survival. By taking refuge in rock crevices and boulder fields where they escaped the heat of the wildfires, *P. nettingi* were able to repopulate at least some of their original range (Pauley, 2008a). At the same time, second growth stands of forests regenerated across the mountains and have since experienced only a small fraction of controlled timber harvests. The vegetation of *P. nettingi* habitat is described as forests dominated by red spruce or yellow birch, and sometimes hemlock (Pauley, 2005). My observations of the forests at the four *P. nettingi* sites used in this study are consistent with these descriptions.

Clovis (1979) was the first to quantify vegetation characteristics at all four sites. The site with the highest elevations, Spruce Knob, was predominantly yellow birch, followed by red spruce, red maple, and black cherry. Dolly Sods, the most uncharacteristic of *P. nettingi* habitat out of the four sites, was abundant with red maple. Yellow birch, red maple, and red spruce dominated Stuart Knob; and Gaudineer Knob was most representative of a true red spruce forest.

Vegetation has not been found to be a significant indicator of *P. nettingi* (Clovis, 1979; Pauley and Clovis, 1980); however, observations of changes in forest characteristics could suggest alterations in salamander microhabitats. From personal experience visiting these sites regularly since 1976, Pauley observed changes such as the decline of *Bazzania sp.* (most likely *Bazzania trilobata*) and the recent presence of poison ivy (*Toxicodendron radicans ssp.*) (pers. comm., 2011). *Bazzania* is a liverwort that often grows in moist areas and is commonly associated with *P. nettingi* habitat (Pauley, 2005). Evaluating these sites again may highlight growth trajectories of the forests that could potentially affect *P. nettingi* distributions.

During the summer of 2011, the forests of Spruce Knob, Dolly Sods, Stuart Knob, and Gaudineer Knob were reevaluated using methods identical to those used in 1978 (Clovis, 1979; Pauley and Clovis, 1980). The purpose of this study was to describe the forest vegetation and ground cover of *P. nettingi* habitat. The absence of the 1978 raw data made it impossible to test for statistical significance between the two studies. However, I believed a reexamination of these forests was valuable, particularly for the benefit of characterizing *P. nettingi* habitat in 2011.

Methods – This study used methods identical to those conducted in 1978 (Clovis 1979; Pauley and Clovis, 1980). At four sites within the known range of *P. nettingi*, four transects were established that ran from high to low elevation, and averaged 25 m apart. Along each line five points were randomly placed (20 total points per site). I placed a quadrat of 2 x 10 m at each point and within it measured percent ground cover of rock, leaf litter, and bryophytes. I designated the top-right corner of each quadrat as the "point" for point-quarter measurements and measured four trees from each point. The recorded data included species, diameter at breast height (DBH), and distance from point. Trees were defined as those with woody stems greater than 10 cm DBH.

Results – The forests at all four sites were within approximately 20 years of each other in stand age based on increment boring data (Clovis, 1979). In 1978, Gaudineer Knob had the greatest mean density of the four sites, followed by Dolly Sods, Stuart Knob, and lastly Spruce Knob, for trees with DBH greater than 10 cm. Out of the four sites in 2011, Stuart Knob had the greatest mean density and Dolly Sods had the lowest (Table 11). In terms of average basal area, Dolly Sods had the greatest, while Stuart Knob had the lowest. Interestingly, this was reversed back in 1978; Stuart Knob had the greatest average basal area and Dolly Sods had the lowest. Although we were unable to test for statistical significance on this data, it may be indicative of potential growth patterns of these forests. Results suggest density increased at both Spruce Knob and Stuart Knob; and basal area has increased at Dolly Sods.

Table 11. Forest data from 1978 and 2011 at four sites with known *Plethodon nettingi* populations. Measurements were based on trees with > 10 cm DBH. *Data from Pauley and Clovis (1980).

Site	Elevation (m) USGS Quad	Stand Age* (years)	Mean Density (stems/ha)		Mean Basal Area (cm^2/ind.)	
			1978*	2011	1978*	2011
Spruce Knob	1341 (4400′) Spruce Knob	81	628	1810	353	236
Dolly Sods	1189 (3900′) Blackbird Knob	71	1470	1257	252	827
Stuart Knob	1158 (3800′) Bowden	89	671	1964	409	233
Gaudineer Knob	1295 (4250′) Durbin	81	2106	1798	277	251

Estimates of forest ground cover in 2011 are comparable to those from 1978 (Table 12). The percent of exposed rock at each site was relatively similar, especially at Gaudineer Knob, which showed zero percent rock during both time periods. Percent leaf littler was slightly more variable; Dolly Sods showed a slight decrease from 1978 to 2011 whereas Gaudineer Knob appears to have had slightly more leaf litter in 2011. But overall percentages were similar. The most variation in ground cover from 1978 to 2011 occurred in bryophytes, which was lower at all four sites in 2011. Gaudineer Knob showed the most reduction in bryophytes dropping from 66.3% to 34.2%. We were unable to test for statistical significance due to lack of raw data from 1978.

Despite not directly testing 1978 data with the 2011 results, a general comparison of summary data showed possible evidence of change in forest composition. At Spruce Knob tree species richness appeared to have declined as sampled data found only seven species in 2011 compared to ten species in 1978. On the other hand, relative density became more diverse; yellow birch was the dominant species in 1978 with 47.5%, but in 2011 American beech had the highest density with 41.3%. Relative frequency showed yellow birch and American beech were both abundant in 2011. In terms of relative basal area, yellow birch seemed to have the largest trees with 62.7% (Table 13).

Table 12. Forest ground cover data from 1978 and 2011 at four sites with known *Plethodon nettingi* populations. *Data from Pauley and Clovis (1980).

Site	Percent Rock		Percent Leaf Litter		Percent Bryophytes	
	1978*	2011	1978*	2011	1978*	2011
Spruce Knob	14.6	11.3	60.8	69.3	27.6	19.9
Dolly Sods	5.8	6.0	88.9	75.8	10.2	3.7
Stuart Knob	3.3	5.7	76.2	79.8	21.9	13.75
Gaudineer Knob	0	0	44.4	59.4	66.3	34.2

Table 13. Tree data from 1978 and 2011 at Spruce Knob, Monongahela National Forest, WV. Data are based on trees with >10 cm DBH. *Data from Pauley and Clovis (1980).

Species	Relative Density		Relative Basal Area		Relative Frequency	
	1978*	2011	1978*	2011	1978*	2011
Red Maple (*Acer rubrum*)	7.5	10.0	13.6	5.5	9.8	17.9
Red Spruce (*Picea rubens*)	11.3	2.5	18.0	1.0	13.7	5.1
Yellow Birch (*Betula alleghaniensis*)	47.5	26.3	34.6	62.7	31.4	23.1
American Beech (*Fagus grandifolia*)	6.3	41.3	7.7	4.6	3.9	28.2
Black Cherry (*Prunus serotina*)	6.3	3.8	11.4	2.1	9.8	2.6
Striped Maple (*Acer pensylvanicum*)	6.3	12.5	3.4	13.2	7.8	15.4
Mountain Holly (*Ilex montana*)	0	3.7	0	11.0	0	7.7
Sugar Maple (*Acer saccharum*)	5.0	0	6.0	0	7.8	0
Mountain Ash (*Sorbus americana*)	6.3	0	3.7	0	9.8	0
Hawthorn (*Crataegus sp*.)	2.5	0	1.4	0	3.9	0
Mountain Maple (*Acer spicatum*)	1.2	0	0.3	0	2.0	0

At Dolly Sods in 1978 relative density was highest with red maple (45.0%) followed by yellow birch (36.3%), and both species also had the highest relative basal area. Relative frequency showed red maple and yellow birch were the most common species, which was true in 2011, with the addition of mountain holly becoming more frequent. Mountain holly had the greatest relative density in 2011 with 30.4%. The 2011 survey found all of the same species as those found in 1978, with the addition of black cherry, which was not reported at Dolly Sods in 1978 (Table 14).

Stuart Knob showed a decline in tree species richness from 1978 to 2011, going from eight to five species. Yellow birch dominated the relative density in 1978 with 40.0%, but in 2011 red spruce had the greatest density with 60.0%. The highest relative basal area in 1978 and 2011 was red maple and red spruce, respectively. In 1978 yellow birch was the most frequent tree and in 2011 red spruce had the greatest relative frequency (Table 15).

Gaudineer Knob had the same tree species richness in 2011 compared to 1978, however I did not find mountain ash in 2011, but did find red maple. Red spruce dominated relative density, basal area, and frequency in both 1978 and 2011. Yellow birch was consistently the second most common tree species (Table 16).

The differences in importance values (IV) of tree species between 1978 and

2011 may also suggest changes in forest composition (Table 17). At Spruce Knob, Dolly Sods, and Stuart Knob the species with the greatest IV varied between the periods. It also suggested Spruce Knob was the most diverse site during both periods and Gaudineer Knob was the least diverse.

Table 14. Tree data from 1978 and 2011 at Dolly Sods, Monongahela National Forest, WV. Data are based on trees with > 10 cm DBH. *Data from Pauley and Clovis (1980).

Species	Relative Density		Relative Basal Area		Relative Frequency	
	1978*	2011	1978*	2011	1978*	2011
Red Maple (*Acer rubrum*)	45.0	16.5	45.7	21.4	43.9	22.2
Red Spruce (*Picea rubens*)	1.3	11.4	3.5	0.3	2.4	13.3
Yellow Birch (*Betula alleghaniensis*)	36.3	21.5	38.0	23.0	39.0	24.4
American Beech (*Fagus grandifolia*)	16.2	13.9	12.1	25.4	12.2	11.1
Black Cherry (*Prunus serotina*)	0	6.3	0	11.2	0	4.4
Mountain Holly (*Ilex montana*)	1.3	30.4	0.5	18.7	2.4	24.4

Table 15. Tree data from 1978 and 2011 at Stuart Knob, Monongahela National Forest, WV. Data are based on trees with > 10 cm DBH. *Data from Pauley and Clovis (1980).

Species	Relative Density		Relative Basal Area		Relative Frequency	
	1978*	2011	1978*	2011	1978*	2011
Red Maple (*Acer rubrum*)	18.8	13.8	47.3	13.3	21.4	15.2
Red Spruce (*Picea rubens*)	20.0	60.0	18.2	34.9	17.0	45.5
Yellow Birch (*Betula alleghaniensis*)	40.0	16.3	18.6	25.2	36.2	21.2
American Beech (*Fagus grandifolia*)	3.7	0	6.5	0	2.2	0
Black Cherry (*Prunus serotina*)	1.3	7.5	0.3	21.1	2.2	12.1
Mountain Holly (*Ilex montana*)	0	2.5	0	5.5	0	6.1
Black Birch (*Betula lenta*)	6.2	0	4.9	0	6.4	0
Mountain Ash (*Sorbus americana*)	5.0	0	1.9	0	8.7	0
Serviceberry (*Amelanchier canadensi)*	3.7	0	1.3	0	2.4	0

Table 16. Tree data from 1979 and 2011 at Gaudineer Knob, Monongahela National Forest, WV. Data are based on trees with > 10 cm DBH. *Data from Pauley and Clovis (1980).

Species	Relative Density		Relative Basal Area		Relative Frequency	
	1978*	2011	1978*	2011	1978*	2011
Red Maple (*Acer rubrum*)	0	1.3	0	0.6	0	3.2
Red Spruce (*Picea rubens*)	95.0	78.8	97.6	85.1	86.9	64.5
Yellow Birch (*Betula alleghaniensis*)	3.8	20.0	1.8	14.4	8.7	32.3
Mountain Ash (*Sorbus americana*)	1.2	0	0.5	0	4.3	0

Table 17. Importance values from 1979 and 2011 at sites with known *Plethodon nettingi* populations. Importance value (IV) is the sum of relative density, relative dominance, and relative frequency. *Data from Clovis (1979).

Species	Spruce Knob		Dolly Sods		Stuart Knob		Gaudineer Knob	
	1978*	2011	1978*	2011	1978*	2011	1978*	2011
Red Maple (*Acer rubrum*)	30.9	29.5	134.8	43.0	87.5	33.0		4.6
Red Spruce (*Picea rubens*)	43.0	7.9	7.2	24.8	55.2	116.2	279.5	167.3
Yellow Birch (*Betula alleghaniensis*)	113.5	67.2	113.3	50.6	94.8	45.3	14.3	56.3
American Beech (*Fagus grandifolia*)	17.9	70.8	40.5	30.1	12.4			
Black Cherry (*Prunus serotina*)	27.5	6.9		13.0	3.8	26.1		
Striped Maple (*Acer pensylvanicum*)	17.5	31.6						
Mountain Holly (*Ilex montana*)		14.6	4.2	58.6		10.2		
Sugar Maple (*Acer saccharum*)	18.8							
Mountain Ash (*Sorbus americana*)	19.8				15.6		6.0	
Hawthorn (*Crataegus sp.*)	7.8							
Mountain Maple (*Acer spicatum*)	3.5							
Black Birch (*Betula lenta*)					17.5			
Serviceberry (*Amelanchier canadensis*)					7.4			

Discussion – The Spruce Knob forest in 1978 had a relatively low density compared to the other three sites as well as a moderate to high average basal area. Often low density and high basal area are characteristic of larger-tree stands, which can indicate older forests (Barbour et al., 1999). Yellow birch was the dominant tree species, but the forest had the greatest species richness of all sites with ten different species represented. By comparison, the 2011 Spruce Knob forest only had seven recorded species. Mean density and basal area were similar to two of the other three sites in 2011. But when compared to 1978, density was over twice as much in 2011 and basal area was slightly lower. In 1978 the IVs of both yellow birch and American beech were comparable. Variation in these characteristics between the years may reflect a shift from a low-density, yellow birch forest to a more evenly diversified forest with many more young trees. The only notable difference in ground cover was the much lower percentage of bryophytes estimated in 2011 versus 1978. Lesica et al. (1991) suggested bryophytes are more successful in old-growth, or more mature forests, and may decline in younger forests. The absence of timbering at this site should thus have supported bryophyte colonization, yet this was not the observed pattern. Other studies have shown that microclimate effects, such as temperature change, from timber harvests are detrimental to bryophyte success (Fenton and Frego, 2005; Nelson and Halpern, 2005). More research is required to determine the pattern and significance of bryophyte colonization at this site.

Dolly Sods had the second highest density and the lowest basal area out of all the sites in 1978. The combination of high density and low basal area is typically indicative of a forest with relatively smaller trees overall (Barbour et al., 1999). Red maple and yellow birch were the dominant species at this time. The 2011 results showed Dolly Sods had the lowest tree density of all sites, which suggested density slightly decreased from 1978. But the most outstanding difference was in basal where Dolly Sods had a much higher average compared to the other three sites. This large increase in biomass may reflect maturity in the growth trajectory of the forest, such that a relatively less dense, but older forest will have larger trees overall (Barbour et al., 1999). This type of thinning pattern is often a symptom of competition during secondary forest succession (Yoda et al., 1963; Christensen and Peet, 1984; Roberts and Richardson, 1985; Gilliam, 2002). Furthermore, the increased IV of red spruce, American beech, and mountain holly, as well as the addition of black cherry in 2011, indicate a difference in overall forest composition. This change may be evidence of a shift from a moderately dense maple-birch forest in 1978 to a more diversified, yet mature forest in 2011.

Mean density was relatively low at Stuart Knob in 1978, but mean basal area was high compared to the other sites. Like the forest at Spruce Knob, the combination of these features may have indicated competitive self-thinning which occurs as forests age (Barbour et al., 1999). Species richness in 1978 was relatively high with eight species represented; the highest IV came from yellow birch followed by red maple. In 2011, mean density was greatest at Stuart Knob out of all the sites, and mean basal area was lowest. Such a pattern suggests the presence of numerous small or young trees growing in close proximity to one another (Barbour et al., 1999). The IV distribution in 2011 was dramatically different from 1978, with red spruce easily dominating other species. Oosting and Billings (1951) mapped the age distribution of red spruce in the White Mountains of New Hampshire and found that the forests had a high density of young trees. Barbour et al. (1999) stated this type of age distribution indicated a forest population with a strong ability to maintain itself as a mature community. The differences in measurements from 1978 to 2011 may therefore be a sign of the forest transforming into a more characteristic red spruce forest. In addition, the 2011 density and basal area are similar to those of Gaudineer Knob, which out of all sites is the most representative of a true red spruce forest.

In 1978 Gaudineer Knob had the highest relative tree density of all four sites and the second lowest average basal area, meaning it likely had many young trees relative to the other sites' forests. It was also the least diverse forest, predominantly composed of red spruce, and very few yellow birch and mountain ash. Similarly, in 2011 only three species were recorded in surveys. Red spruce continued to be the most prominent species, followed by yellow birch, but there was not any mountain ash recorded; instead, red maple was found to be present. The 2011 tree density was slightly less than 1978 as was mean basal area. One of the most notable differences between the two years was in the ground cover estimates. Percent bryophyte cover dropped where percent leaf litter increased in 2011. But overall the measurements seem to indicate a similar forest in 2011 to that of the one in 1978.

CONCLUSION

Plethodon nettingi is a federally threatened salamander species confined to high elevations of the Allegheny Mountains in West Virginia. Historically, *P. nettingi* probably inhabited a wide range that extended beyond the five counties in which they are known to occur. Their small range and disjunct distribution are products of intense logging operations, followed by wildfires, which occurred in West Virginia around the turn of the 19th Century (Pauley, 2008a). More recently, habitat degradation and loss, as well as increased competition with similar species, has limited *P. nettingi* from expanding their distribution (Highton, 1972; Pauley and Clovis, 1980; Pauley, 2005; Adams et al., 2007).

This study found *P. nettingi* occupancy probability increased with elevation, indicating they are more successful at higher elevations. Competitor occupancy probability decreased with elevation, supporting the hypothesis that *P. nettingi* are physiologically better suited than the competitors to inhabit the cooler high elevations. However, at the highest elevations, usually dominated by *P. nettingi*, the occupancy probability of *P. cinerues* showed an increased. At these same elevations, *P. nettingi* occupancy was decreasing. Therefore, I suggest competition at the higher elevations (i.e., between 1229 and 1378 m) is affecting these species' distributions. I hypothesize *P. cinereus* may be outcompeting *P.*

nettingi through a combination of resource exploitation and interference. Territory, burrows, and nesting sites may all potentially be limiting resources at these elevations.

The habitats at Spruce Knob, Dolly Sods, Stuart Knob and Gaudineer Knob generally showed signs of warm to cool microhabitats with cool soils that were slightly acidic. Relative humidity was high as was leaf litter moisture. When compared to similar data collected over 30 years earlier, each site showed different signs of possible patterns, whether it be a cooling, warming, or consistent trend. An overall warming or cooling trend across all sites was absent. More research is needed to determine if these patterns are indicative of environmental changes or simply due to natural seasonal fluctuations; therefore, we cannot make any definitive conclusions at this point in time.

The forests at Spruce Knob, Dolly Sods, Stuart Knob, and Gaudineer Knob were dominated by yellow birch, red spruce, red maple, or a combination of these species. Forests were similar in composition to the forests in 1978. However, comparisons suggested possible growth trajectories, including more even species diversity, and the increase of young, understory trees at some sites. Further research may indicate how potential changes in these forests could be influencing salamander microhabitats, but at this time I cannot determine if these growth patterns are significant.

Although additional surveys are needed to make conclusive links between changes in salamander occupancy and changes in habitat, some observed correlations could potentially have more meaning with future research. Spruce Knob was observed as being warmer and wetter in 2011 compared to 1978. *Plethodon nettingi* presence at Spruce Knob was similar during both time periods, but presence and abundance of *P. cinereus* and *D. ochrophaeus* was much greater in 2011 than 1978, suggesting changes in environment are favoring the competitive species. At Dolly Sods, data indicated habitat might have become warmer and drier over the years. The salamander distribution showed *P. nettingi* decreased in both presence and abundance in 2011, but both competitive species increased in these areas. It is possible a change in species distribution was influenced by habitat dynamics. It also supports the hypothesis that *P. nettingi* may be experiencing increased competition at higher elevations.

Conservation Implications – *Plethodon nettingi* was granted protection under the Endangered Species Act as a federally threatened species; however, their status has remained fragile since the time of their listing in 1989. This study suggested that some *P. nettingi* populations are declining. Competitive interaction between sympatric species is a plausible explanation for such declines, but even this phenomenon may be facilitated by other, larger factors, such as habitat and climate change. These factors may range from the effects of habitat fragmentation to the effects of changing regional weather patterns. Determining how these potential threats are affecting *P. nettingi* populations at present and in the future is important for conserving this species. Establishing benchmark *P. nettingi* monitoring sites at the locations used in this study is a potential strategy to monitor and manage the longterm status of this species. This research, coupled with regular *P. nettingi* monitoring, may aid in identifying opportunities to prevent or curb *P. nettingi* population declines.

BIBLIOGRAPHY

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

Bachmann, M. D. D. 1964. Maternal behavior of the red-backed salamander *Plethodon cinereus*. Ph.D. Thesis, Univ. of Michigan, Ann Arbor.

Bailey, L.L., T.R. Simons, K.H. Pollock. 2004. Estimating detection probability parameters for Plethodon salamanders using the robust capture-recapture design. Journal of Wildlife Management, pp. 1-13.

Barbour, M.G., J.H. Burk, W.D. Pitts, F.S. Gilliam, and M.W. Schwarts. 1999. Terrestrial Plant Ecology, 3rd Edition. Benjamin/Cummings, an imprint of Addison Wesley Longman, Inc. Menlo Park, CA.

Batty, K.T. 2012. Climate. The West Virginia Encyclopedia. West Virginia Humanities Council, 1310 Kanawha Blvd E, Charleston, WV 25301. Retrieved April, 2012 from <http://www.wvencyclopedia.org/articles/1314>

Blaustein, A.R., D.B. Wake, and W.P. Sousa. 1994. Amphibian declines: Judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology, Vol. 8, pp. 67-71.

Bogert, C.M. 1952. Relative abundance, habitats, and normal thermal levels of some Virginian salamanders. Ecology, Vol. 33, No. 1, pp. 16-30.

Brady, N.C. and R.R. Weil. 2008. The nature and properties of soils. Prentice Hall, New Jersey.

Brattstrom, B.H. 1963. A preliminary review of the thermal requirements of amphibians. Ecology 44: 238-255.

Brooks, A.B. 1911. Forestry and Wood Industries. Vol. 5. Morgantown: West Virginia Geological Survey.

Brooks, M.B. 1948. Notes on the Cheat Mountain salamander. Copeia, Vol. 4, No. 239-244.

Brooks, R.T. and T.D. Kyker-Snowman. 2008. Forest floor temperature and relative humidity following timber harvesting in southern New Englad, USA. Forest Ecology and Management, Vol. 254, pp. 65-73.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. A practical information-theoretic approach, 2nd ed. Springer Science + Business Media, LLC. New York, New York, USA. 488 pp.

Byers, E. and S. Norris. 2011. Climate change vulnerability assessment of species of concern in West Virginia. West Virginia Division of Natural Resources.

Calise, C. 1978. Bryophyte ecology in the high elevation forest of West Virginia. Unpublished mater's thesis. West Virginia University.

Christensen, N.L. and R.K. Peet. 1984. Convergence during secondary forest succession. Journal of Ecology Vol. 72, pp. 25-36.

Clarkson, R.B. 1964. Tumult on the Mountains: Lumbering in West Virginia, 1770-1920. McCain Printing Company, Parsons, WV. 410 pp.

Climate Change Science Program (CCSP). 2008. Weather and climate extremes in a changing climate, regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. Final Report, Synthesis and Assessment Product 3.3. US Climate Change Science Program, Suite 250, 1717 Pennsylvania Ave, NW, Washington, DC.

Clovis, J.F. 1979. The importance values in West Virginia Red Spruce forests inhabited by the Cheat Mountain Salamander. Proceedings of the West Virginia Academy of Science, Vol. 54, pp.58-64.

Conant, R. and J.T. Collins, J.T. 1998. A field guide to reptiles and amphibians of eastern and central North America. Houghton Mifflin Company, Boston.

Conservation Commission. 1909. Report of the West Virginia Conservation Commission, 1908. Charleston. Tribune Printing Company.

Deitloff, J., D.C. Adams, B.F.M. Olechnowski, and R.G. Jaeger. 2008. Interspecific aggression in Ohio Plethodon: implications for competition. Herpetologica, Vol. 64, No. 2, pp. 180-188.

Demaynadier, P.G. and M.L. Hunter, Jr.. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology, Vol. 12, No. 2, pp. 340-352.

Department of Agriculture. 1939. Bureau of Agriculture Economics. Appalachian Land Use Conference Tour. November 1939. Appalachian Regional Office, 1934-45. Folder WV 030, Box5B, Regional Group 83. National Archives.

Duiker, S.W. 2004. Soil management. p. 3–13. In E. Martz (ed.) The agronomy guide. The Pennsylvania State Univ., University Park.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual review of Ecology, Evolution, and Systematics, Vol. 34, pp. 487-515.

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.

Fenton, N.J. and K.A. Frego. 2005. Bryophyte (moss and liverwort) conservation under remnant canopy in managed forests. Biological conservation, Vol. 122, No. 3, pp. 417-430.

Fiedler, P. L., and S. K. Jain. 1992. Conservation biology: The theory and practice of nature conservation preservation and management. Chapman and Hall, New York, New York, USA.

Fraser, D.F. 1976a. Empirical evaluation of the hypothesis of food competition in salamanders of the Genus *Plethodon*. Ecology, Vol. 57, pp. 459-471.

Fraser, D.F. 1976b. Coexistence of salamanders in the genus Plethodon: a variation of the Santa Rosalia Theme. Ecology, Vol. 57, No. 2, pp. 238-251.

Gehlhausen, S.M., M.W. Schwartz, and C.K. Augspurger. 2000. Vegetation and microclimatic edge effects in two mixed-mesophytic forest fragments. Plant Ecology, Vol. 147, pp. 21-35.

Gergits, W.F. and R.G. Jaeger. 1990. Site attachment by the red-backed salamander, *Plethodon cinereus*. Journal of Herpetology, Vol. 24, No. 1, pp. 91-93.

Gilliam, F.S. 2002. Effects of harvesting on herbaceous layer diversity of a central Appalachian hardwood forest in West Virginia, USA. Forest Ecology and Management, Vol. 155, pp. 33-43.

Gilliam, F.S., Adams, M.B. 1996. Wetfall deposition and precipitation chemistry for a central Appalachian forest. Journal of Air and Waste Management Association, Vol. 46, pp. 978-984.

Green, N. B.and T. K. Pauley. 1987. Amphibians and Reptiles of West Virginia. University of Pittsburgh Press. Pp 61-62,65-66,69-70,71-74,152-156,161-162.

Griffis, M.R. and R.G. Jaeger. 1998. Competition leads to an extinction-prone species of salamander: interspecific territoriality in a metapopulation. Ecology, Vol. 79, No. 7, pp. 2494-2502.

Grover, M.C. and H.M. Wilbur. 2002. Ecology of ecotones: Interactions between salamanders on a complex environmental gradient. Ecology, Vol. 83, No. 8, pp. 2112-2123.

Hairston, N.G. 1949. The local distribution and ecology of the Plethodontid salamanders of the southern Appalachians. Ecological Monographs, Vol. 19, No. 1, pp. 47-73.

Hairston, N.G. 1951. Interspecies competition and its probable influence upon the vertical distribution of Appalachian salamanders of the Genus *Plethodon*. Ecology, Vol. 32, No. 2, pp.266-274.

Hairston, N.G. 1980. The experimental test of an analysis of field distributions: Competition in terrestrial salamanders. Ecology, Vol. 61, No. 4, pp. 817-826.

Hecnar, S.J. and R.T. M'Closkey. 1996. Regional dynamics and the status of amphibians. Ecology, Vol. 77, No. 7, pp. 2091-2097.

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

Highton, R. 1972. Distributional interactions among eastern North American salamanders of the genus, Plethodon. pp. 139-188 in C. Holt, ed. III; Vertebrates. Virginia Polytechnic Institution, Research Division, Monogr. Volume 4.

Highton, R., and T. Savage. 1961. Functions of the brooding behavior in the female red-backed salamander, *Plethodon cinereus*. Copeia 1961, pp. 95-98.

Hopkins, A.D. 1908. The Spruce in West Virginia. Report of the West Virginia State Board of Agriculture for quarter ending June 30, 1908. Charleston, WV.

Houlahan, J.E., C.S. Findlay, B.R. Schmidt, A.H. Myer, S.L. Kuzmin. 2000. Quantitative evidence for global amphibian population declines. Nature, Vol. 404, pp. 752-755.

Hutchison, V.H. 1961. Critical thermal maxima in salamanders. Physiol. Zool. 34: 92-125.

Intergovernmental Panel on Climate Change (IPCC). 2007. IPCC Fourth Assessment Report: Climate Change 2007. Retrieved May, 2012 from <www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html>

Jaeger, R.G. 1971a. Moisture as a factor influencing the distributions of two species of terrestrial salamanders. Oecologia (Berl.), Vol. 6, pp. 191-207.

Jaeger, R.G. 1971b. Competitive exclusion as a factor influencing the distributions of two terrestrial salamanders. Ecology, Vol. 52, No. 4, pp. 632-637.

Jaeger, R.G. 1972. Food as a limited resource in competition between two species of terrestrial salamanders. Ecology, Vol. 53, pp. 535-546.

Jaeger, R.G. 1974. Competitive exclusion: comments on survival and extinction of species. BioScience, Vol. 24, No. 1, pp. 33-39.

Jaeger, R.G. 1980. Fluctuations in prey availability and food limitation for a terrestrial salamander. Oecologia, Vo. 44, No. 3, pp. 335-341.

Jaeger, R.G., D.E. Barnard, and R.G. Joseph. 1982. Foraging tactics of a terrestrial salamander: assessing prey density. The America Naturalist, Vol. 119, No. 6, pp. 885-890.

Jenkins, A.B. 2002. Organic carbon and fertility of forest soils on the Allegheny Plateau of West Virginia. West Virginia University. Master's thesis. 292 pp.

Kahn, S. 1974. The Government's Private Forests. Southern Exposure 2, Fall 1974: 132-144.

Laurence, W.F., J.L. Camargo, R.C. Luizao, S.G. Laurence, S.L. Pimm, E.M. Bruna, P.C. Stouffer, G.B. Williamson, J. Benitez-Malvido, H.L. Vasconcelos, K.S. Van Houtan, C.E. Zartman, S.A. Boyle, R.K. Didham, A. Andrade, and T.E. Lovejoy. 2011. The fate of Amazonian forest fragments: a 32-year investigation. Biological Conservation, Vol. 144, pp. 56-67.

Lesica, P., B. McCune, S.V. Cooper, and W.S. Hong. 1991. Differences in lichen and bryophyte communities between old-growth and managed second-growth forests in the Swan Valley, Montana. Canadian Journal of Botany, Vol. 69, No. 8, pp. 1745-1755.

Lewis, R.L. 1998. Transforming the Appalachian Countryside: Railroads, Deforestation, and Social Change in West Virginia, 1880-1920. The University of North Carolina Press, Chapel Hill, N.C. 348 pp.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling. Inferring patterns and dynamics of species occurrence. Academic Press, New York, New York, USA. 324 pp.

Maiorana, V.C. 1978. Behavior of unobserved species: Diet selection by a salamander. Copeia, Vol. 1978, No. 4, pp. 664-672.

Marsh, D.M. 2007. Edge effects of gated and ungated roads on terrestrial salamanders. The Journal of Wildlife Management, Vol. 71, No. 2, pp. 389-

394.

Marsh, D.M. and N.G. Beckman. 2004. Effects of roads on the abundance and activity of terrestrial salamanders. Ecological Applications, Vol. 14, No. 6, pp. 1882-1891.

Marshall, J.L., C.D. Camp, and R.G. Jaeger. 2004. Potential interference competition between a patchily distributed salamander (*Plethodon petraeus*) and a sympatric congener (*Plethodon glutinosus*). Copeia, Vol. 2004, No. 3, pp. 488-495.

Mathis, A. 1990. Territoriality in a terrestrial salamander: The influence of resource quality and body size. Behavior 112 (3-4), pp. 162-175.

McBratney, A., Odeh, I., Bishop, T., Dunbar, M., Shatar, T. 2000. An overview of pedometric techniques of use in soil survey. *Geoderma*, Vol. 97, No. 3– 4, pp. 293–327.

McMenamin, S.K., E.A. Hadly, and C.K. Wright. 2008. Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. Proceedings of the National Academy of Sciences of the United States of America, Vol. 105, No. 44, pp. 16988-16993.

National Oceanic and Atmospheric Administration. 2012. National Weather Service, West Virginia. Retrieved April, 2012 from < http://weather.noaa.gov/>

Nee, S. and R.M. May. 1992. Dynamics of metapopulations: Habitat destruction and competitive coexistence. Journal of Animal Ecology, Vol. 61, No. 1, pp. 37-40.

Nelson, C.R. and C.B. Halpern. 2005. Short-term effects of timber harvest and forest edges on ground-layer mosses and liverworts. Canadian Journal of Botany, Vol. 83, pp. 610-620.

Oosting, H.J. and W.D. Billings. 1951. A comparison of virgin spruce-fir forest in the northern and southern Appalachian system. Ecology, Vol. 32, pp. 84-103.

Oliverio, J.E. 1972. Footprints in the Soil and Reflections in the Water: Thirty Years of Soil and Water Conservation in West Virginia. Parsons, WV: McClain.

Petranka, J.W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington.

Paul, A.S., T.J. Fahey, and T.E. Dawson. 1997. Seasonal air and soil temperature effects on photosynthesis in red spruce (*Picea rubens*) saplings. Tree Physiology, Vol. 17, pp. 187-194.

Pauley, T.K. 2008a. The Appalachian inferno: Historical causes for the disjunct distribution of *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).

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, Vol. 79, No. 2, pp. 16-21.

Pauley, T.K. 2007b. Status of four *Plethodon nettingi* populations after 28-year hiatus. Unpublished Report to the U.S. Fish and Wildlife Service, West Virginia Field Office. 16 pp.

Pauley, T.K. 2005. Reflections upon amphibian conservation. In Amphibian Declines: The Conservation Status of the United States Species. M.J. Lannoo, Editor. University of California Press, Berkeley, California. Chapter 40, pp. 277- 281.

Pauley, T.K. 1991. Cheat Mountain Salamander *(Plethodon nettingi)* Recovery Plan. Region Five U.S. Fish and Wildlife Service.

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

Pidwirny, M. 2011. Köppen Climate Classification System. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). Retrieved Feb., 2012 from <http://www.eoearth.org/article/K%C3%B6ppen_Climate_Classification_System?topic=49664>

Qian, B., E. G. Gregorich, S. Gameda, D.W. Hopkins, and X.L. Wang. 2011. Observed soil temperature trends associated with climate change in Canada. Journal of Geophysical Research, Vol.116, 16 pp.

Reichenbach and Sattler. 2007. Effects of timbering on *Plethodon hubrichti* over twelve years. Journal of Herpetology, Vol. 41, No. 4, pp. 622-629.

Richmond, O. M., J. E. Hines, and S. R. Beissinger. 2010. Two-species occupancy models: A new parameterization applied to co-occurrence of secretive rails. Ecological Applications, Vol. 20, pp. 2036–2046.

Roberts, M.R., and C.J. Richardson. 1985. Forty-one years of population change and community succession in aspen forests on four soil types, northern lower Michigan, USA. Canadian Journal of Botany, Vol. 63, pp. 1641-1651.

Shelford, V. E. 1914. Modification of the behavior of land animals by contact with air of high evaporation power. Journal of Animal Behavior, 4: 31-49.

Soule, M.E. 1987. Viable populations for conservation. Cambridge University Press, Cambridge, UK.

Southerland, M.T. 1986a. Coexistence of three congeneric salamanders: The importance of habitat and body size. Ecology, Vol. 67, No. 3, pp. 721-728.

Southerland, M.T. 1986b. The effects of variation in streamside habitats on the composition of mountain salamander communities. Copeia, No. 3, pp. 731-741.

Spight, T.M. 1968. The water economy of salamanders: Evaporative loss. Physiological Zoology, Vol. 41, No. 2, pp. 195-203.

Spotila, J.R. 1972. Role of temperature and water in the ecology of lungless salamanders. Ecological Monographs, Vol. 42, No. 1, pp. 95-125.

Steen, D.A., C.J.W. McClure, J.C. Brock, D.C. Rudolph, J.B. Pierce, J.R. Lee, W.J. Humphries, B.B. Gregory, W.B. Sutton, L.L. Smith, D.L. Baxley, D.J. Stevenson, and C. Guyer. 2012. Landscape level influences of terrestrial snake occupancy within the southeastern United States. Ecological Applications (In press).

Stuart, S.N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, and R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Science, Vol. 306, pp. 1783-1786.

U.S. Fish and Wildlife Service. 2009. Cheat Mountain Salamander (*Plethodon nettingi*) 5 –year review. USFWS West Virginia Field Office, Elkins, WV.

U.S. Forest Service. 2011. Dolly Sods Wilderness. Retrieved Feb, 2012 from http://www.fs.usda.gov/recarea/mnf/recreation/recarea/?recid=12366

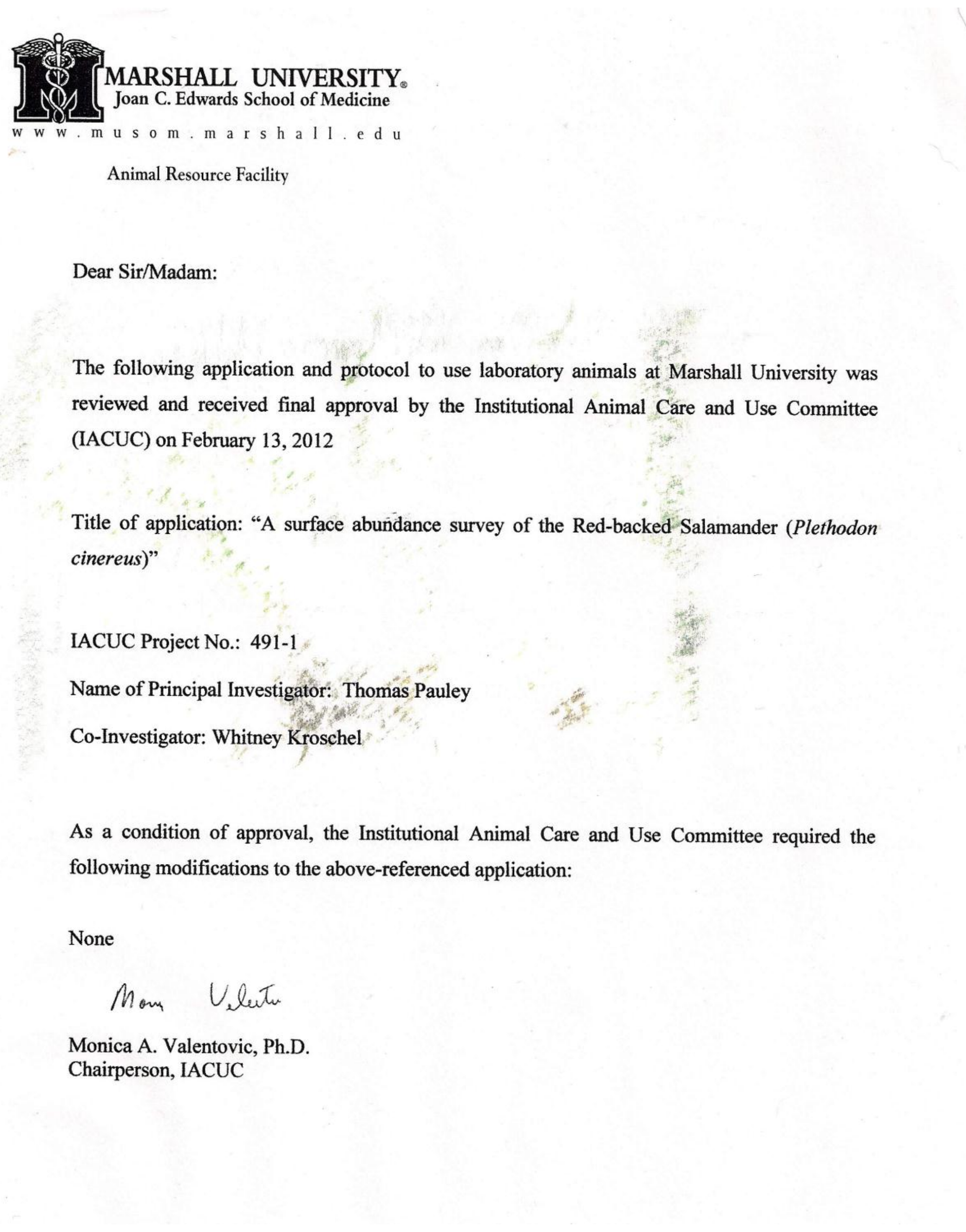
Van Buskirk, J. 2005. Local and landscape influence on amphibian occurrence and abundance. Ecology, Vol. 86, No. 7, pp. 1936-1947.

Venable, N.J. 1996. Dolly Sods. West Virginia University. West Virginia Renewable Resources Unique Areas Series 813.

West Virginia Board of Agriculture. 1900. Biennial Report of the West Virginia State Board of Agriculture, 1899 and 1900. Charleston: Butler Printing Company.

Wicknick, J.A. and T.K. Pauley. 1998. Competition and extinction in terrestrial salamanders: the effect of competition on the distribution of the Cheat Mountains Salamander. Unpublished Report to the West Virginia Division of Natural Resources, Elkins, WV.

Yoda, K., Kira, T., Ogawa, H., Hozumi, K., 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. J. Biol. (Osaka City Univ.) Vol. 14, pp. 107-129.



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Animal Resource Facility

Dear Sir/Madam:

The following application and protocol to use laboratory animals at Marshall University was reviewed and received final approval by the Institutional Animal Care and Use Committee (IACUC) on February 13, 2012

Title of application: “A surface abundance survey of the Red-backed Salamander (*Plethodon cinereus*)”

IACUC Project No.: 491-1

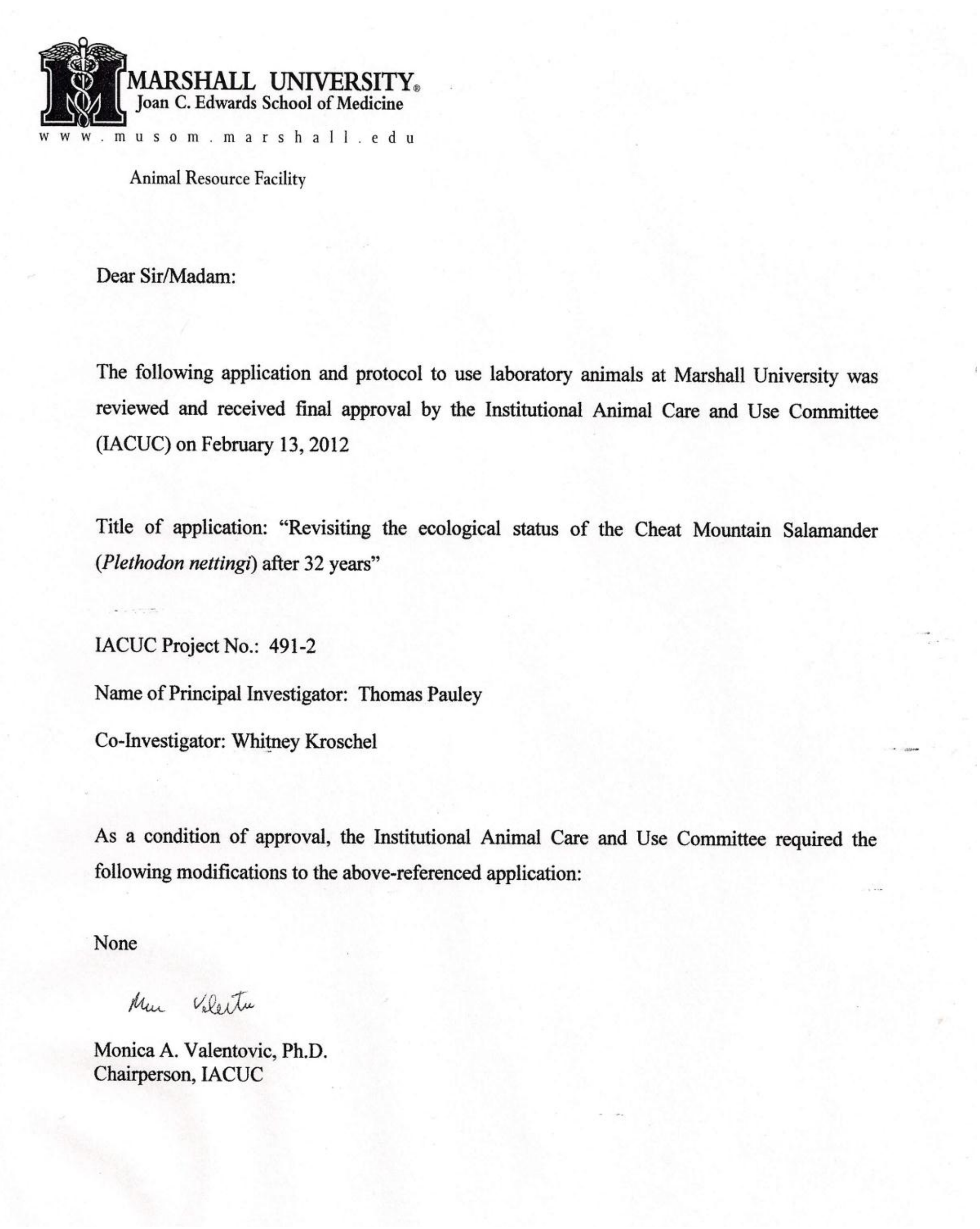
Name of Principal Investigator: Thomas Pauley

Co-Investigator: Whitney Kroschel

As a condition of approval, the Institutional Animal Care and Use Committee required the following modifications to the above-referenced application:

None

Monica A. Valentovic, Ph.D.
Chairperson, IACUC



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www.musom.marshall.edu

Animal Resource Facility

Dear Sir/Madam:

The following application and protocol to use laboratory animals at Marshall University was reviewed and received final approval by the Institutional Animal Care and Use Committee (IACUC) on February 13, 2012

Title of application: "Revisiting the ecological status of the Cheat Mountain Salamander (*Plethodon nettingi*) after 32 years"

IACUC Project No.: 491-2

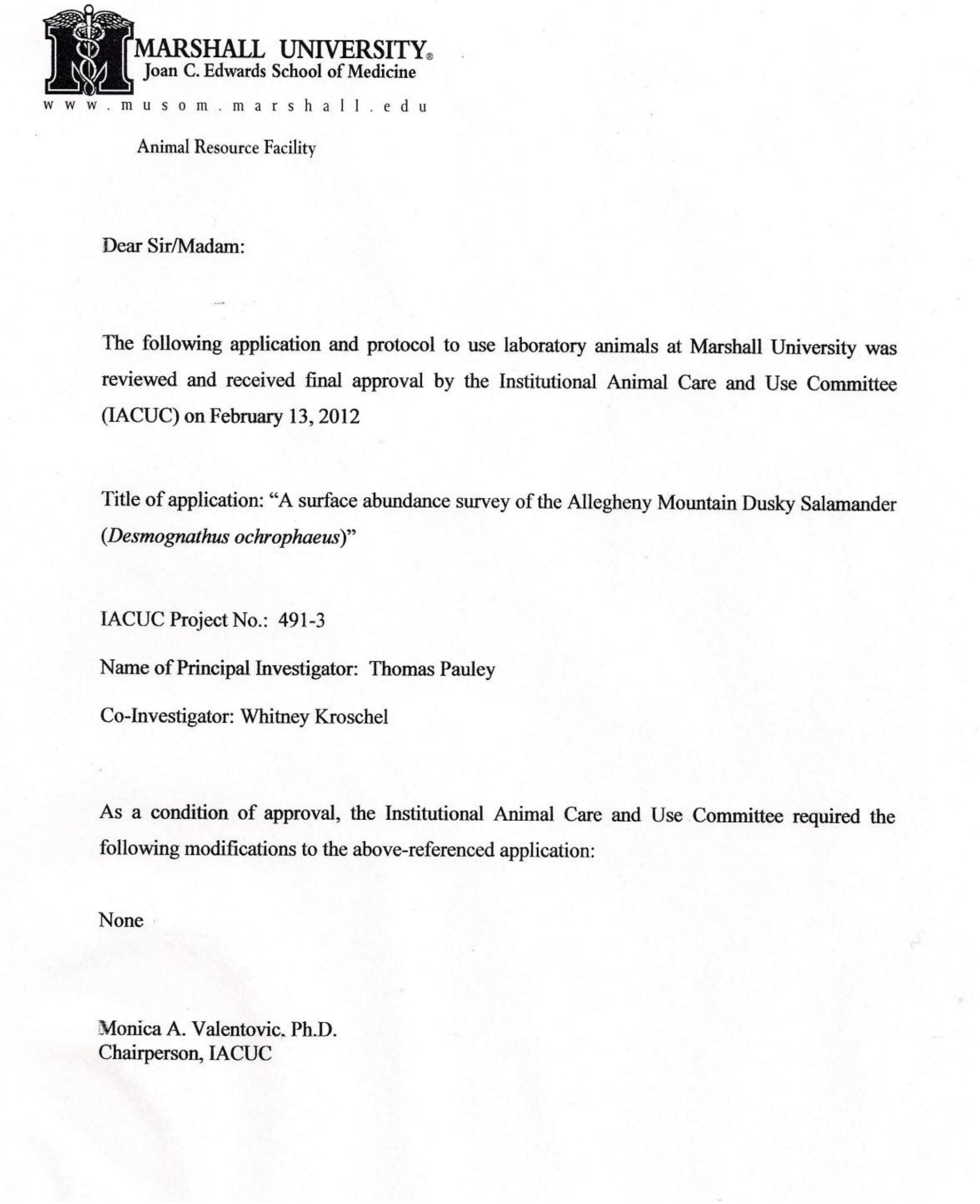
Name of Principal Investigator: Thomas Pauley

Co-Investigator: Whitney Kroschel

As a condition of approval, the Institutional Animal Care and Use Committee required the following modifications to the above-referenced application:

None

Monica A. Valentovic, Ph.D.
Chairperson, IACUC



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Animal Resource Facility

Dear Sir/Madam:

The following application and protocol to use laboratory animals at Marshall University was reviewed and received final approval by the Institutional Animal Care and Use Committee (IACUC) on February 13, 2012

Title of application: "A surface abundance survey of the Allegheny Mountain Dusky Salamander (*Desmognathus ochrophaeus*)"

IACUC Project No.: 491-3

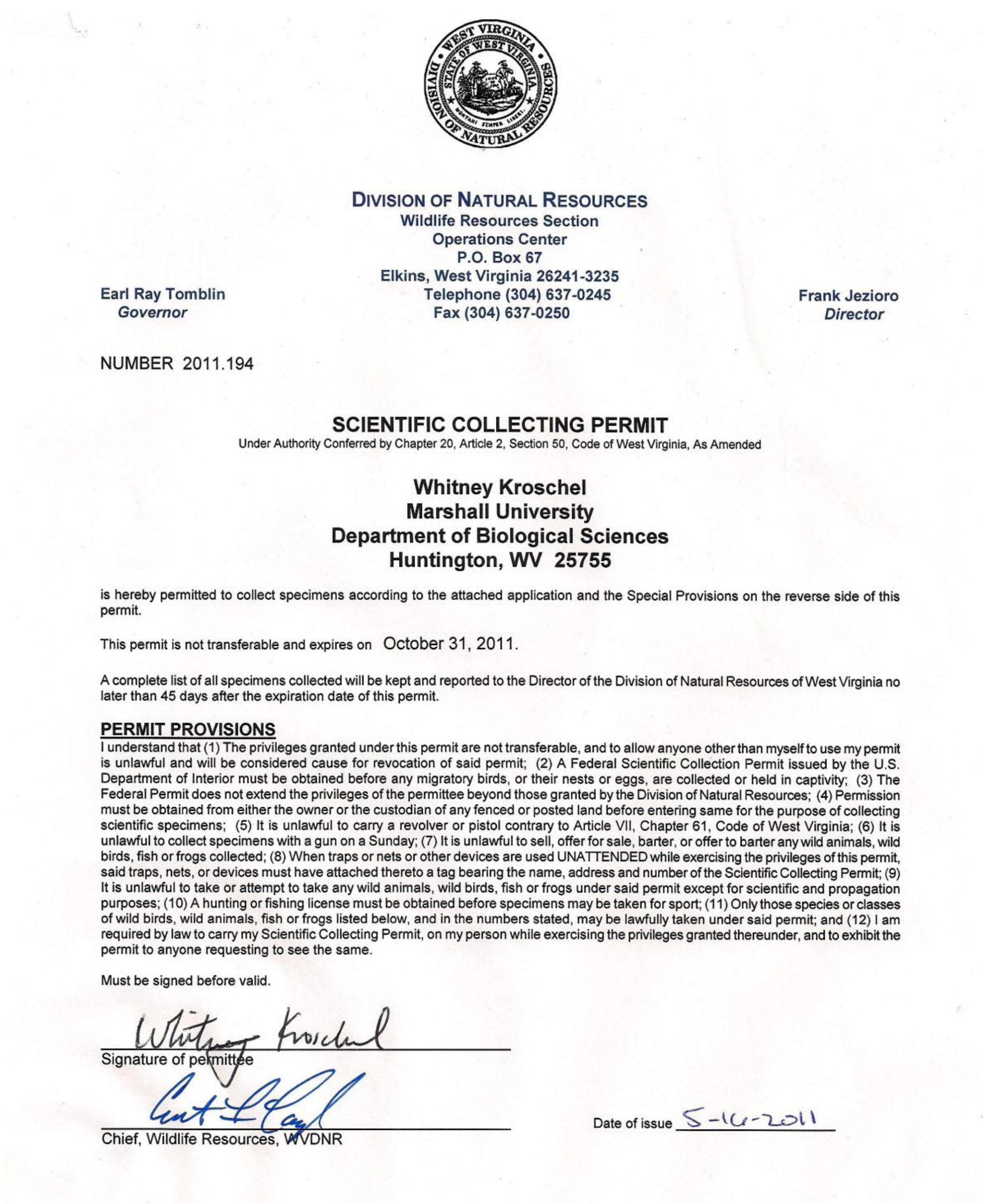
Name of Principal Investigator: Thomas Pauley

Co-Investigator: Whitney Kroschel

As a condition of approval, the Institutional Animal Care and Use Committee required the following modifications to the above-referenced application:

None

Monica A. Valentovic. Ph.D.
Chairperson, IACUC



DIVISION OF NATURAL RESOURCES
Wildlife Resources Section
Operations Center
P.O. Box 67
Elkins, West Virginia 26241-3235
Telephone (304) 637-0245
Fax (304) 637-0250

Earl Ray Tomblin
Governor

Frank Jezioro
Director

NUMBER 2011.194

SCIENTIFIC COLLECTING PERMIT

Under Authority Conferred by Chapter 20, Article 2, Section 50, Code of West Virginia, As Amended

Whitney Kroschel
Marshall University
Department of Biological Sciences
Huntington, WV 25755

is hereby permitted to collect specimens according to the attached application and the Special Provisions on the reverse side of this permit.

This permit is not transferable and expires on October 31, 2011.

A complete list of all specimens collected will be kept and reported to the Director of the Division of Natural Resources of West Virginia no later than 45 days after the expiration date of this permit.

PERMIT PROVISIONS

I understand that (1) The privileges granted under this permit are not transferable, and to allow anyone other than myself to use my permit is unlawful and will be considered cause for revocation of said permit; (2) A Federal Scientific Collection Permit issued by the U.S. Department of Interior must be obtained before any migratory birds, or their nests or eggs, are collected or held in captivity; (3) The Federal Permit does not extend the privileges of the permittee beyond those granted by the Division of Natural Resources; (4) Permission must be obtained from either the owner or the custodian of any fenced or posted land before entering same for the purpose of collecting scientific specimens; (5) It is unlawful to carry a revolver or pistol contrary to Article VII, Chapter 61, Code of West Virginia; (6) It is unlawful to collect specimens with a gun on a Sunday; (7) It is unlawful to sell, offer for sale, barter, or offer to barter any wild animals, wild birds, fish or frogs collected; (8) When traps or nets or other devices are used UNATTENDED while exercising the privileges of this permit, said traps, nets, or devices must have attached thereto a tag bearing the name, address and number of the Scientific Collecting Permit; (9) It is unlawful to take or attempt to take any wild animals, wild birds, fish or frogs under said permit except for scientific and propagation purposes; (10) A hunting or fishing license must be obtained before specimens may be taken for sport; (11) Only those species or classes of wild birds, wild animals, fish or frogs listed below, and in the numbers stated, may be lawfully taken under said permit; and (12) I am required by law to carry my Scientific Collecting Permit, on my person while exercising the privileges granted thereunder, and to exhibit the permit to anyone requesting to see the same.

Must be signed before valid.

Whitney Kroschel
Signature of permittee

Chief, Wildlife Resources, WVDNR

Date of issue 5-16-2011

WHITNEY A. KROSCHEL

15106 50th Street South
Afton, Minnesota
(651) 231-3828
kroschelw@gmail.com

Curriculum Vitae

PROFILE

Competent and knowledgeable natural history researcher. Recently received her M.S. for her research on the distribution of the federally threatened Cheat Mountain salamander (*Plethodon nettingi*). Achieved a B.S. in Biology and Geography while also competing in collegiate track and field as an undergraduate student. Possesses a strong work ethic, excellent time management skills, and a professional attitude in her education and research. Exercises reliable leadership and teamwork skills.

EDUCATION

Master of Science 8/10- 5/12
Biological Sciences
Marshall University
Huntington, WV
Concentration: Herpetology
Thesis Advisor: Dr. Thomas Pauley, pauley@marshall.edu, 304-634-5404
4.0 GPA, passed thesis defense "with distinction" status

Bachelor of Science 9/05- 5/10
Biology (Ecology) and Geography
Minnesota State University- Mankato
Mankato, MN
Advisors
  Biology: Dr. Christopher Ruhland, christopher.ruhland@mnsu.edu, 507-389-1323
  Geography: Dr. Forrest Wilkerson, forrest.wilkerson@mnsu.edu, 507-389-2824
3.97 GPA, graduated Summa Cum Laude

PROFESSIONAL EXPERIENCE

Teaching Assistant 8/10- 5/12
Marshall University Graduate College
Principles of Genetics
Dr. Simon Collier, simon.collier@marshall.edu, 304-696-6111

- Lab instructor for 3 undergraduate labs/week; each lab with 24-26 students
- Duties included planning, preparing, and instructing 3-hour lab sessions; working closely with the professor; proctoring and grading weekly quizzes; fielding daily questions; and assisting students with lab work
- Position included holding weekly office hours and tutoring hours
- Position included assisting multiple professors with office work and duties unrelated to the weekly-taught lab sessions

Biological Science Technician 5/11- 8/11

U.S. Fish and Wildlife Service
Ecological Services, West Virginia Field Office
Elkins, WV
Barbara Douglas, barbara_douglas@fws.gov, 304-636-6586 x19

- Developed and completed federal 5-Year Review for the federally-listed flat-spired three-toothed land snail (*Tridopsis platysayoides*)
- Developed and prepared a federal take statement for the federally-listed Cheat Mountain salamander (*Plethodon nettingi*) as part of a preliminary investigation by law enforcement into possible violation of the Endangered Species Act
- Organized conference calls between U.S. Fish and Wildlife Service, West Virginia Division of Natural Resources, and academic professionals to plan specimen tail tip collections of Cheat Mountain salamanders for population gene analysis
- Co-organized and conducted collections of Cheat Mountain salamander tail tips from multiple field sites for the West Virginia Division of Natural Resources for gene analysis at the University of North Carolina
- Developed and submitted a project summary for a federal application to hold, propagate, and transport federally-endangered mussel species in a multi-state Ohio River habitat restoration project
- Reviewed plans for a house construction project near federally-listed Cheat Mountain salamander habitat and developed a Section 7 Endangered Species Act consultation concurrence letter for the project
- Assisted the West Virginia Division of Natural Resources in conducting bat maternity counts at Hoffman Schoolhouse Cave, Pendleton County, WV
- Conducted bat acoustic-call surveys (both individually and as a team) at Kumbrabow State Forest to assist the West Virginia Division of Natural Resources' effort in monitoring bat populations in the wake of the White-nose Syndrome outbreak
- Participated in a bat mist-netting survey with a five-person team for the U.S. Forest Service in the Monongahela National Forest, WV
- Assisted the West Virginia Division of Natural Resources in monitoring habitat for the federally-listed flat-spired three-toothed land snail.
- Attended and completed the *Interagency Consultation for Endangered Species* course, pertaining to Section 7 of the Endangered Species Act of 1973, at the U.S. Fish and Wildlife Service National Conservation Training Center, Shepherdstown, WV

Biological Science Technician 6/10-8/10

U.S. Fish and Wildlife Service
Minnesota Valley National Wildlife Refuge and Wetland Management District
Bloomington, MN
Chris Trosen, chris_trosen@fws.gov, 715-750-1942

- Led a team of 9 biotech interns on a 6-day project mapping purple loosestrife distributions around and within a lake of about 1000 acres in area. Used GIS, Arcpad software, and Trimble units. Surveyed evidence of biological control, *Galerucella spp.*

- Led a team of 8 biotech interns on a 3-day project chemically treating over 160 acres of invasive woody species with Element-4 on a prairie easement. Substantial care and caution involved.
- Bolstered experience on ag-tractor in efforts to control invasive Canada thistle.
- Strengthened skid steer loader skills.
- Created identification manual for staff and future interns composed of everyday invasive plants often treated at Minnesota Valley NWR & WMD.
- Reinforced and expanded plant identification skills, particularly non-natives.
- Seeded native prairie grasses and controlled erosion.
- Participated in heron and egret survey at a rookery.
- Led multiple groups of 3 to 5 biotech interns for 10 days on a project mapping over 50 water control structure locations on Waterfowl Production Areas. Used GIS, Arcpad software and Trimble units.
- Participated in a meeting with private landowners about a misunderstanding over boundary lines and the plan to install a fence line.
- Conducted and co-led a bathymetry project involving 3-5 other biotech interns.
- Co-led a team of 11 biotech interns to install a permanent ½ mile fence on a Waterfowl Production Area boundary line.
- Participated in landscaping project laying fabric erosion blanket and installing 2 tons of river rock around a Visitor Center generator.
- Often coordinated daily activities of the other biotech interns, fielded questions, and prepared projects

PRESENTATIONS

Revisiting the ecological status of the Cheat Mountain salamander (*Plethodon nettingi*) after 32 years. Whitney A. Kroschel, Thomas K. Pauley, and William B. Sutton. Marshall University, thesis defense (Huntington, WV, May 4, 2012).

Revisiting the ecological status of the Cheat Mountain salamander (*Plethodon nettingi*) after 32 years. Whitney A. Kroschel, Thomas K. Pauley, and William B. Sutton. Seventy-fourth Annual Meeting of the Association of Southeastern Biologists, paper presentation (Athens, GA, April 2012).

Morphological differentiation between aquatic adults and terrestrial eft stages in West Virginia populations of Eastern Red Spotted Newts (*Notophthalmus viridescens*). Danielle E. Peters, Whitney A. Kroschel, Benjamin O. Koester, and Thomas K. Pauley. Seventy-third Annual Meeting of the Association of Southeastern Biologists, poster presentation (Huntsville, AL, April 2011).

COMMUNITY INVOLVEMENT

Guest Speaker 10/11
Midway Elementary School
Charleston, WV
Cheryl Workman, Principal; 304-756-3121

- Gave several show-and-tell presentations to students using live reptiles and amphibians

Summer Intern Position (Volunteer) 5/09- 8/09

U.S. Fish and Wildlife Service
Minnesota Valley National Wildlife Refuge and Wetland Management District
Bloomington, MN
Chris Trosen, chris_trosen@fws.gov, 715-750-1942

- Participated in invasive species management
- Underwent heavy equipment training
- Participated in biological surveys and studies
- Assisted with habitat restoration
- Assisted with refuge land and vehicle maintenance
- Participated in educational experiences

ADDITIONAL SKILLS

GIS Coursework

Marshall University

- Principles of GIS
- GIS Raster Analysis

Esri Training (esri.com)

- Basics of Raster Data for ArcGIS 10
- Deriving Raster Data Using ArcGIS 10
- Displaying Raster Data Using ArcGIS10
- Distance Analysis Using ArcGIS10
- Exploring Spatial Patterns in Your Data Using ArcGIS10
- Georeferencing Rasters in ArcGIS
- Introduction to Surface Modeling Using ArcGIS 10
- Organizing Raster Data Using ArcGIS 10
- Performing Spatial Interpolation Using ArcGIS 10
- Processing Raster Data Using ArcGIS 10
- Understanding GIS Queries
- Using Raster Data for Site Selection for ArcGIS 10

Additional Languages

American Sign Language

- Three years of high school ASL education, and occasional experience with deaf or hard-of-hearing individuals (typically friends or coworkers).

Operation of Special Equipment

U.S. Fish and Wildlife Service Training (2009)

- Ag-tractor
- Skid Steer Loader
- ATV
- Pulling and backing up trailers

REFERENCES

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Huntington, WV 25755
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pauley@marshall.edu

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U.S. Fish and Wildlife Service
West Virginia Field Office
Ecological Services
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Elkins, WV 26241
304-636-6586, ext 19
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Chris Trosen
Wildlife Specialist
U.S. Fish and Wildlife Service
St. Croix Wetland Mgmt. District
1764 95th Street
New Richmond, WI 54017
715-246-7784 (District Number)
chris_trosen@fws.gov

William B. Sutton, Ph.D.
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University of Tennessee
Knoxville, TN 37996
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