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The use of emergent rocks as refugia for the Cheat Mountain salamander, Plethodon nettingi green

Beth Anne Pauley

The Use of Emergent Rocks as Refugia for the Cheat Mountain salamander, Plethodon nettingi Green

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Beth Anne Pauley

Marshall University

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Advisor Dr. Donald C. Carter

Department of Biological Sciences

Leonard J. Deutsch

Dean of the Graduate School

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Abstract

Plethodon nettingi was listed as a threatened species in 1989 by the United States Fish and Wildlife Service (Pauley, 1991). Its total range is within 5 counties in eastern West Virginia. There are fewer then 60 disjunct populations known and most populations are above 3,000 ft. and are associated with emergent rocks or narrow ravines with Rhododendron. It is hypothesized the P. nettingi survived lumbering practices at the turn of the century by taking refuge beneath large emergent rocks and narrow ravines with Rhododendron. This study examined environmental factors associated with emergent rocks that might regulate the distribution of P. nettingi. Two sites with emergent rocks where P. nettingi was known to occur were used as study sites and two sites with emergent rocks where P. nettingi was known not to occur but were within the known range of P. nettingi were used as controls. Each site was examined to determine the distance P. nettingi extends beyond the rocks. Biological data such as snout-to-vent length, mass, and gender of each species observed and environmental factors including air temperature, soil temperature, relative humidity, soil moisture, soil pH, litter mass, and litter moisture were collected along 4 transects in each cardinal direction from the center of the rocks. Soil moisture, litter moisture, and litter mass appear to be important regulating environmental factors in the microhabitat selection of P. nettingi.

Literature Review

Salamanders are an ecologically important part of the forest ecosystem. Burton and Likens (1975a,b) found that the biomass of salamanders in northeastern United States is twice as much as birds and is equal to small mammals in a northeastern forest. Burton and Likens (1975a,b) also found that about 20 percent of all energy available to birds and mammals passes through salamanders. Salamanders are important in energy flow pathways of forest ecosystems. They prey on invertebrates too small for mammals and birds and are prey to larger predators (Pough et al., 1987). Salamanders can convert 40-80 percent of their ingested energy to produce biomass (Burton and Likens,1975a).

Several environmental factors have been shown to influence the microdistribution of woodland salamanders including soil and litter moisture, litter mass, soil pH, soil temperature, and relative humidity. Salamanders of the Plethodontidae family are lungless and must remain moist to respire subcutaneously. Terrestrial salamanders inhabit what has been called "modified aquatic habitats" (Frisbie and Wyman, 1991). In these terrestrial habitats, moisture and certain dissolved ions such as H^+ are absorbed through the skin. It has been shown that the duration of salamander activity is directly related to soil and litter moisture levels (Keen, 1984). This activity includes foraging, and mating. Keen (1984) found that activity of Desmognathus fuscus was greatest on high moisture substrates. Jaeger (1980a) stated that Plethodon cinereus has low mobility during rainless periods so that the risk of desiccation in dry leaf litter is reduced. He further hypothesizes that salamanders move horizontally on the forest floor to cover objects such as rocks and logs during dry conditions. Jaeger (1980b) found that prey availability increased with increasing moisture and that foraging success increased with increasing rainfall. Plethodon cinereus was found more often in forest litter during rainfall while the percentage of salamanders under rocks and logs decreased (Jaeger, 1980a). Plethodon cinereus loses moisture at a rapid rate (0.09%/h) so that it is unlikely that it would inhabit soils that were not moist (Pauley, 1978a).

Wyman and Hawksley-Lescault (1987) found the chronic lethal pH for P. cinereus was between 3 and 4. In study quadrats with a pH of 3.8 and greater, salamanders were observed 50.8 percent of the time while quadrats with soil pH of 3.7 or less contained salamanders only 8.8 percent of the time. No young-of-the-year salamanders were found on soils with a pH of 3.7 or less. Soils containing high H^+ ion concentrations disrupt osmoregulation of P. cinereus by increasing sodium efflux (Frisbee and Wyman, 1991). Sugalski and Claussen (1997) stated that although soil moisture and soil pH significantly affected salamander distribution, soil pH was the most significant factor.

Heatwole (1962) determined that soil temperature regulates habitat selection of P. cinereus. He found that the temperature beneath the litter in oak-pine-aspen forests exceeded the critical thermal maximum temperature of P. cinereus and excluded it from these areas. When not foraging, salamanders retreat beneath cover objects and in underground burrows. Spotila (1972) found that salamander species have thermal preference ranges. These preferred temperatures may be a response to optimum metabolic efficiency at certain temperatures.

Terrestrial plethodontid salamanders are active at night when relative humidity is higher (Spotila, 1972). When air is dry, salamanders often remain near refugia. In laboratory conditions, Spotila (1972) found that salamanders selected areas of high relative humidity. His studies in the field supported these findings. Plethodon yonahlosse, P. glutinosus, and P. jordani were seen with only their heads sticking out from beneath cover objects on nights when relative humidity was low. Heatwole (1962) stated that P. cinereus becomes more active in lower humidities as it searches for moister environments. In water saturated air, they did not wander and often did not move from these spots.

Pauley (1980) investigated the ecological status of P. nettingi. He found that in sites where P. nettingi was found, it was the most abundant salamander species. Although not significantly lower, soil temperature was cooler in the P. nettingi sites. Critical thermal maximum (CTM) data show that P. nettingi (33.8°C) is more tolerant to high temperatures than P. cinereus (33.0°C) but P. nettingi cannot tolerate as great a loss of body moisture as P. cinereus. Field data on relative humidity show that P. nettingi inhabits areas with significantly higher relative humidity than that P. cinereus. These two factors imply that P. nettingi has a narrower tolerance for moist habitats.

Forest management practices that open the canopy, create an edge, and reduce the density of understory vegetation may negatively impact salamander populations. Petranka et al. (1993) estimated that 14 million salamanders are lost annually by clearcutting in U.S. National Forests in western North Carolina. Removing the canopy increases air and soil temperatures and as a result decreases the amount of moisture on the forest floor (Dodd, 1991). It has been shown that although soil moisture remains high in clearcut areas, the top layer of soil remains dry (Blymyer and McGuinnes, 1977). Ash (1988) found that within three years of clearcutting the forest floor was shaded but shade was provided by shrubby understory. Ash (1995; 1996) found that litter dry mass and litter depth decrease significantly after clearcutting and litter moisture is also reduced significantly. Litter is the main foraging habitat of terrestrial salamanders. Pough et al. (1987) found that leaf litter depth was a significant factor in the microdistribution of P. cinereus. Mitchell et al. (1996) found that P. hubrichti populations in Virginia were reduced up to 47 percent, and Ash (1988) observed no P. jordani in North Carolina after clearcutting. These declines may be attributed to loss of litter forage habitat and prey resources associated with litter. Plethodon hubrichti were found to ingest less soft-bodied insects in clearcuts than in mature stands (Mitchell et al., 1996). It has been determined that soft-bodied insects provide more energy than hard-bodied insects because soft-bodied insects pass through digestive tracts quickly providing a positive metabolic balance (Gabor and Jaeger, 1995).

Clearcutting has detrimental effects on the habitat of salamanders. This practice opens the canopy and dries the soil and litter causing temperature fluctuations that can be great. Petranka et al. (1993) found that in North Carolina, salamander abundance in old clearcuts (>50 years) was about 5 times greater than new clearcuts (<10 years) and that species richness was twice as great in old clearcuts. Enge and Marion (1986) studied an old clearcut (40 years old) and adjacent 3-4 year old clearcuts and found that amphibian reproductive success was 10 times greater in the old clearcut. In New England, DeGraaf, and Yamasaki (1992) found that P. cinereus may be dramatically reduced in clearcut areas. Populations in the southern Blue Ridge Mountains have been shown to be reduced by 30-50 percent in clearcut areas (Ash, 1996). All age classes disappear at the same rate indicating that factors causing the decline are applied equally to the whole population. This same study estimated that these populations will return to pre-cut population numbers in 20 years. Other studies (Petranka et al., 1994) estimate the regeneration time to be 50-70 years. Some studies indicate that silvicultural practices such as clearcutting may have temporary effects on forest salamanders. Pauley, et al. (1993) studied P. cinereus in West Virginia and found that after 20 years there were no significant differences in surface abundance or reproductive success. Pauley (1994) examined three different silvicultural treatments (clearcuts, thinning, and uncut) in Pennsylvania and found that P. cinereus was more abundant in uncut forests followed by thincuts and clearcuts.

It is hypothesized that P. nettingi survived lumbering activities during the late 1800s and early 1900s by taking refuge beneath large emergent rocks, rock outcrops, and narrow ravines with Rhododendron. This refugia would have presumably remained moister and cooler and aided P. nettingi to survive the detrimental effects of habitat disturbances. Once the forest began growing back and the forest floor became cooler and more moist, P. nettingi began to move out from the rocks. Plethodon nettingi may now be associated with these rocks because of environmental conditions. Most of the forests within the range of P. nettingi have been completely cut within the last 100 years (Clarkson, 1964). By 1920, nearly all the red spruce had been cut and today, only about 7 % of the original acreage of red spruce exists (Clarkson, 1964). It was the purpose of this study to determine if P. nettingi is associated with emergent rocks and how far out from these rocks P. nettingi has moved.

Taxonomy and Distribution

The Cheat Mountain salamander, Plethodon nettingi Green, is an eastern small Plethodon that is brown to black with brassy flecks on the dorsal side and a uniformly dark ventral side (Green and Pauley, 1987) (Fig. 1). It is a member of the Plethodontidae family which is the largest and most successful group of salamanders (Green and Pauley, 1987). Salamanders of this family are lungless and respire through their skin and the lining of their mouths and throats. Members of the genus Plethodon are terrestrial and nocturnal and are referred to as woodland salamanders. Plethodontids burrow in soil, leaf litter, logs, under rocks, and other debris.

The Cheat Mountain salamander was first found on White Top, Randolph County, West Virginia, in 1935 by Graham Netting. In 1938, Dr. N.B. Green described P. nettingi from museum specimens taken from Barton Knob, 3 miles west of White Top. It was originally thought to only occur on Cheat Mountain. Brooks (1948) first described the range of P. nettingi to be from a point along the headwaters of Condon Run, near Bickle's Knob, Randolph County, on the north, to the southern end of the Cheat Range of Thorny Flat, Pocahontas County, on the south. Highton (1972) found that the range of P. nettingi extended in the northern

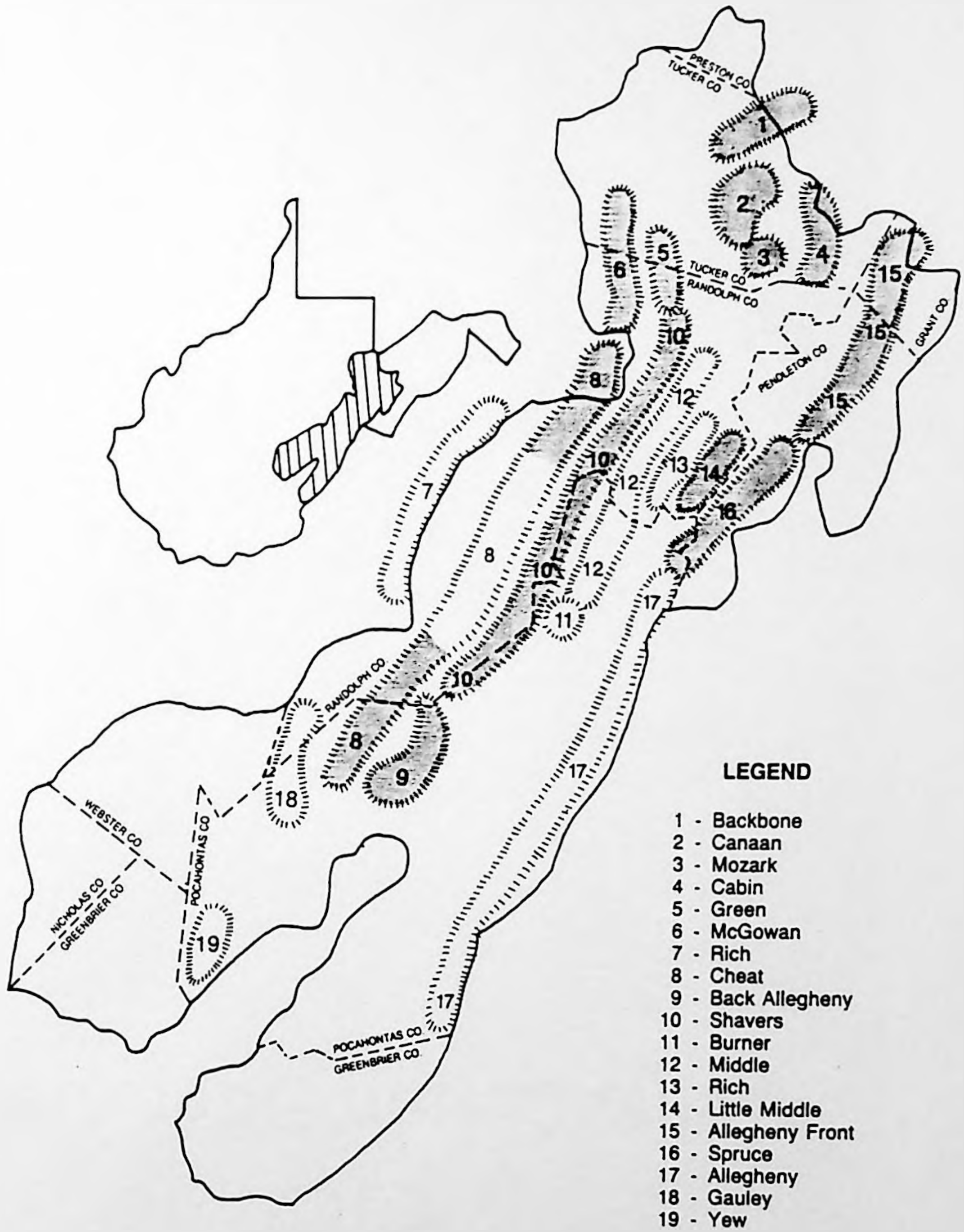
Figure 1. Plethodon nettingi (Photograph by Dr. Wayne VanDevender)

area of the range described by Brooks east to the higher elevations of the Allegheny Front. Today it is known to occur in 59 disjunct populations in five counties in West Virginia (Grant, Pendleton, Pocahontas, Randolph, and Tucker) (Fig. 2). Total horizontal range extends from Blackwater Falls State Park in the north to near Bald Knob in the south (19 X 50 miles). It is a high elevation species found generally above 3,500 ft but in the northern end of its range extends down to 2,640 ft. The total vertical range is 4,862ft Spruce Knob to 2,640 ft at its most northern population at Blackwater Falls State Park (Pauley, 1981; Pauley and Pauley, 1997). The Cheat Mountain salamander was added to the federally threatened species list in 1989 (Pauley, 1991).

The only description of the habitat of P. nettingi is by Brooks (1948). He described the habitat as "nearly pure stands of red spruce, or forest in which red spruce is a prominent species. Furthermore, the abundance of the salamander in any given locality is, seemingly, associated with the age of the spruce stand." Pauley (pers. comm.) described the habitat as mixed deciduous forest with red spruce (Picea rubens) and Bazzania and frequently with large emergent rocks, rock outcrops, and narrow ravines with Rhododendron (Fig. 3). It can also be found with hemlock.

Plethodon nettingi is often found with two sympatric species, P. cinereus and Desmognathus ochrophaeus. The red-backed salamander, P. cinereus (Green), is a small terrestrial salamander. It is dark brown with a straight-edged stripe down the back (Green and Pauley, 1987) (Fig. 4). This stripe may be either reddish or gray to black (lead-backed phase). The belly is black and white with

Figure 2. Distribution of *P. nettingi*



Mountain with *P. nettingi*

Figure 3. Typical Habitat of P. nettingi, Gaudineer Knob, West Virginia.

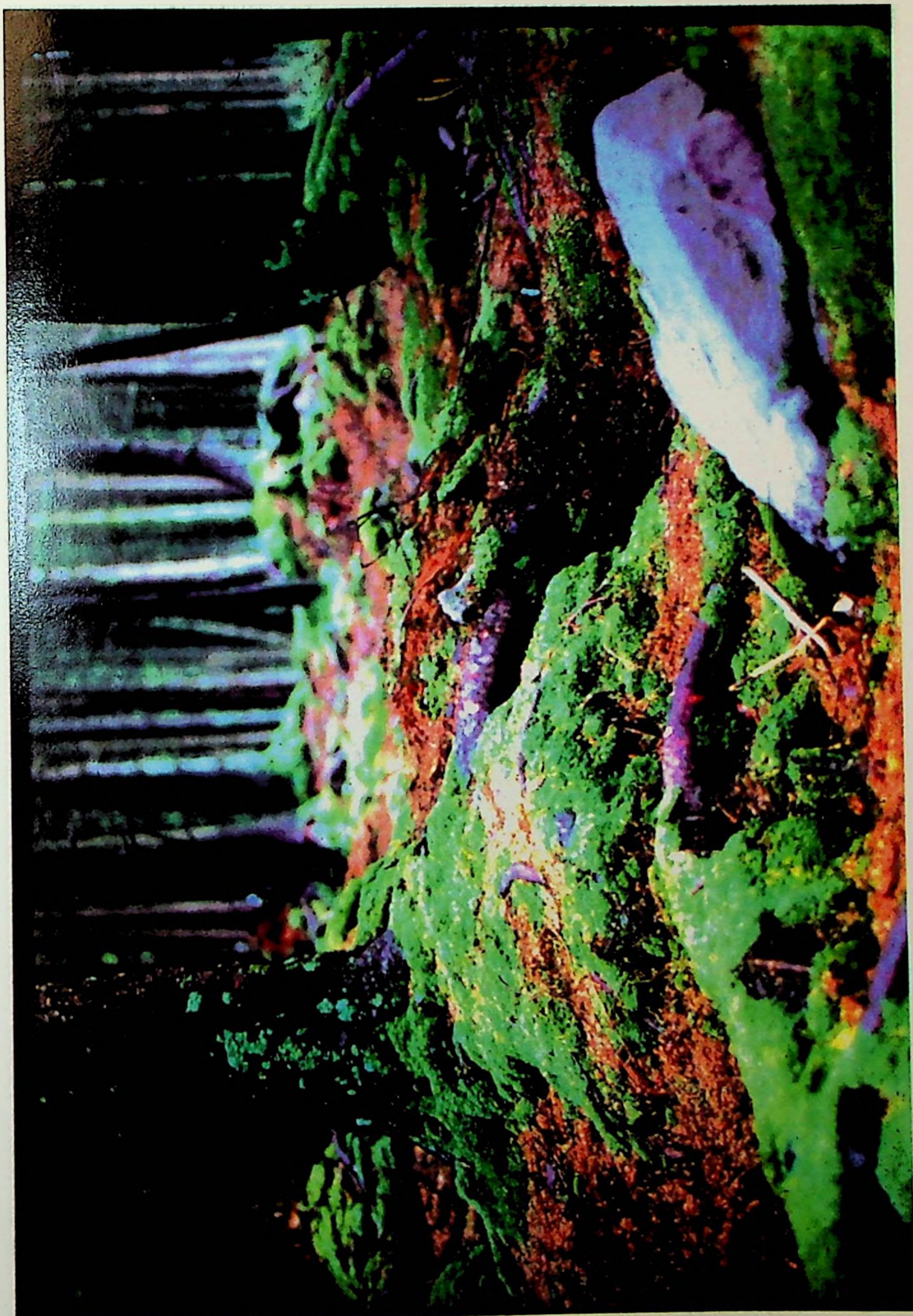
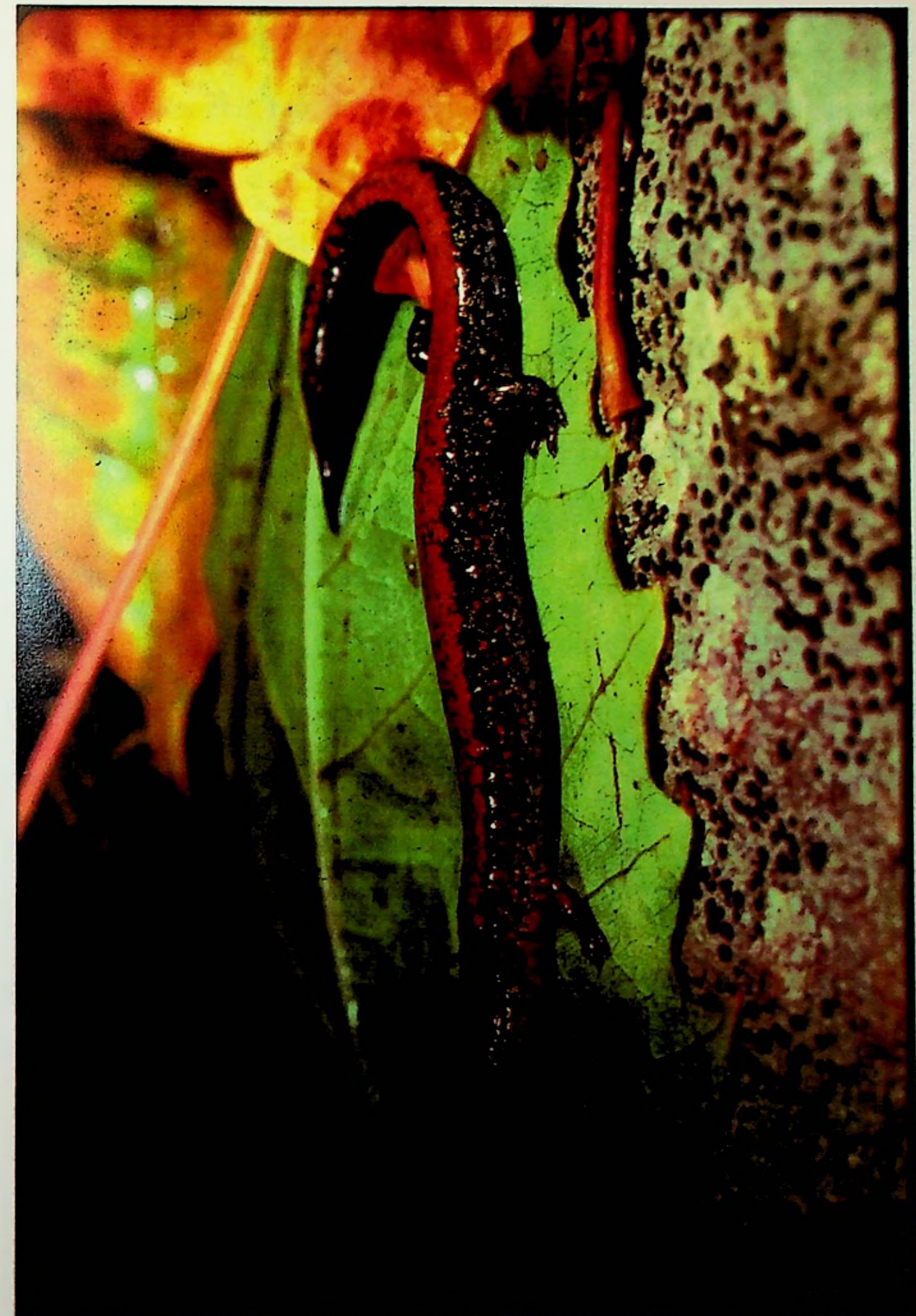


Figure 4. Plethodon cinereus (Photograph by Dr. Wayne VanDevender)



a salt-and-pepper effect. Plethodon cinereus is found in eastern North America from southern Quebec and Nova Scotia to southern North Carolina and Missouri (Conant and Collins, 1991) (Fig. 5). In West Virginia, P. cinereus is found statewide except in the Ohio Valley counties (Green and Pauley, 1987) (Fig. 6). Plethodon cinereus has been found up to 4,800 ft in West Virginia (Pauley, et al., 1993). The habitat of P. cinereus is cool, damp deciduous, coniferous, or mixed deciduous forests (Green and Pauley, 1987).

The mountain dusky salamander, Desmognathus ochrophaeus Cope, is one of the most terrestrial members of the genus Desmognathus. It is a small salamander which is brownish with a straight-edged yellow, red, or tan stripe down the back (Green and Pauley, 1987) (Fig. 7). It occurs from upstate New York south to northern Georgia and Alabama (Conant and Collins, 1991) (Fig. 8). In West Virginia, it occurs mainly in the mountainous and southeastern counties (Green and Pauley, 1987) (Fig. 9). The highest point in West Virginia D. ochrophaeus has been observed is 4,600 ft.(Pauley et al. 1993). Most members of this genus do not stray far from water. Desmognathus ochrophaeus can be found in forests away from water but in environments which have saturated ground (Green and Pauley, 1987).

Figure 5. Range of P. cinereus in the United States (Conant and Collins, 1991).

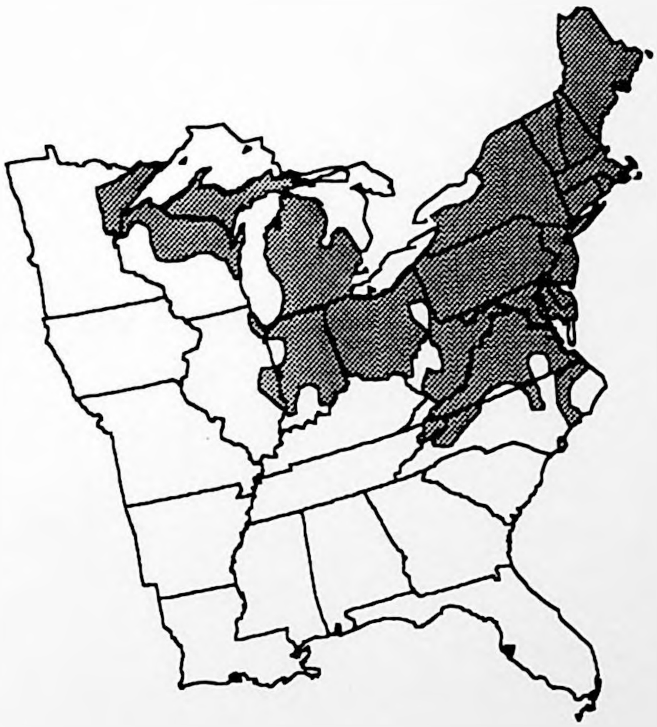
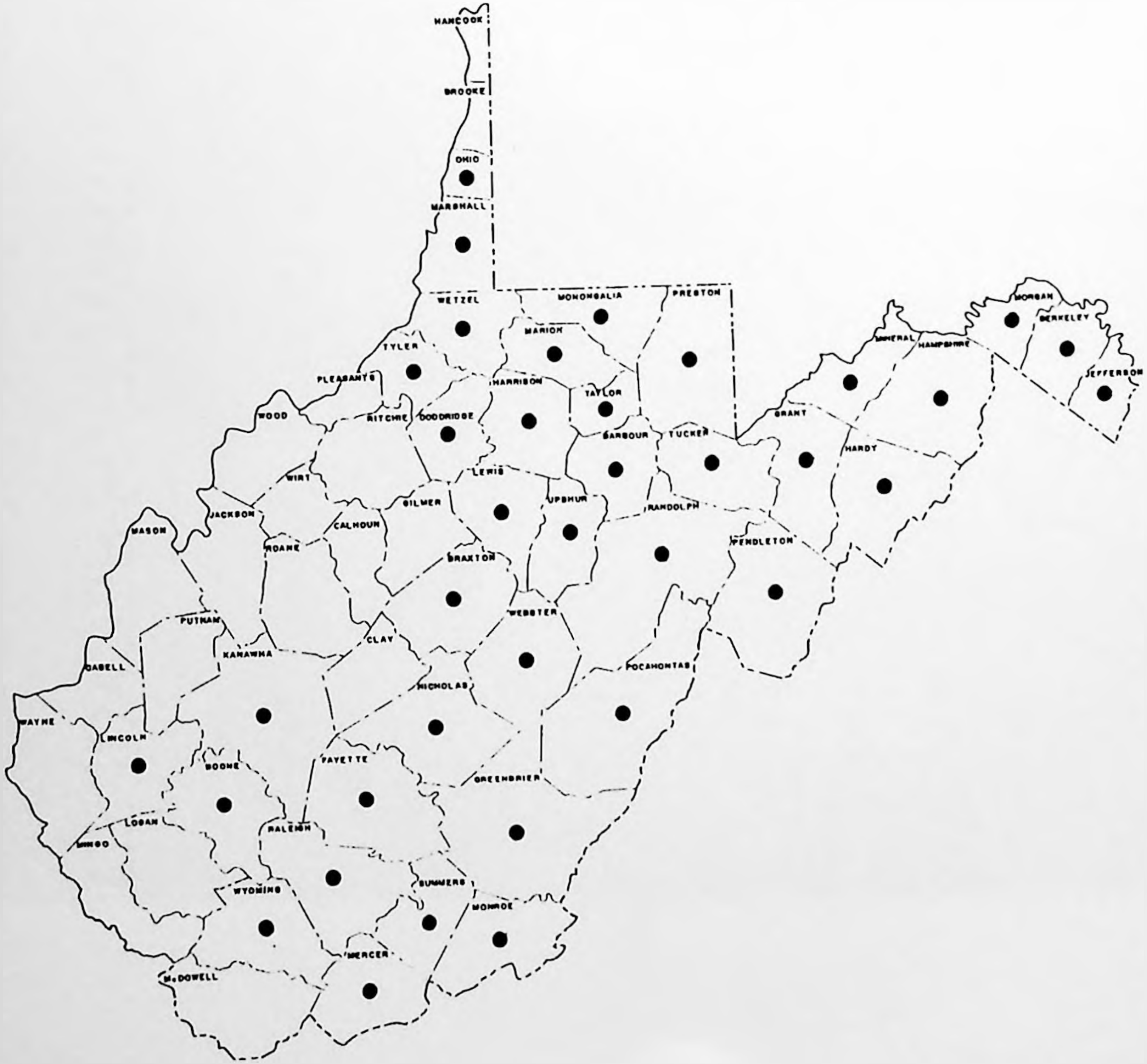


Figure 6. Range of P. cinereus in West Virginia (Green and Pauley, 1987).

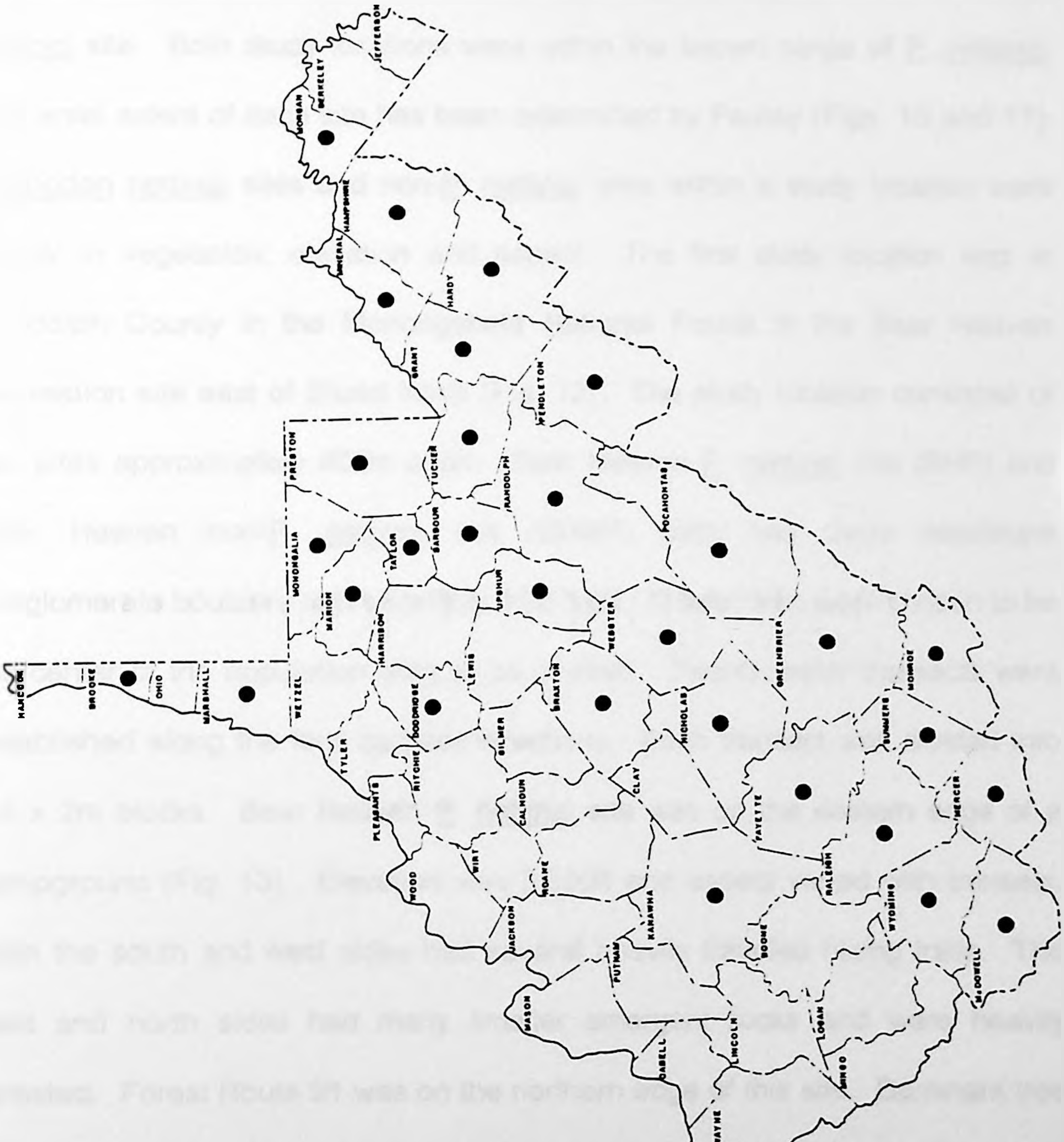


HANCOCK
BROOKE
OHIO
MARSHALL
WETZEL
MONONGALIA
PRESTON
MARION
TYLER
PLEASANTS
HARRISON
TAYLOR
WOOD
RITCHIE
DODDRIDGE
BARBOUR
TUCKER
MINERAL
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON
GRANT
HARDY
WIRT
LEWIS
GILMER
UPSHUR
RANDOLPH
JACKSON
CALHOUN
MASON
ROANE
BRAXTON
PENDLETON
PUTNAM
WEBSTER
KANAWHA
CLAY
CABELL
POCAHONTAS
NICHOLAS
WAYNE
LINCOLN
BOONE
FAYETTE
GREENBRIER
LOGAN
MINGO
RALEIGH
WYOMING
SUMMERS
MONROE
MERCER
McDOWELL

Figure 7. Desmognathus ochrophaeus

Figure 8. Range of D. ochrophaeus in the United States (Conant and Collins, 1991).

Figure 9. Range of D. ochrophaeus in West Virginia (Green and Pauley, 1987).



HANCOCK
BROOKE
OHIO
MARSHALL
WETZEL
TYLER
PLEASANTS
WOOD
RITCHIE
DODDRIDGE
MONONGALIA
MARION
HARRISON
TAYLOR
PRESTON
BARBOUR
TUCKER
RANDOLPH
UPSHUR
LEWIS
GILMER
CALHOUN
WIRT
JACKSON
ROANE
MASON
PUTNAM
KANAWHA
CLAY
BRAXTON
WEBSTER
NICHOLAS
FAYETTE
RALEIGH
BOONE
LOGAN
LINCOLN
CABELL
WAYNE
MINGO
WYOMING
McDOWELL
MERCER
SUMMERS
MONROE
GREENBRIER
POCAHONTAS
PENDLETON
GRANT
HARDY
MINERAL
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON

Materials and Methods

Field Study

Two study locations were used each with a P. nettingi site and a non-P. nettingi site. Both study locations were within the known range of P. nettingi. The areal extent of each site has been determined by Pauley (Figs. 10 and 11). Plethodon nettingi sites and non-P. nettingi sites within a study location were similar in vegetation, elevation and aspect. The first study location was in Randolph County in the Monongahela National Forest in the Bear Heaven Recreation site east of Stuart Knob (Fig. 12). The study location consisted of two sites approximately 400m apart. Bear Heaven P. nettingi site (BHP) and Bear Heaven non-P. nettingi site (BHNP) both had large sandstone conglomerate boulders approximately 15m high. These rocks were chosen to be the center of the population area to be studied. Twenty meter transects were established along the four cardinal directions. Each transect was divided into 5m x 2m blocks. Bear Heaven P. nettingi site was on the eastern edge of a campground (Fig. 13). Elevation was 3,500ft and aspect varied with transect. Both the south and west sides had several heavily traveled hiking trails. The east and north sides had many smaller emergent rocks and were heavily forested. Forest Route 91 was on the northern edge of this site. Dominant tree species included hemlock (Tsuga canadensis), yellow birch (Betula lutea), beech (Fagus grandifolia), mountain maple (Acer spicatum), wild black cherry (Prunus serotina), red maple (Acer rubrum), and red spruce (Picea rubens). The most common understory plants during sampling were greenbrier (Smilax

Figure 10. Areal extent of the P. nettingi population around the Bear Heaven study location.

M O N O N G A H E L A
T I O N A L
F O R E
D R Y
F O
Yellow Creek
Condon Run
Stuart Knob
Middle Point
BHNP
BHP
Mine
Strip Mine

Figure 11. Areal extent of the P. nettingi population around the Plantation study location.

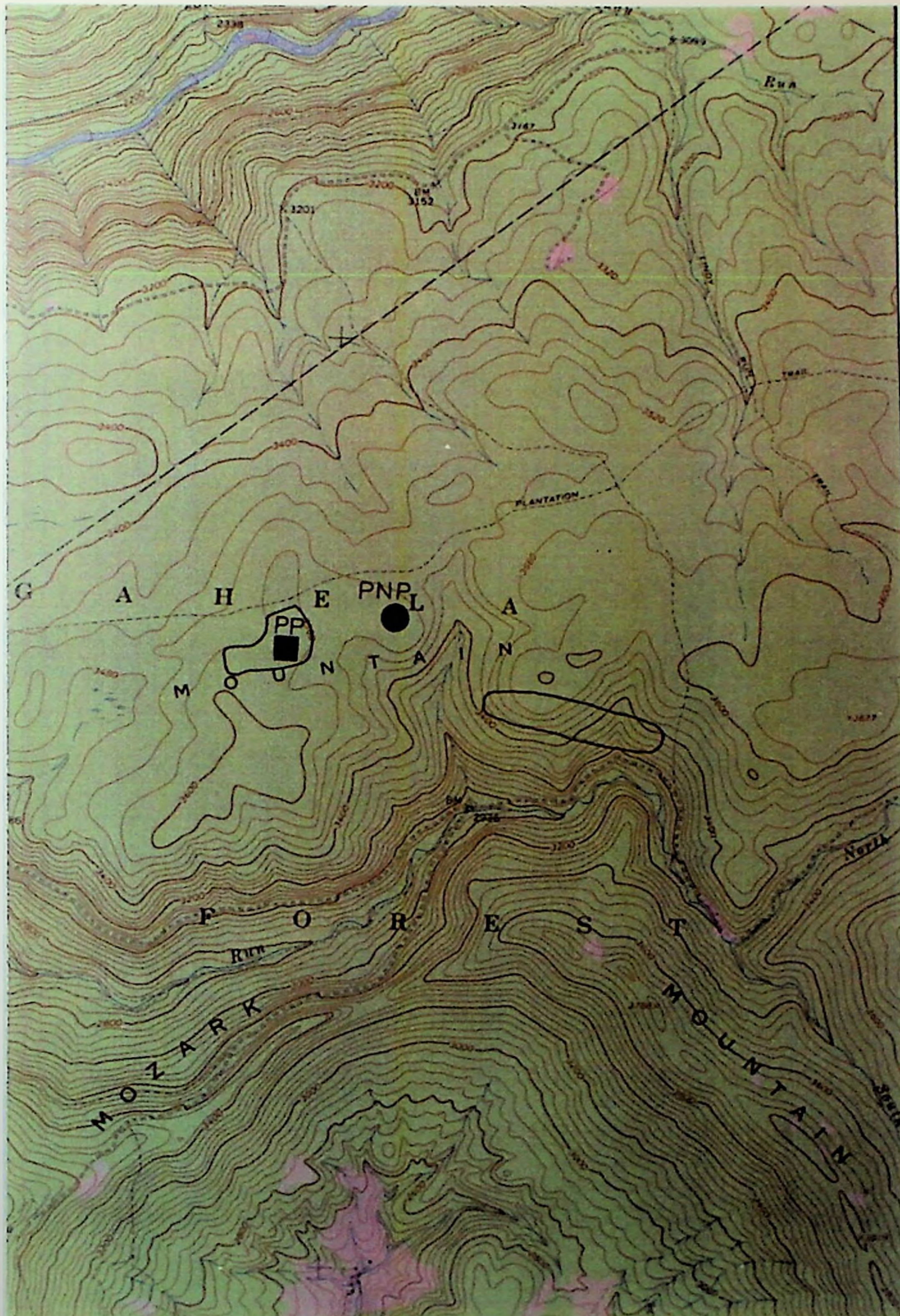
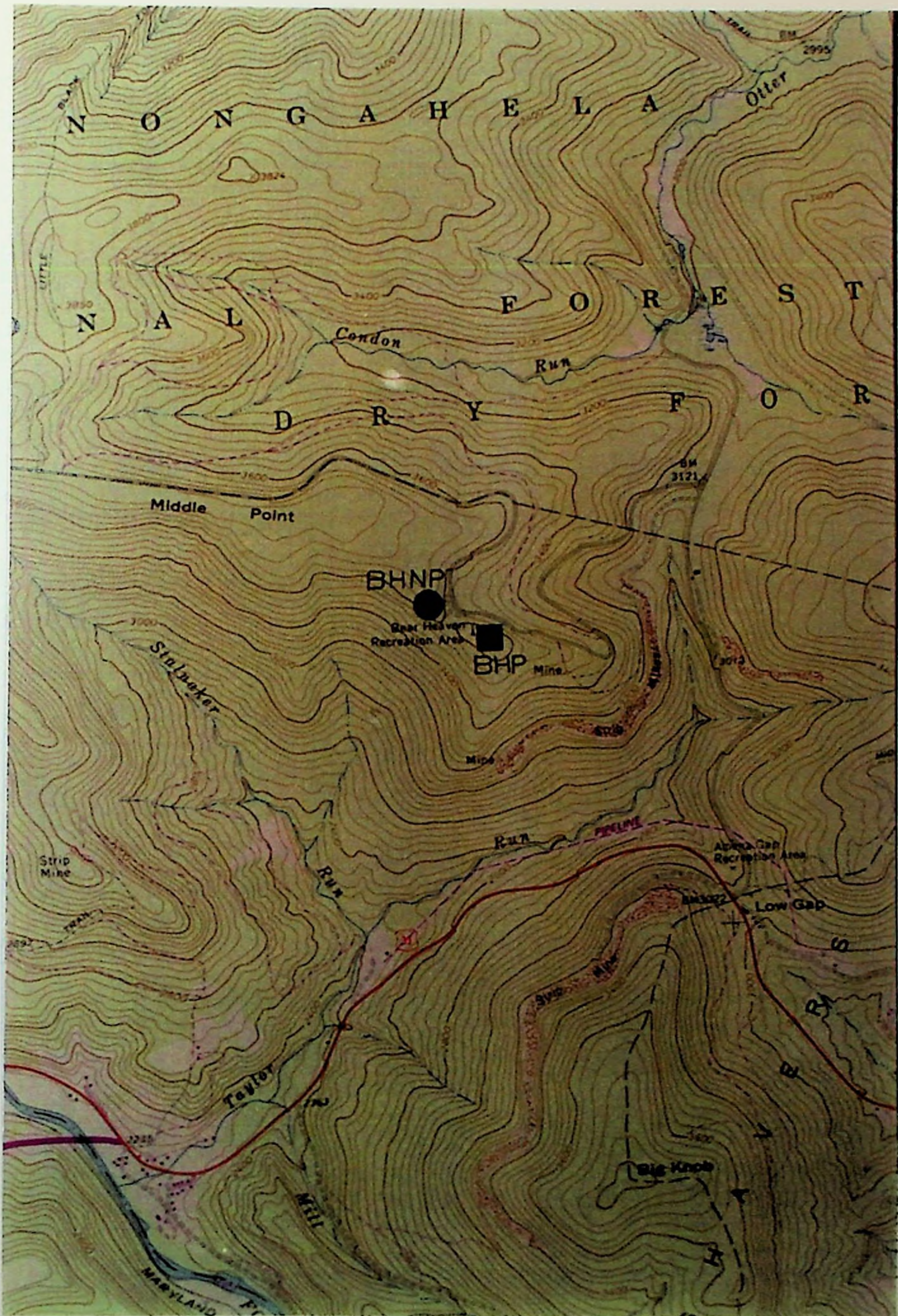

PNP
PP
MOUNTAIN
FOREST
MOZARK
MOUNTAIN
PLANTATION
Run
North

Figure 12. Bear Heaven study location.



NONGAHELA
NAL FOREST
Otter
Condon
Run
DRY FOR
Middle Point
BHNP
Bear Heaven Recreation Area
BHP
Mine
Stulnaker
Run
Strip Mine
Run
PIPELINE
Low Gap
Taylor
Mill
Big Knob
MARYLAND

Figure 13. Bear Heaven P. nettingi site.

rotundifolia) hay-scented fern (Dennstaedtia punctilobula), interrupted fern (Osmunda claytoniana), common wood-sorrel (Oxalis montana), and spinulose woodfern (Dryopteris spinulosa). West of the recreation site was the non-P. nettingi site (Fig. 14). Elevation was 3,500ft and aspect varied with transect. The west and south sides were heavily used by hikers while the east and north sides appeared less used. Dominant tree species were wild black cherry (Prunus serotina), red maple (Acer rubrum), mountain holly (Ilex montana), beech (Fagus grandifolia), and yellow birch (Betula lutea). Common understory plants during sampling included Rhododendron, greenbrier (Smilax rotundifolia), blackberry (Rubus sp.), and spinulose woodfern (Dryopteris spinulosa).

A second study location was in Tucker County in the Monongahela National Forest on Canaan Mountain south of Forest Service trail 101 (Plantation trail) (Fig. 15). The two sites were approximately 1,200m apart on a large flat ridge with very little inclination. Both Plantation P. nettingi site (PP) and Plantation non-P. nettingi (PNP) were at an elevation of 3,560 ft with a north and northwest aspect, respectively (Figs. 16 and 17). Both sites at this location had numerous small emergent rocks with a floor of Bazzania and a canopy of red spruce (Picea rubens) and hemlock (Tsuga canadensis). Four 20m x 2m transects were established along the 4 cardinal directions. Each transect was divided into 5m x 2m blocks. An additional transect was established through the middle of each site. This transect was changed every sampling date to ensure that the entire middle section was studied.

Figure 14. Bear Heaven non-P. nettingi site.

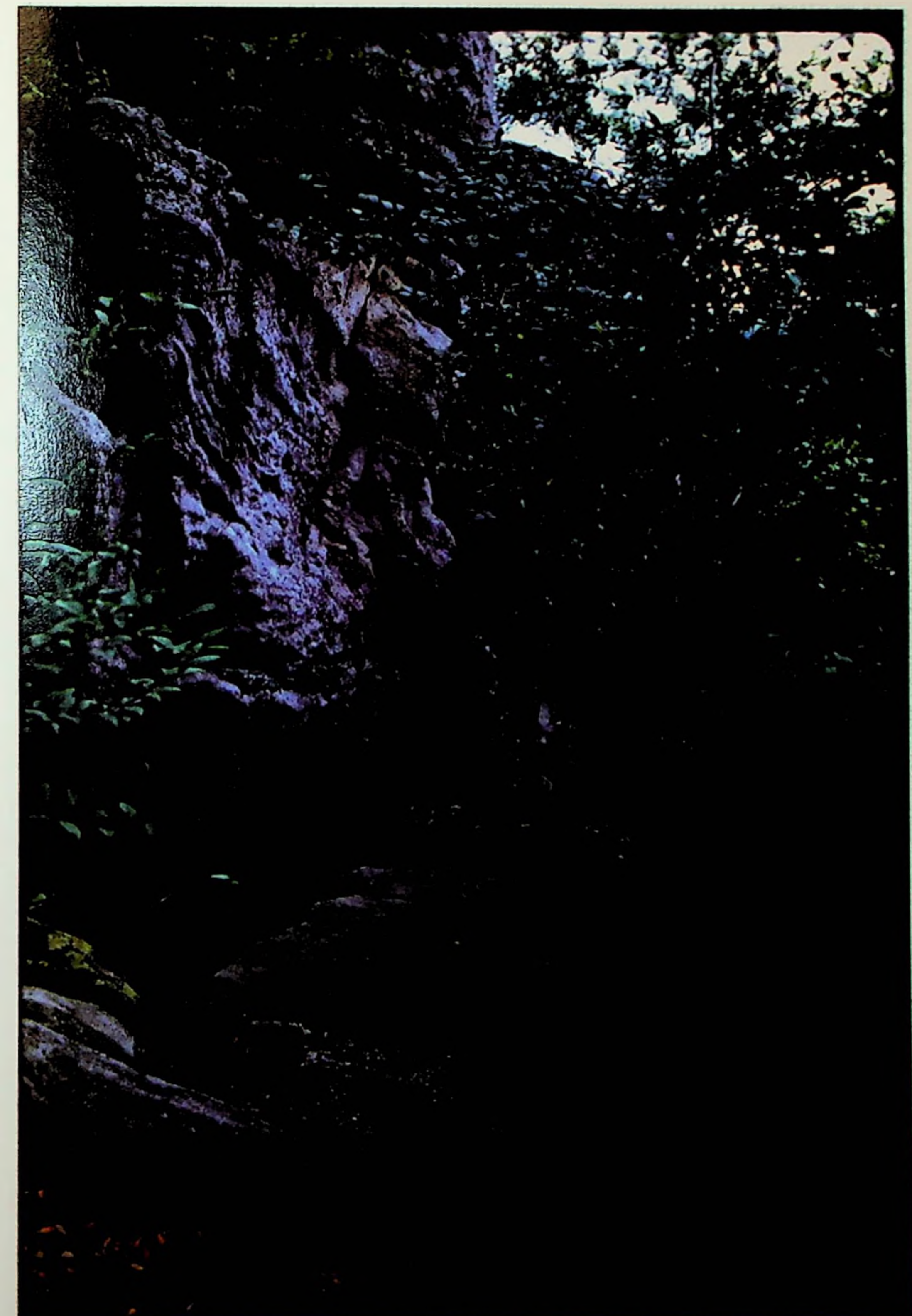


Figure 15. Plantation study location.


PNP
PP
N G A H E L A
M O U N T A I N
A L F O R E S T
M O Z A R K
PLANTATION
Run

Figure 16. Plantation P. nettingi site.

Figure 17. Plantation non- P. nettingi site.

Sites were sampled twice seasonally. At each sampling, transects were moved 2m to the right or left so that the same area along each transect was not sampled more than once. Spring collection dates were June 11, and July 1, summer dates were July 25, and August 16, and fall dates were September 13, and October 18, 1997. Environmental data were collected at each date in every 5m block of each transect. Air temperature was measured at ground level with a reotemp thermometer. The temperature of the first three cm of soil was measured with a reotemp thermometer. Relative humidity was measured with an Extech hygrothermometer placed on the ground but not touching either the substrate or an other object. Once per season (spring, summer, and fall) soil and litter samples were collected. The first 3cm of soil was collected devoid of rocks and sticks. Soil samples were placed in plastic bags and were kept cool to reduce bacterial growth until they were analyzed in the laboratory for moisture content and pH. A 10cm template was used to collect 2 litter samples. One sample was from an area with the thickest litter and the other was from the area with the thinnest litter. In both cases, new litter (non-decomposing litter) and twigs and rocks were not included in the sample. Litter was placed in a paper bag which was then placed in a plastic bag so that moisture could not be transferred from one sample to another. Paper bags were used so that litter could be weighed and dried with minimal handling of the litter sample. Litter was kept cool until it was analyzed for moisture content in the laboratory.

Biological data were collected on every sampling date. All litter and cover objects were removed to search for salamanders. Every salamander was identified to species and the gender was determined. Since collections were made in the breeding season, the gender of adults of the genus Plethodon was determined by observing if the snout was square (male) or round (female). Desmognathus salamanders were sexed by noting the upper lip. Males have a very accentuate notch in their upper lip compared to a slight notch in females. No attempt was made to sex subadults. Females were assessed for reproductive condition, i.e. gravid or non-gravid. All salamanders were weighed to the nearest 0.01g with a 5g Pesola spring scale by placing them in a plastic bag. Snout-to-vent length was measured on all adults and every subadult that had a visible cloaca. Salamanders were placed in a plastic box and a moist sponge was used to hold the salamander straight (Pauley, 1980). Dial calipers were used to measure to the nearest 0.1mm. Subadults without a visible cloaca were measured for total length. Cover objects were noted and all salamanders were released at point of capture.

Laboratory analysis of litter and soil

Soil was weighed and then dried at 40-45°C. The dry weight was subtracted from the wet weight and the percent moisture of the wet weight was determined. Percent moisture of litter was determined as above. The dry mass of litter was considered to be litter mass. Soil pH was measured by mixing a slurry of 1g of soil with 9 ml water. The pH of the slurry was measured with a Fisherbrand table top pH meter.

Moisture Preference

Permission was granted from the United States Fish and Wildlife Service, the United Sates Forest Service, and the West Virginia Department of Natural Resources to collect P. nettingi specimens for laboratory studies. Twelve specimens each of P. nettingi, P. cinereus, and D. ochrophaeus were collected from Shavers Mountain about 1 mile from the Bear Heaven study location. Salamanders were kept in separate jars with damp paper towels and were maintained in a refrigerator at 5°C. Paper towels were changed weekly and salamanders were fed 2-4 Drosophila every other week. After a 24h acclimation to room temperature (≈25°C), 10 salamanders were placed in clear plastic boxes divided into three 4 in x 6 in sections by plastic partitions. The bottom of each section was lined with aquarium pebbles. One section had no water (low), the second section had 50 ml distilled water (medium), and the third section had 100ml distilled water (high). The high section was saturated. A control box had all three sections with 50 ml water (medium). A 3in x 5in index card was placed in each section as a cover object. The index card was changed after every use. Salamanders were placed in the middle section on top of the index card and were observed hourly for a total of 5 hours to determine their position in the box. At each observation they were placed at the start position. All observations took place in the dark. Salamanders were placed in the boxes by themselves and then with another species. They were chosen at random without regard to sex, reproductive condition, or size.

Results

Seven environmental parameters were studied including air temperature, soil temperature, relative humidity, soil moisture, litter mass, and litter moisture. All statistical analysis was performed at the 95 percent confidence level ($p<0.05$).

Salamander Population Structure

Four species of salamanders were observed from BHP (Table 1) including: 3 P. nettingi males, 5 females and 6 subadults; 3 male P. cinereus, 4 females, and 12 subadults; 1 D. ochrophaeus male, 6 females, 3 subadults; and 1 subadult P. wehrlei. Chi-square analysis show that there is no significant difference in the ratio of males to females for all four species. Three species of salamanders were collected from BHNP (Table 1). Of the 5 P. cinereus observed, 1 was a male, 2 were females, and 2 were subadults. One D. ochrophaeus male, 1 female, and 2 subadults and 1 subadult P. wehrlei were observed. There were no significant differences in the number of males and females for all 3 species. Plethodon nettingi and P. cinereus were found at PP (Table 2). Of the 12 P. nettingi, 2 were males, 9 were females, and 1 was a subadult. Six male P. cinereus, 8 females, 5 subadults, and 2 escapes (gender was not determined) were observed. There were no significant differences in the ratios of males and females for both species. Plethodon cinereus was the only salamander observed at PNP (Table 2). Three of the 10 observed were males, 4 were females and 3 were subadults. There was no significant difference in the ratio of males to females.

Table 1. Population structure for Bear Heaven study location.

P. nettingi site	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
Males	3	3	1	0
Females	5	4	6	0
Subadults	6	12	3	1
TOTAL	**14**	**19**	**10**	**1**
Non-P. nettingi site	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
Males	0	1	1	0
Females	0	2	1	0
Subadults	0	2	2	1
TOTAL	**0**	**5**	**4**	**1**

Table 2. Population structure for Plantation study location.

P. nettingi site	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
Males	2	6	0	0
Females	9	8	0	0
Subadults	1	5	0	0
TOTAL	**12**	**19***	**0**	**0**
Non-P. nettingi site	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
Males	0	3	0	0
Females	0	4	0	0
Subadults	0	3	0	0
TOTAL	**0**	**10**	**0**	**0**

* The gender of two escaped P. cinereus could not be determined.

ENVIRONMENTAL

P. nettingi sites compared to non-P. nettingi sites

Bear Heaven P. nettingi site (BHP) and Bear Heaven non-P. nettingi (BHNP) environmental data are shown in Table 3. Soil temperature, relative humidity, and litter moisture were significantly different between the P. nettingi and non-P. nettingi sites. Soil temperature was cooler and relative humidity was lower at BHP than BHNP. Litter moisture was higher at BHP than BHN. Plantation P. nettingi site (PP) and Plantation non-P. nettingi site (PNP) environmental data are shown in Table 4. Air temperature, soil H^+ concentration, and litter mass were significantly different between the P. nettingi and non-P. nettingi sites: Air temperature was cooler at PP than PNP; PNP site had a higher soil H^+ concentration than PP and litter mass was significantly higher at PP than PNP.

Air temperature, soil temperature, soil moisture, H^+ concentration, litter mass, and litter moisture were significantly different between BHP and PP (Table 5): Air temperature and soil temperature were cooler at BHP; soil was drier and H^+ concentration was lower at BHP. Bear heaven P. nettingi site had less litter mass but was moister than PP. Bear Heaven non-P. nettingi site was less humid and had drier, more acidic soil than PNP (Table 6).

Plethodon nettingi microsites

Since no P. nettingi were found at the non-P. nettingi sites, they were not included in the following analyses. Each 5m x 2m block where P. nettingi was

Table 3. Mean environmental data for Bear Heaven _P. nettingi_ site (BHP) and Bear Heaven non-_P. nettingi_ site (BHNP).

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
BHP	17.75 ± 4.10^{a} n = 192	$15.53 \pm 3.54^{a,1}$ n = 192	$78.22 \pm 14.72^{a,2}$ n = 96	53.39 ± 15.79^{a} n = 60	9.7 E - 5 ± 6.26 E -5[a] n = 60	12.54 ± 2.89^{a} n = 127	$41.96 \pm 28.22^{a,3}$ n = 127
BHNP	18.64 ± 5.20^{a} n = 192	$16.53 \pm 4.49^{b,1}$ n = 192	$71.67 \pm 13.26^{b,2}$ n = 96	52.83 ± 15.79^{a} n = 62	7.34 E -5 ± 5.10 E -5[a] n = 61	12.61 ± 2.83^{a} n = 127	$32.38 \pm 12.61^{b,3}$ n = 128

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 1.60

[2] F = 1.23

[3] F = 5.01

Table 4. Mean environmental data for Plantation P. nettingi site (PP) and Plantation non-P. nettingi site (PNP).

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
PP	$18.60 \pm 4.17^{a,1}$ n = 192	16.79 ± 4.17^{a} n = 192	76.20 ± 14.72^{a} n = 96	67.67 ± 12.12^{a} n = 62	$1.38 E -4 \pm 6.59 E -5^{a,2}$ n = 62	$13.84 \pm 2.97^{a,3}$ n = 128	35.68 ± 11.38^{a} n = 128
PNP	$19.43 \pm 4.27^{b,1}$ n = 192	17.89 ± 12.42^{a} n = 192	76.4 ± 9.38^{a} n = 96	66.30 ± 7.32^{a} n = 65	$1.71 E -4 \pm 8.62 E -5^{b,2}$ n = 65	$12.48 \pm 3.84^{b,3}$ n = 128	38.48 ± 53.05^{a} n = 128

Student t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 1.05

[2] F = 1.71

[3] F = 1.67

Table 5. Mean environmental data for Bear Heaven P. nettingi site (BHP) compared to Plantation P. nettingi site (PP).

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
BHP	$17.75 \pm 4.10^{a,1}$ n = 192	$15.53 \pm 3.54^{a,2}$ n = 192	78.22 ± 14.72^{a} n = 96	$53.39 \pm 15.79^{a,3}$ n = 60	$9.7\text{ E - }5 \pm 6.26\text{ E -}5^{a,4}$ n = 60	$12.54 \pm 2.89^{a,5}$ n = 127	$41.96 \pm 28.22^{a,6}$ n = 127
PP	$18.60 \pm 4.17^{b,1}$ n = 192	$16.79 \pm 4.17^{b,2}$ n = 192	76.20 ± 14.72^{a} n = 96	$67.67 \pm 12.12^{b,3}$ n = 62	$1.38\text{ E -}4 \pm 6.59\text{ E -}5^{b,4}$ n = 62	$13.84 \pm 2.97^{b,5}$ n = 128	$35.68 \pm 11.38^{b,6}$ n = 128

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 1.03
[2] F = 1.39
[3] F = 1.98
[4] F = 1.06
[5] F = 1.18
[6] F = 5.84

Table 6. Mean environmental data for Bear Heaven non-P. nettingi site (BHNP) and Plantation non-P. nettingi site (PNP).

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
BHNP	18.64 ± 5.20^{a} n = 192	16.53 ± 4.49^{a} n = 192	71.67 ± 13.26^{a,1} n = 96	52.83 ± 15.79^{a,2} n = 62	7.34 E -5 ± 5.10 E -5^{a,3} n = 61	12.61 ± 2.83^{a} n = 127	32.38 ± 12.61^{a} n = 128
PNP	19.43± 4.27^{a} n = 192	17.89 ± 12.42^{a} n = 192	76.40 ± 9.38^{b,1} n = 96	66.30 ± 7.32^{b,2} n = 65	1.71 E -4 ± 8.62 E -5^{b,3} n = 65	12.48 ± 3.84^{a} n = 128	38.48 ± 53.05^{a} n = 128

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 2.00

[2] F = 4.65

[3] F = 2.87

found on a given date was considered a microsite. No P. nettingi were found at either non-P. nettingi site. Fourteen P. nettingi were observed at BP and 12 at PP. Schematic representations of the P. nettingi microsites at Bear Heaven and Plantation are presented in Figures 18 and 19. Bear Heaven P. nettingi microsites had significantly more litter mass than microsites without P. nettingi (Table 7). Environmental data means for PP microsites are listed in Table 8. Plantation P. nettingi microsites were significantly warmer than non-P. nettingi microsites. Soil temperature was significantly warmer where P. nettingi was found and there was significantly more and moister litter.

Transects

Analysis of variance (ANOVA) was used to determine if the 4 transects at each Bear Heaven site and the 4 transects and the middle section at the Plantation sites were significantly different for any environmental parameter. Results for BHP and BHNP are summarized in Table 9. Bear Heaven P. nettingi site north and west transects had significantly moister soil than the east transect and the north transect had significantly more soil H^+ concentration than the south transect. Litter moisture and mass were significantly different among transects at BHNP. The north transect had significantly more litter mass and moisture than any other transect and the west transect had significantly drier litter than any other transect. Neither Plantation site showed any significant differences among any transect, including the middle section, for any

Figure 18. Schematic representation of the Bear Heaven P. nettingi site.

Bear Heaven P. nettingi site

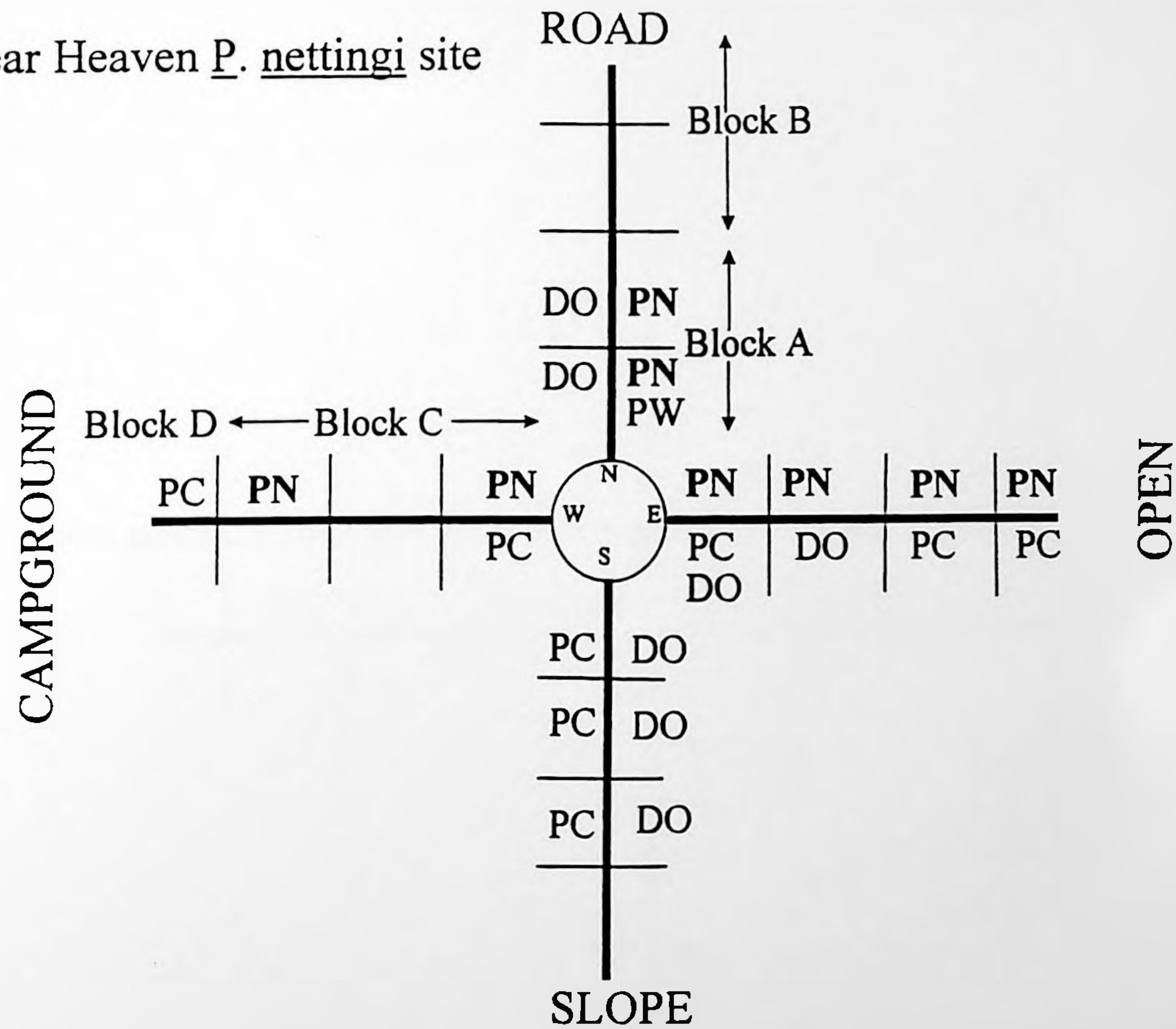


Figure 19. Schematic representation of the Plantation P. nettingi site.

Plantation *P. nettingi* site

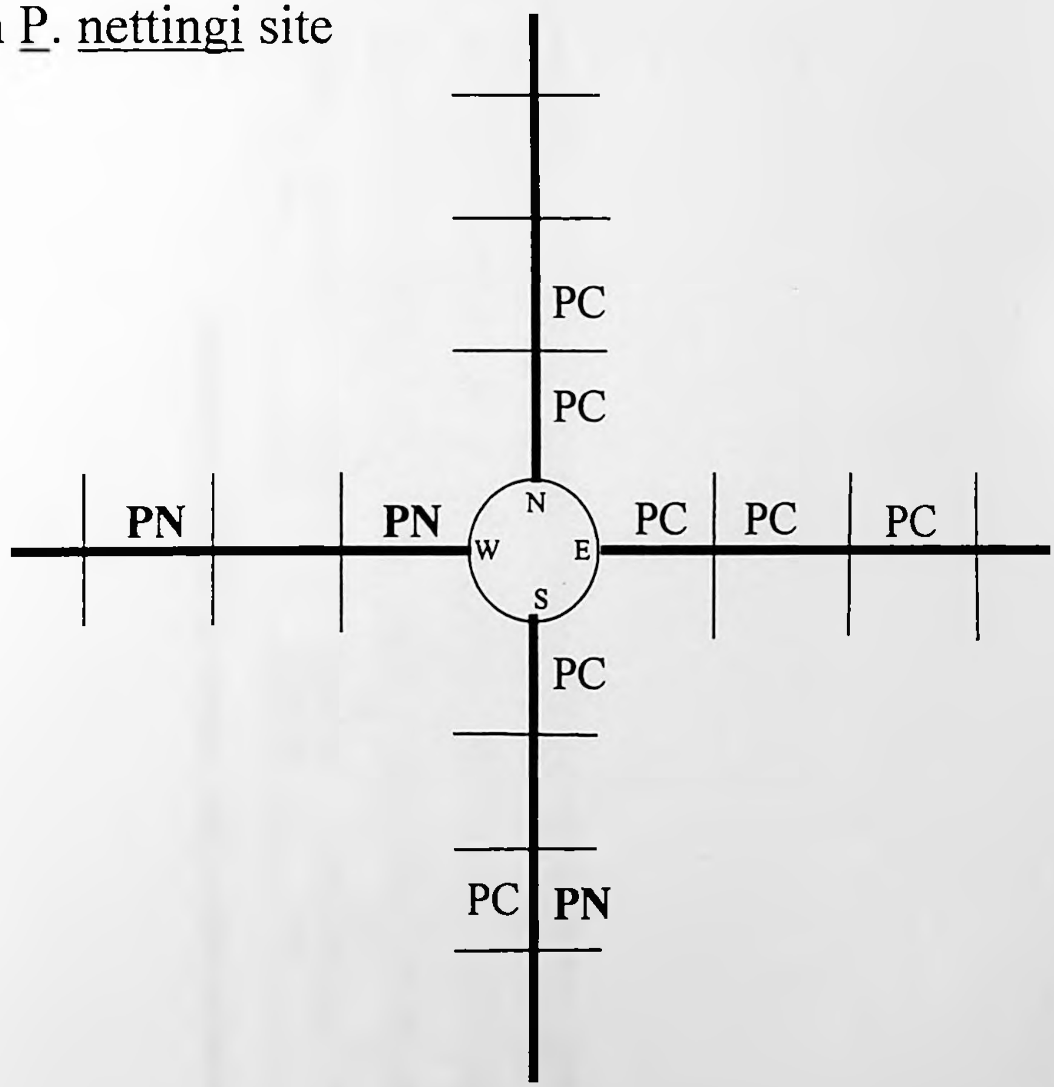


Table 7. Mean environmental data for Bear Heaven P. nettingi microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. nettingi	18.33 ± 3.60[a] n = 12	15.50 ± 3.73[a] n = 12	82.21 ± 12.36[a] n = 10	45.37 ± 19.14[a] n = 7	6.86 E -5 ± 5.70 E -5[a] n = 7	14.77 ± 2.75[a1] n = 7	46.33 ± 15.41[a] n = 7
Without P. nettingi	17.71 ± 4.15[a] n = 180	15.52 ± 3.54[a] n = 180	75.80 ± 14.49[a] n = 110	54.46 ± 15.18[a] n = 53	9.36 E -5 ± 6.29 E -5[a] n = 53	12.41 ± 2.86[b1] n = 120	41.71 ± 28.81[a] n = 120

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 1.32

Table 8. Mean environmental data for Plantation P. nettingi microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. nettingi	20.60 ± 1.64[a1] n = 10	18.80 ± 1.03[a2] n = 10	82.21± 12.36[a] n = 10	67.3 ± 3.87[a] n = 3	1.47 E -4 ± 7.37 E -5[a] n = 3	19.85 ± 2.37[a3] n = 3	54.0 ± 5.20[a4] n = 3
Without P. nettingi	18.5 ± 4.26[b1] n = 230	16.67 ± 4.28[b2] n = 230	75.80± 14.49[a] n = 110	68.0 ± 11.43[a] n = 75	1.34 E -4 ± 6.43 E -5[a] n = 75	13.94 ± 3.05[b3] n = 157	35.65 ± 11.50[b4] n = 157

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] $F = 6.73$

[2] $F = 17.21$

[3] $F = 1.65$

[4] $F = 4.89$

Table 9. Mean environmental data for Bear Heaven _P. nettingi_ site (BHP) and Bear Heaven non-_P. nettingi_ site (BHNP) transects.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
BHP North	17.88 ± 4.32[a] n = 48	15.92 ± 4.12[a] n = 48	82.20 ± 11.54[a] n = 24	58.97 ± 11.47[a,1] n = 16	1.28 E -4 ± 7.95 E -5[a,2] n = 16	12.91 ± 3.77[a] n = 32	44.9 ± 13.47[a] n = 32
BHP South	17.90 ± 4.45[a] n = 48	15.75 ± 3.62[a] n = 48	73.31 ± 18.44[a] n = 24	52.89 ± 18.09[a,b,1] n = 13	5.85 E -5 ± 3.51 E -5[c,2] n = 13	12.32 ± 2.03[a] n = 31	36.68 ± 13.72[a] n = 31
BHP East	17.65 ± 4.07[a] n = 48	15.23 ± 3.38[a] n = 48	82.78 ± 8.78[a] n = 24	43.78 ± 14.46[b,1] n = 16	8.38 E -5 ± 5.29 E -5[a,b,2] n = 16	12.77 ± 2.69[a] n = 32	41.34 ± 12.28[a] n = 32
BHP West	17.58 ± 3.67[a] n = 48	15.19 ± 3.03[a] n = 48	74.60 ± 16.37[a] n = 24	58.15 ± 15.43[a,1] n = 15	8.39 E -5 ± 5.33 E -5[a,b,2] n = 15	12.15 ± 2.85[a] n = 32	45.58 ± 51.73[a] n = 32
BHNP North	18.47 ± 4.78[a] n = 48	15.54 ± 3.97[a] n = 48	74.15 ± 10.44[a] n = 24	50.80 ± 23.26[a] n = 15	6.01E -5 ± 4.09 E -5[a] n = 15	14.09 ± 3.21[a,3] n = 32	41.8 ± 9.97[a,4] n = 32
BHNP South	18.89 ± 5.48[a] n = 48	16.83 ± 4.66[a] n = 48	70.60 ± 15.14[a] n = 24	57.71 ± 12.92[a] n = 16	8.18 E -5 ± 6.02 E -5[a] n = 16	12.05 ± 2.08[b,3] n = 32	29.82 ± 13.79[b,4] n = 32
BHNP East	18.65 ± 5.17[a] n = 48	16.10 ± 4.41[a] n = 48	71.89 ± 14.52[a] n = 24	51.59 ± 13.24[a] n = 16	6.81 E -5 ± 5.06 E -5[a] n = 16	12.61 ± 1.92[b,3] n = 32	34.63 ± 9.97[b,4] n = 32
BHNP West	18.56 ± 5.51[a] n = 48	16.89 ± 4.87[a] n = 48	70.11 ± 12.92[a] n = 24	50.97 ± 11.89[a] n = 15	8.28 E -5 ± 5.22 E -5[a] n = 14	11.72± 3.34[b,3] n = 32	24.0 0± 9.21[c,4] n = 32

One-way ANOVA values with different letters are significantly different at the 95% confidence level.

[1] F = 3.50

[2] F = 3.69

[3] F = 4.77

[4] F = 13.77

environmental parameter (Table 10). Table 11 lists the number of salamanders collected along each transect.

Distance from center

In order to determine if environmental conditions change significantly with increasing distance from the center of each treatment study site, transects were divided into 5m blocks. The first 10 m were combined into Block "A" and the second 10m were combined into Block "B". Environmental data by Block A and Block B for each transect at Bear Heaven are summarized in Table 12. There was significantly more, moister litter mass in Block A of the north transect at BHP than Block B (Fig. 18). The first 15m were combined into Block "C" and the last 5m was Block "D" for the following analyses. Soil in the west transect was less acidic in Block C than Block D (Table 13 and Fig. 18). There was less litter in the first 20m (transect) of the east transect than the open area 25m from the center however; the litter was significantly drier in this open area (Table 14 and Fig. 18). There were no significant differences along any transect at either Plantation site (Table 15 and Fig. 19). Number of salamanders collected per block at each site is listed in Tables 16 and 17.

Plethodon cinereus microsites

Plethodon cinereus was found at both P. nettingi sites and non-P. nettingi sites. Nineteen were found at BHP and 5 at BHNP (Fig. 18). Nineteen were observed at PP and 10 at PNP (Fig. 19). The only significant factors observed

Table 10. Mean environmental data for Plantation P. nettingi site (PP) and Plantation non-P. nettingi site (PNP) transects.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
PP North	18.25 ± 4.22[a] n = 48	16.27 ± 4.00[a] n = 48	75.59 ± 15.28[a] n = 24	71.16 ± 9.07[a] n = 16	1.20 E -4 ± 7.69 E -5[a] n = 16	13.80 ± 2.25[a] n = 32	36.4 ± 12.91[a] n = 32
PP South	19.0 0± 4.23[a] n = 48	17.13 ± 4.34[a] n = 48	77.29 ± 15.34[a] n = 24	63.84 ± 18.31[a] n = 15	1.45 E -4 ± 5.46 E -5[a] n = 15	14.13 ± 3.59[a] n = 32	34.43 ± 10.85[a] n = 32
PP East	18.54 ± 4.29[a] n = 48	16.88 ± 4.50[a] n = 48	75.52 ± 14.63[a] n = 24	68.10 ± 11.63[a] n = 16	1.44 E -4 ± 7.59 E -5[a] n = 16	14.14 ± 2.98[a] n = 32	38.0 ± 12.90[a] n = 32
PP West	18.63 ± 4.02[a] n = 48	16.90 ± 3.91[a] n = 48	76.40 ± 14.50[a] n = 24	67.31 ± 6.51[a] n = 15	1.47 E -4 ± 5.35 E -5[a] n = 15	13.37 ± 2.72[a] n = 32	34.24 ± 11.36[a] n = 32
PP Middle	18.54 ± 4.38[a] n = 48	16.60 ± 4.44[a] n = 48	76.88 ± 13.26[a] n = 24	69.12 ± 6.80[a] n = 16	1.19 E -4 ± 5.66 E -5[a] n = 15	14.88 ± 3.66[a] n = 32	37.24 ± 12.91[a] n = 32
PNP North	19.23 ± 4.25[a] n = 48	20.42 ± 23.85[a] n = 48	74.98 ± 10.13[a] n = 24	66.18 ± 9.18[a] n = 16	1.78 E -4 ± 8.62 E -5[a] n = 16	12.64 ± 3.39[a] n = 31	49.5 ± 91.74[a] n = 31
PNP South	19.75 ± 4.54[a] n = 48	17.29 ± 4.33[a] n = 48	76.56 ± 9.87[a] n = 24	62.66 ± 6.52[a] n = 18	1.84 E -4 ± 1.10 E -4[a] n = 18	13.15 ± 3.58[a] n = 33	42.42 ± 51.41[a] n = 33
PNP East	19.85 ± 3.66[a] n = 48	17.33 ± 4.02[a] n = 48	76.84 ± 8.40[a] n = 24	69.59 ± 4.47[a] n = 16	1.75 E -4 ± 7.58 E -5[a] n = 16	12.92 ± 4.36[a] n = 32	33.28 ± 15.50[a] n = 32
PNP West	18.90 ± 4.49[a] n = 48	16.67 ± 4.04[a] n = 48	75.78 ± 9.52[a] n = 24	67.28 ± 7.16[a] n = 15	1.44 E - 4 ± 6.38 E -5[a] n = 15	11.95 ± 2.50[a] n = 30	31.32 ± 11.03[a] n = 30
PNP Middle	18.60 ± 4.18[a] n = 48	16.85 ± 4.39[a] n = 48	77.17 ± 9.75[a] n = 24	65.33 ± 8.09[a] n = 16	1.39 E -4 ± 5.31 E -5[a] n = 16	13.44 ± 2.22[a] n = 31	37.82 ± 11.93[a] n = 32

One-way ANOVA values with different letters are significantly different at the 95% confidence level.

Table 11. Number of salamanders observed in each transect.

	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
BHP North	8	0	4	1
BHP South	0	10	4	0
BHP East	4	3	2	0
BHP West	2	6	0	0
TOTAL	**14**	**19**	**10**	**1**
BHNP North	0	5	2	1
BHNP South	0	0	0	0
BHNP East	0	0	2	0
BHNP West	0	0	0	0
TOTAL	**0**	**5**	**4**	**1**
PP North	0	5	0	0
PP South	1	4	0	0
PP East	0	6	0	0
PP West	3	0	0	0
PP Middle	8	6	0	0
TOTAL	**12**	**21**	**0**	**0**
PNP North	0	4	0	0
PNP South	0	3	0	0
PNP East	0	0	0	0
PNP West	0	1	0	0
PNP Middle	0	2	0	0
TOTAL	**0**	**10**	**0**	**0**

Table 12. Mean environmental data for Bear Heaven P. nettingi site (BHP) blocks.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H^+ concentration)	Litter Mass g	Litter Moisture %
N-A	18.25 ± 4.80[a] n = 24	16.80 ± 4.35[a] n = 24	81.43 ± 13.21[a] n = 12	54.64 ± 12.54[a] n = 8	1.50 E -4 ± 7.64 E -5[a] n = 8	14.19 ± 4.22[a,1] n = 16	48.93 ± 14.73[a,2] n = 16
N-B	17.50 ± 3.83[a] n = 24	15.75 ± 3.59[a] n = 24	82.98 ± 10.12[a] n = 12	63.30 ± 9.04[a] n = 8	1.8 E -4 ± 7.87 E -5[a] n = 8	11.63 ± 2.82[b,1] n = 16	39.24 ± 10.38[b,2] n = 16
S-A	18.50 ± 4.52[a] n = 24	15.83 ± 3.40[a] n = 34	73.18 ± 19.84[a] n = 12	49.2 ± 21.64[a] n = 6	6.83 E -5 ± 4.75 E -5[a] n = 6	12.90 ± 2.38[a] n = 15	38.90 ± 14.40[a] n = 15
S-B	17.70 ± 4.39[a] n = 24	15.91 ± 3.89[a] n = 24	73.45 ± 17.80[a] n = 12	56.2 ± 15.38[a] n = 7	5.0 E -5 ± E 2.00 E -5[a] n = 7	11.78 ± 1.55[a] n = 16	34.58 ± 13.17[a] n = 16
E-A	17.67 ± 3.97[a] n = 24	15.17 ± 3.57[a] n = 24	80.73 ± 8.39[a] n = 12	47.74 ± 17.04[a] n = 8	9.87 E -5 ± 6.37 E -5[a] n = 8	12.52 ± 2.85[a] n = 16	41.83 ± 13.29[a] n = 16
E-B	14.63 ± 4.25[a] n = 24	15.29 ± 3.26[a] n = 24	84.84 ± 9.04[a] n = 12	39.81 ± 11.04[a] n = 8	6.87 E -5 ± 3.76 E -5[a] n = 8	13.02± 2.59[a] n = 16	40.84 ± 11.50[a] n = 16
W-A	18.00 ± 2.99[a] n = 24	15.29 ± 3.08[a] n = 24	74.47 ± 16.19[a] n = 12	65.51 ± 14.55[a] n = 7	6.43 E -5 ± 3.51 E -5[a] n = 7	12.50 ± 2.75[a] n = 16	53.93 ± 71.95[a] n = 16
W-B	17.17 ± 4.26[a] n = 24	15.8 ± 3.04[a] n = 24	74.73 ± 17.26[a] n = 12	51.71 ± 13.89[a] n = 8	1.30 E -4 ± 6.16 E -4[a] n = 8	12.25 ±3.04[a] n = 16	37.24 ± 14.37[a] n = 16

"A" refers to the first two 5m blocks in a transect.
"B" refers to the second two 5m blocks in a transect.
One-way ANOVA values with different letters are significantly different at the 95% confidence level.
[1] F = 2.24
[2] F = 2.01

Table 13. Mean environmental data for Bear Heaven P. nettingi site (BHP) blocks.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H^+ concentration)	Litter Mass g	Litter Moisture %
N-C	18.11 ± 4.51[a] n = 36	16.11 ± 4.51[a] n = 36	81.67 ± 12.45[a] n = 18	58.57 ± 11.62[a] n = 12	1.45 E -4 ± 7.84 E -5[a] n = 12	13.41 ± 4.12[a] n = 24	45.64 ± 14.57[a] n = 24
N-D	17.17 ± 3.76[a] n = 12	15.33 ± 3.52[a] n = 12	83.80 ± 10.33[a] n = 6	60.18 ± 12.62[a] 60.19 n = 4	8.00 E -4 ± 6.97 E -5[a] n = 4	12.33 ± 2.51[a] n = 8	39.43 ± 8.52[a] n = 8
S-C	18.6 ± 4.40[a] n = 36	15.61 ± 3.62[a] n = 36	73.40 ± 18.53[a] n = 18	53.47 ± 19.98[a] n = 9	6.55 E -5 ± 4.00 E -5[a] n = 9	12.31 ± 2.17[a] n = 23	37.40 ± 14.38[a] n = 23
S-D	17.42 ± 4.76[a] n = 12	16.12 ± 3.74[a] n = 12	73.41 ± 19.89[a] n = 6	51.60 ± 15.54[a] n = 4	4.25 E -5 ± 1.26 E -5[a] n = 4	12.36 ± 1.72[a] n = 8	33.59 ± 12.26[a] n = 8
E-C	17.58 ± 3.88[a] n = 32	15.28 ± 3.61[a] n = 36	81.97 ± 8.49[a] n = 18	47.28 ± 14.33[a] n = 12	8.91 E -5 ± 5.69 E -5[a] n = 12	12.75 ± 2.55[a] n = 24	40.46 ± 12.67[a] n = 24
E-D	17.83 ± 4.78[a] n = 12	15.8 ± 2.75[a] n = 12	85.22 ± 10.02[a] n = 6	33.25 ± 9.79[a] n = 12	6.75 E -5 ± 4.03 E -5[a] n = 4	12.84 ± 3.24[a] n = 8	43.96 ± 11.19[a] n = 8
W-C	17.81 ± 3.33[a] n = 36	15.17 ± 3.03[a] n = 36	74.73 ± 16.07[a] n = 18	58.15 ± 16.64[a] n = 11	6.73 E -5 ± 3.64 E -5[a,1] n = 11	11.65 ± 2.53[a] n = 24	47.44 ± 59.34[a] n = 24
W-D	16.92 ± 4.66[a] n = 12	15.25 ± 3.17[a] n = 12	74.74 ± 18.84[a] n = 6	58.18 ± 13.68[a] n = 4	1.36 E -4 ± 6.61 E -5[b,1] n = 4	13.66 ± 3.38[a] n = 8	40.1 ± 15.38[a] n = 8

"C" refers to the first three 5m blocks.
"D" refers to the last 5m block.
One-way ANOVA values with different letters are significantly different at the 95% confidence level.
[1] F = 3.30

Table 14. Mean environmental data for Bear Heaven P. nettingi site (BHP) east transect.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
East Transect	17.65 ± 4.07^{a} n = 48	15.23 ± 3.38^{a} n = 48	82.78 ± 8.78^{a} n = 24	43.13 ± 15.20^{a} n = 12	9.92 E -5 ± 4.92 E -5^{a} n = 12	12.27 ± 2.49^{a1} n = 24	44.31 ± 10.75^{a2} n = 24
East Road	16.63 ± 4.92^{a} n = 8	14.75 ± 5.01^{a} n = 8	83.68 ± 11.13^{a} n = 4	46.87 ± 14.74^{a} n = 3	6.67 E -5 ± 1.15 E -5^{a} n = 3	16.75 ± 4.33^{b1} n = 7	34.84 ± 12.72^{b2} n = 7

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 3.01

[2] F = 1.40

Table 15. Mean environmental data for Plantation P. nettingi site (PP) blocks.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H^+ concentration)	Litter Mass g	Litter Moisture %
N-A	18.13 ± 4.12[a] n = 24	16.21 ± 4.30[a] n = 24	75.77 ± 16.20[a] n = 12	71.20 ± 8.86[a] n = 8	1.26 E - 4 ± 8.95 E -5[a] n = 8	12.93 ± 2.49[a] n = 16	35.08 ± 11.23[a] n = 16
N-B	18.38 ± 4.11[a] n = 24	16.33 ± 3.76[a] n = 24	75.42 ± 15.03[a] n = 12	71.13 ± 9.90[a] n = 8	1.13 E -4 ± 6.76 E -5[a] n = 8	13.22 ± 2.05[a] n = 16	37.02 ± 9.74[a] n = 16
S-A	19.17 ± 4.21[a] n = 24	17.54 ± 4.51[a] n= 24	76.68 ± 15.97[a] n = 12	62.49 ± 25.80[a] n = 7	1.34 E -4 ± 6.00 E -5[a] n = 7	13.52 ± 3.73[a] n = 12	34.03 ± 11.72[a] n = 16
S-B	18.83 ± 4.33[a] n = 24	16.71 ± 4.22[a] n = 24	77.89 ± 15.37[a] n = 12	65.01 ± 9.60[a] n = 8	1.53 E -4 ± 5.18 E -5[a] n = 8	14.76 ± 3.46[a] n = 12	34.85 ± 10.28[a] n = 16
E-A	18.67 ± 4.58[a] n = 24	16.79 ± 4.74[a] n = 24	74.93 ± 15.11[a] n = 12	72.31 ± 10.06[a] n = 8	1.40 E -4 ± 9.15 E -5[a] n = 8	14.24 ± 2.31[a] n = 16	39.92 ± 12.24[a] n = 16
E-B	18.41 ± 4.07[a] n = 24	16.96 ± 11.33[a] n = 24	76.11 ± 14.78[a] n -= 12	63.89 ± 12.17[a] n = 8	1.49 E -4 ± 6.26 E -5[a] n = 8	15.33 ± 3.51[a] n = 16	36.08 ± 13.64[a] n = 16
W-A	19.13 ± 4.14[a] n = 24	17.21 ± 3.95[a] n = 24	75.98 ± 14.91[a] n = 12	68.21 ± 4.11[a] n = 7	1.58 E -4 ± 5.30 E -5[a] n = 7	12.85 ± 2.49[a] n = 16	34.50 ± 10.34[a] n = 16
W-B	18.13 ± 4.02[a] n = 25	16.58 ± 4.06[a] n = 25	76.83 ± 14.73[a] n = 12	66.53 ± 8.30[a] n = 8	1.36 E -4 ± 5.52 E -5[a] n = 8	13.88 ± 2.92[a] n = 16	33.98 ± 12.64[a] n = 16

"A" refers to the first two 5m blocks.
"B" refers to the second two 5m blocks.
One-way ANOVA values with different letters are significantly different at the 95% confidence level.

Table 16. Number of salamanders observed in each block at Bear Heaven study location.

	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
BHP North 1	4	0	3	1
BHP North 2	4	0	1	0
BHP North 3	0	0	0	0
BHP North 4	0	0	0	0
BHP South 1	0	3	1	0
BHP South 2	0	2	1	0
BHP South 3	0	5	2	0
BHP South 4	0	0	0	0
BHP East 1	1	1	1	0
BHP East 2	1	0	1	0
BHP East 3	1	1	0	0
BHP East 4	1	1	0	0
BHP West 1	1	4	0	0
BHP West 2	0	0	0	0
BHP West 3	1	0	0	0
BHP West 4	0	2	0	0
BHNP North 1	0	1	1	1
BHNP North 2	0	2	0	0
BHNP North 3	0	2	0	0
BHNP North 4	0	0	1	0
BHNP South 1	0	0	0	0
BHNP South 2	0	0	0	0
BHNP South 3	0	0	0	0
BHNP South 4	0	0	0	0
BHNP East 1	0	0	2	0
BHNP East 2	0	0	0	0
BHNP East 3	0	0	0	0
BHNP East 4	0	0	0	0
BHNP West 1	0	0	0	0
BHNP West 2	0	0	0	0
BHNP West 3	0	0	0	0
BHNP West 4	0	0	0	0

Table 17. Number of salamanders observed in each block at Plantation study location.

	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
PP North 1	0	1	0	0
PP North 2	0	4	0	0
PP North 3	0	0	0	0
PP North 4	0	0	0	0
PP South 1	0	2	0	0
PP South 2	0	0	0	0
PP South 3	1	2	0	0
PP South 4	0	0	0	0
PP East 1	0	4	0	0
PP East 2	0	1	0	0
PP East 3	0	1	0	0
PP East 4	0	0	0	0
PP West 1	2	0	0	0
PP West 2	0	0	0	0
PP West 3	1	0	0	0
PP West 4	0	0	0	0
PP Middle 1	4	4	0	0
PP Middle 2	1	1	0	0
PP Middle 3	2	1	0	0
PP Middle 4	1	0	0	0
PNP North 1	0	1	0	0
PNP North 2	0	2	0	0
PNP North 3	0	1	0	0
PNP North 4	0	0	0	0
PNP South 1	0	0	0	0
PNP South 2	0	2	0	0
PNP South 3	0	1	0	0
PNP South 4	0	0	0	0
PNP East 1	0	0	0	0
PNP East 2	0	0	0	0
PNP East 3	0	0	0	0
PNP East 4	0	0	0	0
PNP West 1	0	1	0	0
PNP West 2	0	0	0	0
PNP West 3	0	0	0	0
PNP West 4	0	0	0	0
PNP Middle 1	0	2	0	0
PNP Middle 2	0	0	0	0
PNP Middle 3	0	0	0	0
PNP Middle 4	0	0	0	0

at any microsites was at BHP. Microsites with P. cinereus had significantly higher soil H^+ concentration and more litter mass (Table 18). Environmental data from BHNP are listed in Table 19. There were no significant differences in any parameter measured between P. cinereus microsites and those microsites which did not have P. cinereus. Plantation P. cinereus microsite data are shown in Table 20. Plethodon cinereus microsites at PP had more litter mass than those sites without P. cinereus. Soil was more moist in PNP P. cinereus microsites (Table 21).

Desmognathus ochrophaeus microsites

Ten D. ochrophaeus were collected from BHP and 4 from BHNP. No D. ochrophaeus were collected from either PP or PNP. Bear Heaven treatment microsites with D. ochrophaeus were significantly warmer and had warmer soil (Table 22 and Fig. 18). Desmognathus ochrophaeus microsites at BHNP were cooler with cooler soil (Table 23).

Cover Objects

Cover objects used by salamanders at all 4 study sites are listed in Table 24. Salamanders were found under 4 types of cover objects: leaf litter, bark, logs, and rocks. Leaf litter was used significantly more than any other cover object at BHP by P. nettingi (92.9%) and P. cinereus (84.2%) and at BHNP by P. cinereus (100%).

Table 18. Mean environmental data for Bear Heaven P. nettingi site P. cinereus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. cinereus	18.21 ± 4.21[a] n = 28	15.32 ± 3.11[a] n = 28	71.13 ± 23.01[a] n = 14	54.33 ± 17.53[a] n = 6	4.50 E -5 ± 3.51 E -5[a,1] n = 6	13.96 ± 3.05[a,2] n = 14	36.37 ± 12.46[a] n = 14
Without P. cinereus	17.73 ± 4.04[a] n = 163	15.60 ± 3.60[a] n = 163	79.44 ± 12.61[a] n = 82	52.27 ± 15.75[a] n = 54	9.57 E -5 ± 6.28 E -5[b,1] n = 54	12.37 ± 2.83[b,2] n = 113	42.65 ± 29.55[a] n = 113

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 3.21

[2] F = 1.60

Table 19. Mean environmental data for Bear Heaven non-P. nettingi site P. cinereus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. cinereus	16.1 ± 6.19[a] n = 10	14.0 ± 4.89[a] n = 10	77.6 ± 10.20[a] n = 5	58.24 ± 16.40[a] n = 7	6.43 E -5 ± 4.72 E -5[a] n = 7	13.43 ± 2.38[a] n = 12	29.63 ± 13.52[a] n = 12
Without P. cinereus	18.78 ± 5.13[a] n = 182	16.47 ± 4.44[a] n = 182	71.39 ± 13.39[a] n = 91	52.52 ± 15.61[a] n = 54	7.44 E -5 ± E -5[a] n = 54	12.53 ± 2.87[a] n = 116	32.67 ± 12.54[a] n = 116

Student's t-test values with different letters are significantly different at the 95% confidence level.

Table 20. Mean environmental data for Plantation P. nettingi site P. cinereus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. cinereus	20.43 ± 3.31[a] n = 42	18.52 ± 3.61[a] n = 42	69.91 ± 17.52[a] n = 21	67.59 ± 6.72[a] n = 21	1.18 E-4 ± 7.58 E -5[a] n = 12	15.55 ± 30[a,1] n = 26	33.1 ± 12.79[a] n = 26
Without P. cinereus	18.23 ± 4.28[a] n = 196	16.41 ± 4.25[a] n = 196	77.75 ± 13.40[a] n = 98	68.3 ± 11.89[a] n = 66	1.38 E -4 ± 6.21 E -4[a] n = 66	13.76 ± 3.09[b,1] n = 134	36.57 ± 11.41[a] n = 134

Student's t-test values with different letters are significantly different at the 95% confidence level.
[1] F = 1.06

Table 21. Mean environmental data for Plantation non-P. nettingi site P. cinereus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With P. cinereus	20.38 ± 3.88[a] n = 16	28.50 ± 40.58[a] n = 16	69.60 ± 13.18[a] n = 8	54.8 ± 10.10[a,1] n = 5	1.84 E -4 ± 5.12 E -5[a] n = 5	11.8 ± 2.36[a] n = 9	31.67 ± 8.57[a] n = 9
Without P. cinereus	19.19 ± 4.28[a] n = 224	16.94 ± 4.13[a] n = 224	76.74 ± 8.99[a] n = 112	66.90 ± 6.58[b,1] n = 76	1.64 E -4 ± 8.32 E -5[a] n = 76	12.94 ± 3.34[a] n = 149	39.26 ± 49.16[a] n = 149

Student's t-test values with different letters are significantly different at the 95% confidence level.
[1] F = 1.06

Table 22. Mean environmental data for Bear Heaven P. nettingi site D. ochrophaeus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With D. ochrophaeus	19.13± 2.18[a,1] n = 16	17.75± 1.61[a,2] n = 16	77.64± 11.00[a] n = 8	44.13± 17.78[a] n = 4	7.00E -5 ± 4.69E -5[a] n = 4	14.36± 4.78[a] n = 10	35.91± 18.96[a] n = 10
Without D. ochrophaeus	17.68± 4.17[b,1] n = 175	15.35± 3.58[b,2] n = 175	78.28± 15.06[a] n = 88	54.06± 15.59[a] n = 56	9.21E -5± 6.34E -5[a] n = 56	12.38± 2.67[a] n = 117	42.48± 28.87[a] n = 117

Student's t-test values with different letters are significantly different at the 95% confidence level.
[1] F = 3.64
[2] F = 4.94

Table 23. Mean environmental data for Bear Heaven non-P. nettingi site D. ochrophaeus microsites.

	Air Temperature °C	Soil Temperature °C	Relative Humidity %	Soil Moisture %	Soil pH (H+ Concentration)	Litter Mass g	Litter Moisture %
With D. ochrophaeus	$13.88 \pm 4.22^{a,1}$ n = 8	$12.75 \pm 2.55^{a,2}$ n = 8	73.20 ± 12.02^{a} n = 4	64.65 ± 9.12^{a} n = 2	$1.15\ E\ {-4} \pm 9.19\ E\ {-5}^{a}$ n = 2	15.67 ± 6.76^{a} n = 4	38.18 ± 15.79^{a} n = 4
Without D. ochrophaeus	$18.91 \pm 5.12^{b,1}$ n = 183	$16.54 \pm 4.48^{b,2}$ n = 183	71.62 ± 13.38^{a} n = 92	52.79 ± 15.74^{a} n = 59	$7.19\ E\ {-5} \pm 5.00\ E\ {-5}^{a}$ n = 59	12.51 ± 2.62^{a} n = 124	32.20 ± 12.53^{a} n = 124

Student's t-test values with different letters are significantly different at the 95% confidence level.

[1] F = 1.46

[2] F = 3.08

Table 24. Use of cover objects by plethodontid salamanders observed in this study.

	P. nettingi	P. cinereus	D. ochrophaeus	P. wehrlei
Bear Heaven P. nettingi site				
Litter	13[a]	16[a]	7[a]	1[a]
Bark	0[b]	1[b]	1[a]	0[a]
Log	0[b]	2[b]	2[a]	0[a]
Rock	1[b]	0[b]	0[a]	0[a]
Bear heaven non-P. nettingi site				
Litter	0[a]	5[a]	3[a]	1[a]
Bark	0[a]	0[b]	0[a]	0[a]
Log	0[a]	0[b]	1[a]	0[a]
Rock	0[a]	0[b]	0[a]	0[a]
Plantation P. nettingi site				
Litter	5[a]	13[a]	0[a]	0[a]
Bark	0[a]	2[a]	0[a]	0[a]
Log	5[a]	6[a]	0[a]	0[a]
Rock	2[a]	0[a]	0[a]	0[a]
Plantation non-P. nettingi site				
Litter	0[a]	5[a]	0[a]	0[a]
Bark	0[a]	1[a]	0[a]	0[a]
Log	0[a]	3[a]	0[a]	0[a]
Rock	0[a]	1[a]	0[a]	0[a]

X^2 values with different letters are significantly different at 95% confidence level.

Laboratory Moisture Preference Study

The percentage of time each species was observed in moisture section is shown in Figure 20. Percentage of observation times that P. nettingi was found in the high, medium, and low sections of the moisture preference chambers is noted in Figure 21. When placed in the chamber alone, P. nettingi was found in the high moisture section 38.5 percent of times, 42.2 percent of times in the medium moisture section, and 19.3 percent of times in the low moisture section. With P. cinereus and P. nettingi in the chamber, P. nettingi was in the high moisture section 64.6 percent of times, the medium moisture section 27.7 percent of times, and the low moisture section 7.7 percent of times. When in the chamber with D. ochrophaeus, P. nettingi was in the high moisture section 65.9 percent of times, the medium moisture section 23.0 percent of times, and the low moisture section 11 percent of times. The number of observation times that P. cinereus was found in each moisture section is shown in Figure 22. When in the chamber alone, P. cinereus was found in the high moisture section 60.7 percent of times, the medium moisture section 26.7 percent of times and the low moisture section 12.6 percent of times. With P. nettingi, P. cinereus was in the high moisture section 66.2 percent of times, the medium moisture section 25.3 percent of times, and the low moisture section 8.5 percent of times and with D. ochrophaeus, 71.1 percent of times in the high moisture section, the medium moisture section 23.7 percent of times and the low moisture section 5.2 percent of times. The number of times D. ochrophaeus was found in each moisture

Figure 20. Laboratory moisture preference of P. nettingi, P. cinereus, and D. ochrophaeus

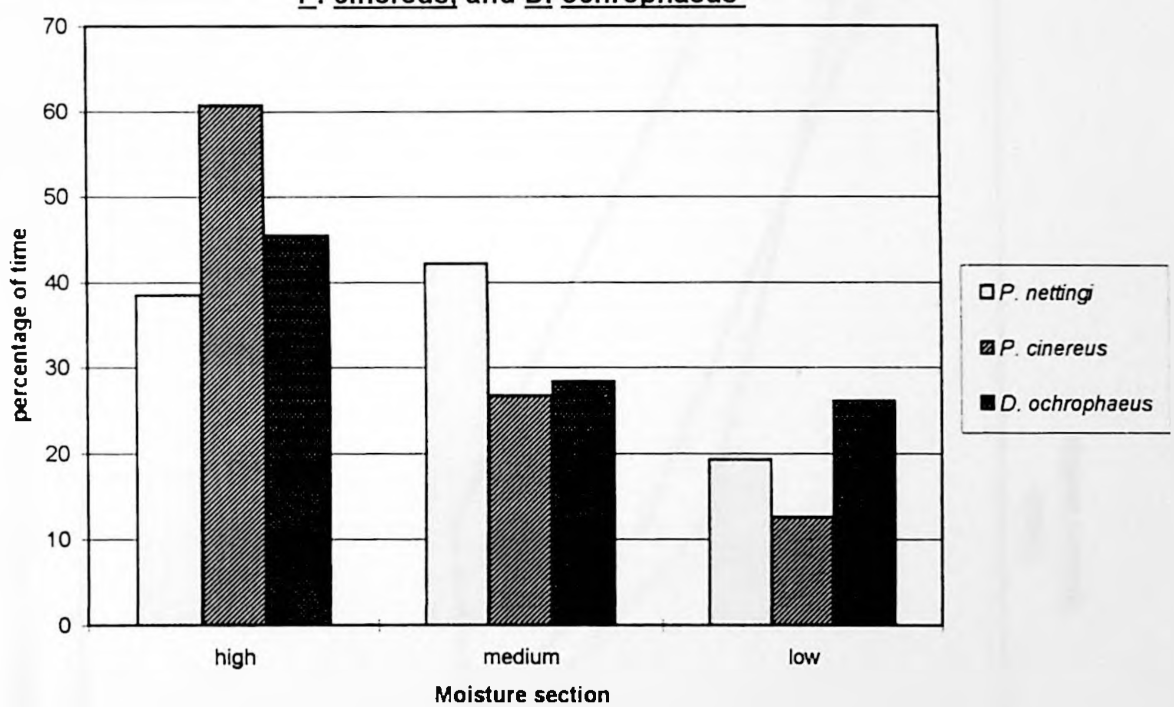


Figure 21. Plethodon nettingi laboratory moisture preference

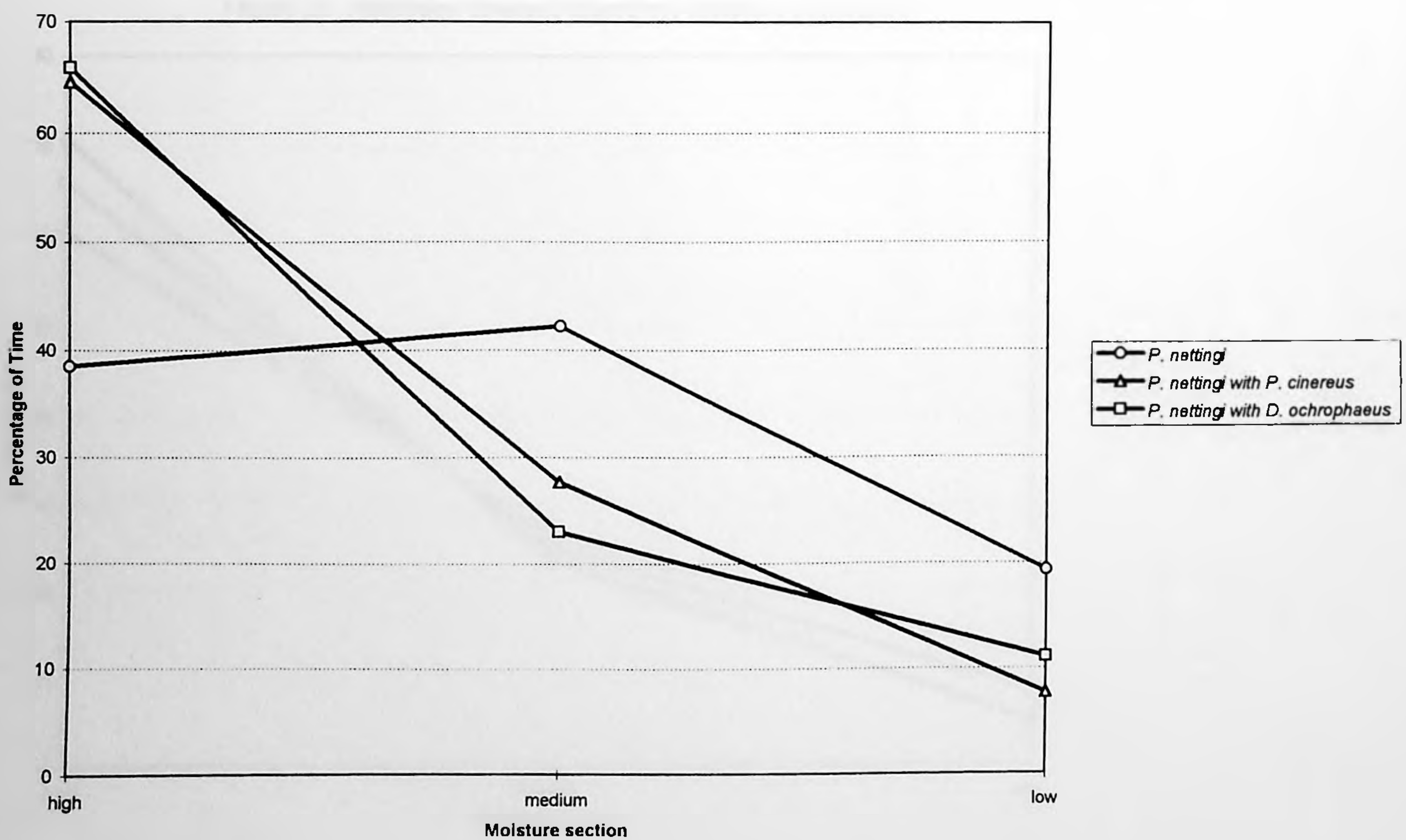
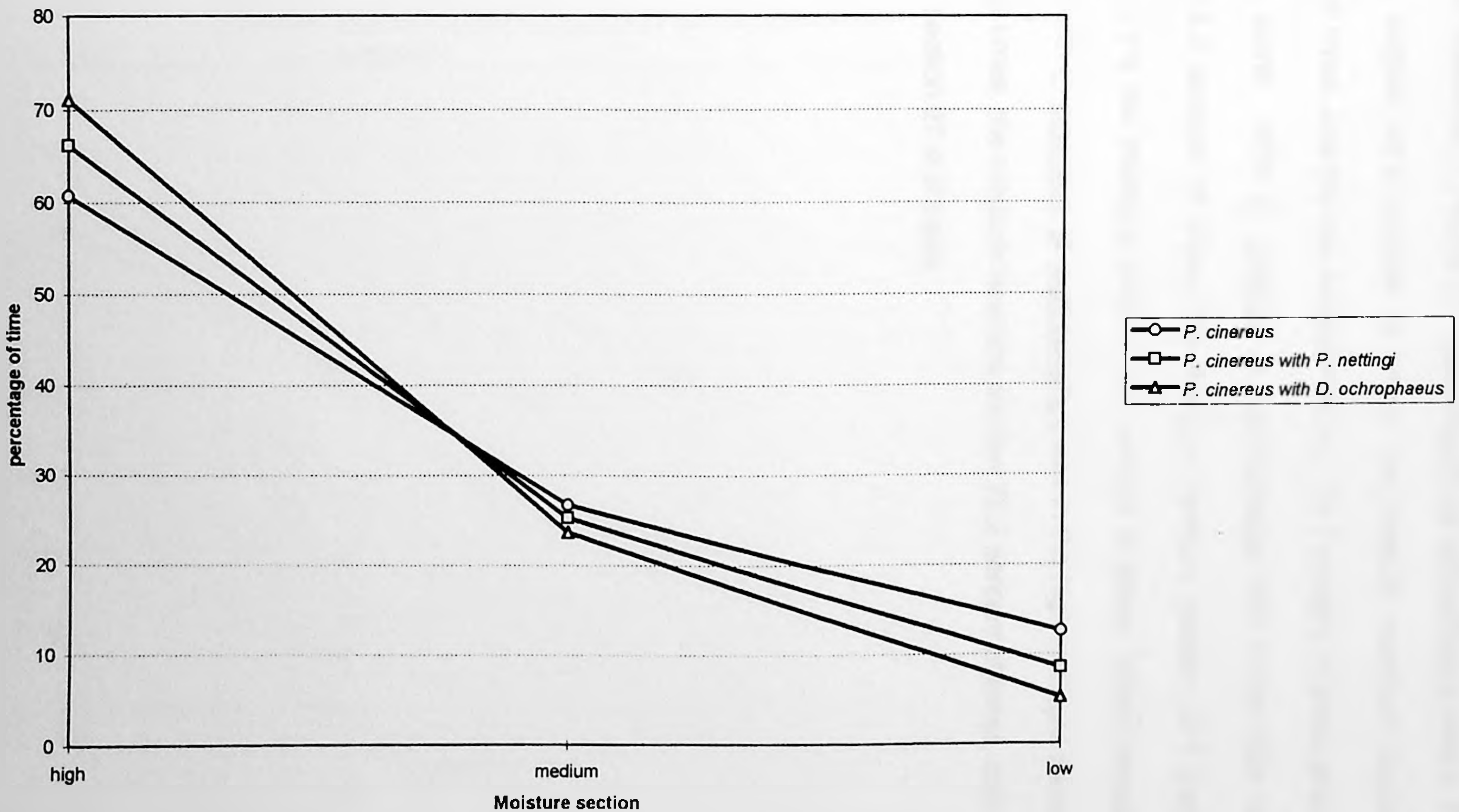
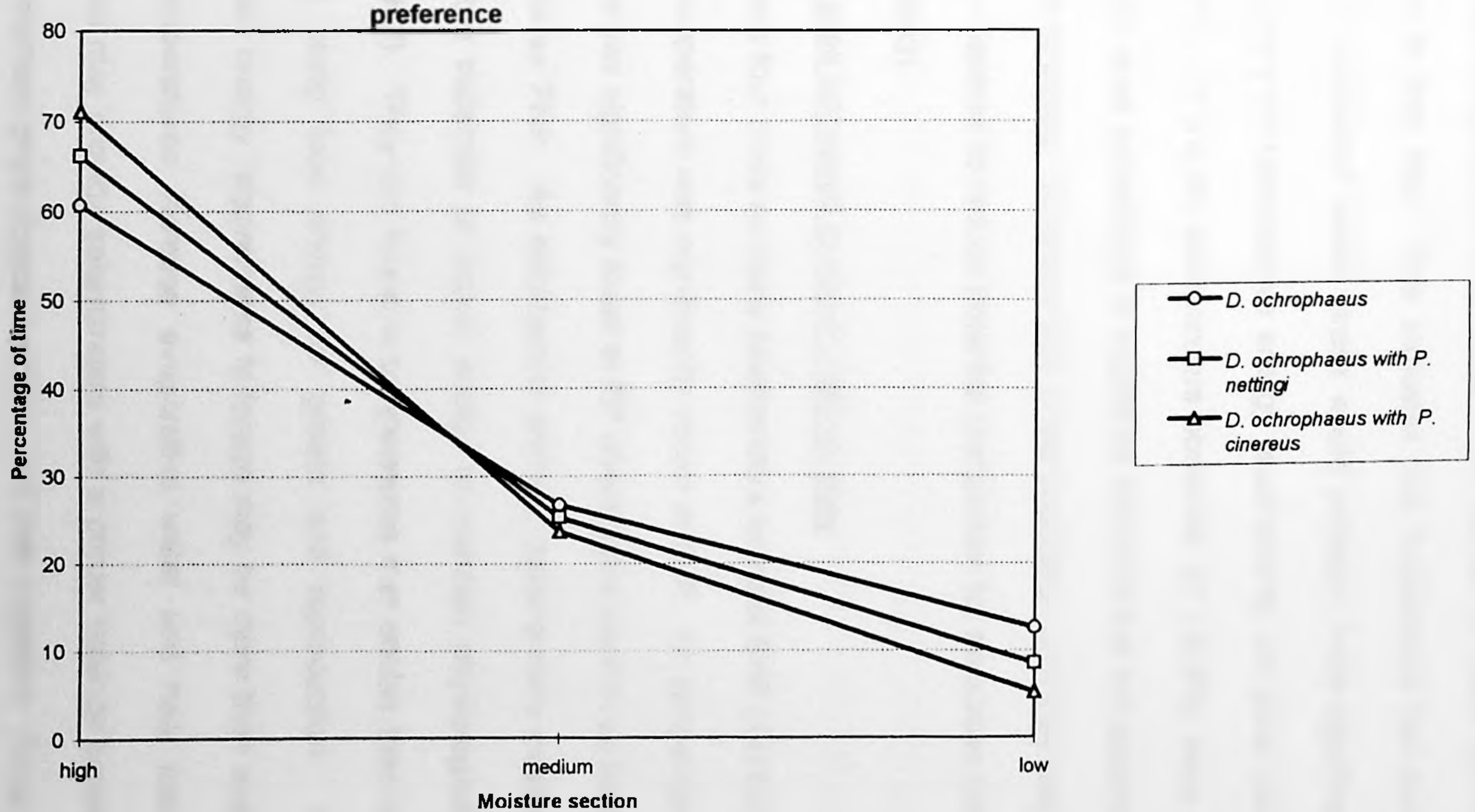


Figure 22. Plethodon cinereus laboratory moisture preference



section is illustrated in Figure 23. Desmognathus ochrophaeus was in the high moisture section 45.5 percent of times, the medium moisture section 28.4 percent of times, and the low moisture section 26.1 percent of times when in the chamber alone. With P. nettingi, D. ochrophaeus was in the high moisture section 45.5 percent of times, the medium moisture section 23.9 percent of times, and the low moisture section 30.6 percent of times. When placed in the chamber with P. cinereus, D. ochrophaeus was in the high moisture section 50.4 percent of times, the medium moisture section 22.2 percent of times, and the low moisture section 27.4 of times.

Figure 23. Desmognathus ochrophaeus laboratory moisture preference



Discussion

Salamander Population Structure

There were no significant differences in the number of males and females for any species at any site. This indicates that populations are probably not stressed. A population under stress would probably have significantly more males because their reproductive energy requirements are lower than females (Smith, 1996). Of the 95 salamanders observed, 35 (36.8%) were subadults. The relatively large percentage of subadults indicates that the populations were probably not stressed. Juveniles stay in the population until they may be forced by adults to disperse to reduce potential competition for resources (Anthony and Wicknick, 1993).

P. nettingi sites compared to non-P. nettingi sites

There were four times as many salamanders found at BHP (44) than at BHNP (10). Soil temperature was significantly cooler at BHP. Air temperature and soil temperature was significantly lower at PP where there were three times as many salamanders as PNP. As ectothermic animals, salamanders must either gain heat from the substrate or ingest energy to maintain physiological functions (Spotila, 1972). They are found in temperatures that enable them to be more efficient at using food energy for growth and reproduction. In warmer temperatures, energy requirements to forage may be more than energy intake. Warmer temperatures increase evaporative water and heat loss. Cooler temperatures may provide salamanders with a proper balance between energy needed to maintain physiological functions and prey ingestion. Feder and Lynch

(1982) found that the active body temperature range for P. cinereus was 8-26°C. Soil and air temperature ranges at all sites were within this range. Plethodon nettingi and D. ochrophaeus are similar in size to P. cinereus and critical thermal maximum values for all three species are within 0.8°C of one another (33.0-33.8°C). This indicates that their active body temperature ranges are similar.

Salamanders must remain moist to maintain proper thermal and osmoregulation. All salamander observed in this study were lungless and so exchange gases subcutaneously. When salamanders are not foraging in the litter or when litter conditions are dry, they retreat to underground burrows (Jaeger, 1980a). These burrows must remain moist not only to facilitate gas exchange through the skin but also to support invertebrate prey populations for food. Although not significant, soil moisture was greater at both P. nettingi sites than at the non-P. nettingi sites where the majority of the salamanders were found.

More salamanders were found at BHP than BHNP where relative humidity was higher at BHP. Relative humidity was measured at ground level where salamanders emerge but also where litter, their forage habitat, is in contact with the air. Higher relative humidity aids in keeping litter moist and therefore making it amenable for salamanders to inhabit. Salamanders are more active when the risk of desiccation is lower (Spotila, 1972). Jaeger (1978) studied plant-climbing behavior by P. cinereus during rainy and foggy nights when relative humidity is higher. Salamanders that climbed plants ingested significantly more food than salamanders on the ground. This study supported Fraser's (1976) conclusion that salamanders increase mobility in high relative humidity. Terrestrial salamanders are active at night when relative humidity is usually higher. All salamanders in this study were encountered during the day but the majority of the salamanders were found where relative humidity was higher.

Litter was significantly more moist at BHP than BHNP. Terrestrial salamanders leave their burrows to forage in the litter and activity is generally limited to night when they emerge onto the forest floor to forage (Jaeger, 1980a). While feeding, salamanders retreat to cover objects during the day. Moist litter affords them proper conditions for subcutaneous respiration and provides adequate prey populations. Vertical retreat to underground burrows occurs when conditions are dry (Jaeger, 1980a). Ash (1988; 1995; 1996) found that P. jordani and P. glutinosus were absent from clearcut areas where litter is exposed and dry. As forests were reestablished, and litter became moist, salamander populations began to return to pre-cut levels. In a 12-year study of the impact of a ski slope on a population of P. nettingi, Pauley (unpub. data) found that P. nettingi was observed significantly less in the area adjacent to the ski slope. This impact area had significantly drier and warmer soil and less litter that was drier than the non-impact sites.

Another important regulating factor in salamander distribution is soil acidity. It has been shown that adult populations of P. cinereus decreased greatly when soil pH fell below 4.0 (Wyman and Hawksley-Lescault, 1987). Soil pH at all 4 study sites ranged from 3.76 at PNP to 4.13 at BHNP. Acidic soils disrupt sodium balance in salamanders. Most salamanders were observed at the Bear

Heaven study site. Soil pH values at both the P. nettingi site and the non-P. nettingi site were above 4.0. Both sites at Plantation had more acidic soils (less than 4.0). The decomposing leaf litter at Plantation which ultimately will break down into soil, is mainly hemlock and spruce. Conifer litter is more acidic than deciduous litter (Priha and Smolander, 1997). Soil acidification at Plantation is probably natural to a certain extent and therefore the salamanders found there may have evolved mechanisms to live in this acidic environment.

There was more litter (litter mass) at PP than at PNP. Pough et al. (1987) stated that the depth of the litter was the best predictor of the occurrence of P. cinereus in New York. Increased litter mass provides more refugia and more prey populations for forage.

Qualitative observations at the Bear Heaven study location lend explanation to small numbers of salamanders observed at BHNP. There were only 10 salamanders found from June to October at this site. This study location is located at a well-used campground and day use area. The large emergent rocks are popular hiking and climbing areas. Many trails cut through the non-P. nettingi site and in some places leaf litter is completely absent. Foot travel probably impedes the growth of understory plants and young saplings which could provide necessary litter and cover objects for salamanders. Pauley (unpublished data) found that heavy foot trails had less litter mass and fewer salamanders crossing them than lightly traveled trails. Plantation study location was far from trails and roads and is presumably undisturbed by current human impacts.

Transects and Blocks

Both study locations have been surveyed for P. nettingi in the past by Pauley (unpub. data). Although both study sites were located within known locations of P. nettingi, it was one of the objectives of this study to determine how far out from the rocks P. nettingi has moved. Populations of P. nettingi tend to be in isolated islands within typical habitat. That is, within the range and habitat of P. nettingi, populations are disjunct and field observations led to the hypothesis that P. nettingi is associated with emergent rock and rock outcrops (Pauley, pers. comm.).

There were no P. nettingi found along the south transect. Plethodon nettingi was not found in the south transect probably due to 2 factors. First, tree species along this transect were different from the other transects. This side was predominately oak-hickory. Pauley (pers. comm.) states that this habitat does not generally support P. nettingi populations. Pauley (1978b) found that sugar maple (Acer saccharum)-beech (Fagus grandifolia) areas supported more P. cinereus than the larger P. wehrlei. This more mesic area is similar to the east and west transects where P. nettingi was observed. A second factor in the absence of P. nettingi may be the terrain. Pauley (1980) stated that P. nettingi decreases in abundance when the elevation drops from 3,600 ft to 3,200 ft at most sites. The elevation at this study site was 3,500 ft. The south transect drops over the mountain which decreases in elevation to 3,400 ft.

Plethodon nettingi was found in 2 microsites in the first 15m of the west transect where the soil was less acidic. Although P. nettingi was found 15m from the large rocks at the center of the site, there were smaller rocks along the transect. It is possible that P. nettingi moved out from these rocks. A trail runs through this transect about 10 m from the beginning of the transect and might explain the hiatus in the P. nettingi distribution.

There were many fallen trees at the end of the east transect. This created an open area with little canopy cover. Plethodon nettingi was found all along this transect but was absent from the open area. Smaller rocks were found throughout this transect and probably provide refugia for P. nettingi. Litter was more moist in the transect than the open area but there was more litter in the open area. Almost all the P. nettingi observed at Bear Heaven were found in litter (92.9%).

Plethodon nettingi was found in 2 microsites in the north transect. The first 10m of this transect had large rocks and once the transect ran past the rocks, no P. nettingi were observed. During a hard rain on July 9, 1997, P. nettingi were found down to the road but not in the transect. It is known that the P. nettingi population resumes again across the road and continues for about a mile to Condon Run (Pauley, pers. comm.). The first 10 m of this transect had significantly more litter and the litter was more moist than last 10 m. Overall, the north transect had higher soil moisture than the other three transects. These moist conditions are favorable for P. nettingi.

When comparing the pooled P. nettingi microsites from all transects, only litter mass was significantly different. There was more litter mass in the microsites where P. nettingi was observed. As stated above, 92.9% of P.

nettingi observed at this site were found in litter. Salamanders probably retreat beneath the numerous large rocks when conditions are dry, and when conditions are moist, salamanders return to the surface and forage in leaf litter. Sufficient leaf litter must be available to support invertebrate prey items. Pauley (pers. comm.) surveyed an area at Spruce Knob within the known range of P. nettingi but did not locate it. However, when large boulders were removed in this location to develop a trail by the United States Forest Service, P. nettingi was found beneath them. This was on top of Spruce Knob where climatic conditions are extreme (i.e. hot or cold and dry). These conditions are probably similar to those of an area which has been clearcut.

At Plantation, there were two P. nettingi microsites in the west transect and one in the south transect. The latter was located in a small Rhododendron thicket. Rhododendron thickets have been shown to harbor P. nettingi populations in other areas (Pauley, pers. comm.). Twice as many P. nettingi were found in the middle of this site but there were no significant differences in environmental conditions between the middle and any transect or block. Pauley (unpublished data) found that suitable habitat exists in all cardinal directions for some distance but the P. nettingi population does not. It is possible that P. nettingi has not expanded into the outer forest because of competition for nesting sites and food with P. cinereus.

P. cinereus microsites

Plethodon cinereus was the only salamander species observed at all 4 study locations. Plethodon cinereus is considered to be the most ubiquitous salamander in the eastern forests (Conant and Collins, 1991). Numerous studies have been conducted on the habits and habitats of this species. There were several factor that influenced P. cinereus distribution within these sites. Soil moisture was less in P. cinereus microsites at the Plantation non-P. nettingi site. Drier soil does not usually support salamanders but this site is unusual in that the soil pH is near the lethal tolerance (3.7) for P. cinereus. There were only 10 salamanders found at this site and this may indicate that this site is sub-optimal for salamanders. Bear Heaven P. nettingi site microsites with P. cinereus were less acidic than microsites without P. cinereus but both values were above pH 4.0 and thus above the lethal tolerance level. Both P. nettingi sites had more litter mass in the P. cinereus microsites than those sites without P. cinereus. As with P. nettingi, it was most likely the amount of litter and not the moisture content that influenced salamander distribution.

D. ochrophaeus microsites

Desmognathus ochrophaeus was only found at the Bear Heaven study location. At the P. nettingi site, air and soil temperature were significantly higher in the D. ochrophaeus microsites, while at the non-P. nettingi site, both factors were significantly lower. Pauley (1980) investigated dehydration rates and high temperature tolerances in D. ochrophaeus. He found that D. ochrophaeus can lose a mean percentage of body mass of 41.3 percent before death and critical thermal maximum value was 33.4°C. This indicates that D. ochrophaeus requires moist spots and can inhabit warmer areas. Desmognathus ochrophaeus was found in the north and east transects at BHNP where temperatures were lower.

Qualitative observations may explain this. These two transects, the north in particular, were very moist from seeps which ran along the center rocks.

Laboratory Studies

Substrate moisture preference studies showed that P. nettingi and P. cinereus were found significantly less in the low moisture section when in the chambers by themselves, and D. ochrophaeus was found in the high moisture section significantly more times than the other two sections. Plethodon nettingi, when placed in the chamber with the other two species, was observed in the high moisture section significantly more times and in the middle moisture section significantly fewer times than when in the chamber by itself. Plethodon nettingi appears to be able to compete for moist spots with P. cinereus and D. ochrophaeus. In this study, the rocks that P. nettingi is associated with provides salamanders with near-optimal microhabitat.

Conclusions

Plethodon nettingi appears to be associated with emergent rocks in this study. The rocks in this study are moister and cooler areas which have been shown to be favored habitat for terrestrial salamanders. The condition of the forage area, that is, litter moisture and mass, appears to be important in the microhabitat selection of *P. nettingi*. It can be hypothesized from this study that *P. nettingi* has not expanded into the outer forest because of competition with *P. cinereus* for food and nesting sites and for food and moist spots with *D. ochrophaeus*.

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