ABSTRACT

SEVIN, JENNIFER ANN. Protecting Biodiversity through Monitoring of Management Indicator Species: Questioning Designations of *Ursus americanus* (black bear) and *Plethodon jordani* (Jordan's salamander). (Under the direction of Dr. Roger A. Powell)

Loss of biological diversity is occurring on a global scale, with the southern Appalachians being no exception. As a result of legislation requiring all national forests to maintain viable plant and animal populations, the Forest Service incorporated use of Management Indicator Species (MIS). For an organism to be a good MIS, it must be easy to monitor, be associated with the community type or habitat it supposedly indicates, respond measurably to changes in habitat caused by management activities, and represent other species response to management activities. This study questions the designations of *Ursus americanus* and *Plethodon jordani* as MIS in Pisgah National Forest and investigates methods and indexes used in monitoring salamanders.

I found a high year-to-year repeatability in sampling of salamander abundances. Single sampling efforts at sites where highly correlated with the average of two or more sampling efforts at the same sites, indicating single searches are efficient in detecting abundances of salamanders at sites. In comparing two area-constrained search methods for salamanders, I found the two methods to produce different densities, Simpson diversity indexes, and species equitability, along with different abundances of most salamander species. Search methods are therefore not equivalent in detection of salamanders.

Searching at night was a more efficient sampling method for *P. jordani* than searches of natural cover during the day. I found *P. jordani*, which is designated as a MIS for woody debris special habitats, to be minimally associated with woody debris as a cover object during the day. Juvenile and small adult *P. jordani* preferred to use woody debris than rocks as a cover object during dry conditions. *P. jordani* were found to use all substrate types at night and preferred woody debris to understory, soil, and rocks. *P. jordani* did not use woody debris more than leaf litter or tree trunk substrates at night and their use of substrates did not differ from those of *Desmognathus ocoee.*

Black bears and salamanders prefer similar mature forest habitats, but whether black bears serve as a good MIS for mature forest salamanders is unclear. *HSIs* did not show many correlations with salamanders. Reduction of the black bear habitat suitability index model showed few habitat factors important for black bears were important for salamanders. Investigating the use of an animal existing on one scale to indicate for an animal on another scale merits further study.

PROTECTING BIODIVERSITY THROUGH MONITORING OF MANAGEMENT INDICATOR SPECIES:

Questioning Designations of *Ursus americanus* (black bear) and *Plethodon jordani* (Jordan's salamander).

by

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DEDICATION

To my family and friends who have encouraged me through the good times and the not so good times. Words cannot express what you mean to me. I am who I am and I am where I am because of your love and support. Thank you. To little Jessica, you have come a long way. Remember the past, but always focus on the joy and accomplishments in your life.

BIOGRAPHY

It all started on July 27, 1975, when Jennifer's brother told her Mom to "put her back in your belly!" Jennifer grew up in Miami Beach, Florida with her mother (Elaine), father (Norman), and brother (Scott). Among various interests, Jennifer loved animals and would spend most of her free time in the alley behind her house playing with stray cats or on the side street giving more water to the tadpoles in the gutter. Jennifer hated school with a passion and always welcomed summertime when her family would trek up to the mountains of North Carolina. There, Jennifer played with frogs, turtles and salamanders in the family pond and documented the behavior of animals, such as squirrels and birds, in a notebook. During the school year back in Florida, she began developing science projects and joined a number of school related science groups.

Despite her love for science and her immense dislike for school, Jennifer wanted to become an elementary school teacher. Her plans changed her senior year of high school when an environmental project for a school club developed into a national campaign. Before long Jennifer changed her major to Environmental Studies, started a not-for-profit organization, became national coordinator of a water pollution education program, and was working with county and state agencies, the U.S. Coast Guard and international organizations. Through these endeavors, she met the most amazing people, traveled to wonderful places, and had great experiences. After graduating with her Bachelor of Science degree from Florida International University in 1998, Jennifer worked on her environmental projects, contemplated graduate school, and then went to Antarctica with The Explorers Club.

It was in Antarctica that Jennifer realized life was an adventure and she was not going to let anything or anybody stand in her way. She had helped educate over two million people about how their actions impacted the environment, and now she wanted to learn how animals interact with each other and their surroundings. The phone rang one day in the spring of 2000, and Dr. Powell invited Jennifer to join a black bear project in Pisgah National Forest. Jennifer did not know much about bears, but passing up the opportunity to learn something new and a chance to go back to her childhood summer playground was never a choice. And thus, the adventures of the bear project began. Jennifer's research allowed her to learn about two wonderfully different animals, black bears and salamanders. She will not soon forget nailing a pissed off bear with a dart or catching salamanders all night in the pouring rain. During the project, Jennifer met lifetime friends and gained a world of knowledge.

Jennifer's heart led her to Maryland where a new adventure in her life began. She worked on her thesis in between part-time jobs and playing with her new puppy. Jennifer does not know what the future holds, but she knows it will be an adventure and she is ready for whatever comes her way.

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This section will be long because I have so many people to thank. The financial contributions, the technical guidance, and mostly the emotional support by many made this possible. First and foremost, I have to thank my parents. You have not always agreed with my decisions, but you let me find my own way and I appreciate your trust and confidence in me. I am grateful for your constant support and always being there for me. To Scott, you have been my friend, my enemy, and my brother and I treasure our relationship. Despite our opposite ways of thinking about life and the broken bones and teeth through the years, you have loved me unconditionally. I know I did not make things easy for you and I likely never will, so get over it. We have all overcome personal challenges in our life and I am proud to be your daughter and sister. I am a Sevin through and through (which is hard to admit and scary). I would also like to thank the rest of my family, from my grandmother, to my aunts and uncles, and my crazy cousins for their love and encouragement. I know many of you did not think I would make it through high school, but hey, what do you know. John, you went from a passing voice in the hallway to someone who turned my life into something new. John, wherever our paths in life go, you will always be a part of me. Thank you for your patience, understanding, support, and love.

There are too many people to thank, but all the EarthWatch teams, the project staff, the project supporters, and the Mitchell boys, Mike and Ryan, contributed to this accomplishment in my life. I would like to extend the deepest of thanks to Betsy, Camille, Dave, Dottie, Fra, Jorie, and Melissa. The data would never have been collected and my sanity would have been lost a long time ago if it were not for you nutcases. We shared in an amazing experience together and I look forward to sharing in many more. Thank you to Mae Lee Hafer (USFS Pisgah Ranger District) and Mark Jones (NC Wildlife Resource Commission) for your technical guidance, encouragement, and friendship over the past three years.

I am grateful to Dr. Roger Powell for giving me this opportunity and for putting up with me, and to his wife, Consie, for her support. Roger, it certainly was not an easy road, but I learned a lot about science and a lot about myself because of you. Thank you to my committee members, Dr. Ken Pollock, Dr. Hal Heatwole, and Alvin Braswell. I only wish I had the statistical expertise of Dr. Pollock, the energy of Dr. Heatwole and the kindness and enthusiasm of Alvin Braswell. I am grateful for the use of field equipment and advice given by Dr. Thomas Wentworth and Dr. Sam Mozley of NCSU. Dr. Mozley, your participation in my defense and seminar was greatly appreciated. Thanks to the guys and gals of the NCSU Department of Zoology, particularly Dr. Grove, Dr. Rice, Sharon, Susan, and Kayde, who made me feel welcome since day one and who provided me with assistance, encouragement, laughs, and, of course, the hugs during my stay. This project and my degree would not have been possible without the financial contributions of NCSU, Budweiser National Fish and Wildlife Foundation Conservation Scholarship, North Carolina Wildlife Federation Education Endowment Fund, EarthWatch/The Center for Field Research, the NCSU Harkema Award, and my parents. The continued support of the USDA Forest Service Pisgah Ranger District, the National Park Service, and the North Carolina Wildlife Resources Commission was most appreciated.

The last, and certainly not the least, person I would like to thank is Dr. James Petranka of UNC Asheville. I cannot express how much your assistance has meant to me. I never thought the research and thesis would come, particularly since at our first meeting I thought I had collected over 10 species of salamanders and you looked at them and told me I only had two species. More than anyone, you made this possible. Thank you for training me on identification, taking me in the field, meeting with me whenever I needed you, letting me use your lab, and for your kindness, honesty, and support. I admire you greatly.

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CHAPTER 1

Monitoring salamanders in Pisgah National Forest

Introduction

Order Urodela (Salamanders) contains 61 genera of approximately 415 species (Pough et al., 2001). Sixty percent of all extant salamander species occur in the Plethodontidae family (Ruben and Boucot, 1989). They occupy fossorial, aquatic, semiaquatic, terrestrial, and arboreal habitats. Plethodontids are distributed across North America, and exist in Central and South America, as well as southern Europe and on Sardinia (Pough et al., 2001). It is widely accepted that the origin of plethodontids occurred in the Appalachian mountains of North America during the Mesozoic period (Duellman and Trueb, 1986; Ruben and Boucot, 1989; Pough et al., 2001). The family Plethodontidae has 27 genera divided into two subfamilies, Desmognathinae and the Plethodontinae (Duellman and Trueb, 1986; Petranka, 1998). It is these two subfamilies this paper is mostly concerned.

Plethodontid salamanders are important in the environment, serving as integral components in nutrient cycling and in the transfer of energy through food chains (Burton and Likens, 1975; Heyer et al., 1994; Petranka, 1998). They eat small invertebrates and in turn are food for birds, reptiles, small mammals, and other amphibians (Kucken et al., 1994; Harpole and Haas, 1999). Salamanders occur in large numbers and their combined biomass in the southern Appalachians exceeds that of all other vertebrate species (Burtons and Likens, 1975; Hairston, 1987).

Over the past few decades, amphibian populations across the globe have experienced declines, fluctuations, and extinctions (Blaustein and Wake, 1990; Hairston and Wiley, 1993; Cohn, 1994; Heyer et al., 1994; Jung et al. 2000). Their permeable skins, complex life cycles, limited mobility, and site fidelity make amphibians susceptible to environmental disturbances (Blaustein et al., 1994; Welsh and Droege, 2001). Studies have linked population changes and physical deformities to myriad causes, including increased ultraviolet radiation, pathogens, parasites, habitat destruction, chemical pollutants, introduction of invasive species, acid precipitation, harvesting by humans for food and science, and natural causes (Blaustein and Wake, 1990; Blaustein et al., 1994; Petranka, 1998; Wear and Gries, 2002). Salamanders and other amphibians are believed to be good indicators of environmental health (Blaustein et al., 1994; Welsh and Droege, 2001).

To determine whether amphibian population declines are caused by anthropogenic perturbations or natural fluctuations, long-term data on habitat associations, life histories, geographic distributions, and population densities are needed (Hairston and Wiley, 1993; Blaustein et al., 1994; Heyer et al., 1994, Jung et al., 2000). Over the course of long-term monitoring, data must be comparable across time and space. Salamander sampling techniques include use of artificial cover boards, drift fences and pitfall traps, mark-recapture, removal studies, searches of particular patch habitats (i.e. leaf litter, moss mats, woody debris), and series of transects or quadrats with either time or area constraints. The search technique employed depends on research objectives. Monitoring salamanders can be challenging with only a small percentage of the population on the ground surface at any given time (Hairston, 1987; Smith and Petranka, 2000; Bailey, 2002).

Recent studies and publications discuss the variability in salamander detection and efficiencies of different sampling techniques (Heyer et al., 1994; Parris, 1999; Jung et al., 2000; Smith and Petranka, 2000; Hyde and Simons 2001; Bailey, 2002; Houze Jr. and Chandler, 2002). The size of a salamander population and the detectability of individuals differ spatially based on macroscale habitat parameters, such as elevation, community type, and disturbance history (Hyde, 2000; Bailey, 2002), as well as on microscale habitat features, including density of cover items, soil moisture or percent herbaceous cover (Heatwole, 1962; Jung et al., 2000; Petranka and Murray, 2001). Detectability also differs temporally by season, weather, and time of peak activity (Heyer et al., 1994; Hyde, 2000). Inconsistent sampling design and numerous observer biases can additionally influence data collection resulting in variability of count across time and space (Corn and Bury, 1990; Smith and Petranka, 2000; Hyde and Simons, 2001).

This chapter focuses on temporal sampling and comparing two area-constrained search techniques, searches by day (observing animals under rocks and woody debris) and searches by night (observing animals on surfaces of substrates), to monitor salamander populations in the southern Appalachians. These two sampling methods were selected based on a number of factors. First, adding artificial cover (i.e. cover boards) conflicted with other research goals, which required studying use of natural cover and habitat patches by salamanders. Second, sites were to be sampled on multiple occasions, with the goal of being used for long-term monitoring. It, therefore, would have been detrimental to disturb the habitat and the inhabitants any more than necessary. This eliminated excavating material at the site for search (i.e. leaf litter and soil layers), breaking apart woody debris and moss mats and using drift fences with pitfall traps. Third, herpetologists who have conducted research in the area have used similar methods with success (i.e. Smith and

Petranka, 2000), permitting data comparison. Fourth, Hyde and Simons (2001) found natural cover searches to have a greater power of detecting population trends than searches of leaf litter and artificial cover boards**.**

The U.S. Forest Service intends to study assemblages of woodland salamanders to detect changes in populations forest-wide and has additionally selected four species of salamanders as Management Indicator Species (MIS)(USDA, 1994). An objective of this study is to provide the U.S. Forest Service with relative abundances and diversity of salamanders at sites of similar, to compare two sampling methods, to determine the year-to-year repeatability of sampling at sites over two years, and to determine if single sampling events differ from the mean of multiple sampling events during the same season.

Considering my sites were similar in age, community type, slope, and elevation, I expected to find equivalent species, abundances, and diversity of salamanders across sites. The efficiency of sampling techniques would differ based on the life history and behavior of each individual species and I hypothesized that the two sampling techniques would yield different counts for each species, as well as species richness and diversity at sites (Hyde and Simons, 2001). Smith and Petranka (2000) found a high year-to-year repeatability in counts at sites between years and I believed I would also see high year-to-year repeatability, assuming there were no major disturbances between sampling years and no changes in sampling protocol. Because detectability of salamanders can vary with each sampling effort due to their random migration below and above the surface (Bailey, 2002), I felt that one time sampling efforts would yield different count data than an average of counts from multiple searches.

Methods

Study Area

My study area was the Pisgah Bear Sanctuary within Pisgah National Forest, western North Carolina (Figure 1). The Bear Sanctuary (235 km^2) was located near Brevard, North Carolina (35° 17’ N latitude; 82° 47’ W longitude) (Powell et al., 1997). That region of the southern Appalachians, and more specifically the southern Blue Ridge Mountain range, was characterized by igneous and metamorphic rock types, mainly of granite, basalt and dunite and slates, schists and gneisses, respectively (USDA, 1994). The Pisgah Bear Sanctuary ranged from 650 m to almost 1800 m in elevation (Powell et al., 1997). At that intermediate level, soils were predominantly loamy with dark topsoil surfaces of varying thickness influenced by organic matter (USDA, 1994). Subsoils were brownish, yellowish, or reddish and contained 15-50 % clay and 10-50 % (by volume) rock fragments (USDA, 1994).

My study area was considered a temperate rainforest, with some parts of the Sanctuary experiencing 250 cm of precipitation per year (Powell et al., 1997). The forest contained many perennial, free-flowing, cold-water streams of a moderate to steep gradient. Charles Vanderbilt once owned the land until 1917, when the USDA Forest Service acquired it. Prior land-use was dominated by farming, mining, and logging. My field research was done in June through August of 2001 and 2002.

Site Selection and Design

A quadrat design was selected to study a particular site thoroughly, to obtain a salamander species list, to estimate relative densities and diversity of salamander species, to estimate relative densities of specific species within certain microhabitats, and to compare data across the landscape. I established eleven 30x40 m sampling sites within the Pisgah Bear Sanctuary, each located at least 1 km from all others to ensure independent sampling (Figure 1). Each perimeter was established along a 30-meter stretch of stream and extended 40 meters up slope, with the entire width of the stream being included (Figure 2). Sites of this size and design were used to ensure enough animals for statistical analyses and to study the species assemblages of salamanders within aquatic, semiaquatic, and terrestrial habitats. Each site was further subdivided into 5x5 m blocks and marked with flagging and PVC pipes. Blocks allowed me to sample sites systematically, record the location of each salamander observed, and to analyze distribution patterns within microhabitats. Habitat occupying each 5x30 m transect (series of blocks) appeared to be homogenous.

To make salamander data comparable across sites, I selected sites based on certain habitat parameters. All sites were of cove hardwood or upland hardwood community types, had stand ages between 70 and 85 years, were located between 927-1292 m in elevation, contained first or second order perennial streams, had slight to moderate slopes, and were accessible for repeated sampling. Additionally, a strict sampling protocol was used and the same, well-trained individuals collected each year’s data. In August 2001, the stream at one site ran dry, forcing me to eliminate this site from the study prior to the end of the field season. I added a new location prior to beginning the 2002 field season. An additional site was eliminated prior to data analysis because of its proximity to recent logging activity, which may have compromised data and ability to compare results with other sites (information on this site is available in Appendix E).

I sampled salamanders within each site using two methods: searches under natural cover objects by day and surface searches during and after rainfall by night. I sampled all sites at least once during the day in each year. One site in 2001 was sampled twice during the day, two sites were sampled twice by day in 2002, and one site was sampled three times by day in 2002. Sites sampled more than once during the day were sampled at least two weeks apart. Weather limited the sampling at night, resulting in two incomplete data sets.

Searches by Day

I conducted searches by day on random dates from June through August, noting starting and ending times. Beginning mid-morning (0900-0945 hours), 3-4 persons systematically turned rocks and woody debris within each 5x30 m transect until an entire site was sampled. We started at the uppermost transect (35-40 m upslope at the 0 m perimeter of the site) and sampled across it. We then moved to the next lower transect and sampled it, and so on (Figure 2). We always sampled the stream from downstream to upstream to prevent counting escaped salamanders more than once.

As we lifted rocks and woody debris, we captured salamanders and placed them in Ziplock bags. We replaced each cover object to its original location and leaves or other material were replaced to minimize moisture and temperature changes. We recorded the species of each salamander, its location in the site, weight, length, cover object type (rock, woody debris), cover object size (by category, see Appendix C), and any injuries or deformities. Each designated data collector followed a strict protocol to insure reliable and consistent recording of data at each site.

Length of each salamander was measured from snout to posterior portion of the hind legs (mm) for quick processing. Although snout-to-hind leg length has been used successfully in other studies (Szuba et al., 2002), I converted these measurements to snout-vent length (SVL) for determination of age class and use in size-frequency histograms (at the suggestion of Alvin Braswell, personal communication). I converted measures using linear regression of snout-to-hind-leg length and snout-to-vent length from a sample of salamanders of each species. We weighed each salamander in its bag with a spring scale (nearest 0.25 g) and then re-weighed the bag after salamander release. Individual animals were released adjacent to the cover under which they were captured. If a salamander escaped capture, genus or species identification, location, cover object type and size, and age category (larval, juvenile, or adult) were recorded. Kucken et al. (1994) successfully placed salamanders in age classes based on visual estimations and Hairston (1986) found this technique to result in only 8% misclassification of juveniles and adults.

Rain gauges were placed at each site and were to be checked regularly. Unfortunately, black bears also checked the gauges and destroyed them. Rainfall data for the area was acquired from the National Weather Service (Pisgah Forest 1 N Station), but site specific data were unavailable. Alternatively, a measure of “degree of wetness” was taken at each site prior to and at completion of sampling. This measures wetness by touch on a scale from 1 (completely dry) to 5 (soaked). Degree of wetness was estimated for foliage, leaf litter, and soil. Water, air, and soil (in 2002) temperatures were taken using mercury thermometers at the beginning and end of sampling. Cloudiness, wind, sunshine, past weather conditions, current weather conditions, and visible prey and predators were also recorded.

Searches by Night

We conducted searches by night only during or after adequate rain. This was defined as water penetrating the canopy and saturating the understory vegetation, leaf litter and soil. We began sampling at dusk (2100 hours) and continued until the entire site was sampled. Using headlamps, we walked or crawled within each 5x30 m transect collecting salamanders on surfaces of leaf litter, vegetation (tree trunks and understory), woody debris, rocks, or soil. Data on salamanders were recorded as described for sampling by day. We turned no cover objects and habitat disturbance was minimal. Due to large numbers of salamanders present on the surface at night, the data collector and, typically, an additional volunteer walked behind the observers and notified the observers of any undetected salamanders. Sites were originally sampled in random order but, due to patchy and limited rainfall, subsequent sampling occurred at sites where criteria for sampling at night were met. Searches by night in 2002 were first conducted at sites where sampling at night did not occur during the previous field season.

Statistics

I initially transformed abundances of salamanders by using log (count + 1). I did not find major differences in analyses when using the transformed abundances versus the actual abundances and I decided to use the actual count data instead of the transformations. Abundances of salamanders were converted to densities based on the life-history of the animal and the area of aquatic, semi-aquatic, and terrestrial area available at each site. The reciprocal of the Simpson diversity index was used and species equitability was derived from the Simpson index. Paired t-tests were used to compare yearly abundances of each salamander species by site (McClave and Dietrich, 1996). Simple linear regression analyses were used to test year-to-year repeatability and to test the correlation between abundances from single sampling efforts with the mean abundances from multiple sampling efforts (Smith and Petranka, 2000). Paired t-tests were used to test the equality of species richness, total salamander density, Simpson diversity index, and species equitability. Simple linear regression tested the correlation between abundances by day with abundances by night for each species (Neter et al., 1996). I used a 0.05 level of significance for all statistical analyses unless otherwise noted.

Results

Searches by day of sites resulted in 517 salamanders comprising 8 species in 2001 (n = 9 sites) and 806 salamanders of 10 species in 2002 (n = 10 sites) (Appendix A). Sampling at night was hindered by drought conditions and both field seasons ended with incomplete data sets. I never sampled Site 4 at night. Searches at night of six sites yielded 642 salamanders of 8 species in 2001 and searches at three sites yielded 975 salamanders of 7 species in 2002 (Appendix B). In total, 2940 salamanders of 11 species were counted (*Desmognathus monticola*, *D. ocoee*, *D. quadramaculatus*, *D. wrighti*, *Eurycea bislineata wilderae*, *Gyrinophilus porphyriticus*, *Notophthalmus viridescens*, *Plethodon* *glutinosus*, *P. jordani, P. serratus, and Pseudotriton ruber)*. Four sites were sampled at least twice during the day, producing an additional 485.

Temporal Comparisons

Abundances resulting from a single sampling effort at four sites were compared with mean abundances ($n \geq 2$) taken at the same sites within the same year. Correlations for these within-year comparisons were high ($P = <0.001$, $R^2=0.95 - 0.98$) (Figure 3). All analyses testing the equality of abundances for each species between years, including those comparing numbers of escaped salamanders, showed no significant difference (Table 1). Additionally, all regression analyses showed a significant correlation between the 2001 and 2002 species and abundances at each site. All p-values were significant at 0.05 level of significance and R-square values were 0.62 - 0.96 (Figure 4).

Due to these results, I used abundances from single sampling efforts to describe species and abundances at each site in further analyses. Because of the high year-to-year repeatability, I also averaged the 2001 and 2002 daytime species abundances at sites. The two night data sets were combined based on the following: (1) searches by day showed high year-to-year repeatability, (2) salamanders are long lived and demonstrate strong site fidelity, (3) lack of natural or anthropogenic disturbance between the two sampling seasons, and (4) sampling efforts in both years were conducted under optimal sampling conditions and a strict sampling protocol.

Indexes and Method Comparisons

Sites searched by day had a species richness of 3-8 species, total salamander density of 250.0-2855.7 salamanders/ha, Simpson diversity index of 1.3-3.0, and species equitability of 0.19-0.91 (Table 2). Searches by night produced a species richness of 4-7 species, total salamander density of 686.1-5007.5 salamanders/ha, Simpson diversity index 2.1-3.8, and equitability of 0.33-0.63 (Table 2). No correlation was seen for total salamander density, Simpson diversity index, and species equitability between searches by day with searches by night. Species richness from searches by day and species richness from searches by night was nearly correlated (P = 0.0577). Abundances by day and abundances by night were correlated for D. monticola (P = <0.001; R^2 = 0.82), D. ocoee (P = 0.004; R^2 = 0.71, and P. jordani (P = 0.001; R^2 = 0.80).

Discussion

Long-term salamander monitoring is essential for understanding population trends (Heyer et al., 1994). The goal of any monitoring program is to find a method or combination of methods that detect changes in population trends. I found year-to-year repeatability for relative abundances to be high (R^2 = 0.62-0.96) during searches by day. This indicates that holding certain conditions constant, one should find similar trends across a sampling area over time (Smith and Petranka, 2001; Bailey, 2002).

Single site search efforts at four sites were nearly equivalent (R^2 = 0.95-0.98) to the mean of two or more site searches at those sites. Single searches of sites would save management agencies time and money, and would reduce the affect multiple searches may have on the habitat and organisms. Smith and Petranka (2000) reported single efforts, over more sites, yielded greater statistical power to detect regional population declines than multiple searches at fewer locations.

It would be beneficial if sampling techniques equally detected salamanders. If this was the case, you would expect to see a strong correlation between any two sampling techniques used (Hyde, 2000). Species richness appeared to be similar during the day and at night and three species of salamanders showed a significant correlation between searches by day with searches by night. The two search methods used, however, did not provide similar results for the majority of species nor for indexes of relative density, Simpson diversity, or species equitability. Hyde and Simons (2001) used four search methods and found them not to be correlated. By relying on a single sampling method to describe sites or in gaining information on a single species, a management agency may become misinformed (also see Chapter 2 for additional information). To gain detailed information on salamanders at a given location, it appears necessary for management agencies either to focus monitoring on a selected species (or a few) using a particular sampling method, or using multiple sampling techniques for an accurate depiction of all salamanders present.

The goal of the monitoring program, along with the efficiency of a sampling method, must be taken into consideration when developing and implementing a monitoring program. The sampling protocols I used produced population indexes commonly used in monitoring (Heyer et al., 1994), such as species richness, total relative density, Simpson diversity index, and species equitability. While useful in discovering locations that support large numbers of animals, these multiple-species approaches to monitoring may limit other management objectives, such as protecting rare species of salamanders or studying MIS.

Salamanders are susceptible to management, both directly and indirectly. Acute perturbations, such as clearcutting, have affected populations of salamanders almost immediately (Petranka et al., 1993; Petranka, 1994; Ash, 1997; deMaynadier and Hunter, 1995; DeGraff and Yamasaki, 1997; Grialou et al., 2000). Disturbance type, and in turn, salamander response, will vary (Hairston, 1987) and effects of chronic disturbances may be subtle (Hairston and Wiley, 1993; Kucken et al., 1994; Smith and Petranka, 2000). Count data, and the subsequent indexes developed, do not provide information on population composition, which could detect possible population changes prior to detecting them from count indexes alone.

Plethodon species are integral components of ecological communities and are likely good indicators (Burton and Likens, 1975; Ash, 1997; Petranka 1998; Herbeck and Larsen, 1999; Welsh and Droege, 2001). A change in *Plethodon* population size, composition, dispersal, or behavior, would affect the rest of the community (Ash, 1997; Hairston, 1981; Welsh and Droege, 2001). This research has shown that count data taken in the same manner should provide high year-to-year repeatability, single site searches are an efficient means of collecting count data, sampling methods are not equivalent in detectability of all salamander species, and that management agencies will likely need to take a multi-method approach in monitoring salamander populations and in studying the effects management has on MIS.

CHAPTER 2

Sampling *Plethodon jordani*

Introduction

Salamanders are important in the environment, serving as integral components in nutrient cycling and in the transfer of energy through food chains (Burton and Likens, 1975; Heyer et al., 1994; Petranka, 1998). They eat small invertebrates and in turn are food for birds, reptiles, small mammals, and other amphibians (Kucken et al., 1994; Harpole and Haas, 1999). Salamanders occur in large numbers and their combined biomass in the southern Appalachians exceeds that of all other vertebrate species (Burtons and Likens, 1975; Hairston, 1987).

Over the past few decades, amphibian populations across the globe have experienced declines, fluctuations, and extinctions (Blaustein and Wake, 1990;; Hairston and Wiley, 1993; Cohn, 1994; Heyer et al., 1994; Jung et al. 2000). Their permeable skins, complex life cycles, limited mobility, and site fidelity make amphibians susceptible to environmental disturbances (Blaustein et al., 1994; Welsh and Droege, 2001). Studies have linked population changes and physical deformities to myriad causes, including increased ultraviolet radiation, pathogens, parasites, habitat destruction, chemical pollutants, introduction of invasive species, acid precipitation, harvesting by humans for food and science, and natural causes (Blaustein and Wake, 1990; Blaustein et al., 1994; Petranka, 1998; Wear and Gries, 2002). Salamanders and other amphibians are believed to be good indicators of environmental health (Blaustein et al., 1994; Welsh and Droege, 2001).

To determine whether amphibian population declines are caused by anthropogenic perturbations or natural fluctuations, long-term data on habitat associations, life histories, geographic distributions, and population densities are needed (Hairston and Wiley, 1993; Blaustein et al., 1994; Heyer et al., 1994, Jung et al., 2000). Over the course of long-term monitoring, data must be comparable across time and space. Salamander sampling techniques include use of artificial cover boards, drift fences and pitfall traps, mark-recapture, removal studies, searches of particular patch habitats (i.e. leaf litter, moss mats, woody debris), and series of transects or quadrats with either time or area constraints. The search technique employed depends on research objectives. Monitoring salamanders can be challenging with only a small percentage of the population on the ground surface at any given time (Hairston, 1987; Smith and Petranka, 2001; Bailey, 2002). Recent studies and publications discuss the variability in salamander detection and efficiencies of different sampling techniques (Heyer et al., 1994; Parris, 1999; Jung et al., 2000; Smith and Petranka, 2000; Hyde and Simons 2001; Bailey, 2002; Houze Jr. and Chandler, 2002).

The size of a salamander population and the detectability of individuals differ spatially based on macroscale habitat parameters, such as elevation, community type, and disturbance history (Hyde, 2000; Bailey, 2002), as well as on microscale habitat features, including density of cover items, soil moisture or percent herbaceous cover (Heatwole, 1962; Jung et al. 2000, Petranka and Murray, 2001). Detectability also differs temporally by season, weather, and time of peak activity (Heyer et al., 1994; Hyde, 2000). Inconsistent sampling design and numerous observer biases can additionally influence data collection resulting in variability of counts across time and space (Corn and Bury, 1990; Smith and Petranka, 2000; Hyde and Simons, 2001).

This research focuses on variability in temporal and spatial sampling and comparing two area-constrained search techniques, searches by day (observing animals under rocks and woody debris) and searches by night (observing animals on surfaces of substrates), to monitor *Plethodon jordani* populations in the southern Appalachians (the species being studied is Metcalf's variation of *P. jordani*). These two methods were selected based on a number of factors. First, adding artificial cover (i.e. cover boards) conflicted with other research goals, which required studying use of natural cover and habitat patches by salamanders. Second, sites were to be sampled on multiple occasions, with the goal of being used for long-term monitoring. It, therefore, would have been detrimental to disturb the habitat and the inhabitants any more than necessary. This eliminated excavating material at the site for search (i.e. leaf litter and soil layers), breaking apart woody debris and moss mats and using drift fences with pitfall traps. Third, herpetologists who have conducted research in the area have used similar methods with success (i.e. Smith and Petranka, 2000), permitting data comparison. Fourth, Hyde and Simons (2001) found natural cover searches to have a greater power of detecting population trends than searches of leaf litter and artificial cover boards**.**

Plethodon jordani

Plethodon jordani is a terrestrial salamander inhabiting moist (mesic) woodlands (Wilson, 1995; Petranka, 1998). It is common in southwestern Virginia, extreme eastern portions of Tennessee, throughout western North Carolina, and is also found in northwest South Carolina and northeast Georgia (Wilson, 1995; Petranka, 1998). Depending on geographic location, its color patterning may vary from solid shades of gray to displaying red cheeks or legs, or a brassy pattern on the dorsum (Petranka, 1998).

Courtship occurs from mid-July through early October (Petranka, 1998). While *P. jordani* nests have never been observed in the field, females are presumed to lay eggs in May underground and demonstrate parental care until hatching occurs 2-3 months later (Hairston, 1983; Petranka, 1998). Similar to other congeners, female *P. jordani* reproduce every other year (Hairston, 1983). Hatchlings are fossorial until the following May when they emerge as yearlings (Hairston, 1983). Sexual maturity occurs at approximately three years of age (~43 mm SVL) for males and beginning at 4 years of age (~46 mm SVL) for females (Petranka, 1998).

P. jordani use burrows or remain under cover during the day and emerge onto the surface at night (Brooks, 1946; Petranka, 1998). Night activity peaks two to four hours after dusk, and individuals do not emerge in unison (Merchant, 1972; Petranka, 1998). They are opportunistic foragers and prey on a wide variety of invertebrates (Powders and Tietjen, 1974). *P. jordani* appear to be territorial and demonstrate aggressiveness to both conspecifics and heterospecifics (Hairston, 1987). They have distinct home ranges, with males having on average 11.4 m^2, females 2.8 m^2, and juveniles 1.7 m^2 (Nishikawa, 1990).

Glands at the tail base of *P. jordani* secrete a slimy substance to deter predators and these salamanders will readily autotomize their tails (Petranka, 1998). Despite this, they are prey for larger aquatic and semiaquatic species of salamanders (i.e. spring salamander and black-bellied salamander) and snakes (Petranka, 1998). *P. jordani* are susceptible to habitat disturbance, such as clear-cutting, where populations disappear within 2 years and take at least 24 years to re-colonize a site (Petranka et al., 1993, 1994; deMaynadier and Hunter, Jr., 1995; Ash, 1997).

P. jordani has been designated by the USDA Forest Service as a Management Indicator Species (MIS) for Pisgah National Forest, North Carolina (USDA, 1994). Its population change is believed to indicate the effects of forest management activities on certain habitats and on plants and animals relying on the same habitats (USDA, 1994). *P. jordani* is a MIS for shaded rock outcrop communities and woody debris habitats. Additionally, the Forest Service intends to study assemblages of woodland salamanders to detect changes in populations forest-wide (USDA, 1994). It is essential to establish a suitable monitoring program for *P. jordani* and to record distribution, population composition, and estimates of density for future comparison in Pisgah National Forest. I selected *P. jordani* as a target species of this study with the goal of providing management agencies with information vital for future monitoring efforts.

Considering that *P. jordani* is a common terrestrial species (Wilson, 1995; Hairston, 1987; Petranka, 1998) and because habitat differences between study sites are minimized, I hypothesized that its relative abundance would not differ across the landscape, nor within the terrestrial portions of sites. I expected to find similar results of high year-to-year repeatability at my sites to those of Smith and Petranka (2000), baring there were no major disturbances or changes in sampling protocol between sampling years. Due to varying salamander behaviors and life histories, differing sampling methods do not yield the same results (Hyde and Simons, 2001). I hypothesized that sampling *P. jordani* by day and sampling *P. jordani* by night would not provide equivalent results.

Methods

Study Area

My study area was the Pisgah Bear Sanctuary within Pisgah National Forest, western North Carolina (Figure 1). The Bear Sanctuary (235 km^2) was located near Brevard, North Carolina (35° 17' N latitude; 82° 47' W longitude) (Powell et al., 1997). That region of the southern Appalachians, and more specifically the southern Blue Ridge Mountain range, was characterized by igneous and metamorphic rock types, mainly of granite, basalt and dunite and slates, schists and gneisses, respectively (USDA, 1994). The Pisgah Bear Sanctuary ranged from 650 m to almost 1800 m in elevation (Powell et al., 1997). At that intermediate level, soils were predominantly loamy with dark topsoil surfaces of varying thickness influenced by organic matter (USDA, 1994). Subsoils were brownish, yellowish, or reddish and contained 15-50 % clay and 10-50 % (by volume) rock fragments (USDA, 1994).

My study area was considered a temperate rainforest, with some parts of the Sanctuary experiencing 250 cm of precipitation per year (Powell et al., 1997). The forest contained many perennial, free-flowing, cold-water streams of a moderate to steep gradient. Charles Vanderbilt once owned the land until 1917, when the USDA Forest Service acquired it. Prior land-use was dominated by farming, mining, and logging. My field research was done in June through August of 2001 and 2002.

Site Selection and Design

A quadrat design was selected to study a particular site thoroughly, to obtain a salamander species list, to estimate relative densities and diversity of salamander species, to estimate relative densities of specific species within certain microhabitats, and to compare data across the landscape. I established eleven 30x40 m sampling sites within the Pisgah Bear Sanctuary, each located at least 1 km from all others to ensure independent sampling (Figure 1). Each perimeter was established along a 30-meter stretch of stream and extended 40 meters up slope, with the entire width of the stream being included (Figure 2). Sites of this size and design were used to ensure enough animals for statistical analyses and to study the species assemblages of salamanders within aquatic, semiaquatic, and terrestrial habitats. Each site was further subdivided into 5x5 m blocks and marked with flagging and PVC pipes. Blocks allowed me to sample sites systematically, record the location of each salamander observed, and to analyze distribution patterns within microhabitats. Habitat occupying each 5x30 m transect (series of blocks) appeared to be homogenous.

To make salamander data comparable across sites, I selected sites based on certain habitat parameters. All sites were of cove hardwood or upland hardwood community types, had seral ages between 70 and 85 years, were located between 927-1292 m in elevation, contained first or second order perennial streams, had slight to moderate slopes, and were accessible for repeated sampling. Additionally, a strict sampling protocol was used and the same, well-trained individuals collected each year’s data. In August 2001, the stream at one site ran dry, forcing me to eliminate this site from the study prior to the end of the field season. I added a new location prior to beginning the 2002 field season. An additional site was eliminated prior to data analysis because of its proximity to recent logging activity, which may have compromised data and ability to compare results with other sites (information on this site is available in Appendix E).

I sampled salamanders within each site using two methods: searches under natural cover objects by day and surface searches during and after rainfall by night. Based on the findings of Smith and Petranka (2000), I intended to sample each site once during the day and once at night per field season. Sites were sampled once each year during the day, but weather limited the sampling at night, resulting in two incomplete data sets.

Searches by Day

I conducted searches by day on random dates between June 6 and July 31, 2001 and 2002, noting starting and ending times. Beginning mid-morning (0900-0945 hours), 3-4 persons systematically turned rocks and woody debris within each 5x30 m transect until an entire site was sampled. We started at the uppermost transect (35-40 m upslope at the 0 m perimeter of the site) and sampled across it. We then moved to the next lower transect and sampled it, and so on (Figure 2). We always sampled the stream from downstream to upstream to prevent counting escaped salamanders more than once.

As we lifted rocks and woody debris, we captured salamanders and placed them in Ziplock bags. We replaced each cover object to its original location and leaves or other material were replaced to minimize moisture and temperature changes. We recorded the species of each salamander, its location in the site, weight, length, cover object type (rock, woody debris), cover object size (by category, see Appendix C), and any injuries or deformities. Each designated data collector followed a strict protocol to insure reliable and consistent recording of data at each site.

Length of each salamander was measured from snout to posterior portion of the hind legs (mm) for quick processing. Although snout-to-hind leg length has been used successfully in other studies (Szuba et al., 2002), I converted these measurements to snout-vent length (SVL) for determination of age class and use in size-frequency histograms (at the suggestion of Alvin Braswell, personal communication). I converted measures using linear regression of snout-to-hind-leg length and snout-to-vent length from a sample of salamanders of each species. We weighed each salamander in its bag with a spring scale (nearest 0.25 g) and then re-weighed the bag after salamander release. Individual animals were released adjacent to the cover under which they were captured. If a salamander escaped capture, genus or species identification, location, cover object type and size, and age category (larval, juvenile, or adult) were recorded. Kucken et al. (1994) successfully placed salamanders in age classes based on visual estimations and Hairston (1986) found this technique to result in only 8% misclassification of juveniles and adults.

Rain gauges were placed at each site and were to be checked regularly. Unfortunately, black bears also checked the gauges and destroyed them. Rainfall data for the area was acquired from the National Weather Service (Pisgah Forest 1 N Station), but site specific data were unavailable. Alternatively, a measure of “degree of wetness” was taken at each site prior to and at completion of sampling. This measures wetness by touch on a scale from 1 (completely dry) to 5 (soaked). Degree of wetness was estimated for foliage, leaf litter, and soil. Water, air, and soil (in 2002) temperatures were taken using mercury thermometers at the beginning and end of sampling. Cloudiness, wind, sunshine, past weather conditions, current weather conditions, and visible prey and predators were also recorded.

Searches by Night

We conducted searches by night only during or after adequate rain. This was defined as water penetrating the canopy and saturating the understory vegetation, leaf litter and soil. We began sampling at dusk (2100 hours) and continued until the entire site was sampled. Using headlamps, we walked or crawled within each 5x30 m transect collecting salamanders on surfaces of leaf litter, vegetation (tree trunks and understory), woody debris, rocks, or soil. Data on salamanders were recorded as described for sampling by day. We turned no cover objects and habitat disturbance was minimal. Due to large numbers of salamanders present on the surface at night, the data collector and, typically, an additional volunteer walked behind the observers and notified the observers of any undetected salamanders. Sites were originally sampled in random order but, due to patchy and limited rainfall, subsequent sampling occurred at sites where criteria for sampling at night were met. Searches by night in 2002 were first conducted at sites where sampling at night did not occur during the previous field season.

Sampling of Habitat

I sampled habitat at both the macro and microhabitat scale. On average, ten 5 m^2 blocks (~20% of each site) were sampled on a micro level, with 1-2 blocks being sampled within each parallel line of blocks (Figure 2). I characterized each site with the mean values of its block samples. Individual block data were used in analyzing salamander distribution within each site and between the three main microhabitats (aquatic, semi-aquatic, and terrestrial) across the landscape.

For each block, I visually estimated canopy cover and the percent of surface area covered by each type of substrate (understory vegetation, leaf litter, woody debris, tree trunk, barren soil, rocks). I counted numbers of rocks and woody debris found in pre-established size categories (Appendix C). I noted the dominant vegetative species in the overstory and understory, and recorded diameters of trees >5 cm DBH.

I visually estimated percent cover of hemlock, rhododendron and laurel for each site. Mean litter depth was based on over 30 samples using a ruler (nearest mm). Leaf litter and soil samples were collected from all sites by three groups of people in one afternoon to minimize variation in moisture caused by rain. We placed 4 samples (every 10 meters up slope) of soil and leaf litter at each site into Ziplock bags. Samples were transferred to paper bags later that day, weighed, placed in storage, and then reweighed four months later. One minus the ratio of dry weight to wet weight is presented as percent moisture (Hyde, 2000).

I recorded slope, aspect, landform index (LFI), terrain shape index (TSI), and stream area, depth, velocity, and substrate at each site. LFI measured the topographic position of the site within the landscape (McNab, 1993) and the TSI measured the local curvature of the site (McNab, 1989). I categorized block topography for all 48 blocks within each site (Appendix C). I recorded any uncharacteristic land formations (such as exposed bedrock). I used the elevation from USGS topographic maps in analyses. I acquired stand age, site index values, and CISC community type from the USDA Forest Service (CISC database).

Distance of sites to roads and other habitat features were estimated based on ground surveys, topographic maps, and CISC data.

Statistics

I transformed abundances of *P. jordani* by using the log (count + 1). I did not find major differences in analyses when using the transformed abundances versus the actual abundances and I decided to use the actual count data instead of the transformations. Relative abundances of salamanders were converted to relative densities based on available terrestrial land area (1200 m^2 site minus stream area). Paired t-tests were used to compare yearly differences for degree of wetness, average daily temperature, and relative abundances of *P. jordani* (McClave and Dietrich, 1996). The equality of *P. jordani* snout-vent lengths and the population compositions between 2001 and 2002 were tested using t-tests. The relationship between abundances of *P. jordani* and macroscale habitat characteristics were compared using t-tests.

T-tests were also used to test equality between day and night searches of mean snout-vent length and percent composition. Simple linear regression analysis determined the correlation between the 2001 abundances of *P. jordani* with the 2002 abundances, between abundances of *P. jordani* for average day searches with night searches, and between abundances of *P. jordani* with distance from water (Neter et al., 1996). Multiple stepwise regression analyses were used to determine which habitat features explained for the abundances of *P. jordani* at both the site and block level (Neter et al., 1996). Comparing equality of mean snout-vent length and mean weights of *P. jordani* across the landscape was determined by analyses of variance. Distribution of *P. jordani* within sites was tested using Lloyd's mean crowding index (Lloyd, 1967). I used a 0.05 level of significance for all statistical analyses unless otherwise noted.

Results

I searched 10 sites in both 2001 and 2002 during the day and captured totals of 24 and 67 *Plethodon Jordani,* respectively (Table 3). Lack of rainfall prevented sampling of all sites at night. I sampled six sites in 2001 and three sites in 2002 at night and observed 250 and 467 *P. jordani*. The amount of terrestrial area searched at each site differed slightly, depending on stream area and, therefore, I used *P. jordani* densities (*P. jordani*/ha) in certain analyses (Table 3). Densities reported are of animals captured (relative) and not total (absolute) densities of *P. jordani* at sites. Densities by day were 0-204 *P. jordani*/ha, while night densities were 0-2192 *P. jordani*/ha.

Temporal Comparisons

The 2001 and 2002 field seasons were conducted under drought conditions (third year of four year drought), but average daily temperatures were considered normal (Figures 5 and 6). Average daily temperature and degree of wetness at each site was compared between 2001 and 2002. No difference in average daily temperature was seen between the years, but degree of wetness differed ($P=0.0092$), with 2002 having a lower mean (Table 4). *P. jordani* data showed similarities between years. No difference between 2001 and 2002 densities of *P. jordani* were seen by day and a regression analysis on abundances showed significant between year repeatability for day searches ($P=0.020$, $R^2 = 0.52$) (Table 5, Figure 7). Furthermore, age class distribution (juvenile and adult) did not differ between years for either day or night searches (Table 6), nor did mean snout-vent lengths differ between years for either sampling method (Table 7).

Due to the high repeatability between 2001 and 2002 searches by day, mean site values for abundances by day and densities were used in other analyses (Table 8). Lack of rainfall inhibited nighttime sampling efforts, resulting in two incomplete night data sets. Based on the yearly relationships, the fact that salamanders are long lived and have site fidelity, the lack of natural or anthropogenic perturbations between the years at the study sites, and the use of a strict, visual search protocol, I assumed that night abundances would not differ between years, either. I combined the data from night samples at each site into one data set. Site 4 was not sampled at night during either year because of the drought. The combined year abundances and densities will be used for the rest of the analyses (Table 8).

Method Comparisons

I compared two sampling methods for monitoring *P. jordani*. The abundances of *P. jordani* from searches by day correlated strongly with abundances by night (SLR, P=0.00129, R^2=0.79, Correlation = 0.89) (Figure 8). On average, searches by day yielded 7% of the night search abundances. The proportion of juveniles in the population did not differ between day and night searches, but mean snout-vent length did differ (P= <0.0001), with larger *P. jordani* observed at night (mean SVL day = 30.1 mm, mean SVL night = 40.3 mm) (Table 9). Size frequency histograms for the two sampling techniques showed different population structures (Figure 9). I found relatively fewer *P. jordani* of reproductive size (≥ 45 mm SVL) during day sampling than at night.

Efficiency, in regard to accomplishing research objectives, is important in salamander monitoring. Catch per unit effort differed between the two sampling methods (Table 10). Sites were sampled on average in 4 hours and 42 minutes during the day and 6 hours and 9 minutes at night. This yields, on average, one *P. jordani* for every 4.6 minutes of search time at night and one individual for every 61.3 minutes searched during the day. Stream searches during the day occupied a good portion of the search time. If I subtracted the estimated 90 minutes it took to sample the stream from the entire search time, the yield becomes one *P. jordani* for every 44.7 minutes searched during the day. Species-detection is another concern in monitoring. *P. jordani* were not detected at Site 1 during the day, but were observed at night. Sampling by day of Site 10 produced only one *P. jordani* between the two sampling years, but 79 individuals were seen at night. Sampling techniques have species-specific biases. *P. jordani* accounted for only 9 % of the daytime species composition, while contributing to 44% of the nighttime composition (Figure 10).

Spatial Comparisons

P. jordani were not distributed homogenously across the Pisgah Bear Sanctuary (coefficient of variation > 100% for day and night searches). *P. jordani* were not detected at Sites 3 and 7 during any sampling effort. Mean SVL did not differ across the landscape, but mean *P. jordani* weight did vary significantly (P=0.0018) (Figure 11 and 12). Sampling protocol was very strict and I conducted every search with the same trained interns each summer, decreasing observer bias.

I investigated how numbers of *P. jordani* varied spatially with macro and micro-scale habitat parameters. I compared abundances of *P. jordani* between community type, CISC community designations, aspect, Ericaceae presence (Rhododendron and Laurel), Pinaceae presence (Hemlock), elevation, distance from road, site index and slope. I also tested for a correlation between *P. jordani* density and land-form index (LFI), terrain-shape index (TSI), distance to road, elevation, and age of stand. I found no relationship between any macrohabitat characteristic and abundance of *P. jordani* either in the day or at night (Table 11). Out of 30 habitat variables, 100% of the variability in site abundance (stepwise multilinear regression; alpha=0.15) was explained by seven habitat variables, including woody debris (Sizes C, D, and E), total woody debris > 5 cm in diameter (negative correlation), average soil moisture, percent hemlock (negative correlation), and average leaf litter depth (Table 12).

Spatial variability of *P. jordani* also occurred within sites. *P. jordani* were not readily found in close proximity to streams (Figure 13). Day (P=0.0050) and night (P=0.00013) searches showed *P. jordani* abundances increasing with distance away from riparian areas (stream bank) (Figure 14). Lloyd's mean crowding index (Lloyd, 1967) showed that *P. jordani* had a clumped distribution. Thirty-three percent of the variability of P. jordani in blocks at night was attributed to the presence of laurel (negative relationship), volume of woody debris, and woody debris (Size D) found within blocks (Table 13). I found *P. jordani* under both rocks and woody debris during the day and using all patch habitats as a substrate at night, including leaf litter, tree trunks, understory vegetation, rocks, and woody debris. *P. jordani* preferred woody debris to rocks for a cover item in 2002 when there was less moisture (P=0.0345), and preferred woody debris to rock, soil, and understory as a substrate during nighttime activity (P = 0.011) (see Chapter 3).

Discussion

Variability in Time

I sampled sites in the same manner and time of year. I found year-to-year repeatability for relative abundances, age class distribution, and snout-vent-length to be high during daytime searches, indicating that holding certain conditions constant, one should find similar trends across a sampling area over time (Smith and Petranka, 2001). Lack of rain prohibited me from comparing the same sites between years for night searches. Although night data were from different sites in each year, I found no differences between years for the age class distributions or SVLs at night, and saw no evidence to believe that night sampling would produce a different trend in abundances between years. Search results by day and by night were highly correlated.

I found a difference between degree of wetness at sites between the years. I attribute the greater abundance, although not significant, of *P. jordani* observed under cover objects in 2002 to lower moisture levels. Terrestrial salamanders will relocate horizontally from leaf litter to be under cooler, moister cover objects during dry periods (Heatwole, 1962; Jaeger et al., 1995). Jaeger (1980) reported a positive correlation between the number of *P. cinereus* observed under cover objects and rainfall.

Sampling the same salamander population at sites during the day and at night, I found greater abundances, larger mean SVL, and a more diversified size-frequency histogram at night than during the day. Admittedly, I did not search leaf litter during the day and I sampled only under optimal conditions at night. Petranka and Murray (2001) found, however, differing moisture conditions did not influence the surface activity of large

Plethodon species, and Hyde (2000) found larger *P. jordani* on night transect searches than on leaf litter searches, natural cover transects, and cover board searches.

I believe the difference in mean SVL seen between the two sampling methods is a result of habitat preference and competition. Gordon et al. (1962) claimed that *P. jordani* retreat below ground into deep burrows, making them unavailable for detection when lifting rocks or logs. Petranka (1998) also mentioned the use of burrows by adult *P. jordani*. *P. jordani* display intraspecific aggression and defend territories (Hairston, 1987). If burrows are a limited resource (Hairston, 1987, suggested space was limiting factor between *P. jordani* and *P. glutinosus*), larger *P. jordani* may exclude juveniles and small adults from subterranean levels. These smaller individuals are left to retreat under leaf litter, rocks or woody debris. This topic needs additional study and is very important in the use of cover object searches in monitoring large *Plethodon* species. These types of data may provide information on limiting resources and predation and competition, which will be useful in addressing the effects of management activities on salamander populations.

Variability in Space

I did not find a homogenous distribution of *P. jordani* across the Pisgah Bear Sanctuary. One assumption when conducting a visual search is that every individual of every species has the same opportunity for detection (Heyer et al., 1994); in practice, this is not possible. Nighttime removal and mark-recapture studies show 10-25% of a *P. jordani* population is active above ground on any given night (Nishikawa, 1985; Hairston, 1987; Petranka and Murray, 2001). Salamanders present on the ground surface will vary with season, time of night, and individual salamander tolerances to the conditions. Emergence times of *P. jordani* onto the forest floor vary with individuals (Merchant, 1972) and age classes (Gorden et al., 1962). Hatchling *P. jordani* remain below the surface until the following May when they emerge as yearlings (Hairston, 1987; Petranka, 1998). *P. jordani* also migrate randomly below the ground surface during nighttime activity making them undetectable (Bailey, 2002). Salamanders have limited exposure times and *P. jordani* will retreat to burrows or under cover even on moist nights (Spotila, 1972). Additionally, female *P. jordani* are not active while guarding egg clutches, which typically occurs May through August in the southern Appalachians (Hairston, 1987; Petranka, 1998). Despite these sources of variation in detectability of *P. jordani*, they had little affect on my conclusions for the following reasons.

I began sampling at the same time each night, under the same moisture conditions, and starting at the same location in each site. I proceeded to sample each site in the same systematic fashion with the same trained personnel throughout each field season. Sampling took place between mid-June and mid-August, which was after the May emergence of yearling *P. jordani*. Clutch guarding occurred throughout this time and I did not find any gravid females during the sampling season. Therefore, presence of yearlings and absence of reproductive females was consistent during the sampling period and did not bias estimates of relative abundances. Smith and Petranka (2000) showed that surface counts correlated strongly with estimates of absolute population sizes for salamanders at sites in the Smokey Mountains and along the Blue Ridge Parkway. My observed differences in density most likely reflect absolute population sizes, rather than variability caused by sampling (Smith and Petranka, 2000).

P. jordani abundances did not correlate with any macrohabitat characteristic and, thus, large-scale habitat factors did not affect spatial sampling. I designed this study to reduce variability caused by macroscale habitat features and my attempt appeared successful. Further research is needed regarding *P. jordani* habitat associations, but I found distributions of *P. jordani* within sites and blocks to be related with woody debris and negatively correlated with vegetation (hemlock and laurel) that grows in acidic soils. While I did not find a difference in mean SVL across sites, mean weight did vary. This also warrants further study, as weight (or biomass) can indirectly measure habitat quality for *P. jordani* (i.e. prey availability). Additionally, intraspecific and interspecific competition for resources can be studied by differences in salamander weights. Salamander mass is important in determining energy-flow in terrestrial systems (Burton and Likens, 1975; Petranka and Murray, 2001).

Method Comparison

Long-term salamander monitoring is essential for understanding population trends. The goal of any monitoring program is to find a method or combination of methods that detect changes in population size or structure for the target species over time. Ideally, measured relative abundances should index the absolute population size of a particular species accurately. Sampling techniques that are equally efficient in detecting trends will have a strong positive correlation (Hyde, 2000). Even though only 7% of night abundances were observed during the day, the correlation (89%) between the two sampling methods was strong. Night sampling, however, did reveal *P. jordani* present at Site 1 and Site 10 where none and only one *P. Jordani*, respectively, were found during day sampling. Though inconvenient and more time consuming than sampling by day (for the same size area), sampling by night appears necessary to document presence or absence of *P. jordani*, to estimate relative densities at all sampling locations and to provide larger sample sizes for greater statistical power.

Detectability of *P. jordani* differed depending on the search method, with *P. jordani* accounting for only 9% of the total salamander abundance observed during the day, compared to 44% of the abundance found at night. My data are similar to those of Gordon et al. (1962), who showed *P. jordani* in the southern Appalachians to comprise 19% of the salamander abundance during the day and 49% of the composition seen at night. I found larger and more *P. jordani* at night. The two sampling methods provided very different interpretations of the overall population composition, with day sampling showing fewer *P. jordani* of reproductive size and more yearling salamanders than night sampling. Night sampling proved to be the more efficient method for observing *P. jordani*.

Monitoring of *P. jordani*

The USDA Forest Service is concerned with studying population fluctuations and how land management decisions affect *P. jordani* (USDA, 1994). Monitoring must be species specific, consider the life history, behavior, and habitat associations of the target species, take monitoring constraints into account, such as time, finances, and manpower, and consider temporal and spatial variability that results from these factors (Heyer et al., 1994; Smith and Petranka, 2000; Hyde and Simons, 2001; Bailey, 2002). Mark-recapture and removal studies provide estimates of absolute populations but these methods are time consuming and often costly. Petranka and Murray (2001) estimated that 14 sample nights per site are needed to approximate absolute density of *P. jordani*. Heyer et al. (1994) suggested sampling at least 10 sites to get statistically significant numbers using visual searches. It would be impossible for a single team to sample 140 sample-nights in one season. Because of constraints, management agencies will likely rely on relative abundance indices in their monitoring efforts. Bailey (2002), however, warned against using counts alone to estimate population sizes without incorporating some index of the number of *P. jordani* temporarily located beneath the ground during sampling. She suggested calculating absolute density at a subset of sites to validate surface counts.

Hairston and Wiley (1993) found *P. jordani* populations in the southern Appalachians not to have declined in 14 years (between 1976-1990), despite some temporal fluctuations. *P. jordani*, however, is sensitive to management activities. Acute perturbations, such as clearcutting, result in the disappearance of *P. jordani* populations within two years (Petranka, 1993, 1994; Ash 1997; deMaynadier and Hunter, 1995; DeGraff and Yamasaki, 1997; Grialou et al., 2000).

Not all management activities will result in immediate population declines. Chronic disturbances may be subtler and prove more difficult to detect (Hairston and Wiley, 1997; Smith and Petranka, 2000). Disturbance type, and in turn, salamander response, will vary (Hairston, 1987). Immature stages are often more sensitive to disturbance (Hairston, 1987). *P. jordani* response to management may differ based on the degree, extent, and additive affects of management. Management agencies will likely need to monitor more than *P. jordani* population sizes to detect a response by *P. jordani* to management. Management could change the population structure, composition, distribution, or habitat use by *P. jordani*. It is also important to study population trends over a generation to assess affects of possible disturbance. The mean generation time for *P. jordani* is 9.79 years (Hairston, 1987).

CHAPTER 3

Plethodon jordani as a Management Indicator Species for woody debris habitats

Introduction

Habitat loss, fragmentation, and degradation have resulted in loss of global biological diversity (Flebbe and Herrig, 2000; Wear and Gries, 2002). The southern Appalachians, considered a center of biological diversity, have experienced similar population declines and loss (Jackson, 1989). The largest publicly owned land area in the eastern United States, including six national forests and the Great Smokey National Park, lies within the southern Appalachians (Jackson, 1989). These public lands and interspersed private holdings, support urban development, forestry, agriculture, many forms of recreation, and watersheds for drinking water.

In efforts to address concerns over loss of species, land managers have incorporated biodiversity preservation in their multiple-use management plans (Jackson, 1989; Simberloff, 1998). Pursuant to the National Forest Management Act, all national forests must maintain viable plant and animal populations (USDA FS 36.C.F.R.219; USDA 1994). This, however, becomes a difficult task. Pisgah National Forest in western North Carolina, for example, has well over 2,000 species of flora and fauna. It becomes logistically impossible to monitor and protect each individual species. As a result, land managers of all national forests, included Pisgah National Forest, designated Management Indicator Species (MIS) with the intent "to represent all biological communities and special habitats within a planning area" (Hillman, 1994). These MIS are supposed to indicate for "the effects of management on biological communities, special habitats, and population viability of all native and desired non-native plants and animals across the planning area" (Hillman, 1994).

Designation of MIS should not be taken lightly. Implementing management plans based on unsubstantiated assumptions can have negative consequences on biodiversity, environmental quality, and future management efforts. The Forest Service's Southern Regional Office has provided their criteria for selection of MIS (USDA, 1994).

MIS Selection Criteria:

1. Sensitivity to management activities across the planning area
2. Ability to monitor
3. Representative of a community, community assemblage, or special habitat
4. Responsiveness to public input
5. Consideration of proposed, threatened, or endangered species
6. Consideration of sensitive species
7. Representation of special habitat and rare or unique communities
8. Management of species or groups of species for specific purposes
9. Responsiveness of population is proportional to habitat quality
10. Population stability
11. Availability of specific research relative to species biology
12. Avoidance of duplication in the MIS system

Plethodon jordani (Jordan's salamander) has been selected as one of 64 MIS for Pisgah National Forest. *P. jordani* represent woody debris habitats (USDA, 1994) under Criteria 3, stated above. The validity of using MIS, however, has been questioned (Patton, 1987; Landres et al., 1988; Hillman, 1994; Niemi et al., 1997; Simberloff, 1998). A MIS should (1) be easy to monitor, (2) be associated with the habitat it represents as an MIS, (3) be sensitive to management practices and respond to changes in habitat quality in a measurable way, and (4) represent other organisms' responses to changes in habitat quality (Patton, 1987; Landres et al., 1988; Hillman, 1994; Niemi et al., 1997; Simberloff, 1998).

The objective of this chapter is to examine the relationship of *P. jordani* with woody debris as a cover object during the day and as a foraging substrate at night. The Forest Service describes woody debris habitats as woody debris greater than or equal to 7.5

cm, including downed woody debris, standing dead trees, fallen logs, and decomposing roots Mae Lee Hafer, Pisgah Ranger District, personal communication). Because salamanders can use even small sizes and pieces of woody debris, this paper examines the use of woody debris of all sizes by *P. jordani*. *P. jordani*, however, mostly use burrows as a retreat during the day (Brooks, 1946; Petranka, 1998), and, therefore, I expected to find *P. jordani* use of woody debris as a cover object to be limited. Ash (1997) has suggested *P. jordani* use leaf litter as their main foraging substrate. I expected to find that *P. jordani* do not prefer woody debris to other substrates as a foraging surface at night.

Methods

Study Area

My study area was the Pisgah Bear Sanctuary within Pisgah National Forest, western North Carolina (Figure 1). The Bear Sanctuary (235 km^2) was located near Brevard, North Carolina (35° 17’ N latitude; 82° 47’ W longitude) (Powell et al., 1997). That region of the southern Appalachians, and more specifically the southern Blue Ridge Mountain range, was characterized by igneous and metamorphic rock types, mainly of granite, basalt and dunite and slates, schists and gneisses, respectively (USDA, 1994). The Pisgah Bear Sanctuary ranged from 650 m to almost 1800 m in elevation (Powell et al., 1997). At that intermediate level, soils were predominantly loamy with dark topsoil surfaces of varying thickness influenced by organic matter (USDA, 1994). Subsoils were brownish, yellowish, or reddish and contained 15-50 % clay and 10-50 % (by volume) rock fragments (USDA, 1994).

My study area was considered a temperate rainforest, with some parts of the Sanctuary experiencing 250 cm of precipitation per year (Powell et al., 1997). The forest contained many perennial, free-flowing, cold-water streams of a moderate to steep gradient. Charles Vanderbilt once owned the land until 1917, when the USDA Forest Service acquired it. Prior land-use was dominated by farming, mining, and logging. My field research was done in June through August of 2001 and 2002.

Site Selection and Design

A quadrat design was selected to study a particular site thoroughly, to obtain a salamander species list, to estimate relative densities and diversity of salamander species, to estimate relative densities of specific species within certain microhabitats, and to compare data across the landscape. I established eleven 30x40 m sampling sites within the Pisgah Bear Sanctuary, each located at least 1 km from all others to ensure independent sampling (Figure 1). Each perimeter was established along a 30-meter stretch of stream and extended 40 meters up slope, with the entire width of the stream being included (Figure 2). Sites of this size and design were used to ensure enough animals for statistical analyses and to study the species assemblages of salamanders within aquatic, semiaquatic, and terrestrial habitats. Each site was further subdivided into 5x5 m blocks and marked with flagging and PVC pipes. Blocks allowed me to sample sites systematically, record the location of each salamander observed, and to analyze distribution patterns within microhabitats. Habitat occupying each 5x30 m transect (series of blocks) appeared to be homogenous.

To make salamander data comparable across sites, I selected sites based on certain habitat parameters. All sites were of cove hardwood or upland hardwood community types, had seral ages between 70 and 85 years, were located between 927-1292 m in elevation, contained first or second order perennial streams, had slight to moderate slopes, and were accessible for repeated sampling. Additionally, a strict sampling protocol was used and the same, well-trained individuals collected each year's data. In August 2001, the stream at one site ran dry, forcing me to eliminate this site from the study prior to the end of the field season. I added a new location prior to beginning the 2002 field season. An additional site was eliminated prior to data analysis because of its proximity to recent logging activity, which may have compromised data and ability to compare results with other sites (information on this site is available in Appendix E).

I sampled salamanders within each site using two methods: searches under natural cover objects by day and surface searches during and after rainfall by night. Based on the findings of Smith and Petranka (2000), I intended to sample each site once during the day and once at night per field season. Sites were sampled once each year during the day, but weather limited the sampling at night, resulting in two incomplete data sets.

Searches by Day

I conducted searches by day on random dates between June 6 and July 31, 2001 and 2002, noting starting and ending times. Beginning mid-morning (0900-0945 hours), 3-4 persons systematically turned rocks and woody debris within each 5x30 m transect until an entire site was sampled. We started at the uppermost transect (35-40 m upslope at the 0 m perimeter of the site) and sampled across it. We then moved to the next lower transect and sampled it, and so on (Figure 2). We always sampled the stream from downstream to upstream to prevent counting escaped salamanders more than once.

As we lifted rocks and woody debris, we captured salamanders and placed them in Ziplock bags. We replaced each cover object to its original location and leaves or other material were replaced to minimize moisture and temperature changes. We recorded the species of each salamander, its location in the site, weight, length, cover object type (rock, woody debris), cover object size (by category, see Appendix C), and any injuries or deformities. Each designated data collector followed a strict protocol to insure reliable and consistent recording of data at each site.

Length of each salamander was measured from snout to posterior portion of the hind legs (mm) for quick processing. Although snout-to-hind leg length has been used successfully in other studies (Szuba et al., 2002), I converted these measurements to snout-vent length (SVL) for determination of age class and use in size-frequency histograms (at the suggestion of Alvin Braswell, personal communication). I converted measures using linear regression of snout-to-hind-leg length and snout-to-vent length from a sample of salamanders of each species. We weighed each salamander in its bag with a spring scale (nearest 0.25 g) and then re-weighed the bag after salamander release. Individual animals were released adjacent to the cover under which they were captured. If a salamander escaped capture, genus or species identification, location, cover object type and size, and age category (larval, juvenile, or adult) were recorded. Kucken et al. (1994) successfully placed salamanders in age classes based on visual estimations and Hairston (1986) found this technique to result in only 8% misclassification of juveniles and adults.

Rain gauges were placed at each site and were to be checked regularly. Unfortunately, black bears also checked the gauges and destroyed them. Rainfall data for the area was acquired from the National Weather Service (Pisgah Forest 1 N Station), but site specific data were unavailable. Alternatively, a measure of "degree of wetness" was taken at each site prior to and at completion of sampling. This measures wetness by touch on a scale from 1 (completely dry) to 5 (soaked). Degree of wetness was estimated for foliage, leaf litter, and soil. Water, air, and soil (in 2002) temperatures were taken using mercury thermometers at the beginning and end of sampling. Cloudiness, wind, sunshine, past weather conditions, current weather conditions, and visible prey and predators were also recorded.

Searches by Night

We conducted searches by night only during or after adequate rain. This was defined as water penetrating the canopy and saturating the understory vegetation, leaf litter and soil. We began sampling at dusk (2100 hours) and continued until the entire site was sampled. Using headlamps, we walked or crawled within each 5x30 m transect collecting salamanders on surfaces of leaf litter, vegetation (tree trunks and understory), woody debris, rocks, or soil. Data on salamanders were recorded as described for sampling by day. We turned no cover objects and habitat disturbance was minimal. Due to large numbers of salamanders present on the surface at night, the data collector and, typically, an additional volunteer walked behind the observers and notified the observers of any undetected salamanders. Sites were originally sampled in random order but, due to patchy and limited rainfall, subsequent sampling occurred at sites where criteria for sampling at night were met. Searches by night in 2002 were first conducted at sites where sampling at night did not occur during the previous field season.

Sampling of Habitat

I sampled habitat at both the macro and microhabitat scale. On average, ten 5 m^2 blocks (~20% of each site) were sampled on a micro level, with 1-2 blocks being sampled within each parallel line of blocks (Figure 2). I characterized each site with the mean values of its block samples. Individual block data were used in analyzing salamander distribution within each site and between the three main microhabitats (aquatic, semi-aquatic, and terrestrial) across the landscape.

For each block, I visually estimated canopy cover and the percent of surface area covered by each type of substrate (understory vegetation, leaf litter, woody debris, tree trunk, barren soil, rocks). I counted numbers of rocks and woody debris found in pre-established size categories (Appendix C). I noted the dominant vegetative species in the overstory and understory, and recorded diameters of trees >5 cm DBH.

I visually estimated percent cover of hemlock, rhododendron and laurel for each site. Mean litter depth was based on over 30 samples using a ruler (nearest mm). Leaf litter and soil samples were collected from all sites by three groups of people in one afternoon to minimize variation in moisture caused by rain. We placed 4 samples (every 10 meters up slope) of soil and leaf litter at each site into Ziplock bags. Samples were transferred to paper bags later that day, weighed, placed in storage, and then reweighed four months later. One minus the ratio of dry weight to wet weight is presented as percent moisture (Hyde, 2000).

I recorded slope, aspect, landform index (LFI), terrain shape index (TSI), and stream area, depth, velocity, and substrate at each site. LFI measured the topographic position of the site within the landscape (McNab, 1993) and the TSI measured the local curvature of the site (McNab, 1989). I categorized block topography for all 48 blocks within each site (Appendix C). I recorded any uncharacteristic land formations (such as exposed bedrock). I used the elevation from USGS topographic maps in analyses. I acquired stand age, site index values, and CISC community type from the USDA Forest Service (CISC database). Distance of sites to roads and other habitat features were estimated based on ground surveys, topographic maps, and CISC data

Statistics

I transformed abundances of *P. jordani* by using the log (count + 1). I did not find major differences in analyses when using the transformed abundances versus the actual abundances and I decided to use the actual count data instead of the transformations. Abundances of *P. jordani* found under cover objects during the day and on substrates at night were converted to densities based on the area of each available cover and substrate found at each site. Simple linear regression analyses were used to detect the correlation between densities of *P. jordani* found under cover objects with the area of available cover for each study year (Neter et al., 1996). Differences in the use of cover objects between years was tested using a paired t-test. T-tests were used to test equality of mean snout-vent length of *P. jordani* found under cover objects between years, of mean snout-vent length between cover objects within the same sampling year, and between the use of rocks and woody debris by *P. jordani* for each year (McClave and Dietrich, 1996). Analysis of variance determined if *P. jordani* chose to use substrate types similarly at night. Subsequent Bonferroni multiple comparisons were used to tests the differenced in the use of substrates. T-tests compared use of each substrate at night between *P. jordani* and *D. ocoee*. Correlation between abundance of *P. jordani* with area of woody debris and with volume of woody debris at each site was tested using simple linear regression analyses. All analyses used a 0.05 level of significance, unless otherwise noted.

Results

For *P. jordani* to be a good MIS for woody debris special habitats, it must be associated heavily with woody debris. Searches by day of nine sites in 2001 resulted in the collection of 20 *P. jordani* under rocks and woody debris (Table 14). At the same nine sites in 2002, I observed 44 *P. jordani* under rocks and woody debris. Site 6 was added in 2002 and I observed 15 additional *P. jordani* under cover objects at that site (total of 59 *P. jordani* in 2002) (Table 14). Amount of cover of rock and woody debris differed at sites and I therefore, calculated the density of *P. jordani* (*P. jordani*/ha of cover type) for each site and year (Table 15). Site 6 was added in 2002 and was not included in analyses comparing years. Densities of *P. jordani* using cover items varied between sites (Figure 15). Densities of *P. jordani* using rocks and woody debris varied from 0-520.3 *P. jordani*/ha of rocks and 0-2366.9 *P. jordani*/ha of woody debris across sites.

In 2001, I found *P. jordani* under rocks at 22% of the sites and under woody debris at 44% of the sites. In 2002, 20% and 60% of the sites searched during the day were found to have *P. jordani* under rocks and woody debris, respectively. At all sites where *P. jordani* were observed under rocks, they were also found under woody debris. At other locations, *P. jordani* exclusively used woody debris as a cover object over rocks. *P. jordani* densities did not correlate with area of available cover for rocks or woody debris at sites for either year (Figure 16).

The abundances of *P. jordani* found under each cover type did not differ between the years (Table 16). No difference in mean snout-vent length (SVL) of *P. jordani* found under rocks and woody debris in 2001 and those found under rocks and woody debris in 2002 was observed (Table 17). In 2001, *P. jordani* did not use either rocks or woody debris significantly more than the other. In 2002, however, *P. jordani* preferred woody debris to rocks as a cover type (P = 0.0345) (Table 18). I found no difference in the mean SVL between *P. jordani* using rocks and *P. jordani* using woody debris as cover for either year (Table 19). I compared these results with those of *Desmognathus ocoee,* which was also prevalent at sites. The numbers of *D. ocoee* using cover objects did not differ between years, nor was there a preference for either rocks or woody debris in 2001 and 2002.

I used night observations in determining substrate preference of *P. jordani* during nighttime activity (i.e. foraging). I did not sample all study sites during 2001 or during 2002 because of drought conditions. Six sites (Sites 2, 3, 5, 7, 9, and 10) were sampled in 2001 and data on substrate use for 239 *P. jordani* were recorded (Table 20). I observed no *P. jordani* at sites 3 and 7. In 2002, three sites (Sites 1, 6, and 8) were sampled with 465 *P. jordani* observed. Site 4 was not sampled at night during either year. Abundances of *P. jordani* found on each substrate were converted to density (*P. jordani*/ha of substrate type) based on the available area of each substrate found at each site (Table 21). Substrate types included leaf litter, rocks, soil, understory, tree trunks, and woody debris. I separately examined *P. jordani* substrate use for each year. Based on high year-to-year repeatability seen in Chapter 2, I also conducted analyses on *P. jordani* substrate preference using the combined (2001+2002) densities from night searches (Table 21).

I found a significant difference in *P. jordani* use of at least one substrate type in 2001 (P = 0.0310) and 2002 (P = 0.049), and for the combined years (P = 0.0013). At sites sampled at night in 2001, *P. jordani* preferred woody debris to understory substrates, and they used tree trunks more than understory substrates. In 2002, mean use of woody debris differed from soil use. Combined year data showed that *P. jordani* preferred woody debris to rocks, soil, and understory substrates. I found the mean snout-vent length of *P. jordani* to differ with substrate type (P = 0.011) (Figure 17).

I compared the substrate use by *P. jordani* to that of *D. ocoee*, the most prevalent and second most prevalent species found during the day and at night, respectively. *D. ocoee* showed no substrate preference in 2001 or 2002, but when yearly data were combined, *D. ocoee* displayed a preference for at least one substrate type (P = 0.0491). At 0.20 level of significance, I found *D. ocoee* to prefer woody debris to understory and soil as a nighttime substrate. No difference in use of any substrate was found between *P. jordani* and *D. ocoee* (Figure 18).

Substrate use and preference varied within and among sites (Figure 19). *P. jordani* preferred woody debris habitats to all other substrate types at 71% of the sites. At the remaining sites, *P. jordani* chose to use tree trunks more than other substrates. Overall, 39% of the salamanders selected woody debris as a nighttime substrate (Figure 20). No correlation between area or volume of woody debris and the total number of *P. jordani* was found (Figure 21).

I found no correlation between any macrohabitat characteristic and *P. jordani* abundances either by day or at night (see Chapter 2). Out of 30 habitat variables, 100% of the variability in site abundance (stepwise multilinear regression; alpha=0.15) was explained by seven habitat variables, including woody debris (Sizes C, D, and E), woody debris > 5 cm in diameter (slight negative correlation), average soil moisture, percent hemlock (negative correlation), and average leaf litter depth (Table 12). Thirty-three percent of the *P. jordani* variability within blocks was attributed to the presence of laurel (negative relationship, alpha = 0.05), volume of woody debris, and woody debris (Size D) found within blocks (Table 13).

Discussion

An interwoven matrix of abiotic and biotic factors allow for diversity. It is the disruption of this complex natural system, by pollution, habitat loss, and other anthropogenic perturbations, that has most likely caused population declines and loss of species. In an effort to follow a multiple-use system that includes biodiversity, the USDA Forest Service must manage to maintain viable plant and animal populations (Jackson, 1989; Welsh, 1990; USDA, 1994). As a result, the Forest Service incorporated using Management Indicator Species in management plans. But can we study a few species to represent all communities and special habitats within a diverse forest, and will these species provide adequate information on how management activities impact communities, special habitats, and populations of other plants and animals? In this chapter, I specifically question the designation of *P. jordani* as a MIS in Pisgah National Forest, NC. For *P. jordani* to be considered a good MIS, they must be associated with woody debris special habitats.

Is P. jordani associated or does it show a relationship with woody debris?

Use of Woody Debris for Cover

P. jordani showed no preference for a particular cover type in 2001, but more individuals selected woody debris over rocks in 2002. I found 43 more *P. jordani* under the same cover objects in 2002 than in 2001. I attribute the greater abundance of *P. jordani* in 2002, and their preference for woody debris as a cover type, to the lack of moisture I observed during that year (See Chapter 1). Moisture levels are higher under woody debris than rocks (Grover, 2000), and terrestrial salamanders will relocate from leaf litter, to cooler, moister cover objects during dry periods (Heatwole, 1962; Jaeger, 1980; Jaeger et al., 1995). *D. ocoee* (the most prevalent species found during the day and second most prevalent species at night) did not prefer either rocks or woody debris as a cover item. I found *D. ocoee* to be more abundant closer to streams and therefore they may have moister conditions readily available.

P. jordani found under cover objects were smaller, on average, than those observed on substrates at night (see Chapter 2). Therefore, cover objects may be more important as a refuge for juveniles and small adults, compared to large adults. Despite their use of cover objects, *P. jordani* were found in limited numbers under rocks and woody debris. Daytime searches yielded 7% of nighttime abundances. *P. jordani* have a tendency to use burrows for retreats (Brooks, 1946; Heatwole, 1960; Gordon et al., 1962; Petranka, 1998), limiting their association with any cover object, including woody debris. Ultimately, *P. jordani* use both rocks and woody debris as cover items in a limited capacity. The relationship and extent to which woody debris is used for cover may be dependent on *P. jordani* size and availability of burrows.

Use of Woody Debris as a Foraging Substrate at Night

P. jordani used leaf litter, rocks, soil, understory vegetation, tree trunks, and woody debris as nighttime substrates. I did find *P. jordani* to prefer woody debris as a substrate at night over some substrate types (rocks, soil, and understory vegetation), but not over leaf litter or tree trunks. Ash (1997) reported that *P. jordani* and other species of *Plethodon* at a western North Carolina site used leaf litter as the main foraging substrate. My data do not support his finding. I found 39% of the *P. jordani* to be on woody debris, 31% on tree trunks, and 12% on leaf litter at night. Use of substrates by *P. jordani* at night did not differ from that of *D. ocoee*.

Macrohabitat factors, such as aspect, community type and stand age, which could indirectly affect volume, size, and decay rate of woody debris, showed no relationship with *P. jordani* densities. Variability in abundance of *P. jordani* at the site and block level was attributed, in part, to certain size categories of woody debris. The volume of woody debris in blocks, within sites, also contributed to abundances of *P. jordani* found on the microscale. I did not find a correlation between area or volume of woody debris at sites and abundance of *P. jordani*.

Association of *Plethodon* species with particular sizes and decay classes of woody debris has been documented (Petranka et al., 1994; deMaynadier and Hunter, 1995; Herbeck and Larsen, 1998; Butts and McComb, 2000). I did not, however, collect data on the type or decay class of downed woody debris. *P. jordani* are generalist feeders and are known to eat 78 different invertebrate species (Whitaker and Rubin, 1971; Mitchell and Taylor, 1986). Particular invertebrates associated with woody debris, however, do not appear to serve as prey for *P. jordani*. Carabid beetles, which are found under logs, are eaten infrequently by *P. jordani*, and wood roaches, common in rotting logs, are not eaten (Whitaker and Rubin, 1971). Nest sites of *P. jordani* have never been observed and therefore the need of woody debris for nesting is unknown (Hairston, 1983; Petranka, 1998). While there seems to be some association between *P. jordani* and woody debris, the exact relationship and extent, is unclear. Further fieldwork investigating the association of *P. jordani* to woody debris in different community types of varying ages needs to take place.

Is P. jordani a good MIS for woody debris *special habitats?*

My research has found a limited association of *P. jordani* with woody debris and I am not convinced *P. jordani* is a good MIS designation for woody debris special habitats. Additionally, the USDA Forest Service (1994) defines a special habitat as “a component or condition of the environment that may be common across several biological communities.” Woody debris (size, volume, type, and decay rate) is not “common” across community types (Tainter and McMinn, 1999; Butts and McComb, 2000; Knoepp et al., 2000; Adams and Owens, 2001). I found the volume of woody debris not to be consistent among cove and hardwood community types of similar stand ages and elevation. The condition of the woody debris will influence what organisms rely on it (USDA, 1993). In addition to salamanders, other organisms rely, to a certain extent, on woody debris characteristics, including mammals (Loeb, 1993, 1999; Butts and McComb, 2000; Greenberg, 2002), birds (Lanham and Guynn Jr., 1993), fungi (Nakasome, 1993), macroinvertebrates (Caldwell, 1993; Hanula, 1993; Hendrix, 1993), reptiles (Whiles and Grubagh, 1993), and aquatic organisms (Dolloff, 1993; Wallace et al., 1993). Whether *P. jordani* can predict for any of these organisms is not known.

If *P. jordani* displays a strong association with woody debris, it would likely be with a particular characteristic of woody debris (i.e. decay class) rather than all kinds of woody debris habitats. In that case, *P. jordani* would not indicate for all woody debris habitats or all organisms relying on woody debris, but rather a specific subset of woody debris and organisms. Ultimately, the terms "woody debris special habitat" and monitoring of *P. jordani* "population trends" are too broad in scope. And lastly, it may be more efficient to study woody debris habitats directly than to study *P. jordani* population trends.

CHAPTER 4

Ursus americanus as a Management Indicator Species in Pisgah National Forest

Introduction

Habitat loss, fragmentation, and degradation have resulted in loss of global biological diversity (Flebbe and Herrig, 2000; Wear and Greis, 2002). The southern Appalachian Mountains, considered a center of biological diversity, have experienced similar population declines and loss (Jackson, 1989). Six national forests and the Great Smokey Mountain National Park make the southern Appalachians the largest publicly owned land area in the eastern United States (Jackson, 1989). These public lands and interspersed private holdings, support urban development, forestry, agriculture, many forms of recreation, and watersheds for drinking water.

In efforts to address concerns over loss of species, land managers have incorporated biodiversity preservation in their multiple-use management plans (Jackson, 1989; Simberloff, 1998). Pursuant to the National Forest Management Act, all national forests must maintain viable plant and animal populations (USDA FS 36.C.F.R.219; USDA 1994). This, however, becomes a difficult task. Pisgah National Forest in western North Carolina, for example, has well over 2,000 species of flora and fauna. It becomes logistically impossible to monitor and protect each individual species. As a result, land managers of all national forests, included Pisgah National Forest, designated Management Indicator Species (MIS) with the intent "to represent all biological communities and special habitats within a planning area" (Hillman, 1994). These MIS are supposed to indicate for "the effects of management on biological communities, special habitats, and population viability of all native and desired non-native plants and animals across the planning area" (Hillman, 1994).

The validity of using MIS has been questioned (Patton, 1987; Landres et al., 1988; Hillman, 1994; Niemi et al., 1997; Simberloff, 1998). Despite the controversy, MIS are still written into forest management plans. The black bear (*Ursus americanus*) is one of the 64 MIS written into the Land and Resource Management Plan of Pisgah National Forest (USDA, 1994).

Designation of MIS should not be taken lightly. Implementing management plans based on unsubstantiated assumptions can have negative consequences on biodiversity, environmental quality, and future management efforts. The Forest Service's Southern Regional Office has provided their criteria for selection of MIS. The black bear meets criteria 1, 3, 4, and 9 listed below (USDA, 1994).

MIS Selection Criteria

1. Sensitivity to management activities across the planning area
2. Ability to monitor
3. Representative of a community, community assemblage, or special habitat
4. Responsiveness to public input
5. Consideration of proposed, threatened, or endangered species
6. Consideration of sensitive species
7. Representation of special habitat and rare or unique communities
8. Management of species or groups of species for specific purposes
9. Responsiveness of population is proportional to habitat quality
10. Population stability
11. Availability of specific research relative to species biology
12. Avoidance of duplication in the MIS system

The black bear has been designated as a MIS for the following habitats (USDA, 1994): (1) Old growth forest, (2) Hard mast producing species >40 years old, (3) Mixed pine and hardwood forest types for successional stage and hard mast, (4) Contiguous area with low disturbance level (< 1.6 km open motorized travelway per 6.4 km), (5) Snags and dens (trees > 90 cm dbh), and (6) Downed woody debris (all communities).

Black Bear Habitat Suitability Index Model

Zimmerman (1992) developed a Habitat Suitability Index model (HSI) for black bears in the southern Appalachians based on available literature. The model contained habitat variables important to black bears that revolved around three requirements of the black bear: food, den areas, and cover for escape (Zimmerman, 1992; Powell et al., 1997) (see Appendix D). To determine habitat suitability for black bears in the Pisgah Bear Sanctuary, Pisgah National Forest, data for each habitat variable were collected at evenly spaced intervals (at Universal Transverse Mercator (UTM)) in the Sanctuary. Data were obtained from Forest Service Continuous Information of Stand Condition (CISC) database, topographic maps, aerial photographs and ground surveys. Ultimately, a habitat quality value, or *HSI,* ranging from 0 (unsuitable habitat) to 1 (optimal habitat) was assigned at sample sites. Interpolation values were constructed from sample site data to provide a *HSI* estimate for each XY coordinate in the Sanctuary.

Mitchell (1997) improved on Zimmerman's (1992) model by sampling more sites and using both landform modeling and interpolation to achieve *HSI* values at intermittent locations. The HSI model was tested twice using independent black bear telemetry data. Results showed *HSI* classes to strongly indicate for black bear habitat preference (Zimmerman, 1992; Mitchell, 1997; Powell et al., 1997).

Black Bear as MIS for Salamanders

To be a good MIS, black bears must be easy to monitor, be associated with habitat they supposedly indicate, respond measurably to altered habitat quality caused by management activities, and represent other species' responses to changes in habitat quality (Patton, 1987; Noss, 1990; Lambeck, 1997; Caro and O'Doherty, 1999; Simberloff, 1999; Rolsted et al., 2002). Using the black bear HSI model, we can predict habitat quality for black bears within the Pisgah Bear Sanctuary (Zimmerman, 1992; Mitchell, 1997; Powell et al., 1997). Black bear use of habitat does change in relation to the quality of the habitat (Zimmerman, 1992; Mitchell, 1997; Powell et al., 1997). But do other species existing in the same biological community respond when habitat quality changes for black bears? In answering this question, I have selected salamanders to study.

I chose salamanders for multiple reasons. First, amphibians, including salamanders, are experiencing worldwide population declines (Blaustein and Wake 1990; Blaustein et al., 1994; Petranka, 1998; Wear and Gries, 2002). Long term data are essential in understanding if population changes are naturally occurring or induced by human disturbance (Hairston and Wiley, 1993; Blaustein et al., 1994; Heyer et al., 1994; Jung et al., 2000).). This study will provide land managers with information on species richness, relative species' densities, species diversity and species' distributions.

Second, their permeable skin, life histories, site fidelity, and limited mobility make salamanders highly susceptible to environmental change and they, themselves, are considered good indicators of environmental health (Carfioli et al., 2000; Welsh and Droege, 2001). Four salamander species have been designated as MIS for Pisgah National Forest (USDA, 1994). This study will provide relative densities and distribution data for two of those designated species, *Plethodon jordani* and *Eurycea bislineata wilderae*.

Third, salamanders occur in large numbers and their combined biomass in the southern Appalachians exceeds that of all other vertebrate species (Burtons and Likens, 1975; Hairston, 1987). They serve as an integral component in nutrient cycling and in the transfer of energy through food chains (Burton and Likens, 1975; Heyer et al., 1994; Petranka, 1998). The Pisgah Ranger District intends to study population changes in assemblages of woodland salamanders (USDA, 1994). My study uses two sampling techniques and results will be useful for establishing salamander monitoring efforts in Pisgah National Forest.

Fourth, salamanders and black bears use and prefer similar mature forest/old growth habitats (Table 22). Fifth, salamanders respond directly and indirectly to changes in habitat quality. Local populations of *P. jordani*, for example, in the southern Appalachians have crashed soon after clearcutting (Petranka 1993,1994; deMaynadier and Hunter, 1995; Ash, 1997), and another population experienced a change in composition after an adjacent steam was contaminated (Smith and Petranka, 2000).

The largest difference between black bears and salamanders is one of scale. Black bears use large tracts of land (in kilometers) (Powell et al., 1997), while home ranges of salamanders are small (in meters) (Petranka, 1998). The question of how well animals on different scales indicate for each other needs to be addressed when using MIS. The objective of this study was to test the correlation between habitat quality for black bears with species richness, density, and diversity of salamanders within the Pisgah Bear Sanctuary. A positive correlation between habitat quality for black bears (*HSI*) and species richness, density, and diversity of salamanders is hypothesized based on the similarities in habitat use of the two animals.

Methods

Study Area

My study area was the Pisgah Bear Sanctuary within Pisgah National Forest, western North Carolina (Figure 1). The Bear Sanctuary (235 km^2) was located near Brevard, North Carolina (35° 17' N latitude; 82° 47' W longitude) (Powell et al., 1997). That region of the southern Appalachians, and more specifically the southern Blue Ridge Mountain range, was characterized by igneous and metamorphic rock types, mainly of granite, basalt and dunite and slates, schists and gneisses, respectively (USDA, 1994). The Pisgah Bear Sanctuary ranged from 650 m to almost 1800 m in elevation (Powell et al., 1997). At that intermediate level, soils were predominantly loamy with dark topsoil surfaces of varying thickness influenced by organic matter (USDA, 1994). Subsoils were brownish, yellowish, or reddish and contained 15-50 % clay and 10-50 % (by volume) rock fragments (USDA, 1994).

My study area was considered a temperate rainforest, with some parts of the Sanctuary experiencing 250 cm of precipitation per year (Powell et al., 1997). The forest contained many perennial, free-flowing cold-water streams of a moderate to steep gradient. Charles Vanderbilt once privately owned the area until 1917, when the USDA Forest Service acquired the land. Prior land-use was dominated by farming, mining, and logging. My field research was done in June through August of 2001 and 2002.

Site Selection and Design

Using a map generated from a tested HSI model for black bears (Zimmerman, 1992; Mitchell, 1997; Powell et al., 1997), I selected 11 study sites of differing black bear habitat quality (*HSI*) in the Pisgah Bear Sanctuary. The *HSI* values from the map were calculated in 1994 and study sites were found to range from 0.23-0.71. To make salamander data comparable across sites and to focus on differences in *HSI*, I stratified study sites based on certain habitat parameters. All sites were of cove hardwood or upland hardwood community types, had stand ages between 70 and 85 years, and were located between 927 and 1292 m in elevation. In the field, I found the closest first or second order stream to the known *HSI* location. Sites also needed to be accessible and have a slight to moderate slope for use in repeated sampling. A strict sampling protocol was used and the same, well-trained individuals collected each year's data.

A quadrat design was selected to study a particular area thoroughly, to obtain a salamander species list, to estimate relative densities and diversity of salamander species, to estimate relative densities of specific species within certain microhabitats, and to compare data across the landscape. At each site, I established 30x40 m quadrats, each located at least 1 km from all others to ensure independent sampling (Figure 1). Each perimeter was established along a 30-meter stretch of stream and extended 40 meters up slope, with the entire width of the stream included (Figure 2).

Sites of this size and design were used to ensure enough animals for statistical analyses and to study species assemblages of salamanders within aquatic, semiaquatic, and terrestrial habitats. Each site was further subdivided into 5x5 m blocks and marked with flagging and PVC pipes. Blocks allowed me to sample sites systematically, and to record the location of each salamander observed. Habitat occupying each 5x30 m transect (series of blocks) appeared to be homogenous.

In August 2001, the stream at one site ran dry. I eliminated this site from the study because I felt the lack of water would affect species composition and detectability of salamanders. I added one new location prior to beginning the 2002 field season. An additional site was eliminated prior to data analysis because of its proximity to recent logging activity, which may have compromised data and ability to compare results with other sites (information on this site is available in Appendix E).

Because of species-specific biases in sampling methods (Hyde and Simons, 2001), I sampled salamanders using two methods: daytime searches under natural cover objects and nighttime surface searches after and during rainfall. Based on the findings of Smith and Petranka (2000; Petranka, personal communication), I intended to sample each site once during the day and once at night per field season. Sites were sampled once each year during the day, but weather limited sampling at night, resulting in two incomplete data sets.

Searches by Day

I conducted searches by day on random dates between June 6 and July 31, 2001 and 2002, noting starting and ending times. Beginning mid-morning (0900-0945 hours), 3-4 persons systematically turned rocks and woody debris within each 5x30 m transect until the entire site was sampled. We started at the uppermost transect (35-40 m upslope at the 0 m perimeter of the site) and sampled across it. We then moved to the next lower transect and sampled it, and so on (Figure 2). We always sampled the stream from downstream to upstream to prevent counting escaped salamanders more than once.

As we lifted the rocks and woody debris, we captured salamanders and placed them in Ziplock bags. We replaced each cover object immediately in its original location and leaves or other material were replaced to minimize moisture and temperature changes. We recorded the species of each salamander, its location in the site, weight, length, cover object type (rock or woody debris), cover object size (by category, see Appendix C), and any injuries or deformities. Each designated data collector followed a strict protocol to insure reliable and consistent recording of data at each site.

Searches by Night

We conducted searches by night only during or after adequate rain. This was defined as water penetrating the canopy and saturating the understory vegetation, leaf litter and soil. We began sampling at dusk (2100 hours) and continued until the entire site was sampled. Using headlamps, we walked or crawled within each 5x30 m transect collecting salamanders on surfaces of leaf litter, vegetation (tree trunks and understory), woody debris, rocks, or soil. Data on salamanders were recorded as described for sampling by day. We turned no cover objects and habitat disturbance was minimal. Due to large numbers of salamanders present on the surface at night, the data collector and typically an additional volunteer walked behind the observers and notified the observers of any undetected salamanders. Sites were originally sampled in random order but, due to patchy and limited rainfall, subsequent sampling occurred at sites where criteria for night sampling were met. Searches at night in 2002 were first conducted at sites where sampling did not occur during the previous field season.

Sampling of Habitat

Based on Zimmerman's (1992) HSI model equations, I calculated the *HSI* at my study sites with habitat data I collected in 2001. The number of logs ≥15 cm in diameter and percent understory vegetation cover were averaged across 10 5m^2 blocks (~20% of site), with 1-2 blocks being sampled within each 5x30 m transect (Figure 2). I noted the top three dominant overstory species within each of the sampled blocks and I used the most common species to characterize the site. Percent berry cover and number of grape vines were estimated by taking the average of two randomly selected 5m^2 blocks. Number of trees > 90cm in diameter at breast height (dbh) were estimated for the entire 1200 m^2 site. Slope of inclination was acquired using a clinometer. Distance to nearest anthropogenic food source was estimated from maps and ground surveys. All other variables for the HSI model were obtained from topographic maps or USDA Forest Service CISC.

Statistics

The *HSI* of sites was calculated based on Zimmerman's (1992) habitat suitability index model for black bears (Appendix D). I transformed abundances of salamanders by using the log (count + 1). I did not find major differences in analyses when using the transformed abundances versus the actual abundances and I decided to use the actual count data instead of the transformations. Paired t-tests were used to compare abundances of salamanders between sampling years at each site (McClave and Dietrich, 1996). Simple linear regression analyses were used to compare abundance by day with abundances by night for each species of salamanders found at sites (Neter et al., 1996). Densities of salamanders were calculated based on the salamander species and the area of available aquatic, semiaquatic, and terrestrial habitat found at each site (Table 23). The reciprocal of the Simpson diversity index was used as the diversity index and the equitability was determined using the Simpson diversity index. Simple linear regression analyses were used to test the correlation between the *HSI* with salamander species richness, density, and the Simpson diversity index. A multiple stepwise regression analysis was used to determine which variables from the black bear habitat suitability index model best fit for each salamander variable (Neter et al., 1996). All analyses used a 0.05 level of significance, unless otherwise noted.

Results

My calculations of the *HSI*s for sample sites ranged from 0.31 to 0.40. Searches by day of sites resulted in 517 salamanders comprising 8 species in 2001 (n = 9 sites) and 806 salamanders of 10 species in 2002 (n = 10 sites) (Appendix A). Sampling at night was hindered by drought conditions and both field seasons ended with incomplete data sets. I never sampled Site 4 at night. Searches at night of six sites yielded 642 salamanders of 8 species in 2001 and 975 salamanders of 7 species in 2002 (Appendix B). In total, 2940 salamanders of 11 species were counted (*Desmognathus monticola*, *D. ocoee*, *D. quadramaculatus*, *D. wrighti*, *Eurycea bislineata wilderae*, *Gyrinophilus porphyriticus*, *Notophthalmus viridescens*, *Plethodon glutinosus*, *P. jordani, P. serratus, and Pseudotriton ruber).*

All analyses testing the equality of abundances between the 2001 with the 2002 field season, including those comparing numbers of escaped salamanders, showed no significant difference (Table 1). Because of this year-to-year repeatability, I averaged the

2001 and 2002 daytime species abundances at sites. The two night data sets were combined based on the following: (1) searches by day showed high year-to-year repeatability, (2) salamanders are long lived and demonstrate strong site fidelity, (3) lack of natural or anthropogenic disturbance between the two sampling seasons, and (4) sampling efforts in both years were conducted under optimal sampling conditions and a strict sampling protocol. I did not add abundances of salamanders observed during the day or at night because the data correlated for only two species. The mean abundances observed by day and the compiled abundances for salamanders observed at night were used in further analyses.

In analyses, I used densities from searches by day and at night (Table 24 and 25), and I used densities in which I compiled the greatest density observed from either during the day or at night into one table. I found the species richness, density, diversity and equitability of salamanders to vary depending on the densities used (day, night, or compiled) (Table 26). Variability in salamander species and numbers also existed across the landscape (Figure 22).

HSI values only showed a correlation with the number of salamander species found at sites during the night ($P = 0.0278$, $R^2 = 0.52$) (Table 27). Salamander species vary in life histories and habitat use (Petranka, 1998). Therefore, not all salamanders should demonstrate the same relationship with *HSI* or to the individual habitat variables of the HSI model. I broke down salamander densities for the three microhabitats, two subfamilies and 11 individual species for analyses. I saw a negative relationship between the *HSI* and the density of *D. monticola* found at sites during the day. Relationships with *HSI* were also seen with nighttime species richness and aquatic species' densities, and with *P. ruber* for compiled searches.

Few individual HSI variables explained for salamander variability (Table 28). Nonetheless, 77% of all bear habitat variables contributed to salamander variability were within the food component of the HSI model. The most common variable included in salamander models was the black bear HSI variable Ff_{1a} (Forest Cover Type). The number of grapes per hectare predicted on average 69% of the variability of finding *D. ocoee*, *D. wrighti*, *P. jordani*, and overall semiaquatic species under cover objects during the day, and 46% of the variability in overall salamander density at night. Although anecdotal, I did find evidence of black bears at 5 sites: scats, turned rocks, unearthed yellow jacket nests, torn logs, and destroyed rain gauges.

Discussion

To incorporate protection of biodiversity into a multiple-use system, the USDA Forest Service must maintain viable plant and animal populations (Jackson, 1989; Welsh, 1990; USDA, 1994). Consequently, the Forest Service incorporated Management Indicator Species in management plans. But can we expect a few species to represent all communities and special habitats within a diverse forest? And will these species provide adequate information on how management affects communities, special habitats, and populations of other plants and animals?

In this chapter, I specifically question the use of black bear as a MIS in Pisgah National Forest, NC. For the black bear to be considered a good MIS, it must 1) be easy to monitor, 2) be associated with communities it is designated to indicate, 3) be sensitive to different management efforts and respond measurably to changes in habitat quality, and 4) represent other species' responses when habitat quality for black bears changes. My research focused on the fourth criteria of whether black bears can represent salamanders.

From the results, I cannot determine whether black bears indicate anything for salamanders. Ultimately, the range of *HSI* values between the sites was not as large as had been anticipated from the 1994 map. Multiple reasons may have contributed to this small range. In my attempts to minimize differences in salamander species, I affected the range of *HSI* values for my sites. All of my sites were on streams, had stand ages within 15 years of each other, had similar community types, and had slight to moderate slopes. In other words, values for these factors were similar for all sites, minimizing their differences.

Over the time span between Mitchell's calculations and mine, habitat quality may have changed. Tropical storms, ice storms, drought and flooding conditions, invasive species, forest management practices and natural forest succession could have altered the habitat quality of sites over seven years. Most importantly, I did not sample at those exact locations. I established my sites along the closest first or second order stream and where all site criteria (stand age, elevation, slope) were met. The differences in map location versus the field location of sites likely contributed the most to the differences in *HSI*.

Interpreting Use of Habitat on Different Scales

Zimmerman (1992) and Mitchell (1994) both questioned scale when using the HSI model for purposes other than predicting the habitat use of black bear populations. Mitchell's (1997) calculations resulted in maps that he considered to be fine-grained depictions of black bear habitat suitability in the Pisgah Bear Sanctuary. The measurement of *HSI* for black bears was averaged on a large scale but predicted on small scales, and I believed it could be used for comparison between the two animals. This perhaps was not possible and scale may play a significant role in the success or failure of using MIS existing on one scale to predict for an organism on another scale.

Habitat manipulations will affect populations in a different manner depending on the organisms. Bears are mobile and can adapt and move away from disturbed areas. Salamanders, on the other hand, have strong site fidelity, rely strictly on certain habitat characteristics (i.e. moisture) and rarely travel far from location of birth (Petranka, 1998; Baker and Hunter, 2002). Management efforts resulting in habitat disturbance may not change the bear population, but may devastate a salamander metapopulation. Rare salamanders, or those relying specifically on one habitat characteristic, may be in jeopardy when localized habitat disturbance occurs. *D. wrighti*, for example, is associated with mature forests (Petranka, 1998 and personal communication). All study sites had stands 70-85 years of age, but yet I only observed *D. wrighti* at one study site. Management efforts impacting that location of that site would likely not alter the *HSI* for bears, but would affect the habitat quality for *D. wrighti*.

Some habitat variables for the HSI, such as percent understory and number of logs, were measured at the site and they provide a local scale measure of these variables (i.e. at a level important to salamanders). I reduced the black bear model to explain better the importance of *HSI* variables to salamanders. I got differing results depending on whether I used day, night, or the compiled search densities. Zimmerman (1992) and Mitchell (1997) found the food component of the black bear HSI model to predict well for overall bear use of habitat. Interestingly, the majority of factors explaining for salamander variability were also within the black bear food component of the model.

Considerations

Studying individual bear responses to habitat change may provide finer scale information on habitat important to salamanders. This may not be feasible because individual bear's may select habitat differently than what is optimal (Mitchell, 1997). Black bears are landscape scale animals and it may be they can only indicate for salamanders on a large scale. In other words, the distribution of a particular salamander species or assemblage across the landscape may be related to areas where bears prefer to establish home ranges. Other black bear HSI models are available for the southern Appalachians and those could be used to confirm the relationships between black bear habitat quality and salamanders.

Conclusion

Based on the information found in this study, it is premature to determine whether black bears indicate anything for salamanders. The Forest Service's goal in designating black bears as MIS for Old Growth Forests, and other special habitats, is unclear. If it is the intention of the Forest Service to preserve, for example, large areas of Old Growth, it would be simpler to directly measure the amount of Old Growth available. If, on the other hand, the Forest Service wants to know how much old growth is needed to maintain a viable bear population, then monitoring black bears would be beneficial. Neither of these options, however, support the use of MIS. In the former, black bears are not needed to directly measure forest characteristics and in the latter, monitoring black bears would indicate for the black bears themselves and not other populations.

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TABLES AND FIGURES

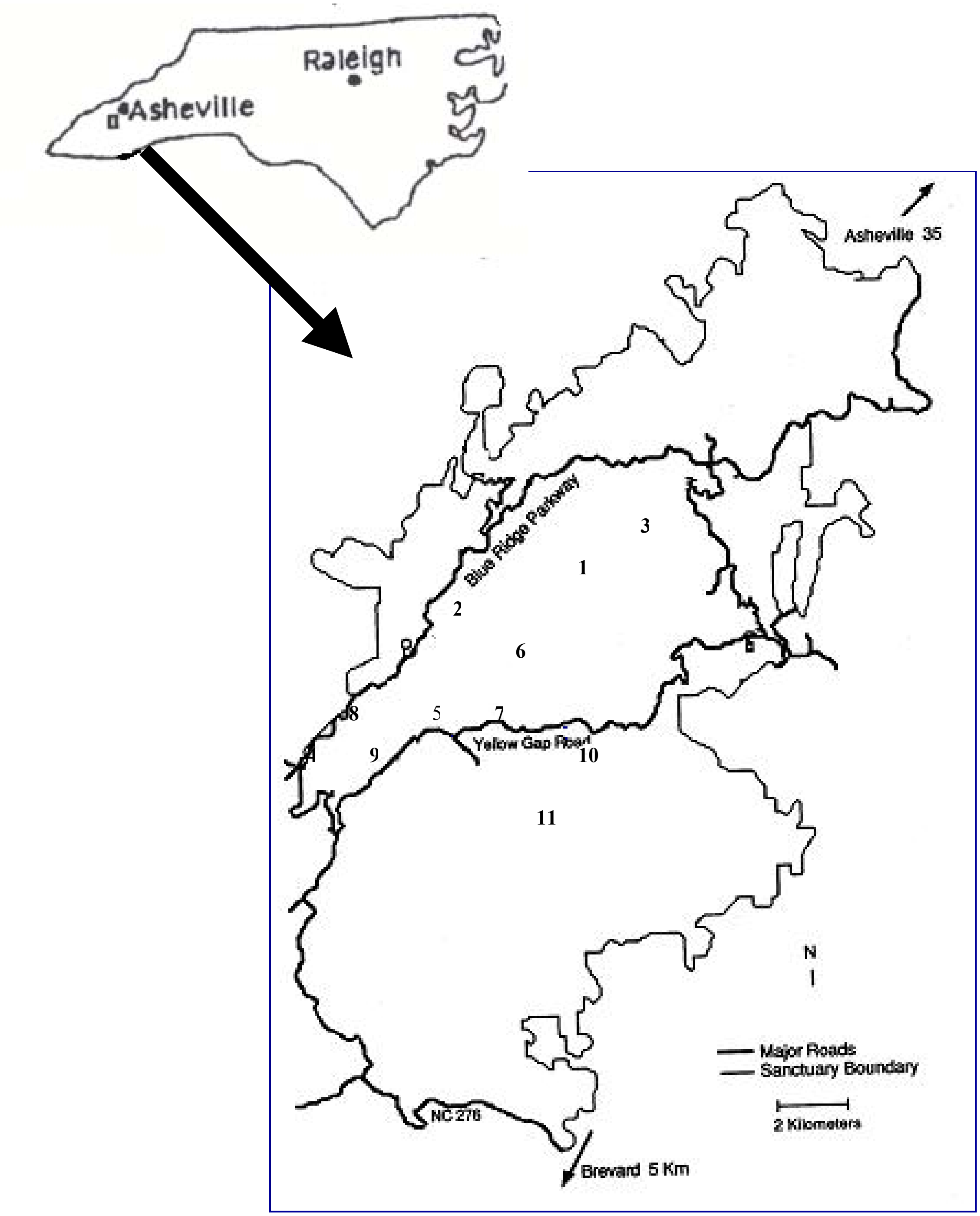


Figure 1. Map of study area and sampling sites in the Pisgah Bear Sanctuary, within Pisgah National Forest, western North Carolina

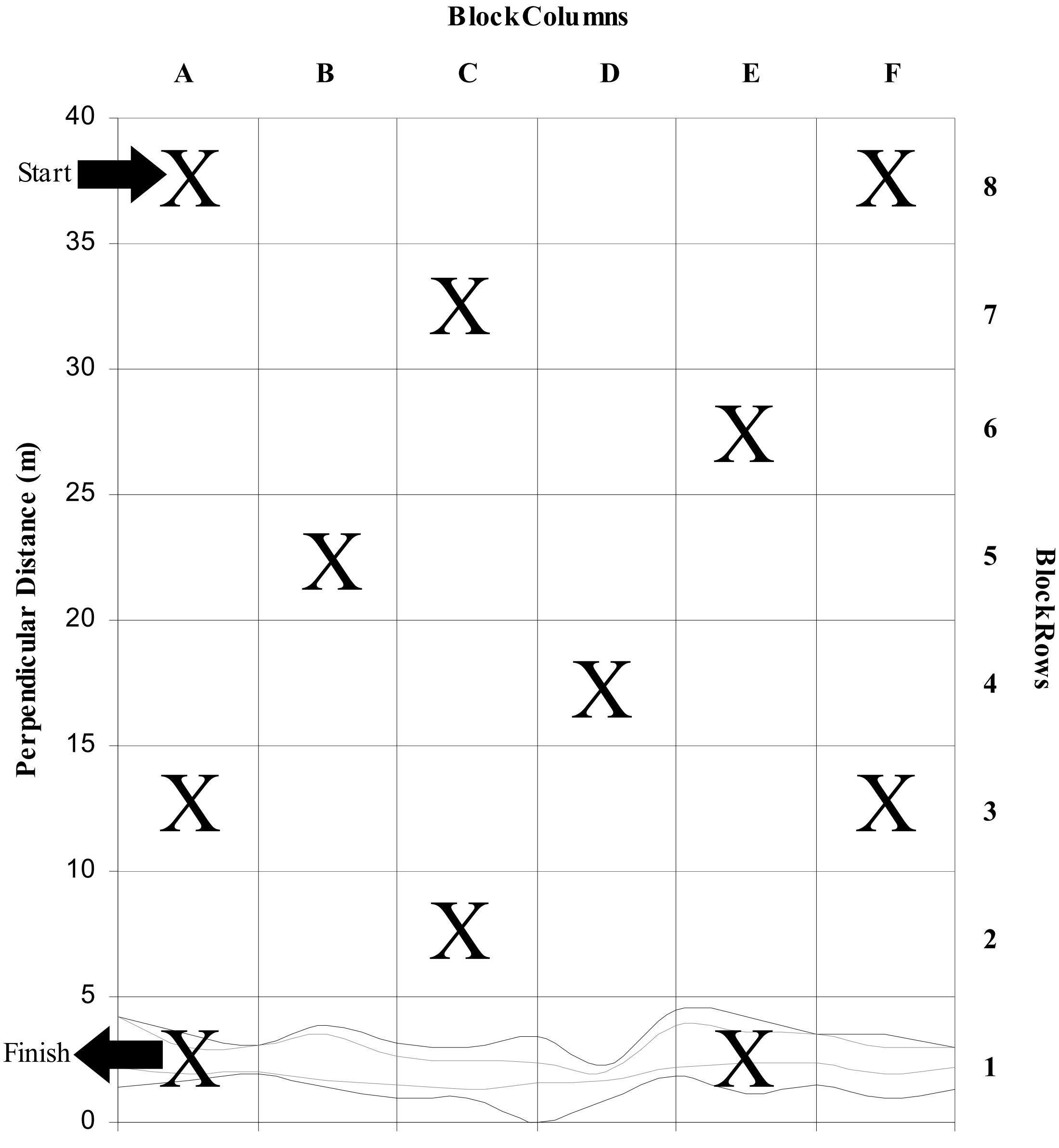
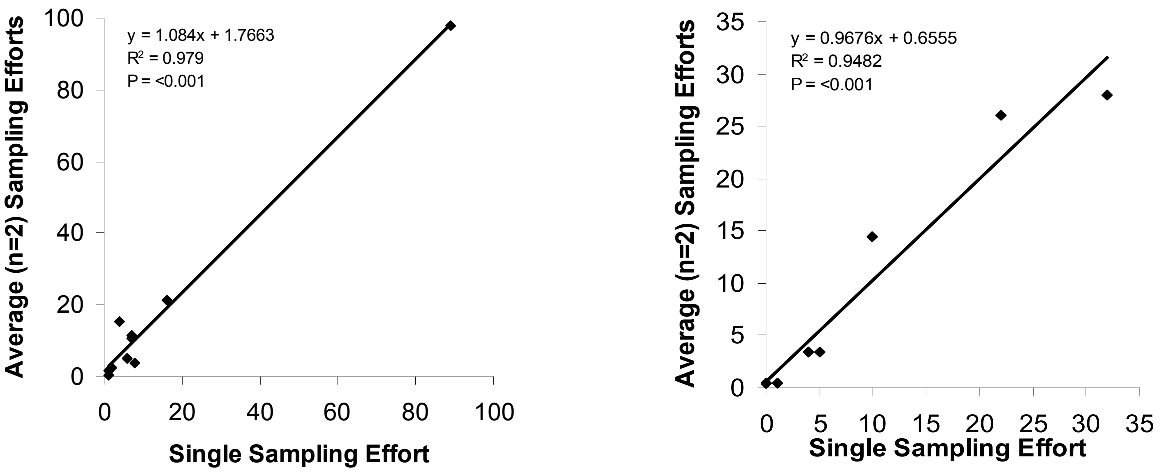
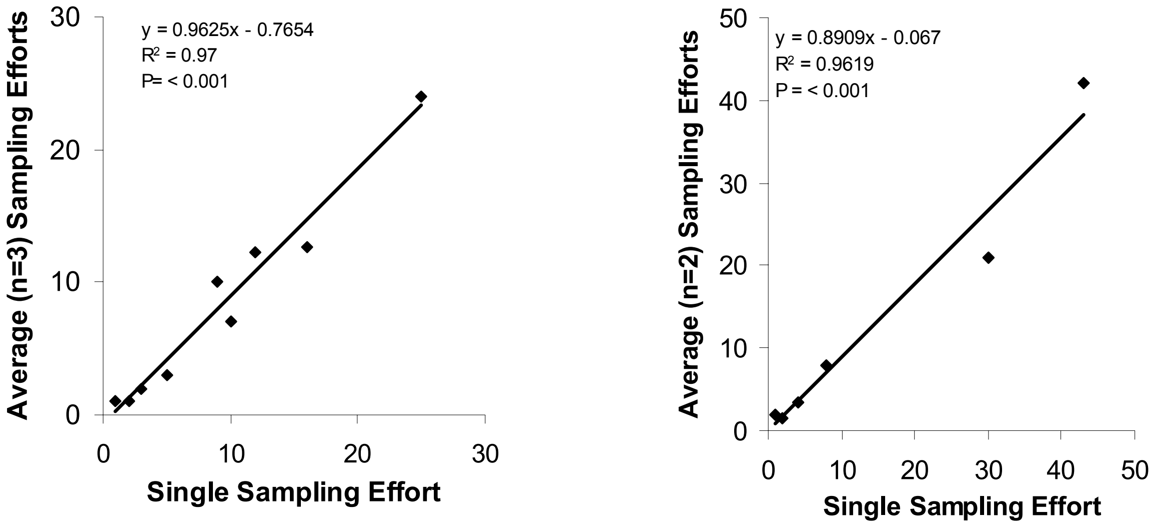


Figure 2. Site design and protocol for sampling. Sampling began at uppermost 5x30 m transect and finished at lowermost transect. The stream was always sampled from downstream to upstream. Horizontal and perpendicular distances were used to record locations of salamanders. Black lines indicate stream bank and gray lines depict water. Blocks with an "X" indicate, for example, where habitat sampling occurred. Blocks = {A1, A2,.,F8}.


Site 6

Site 7


Site 9

Site 11

Figure 3. Correlation between single sampling effort at site with average of two or more sampling efforts at the same site. This correlation was tested for four different sites., where multiple samples at sites were conducted at least two weeks apart.

Table 1. Equality between 2001 and 2002 abundances of salamanders by day by site (n = 9 sites). Site 6 was not included because it was only sampled in 2002. Paired t-test results are shown below for all salamander species found in 2001 and 2002 with an abundance >1 salamander. No significant difference for any species, or for the number of salamanders which escaped capture, differed between sampling years.

Desmognathus monticola	2001	2002
Mean	7.89	16.00
Variance	80.11	712.00
Observations	9	9
Pearson Correlation	0.76	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.17	
P(T≤t) one-tail	0.137	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.275	
t Critical two-tail	2.31	

D. ocoee	2001	2002
Mean	21.44	26.44
Variance	291.03	502.03
Observations	9	9
Pearson Correlation	0.96	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.00	
P(T≤t) one-tail	0.040	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.081	
t Critical two-tail	2.31	

D. quadramaculatus	2001	2002
Mean	16.00	16.22
Variance	177.50	124.94
Observations	9	9
Pearson Correlation	0.74	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.07	
P(T≤t) one-tail	0.471	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.943	
t Critical two-tail	2.31	

Euycea b. wilderae	2001	2002
Mean	2.33	4.11
Variance	7.25	16.61
Observations	9	9
Pearson Correlation	0.67	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.76	
P(T≤t) one-tail	0.058	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.117	
t Critical two-tail	2.31	

Table 1 continued.

Gyrinophilus porphyriticus	2001	2002
Mean	0.33	0.11
Variance	0.50	0.11
Observations	9	9
Pearson Correlation	-0.18	
Hypothesized Mean Difference	0	
df	8	
t Stat	0.80	
P(T≤t) one-tail	0.223	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.447	
t Critical two-tail	2.31	

Plethodon glutinosus	2001	2002
Mean	0.44	0.22
Variance	1.78	0.19
Observations	9	9
Pearson Correlation	-0.19	
Hypothesized Mean Difference	0	
df	8	
t Stat	0.45	
P(T≤t) one-tail	0.332	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.665	
t Critical two-tail	2.31	

P. jordani	2001	2002
Mean	2.67	5.67
Variance	17.00	64.75
Observations	9	9
Pearson Correlation	0.70	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.52	
P(T≤t) one-tail	0.084	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.168	
t Critical two-tail	2.31	

P. serratus	2001	2002
Mean	0.11	0.56
Variance	0.11	2.78
Observations	9	9
Pearson Correlation	-0.13	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.77	
P(T≤t) one-tail	0.233	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.466	
t Critical two-tail	2.31	

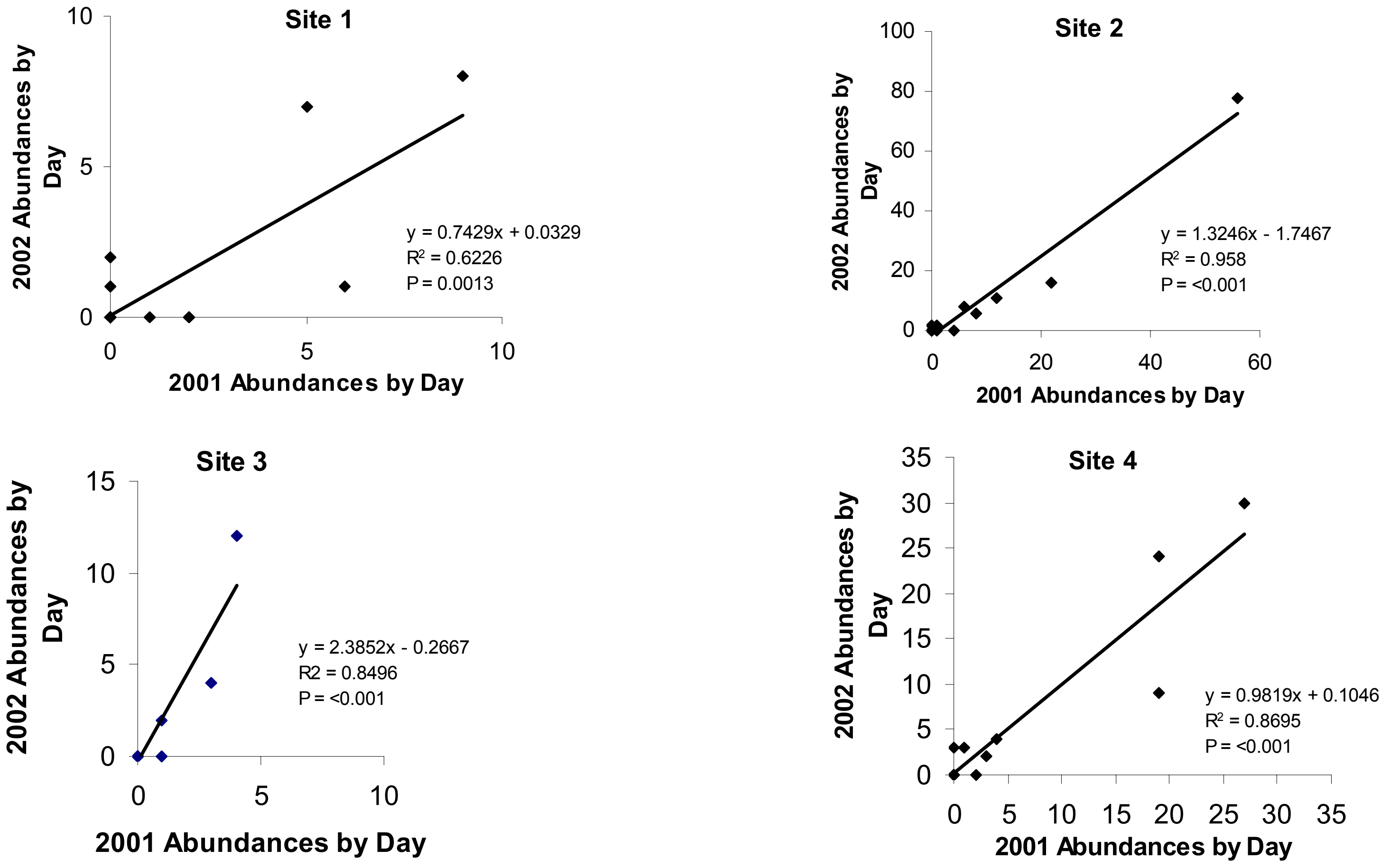


Figure 4. Correlation between 2001 with 2002 abundances of salamanders by day for each site. Site 6 was only sampled in 2002 and not included.

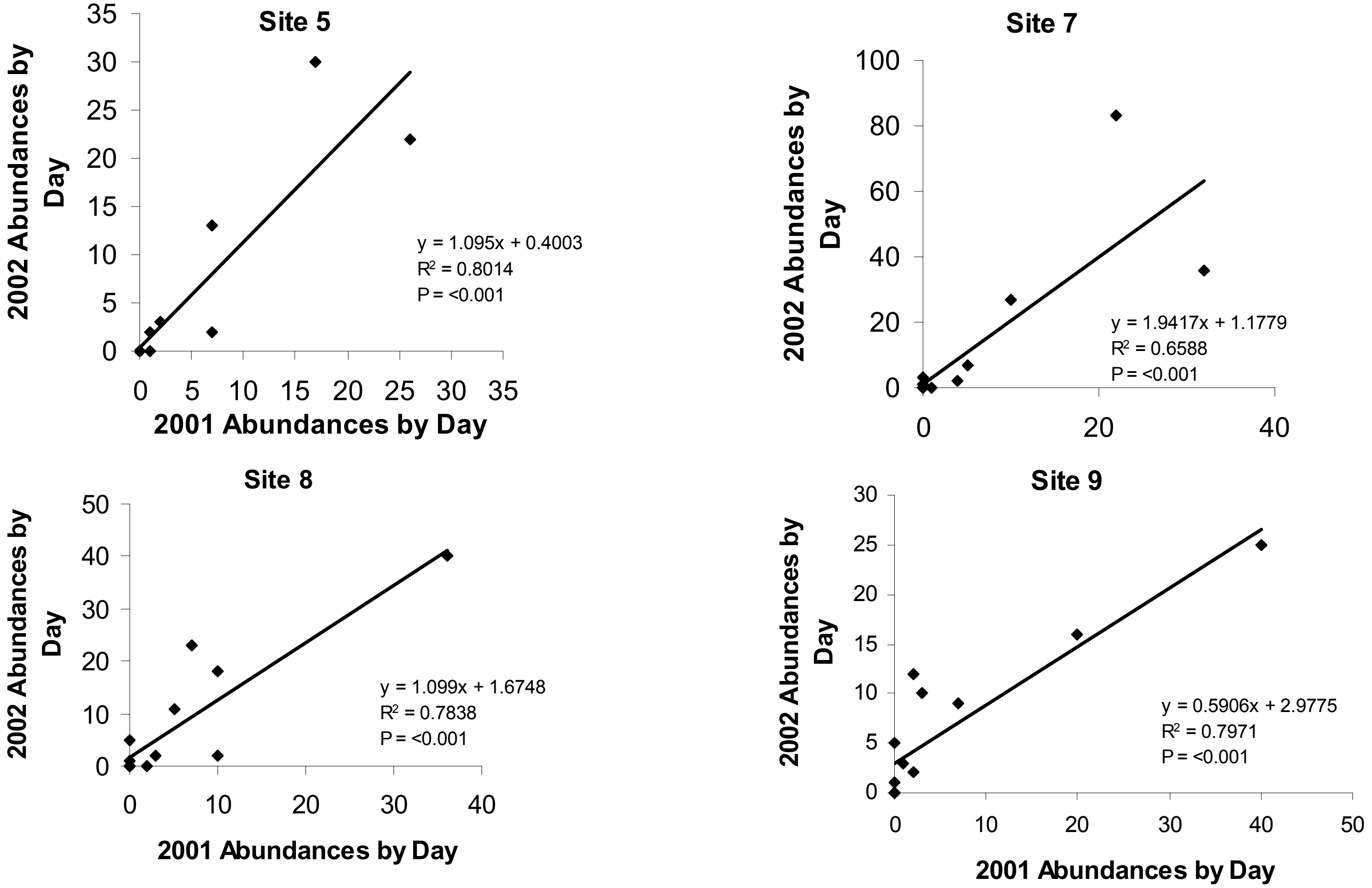


Figure 4 continued.

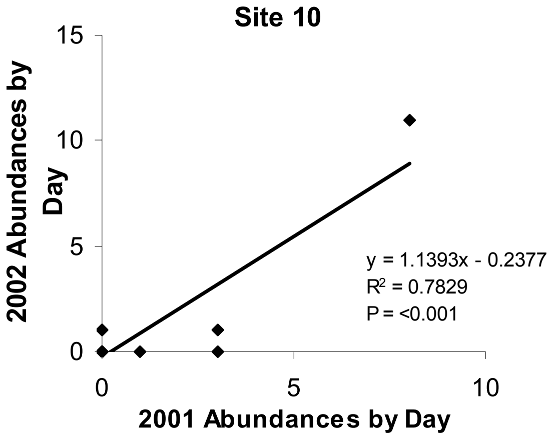


Figure 4 continued.

Table 2. Species richness, total salamander density, Simpson index, and species equitability for average searches by day and searches by night. Site 4 was not sampled at night.

	Average Daytime Searches				Night Searches			
Site	**Species Richness**	**Total Density**	**Simpson Index**	**Species Equitability**	**Species Richness**	**Total Density**	**Simpson Index**	**Species Equitability**
1	5	908.0	1.6	0.32	5	1187.2	2.7	0.53
2	7	2848.8	1.9	0.27	6	2259.1	2.4	0.41
3	3	250.0	2.7	0.91	4	686.1	2.1	0.52
4	5	1595.1	1.4	0.29	n/a	n/a	n/a	n/a
5	5	1537.2	1.3	0.25	7	978.6	3.6	0.52
6	8	2304.4	2.9	0.37	7	5007.5	3.6	0.51
7	6	1276.6	1.8	0.30	7	2050.5	2.3	0.33
8	7	2647.8	1.8	0.25	6	4565.6	2.9	0.48
9	7	2855.7	1.3	0.19	6	970.6	3.5	0.58
10	5	269.3	3.0	0.59	6	1711.3	3.8	0.63

Table 3. Abundances and densities of P. jordani observed during searches of sites by day and night during 2001 and 2002. a) Numbers of *P. jordani* observed during day searches (lifting of rocks and woody debris) and night searches (on surfaces after or during rain) during 2001 and 2002 field seasons, b) Densities of *P. jordani* based on amount of available terrestrial area in each site. Densities are presented as *P. jordani*/ha.

a)

Sample	Day Search		Night Search[b]		Grand
Site	2001	2002	2001	2002	Total
1	0	0	-	15	15
2	12	11	117	-	140
3	0	0	0	-	0
4	1	3	-	-	4
5	1	2	9	-	12
6[a]	-	16	-	205	221
7	0	0	0	-	0
8	7	23	-	247	277
9	2	12	45	-	59
10	1	0	79	-	80
Total	24	67	250	467	808

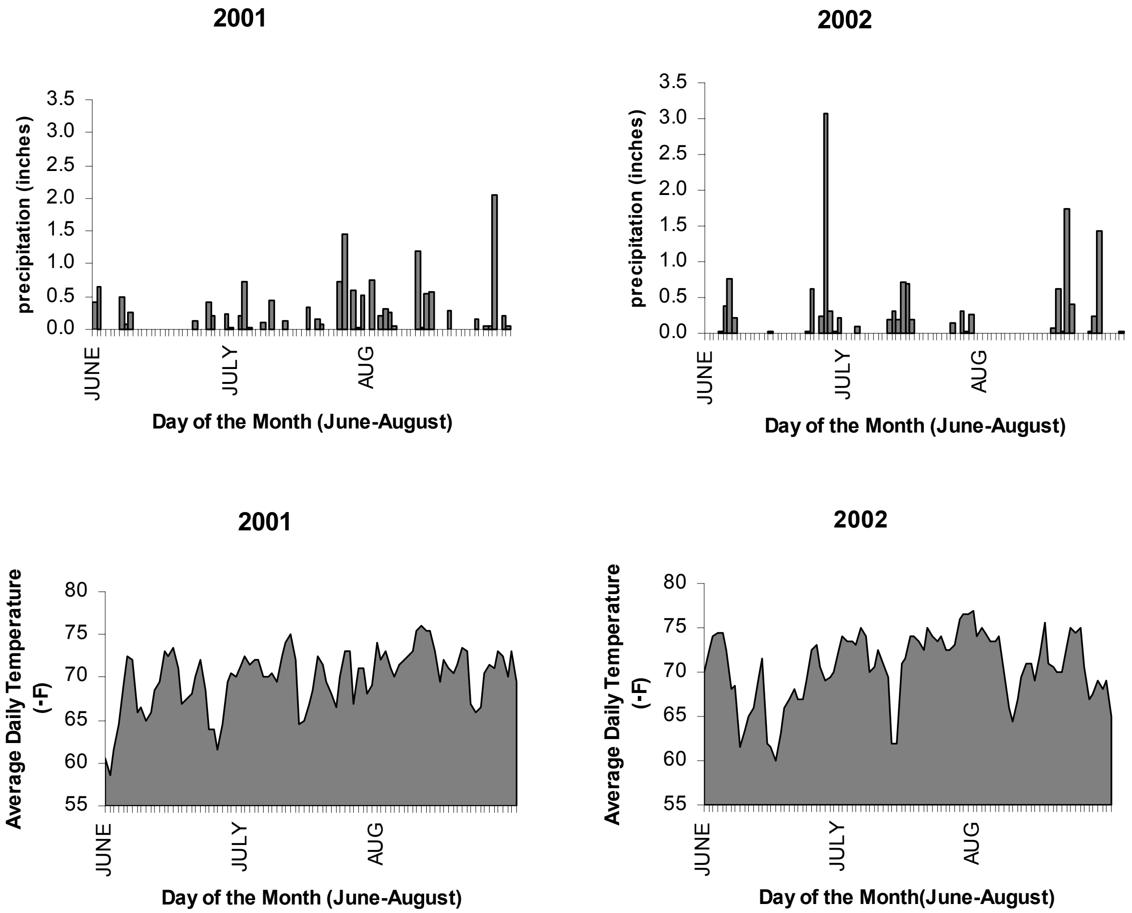
b)

Sample	Terrestrial	Day Search		Night Search[b]	
Site	Area (m^2)*	2001	2002	2001	2002
1	1110.6	0	0	-	135.1
2	1101.7	108.9	99.8	1062.0	-
3	1112.2	0	0	0	-
4	976.6	10.2	30.7	-	-
5	1018.4	9.8	19.6	88.4	-
6[a]	1045.4	-	153.1	-	1961.0
7	982.5	0	0	0	-
8	1126.8	62.1	204.1	-	2192.0
9	1067.3	18.7	112.4	421.6	-
10	1030.5	9.7	0	766.6	-

[a] Site 6 was added during 2002 field season and therefore has no 2001 data.

[b] Visual searches were incomplete for 2001 and 2002 field seasons due to lack of rainfall.

- There are no data points at these locations.



2001

2002

2001

2002

Figure 5. Daily precipitation and average temperature readings from the National Weather Service (Station: Pisgah Forest 1 N) during June-August of 2001 and 2002.

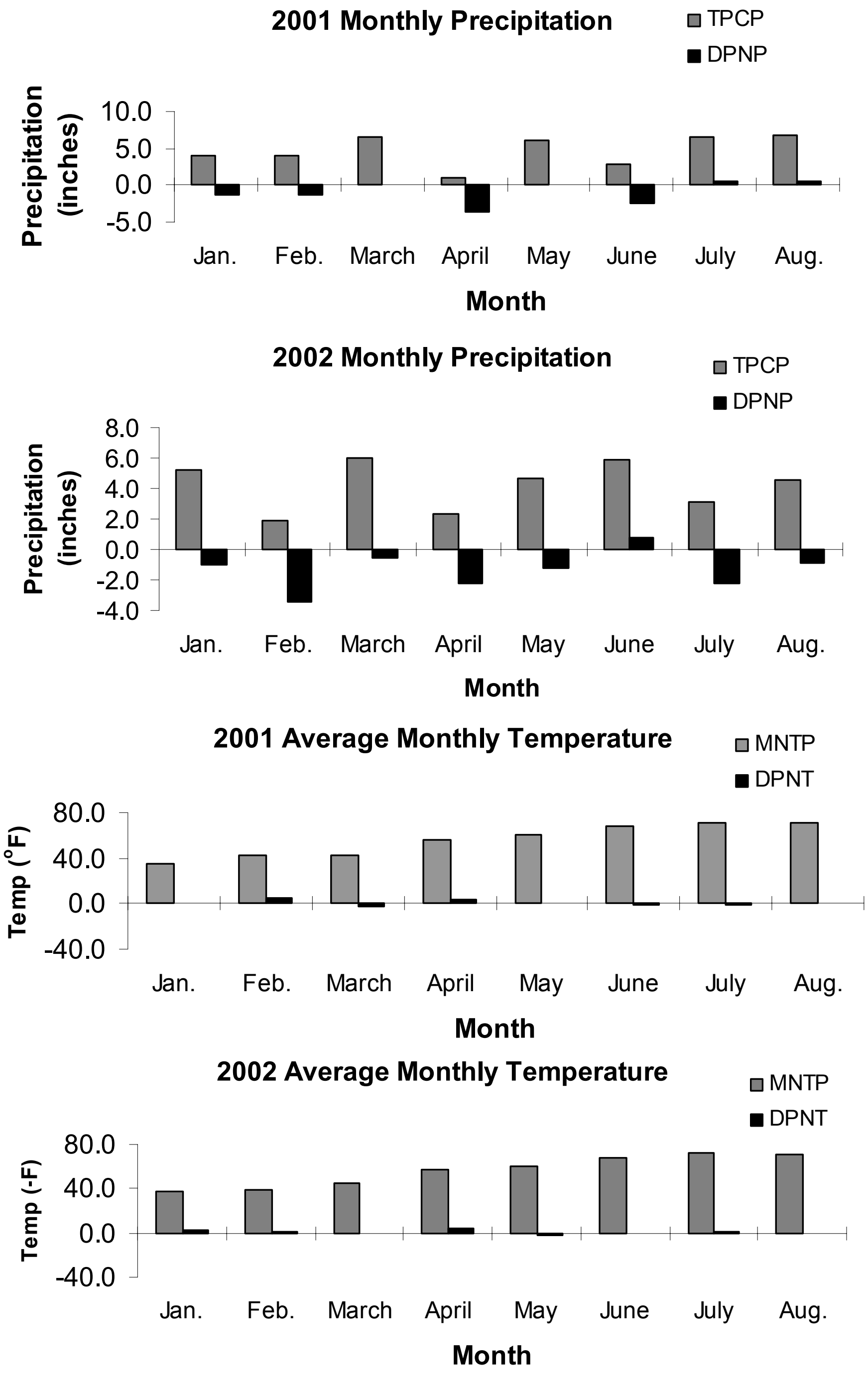


Figure 6. Monthly precipitation and temperature data for the study area in 2001 and 2002. Total monthly precipitation (TPCP), departure from normal monthly precipitation (DPNP), average monthly temperature (MNTP), and departure from normal monthly temperature (DPNT) from the National Weather Service (Station Pisgah Forest 1 N) for January-August of 2001 and 2002.

Table 4. Between year comparisons for Degree of Wetness and average temperature at sites during sampling by day Average temperature is based on air temperature readings (°F) at the start and completion of sampling. Average degree of wetness is based on a wetness scale (1=dry to 5=soaked) taken for each vegetation, leaf litter, and soil at the start and completion of sampling.

Average Daily Temperature

	2001	2002
Mean	69.06	67.50
Variance	5.03	20.88
Observations	9	9
Pearson Correlation	0.27	
Hypothesized Mean Difference	0	
df	8	
t Stat	1.04	
P(T≤t) one-tail	0.165	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.330	
t Critical two-tail	2.31	

Average Degree of Wetness

	2001	2002
Mean	2.81	1.60
Variance	1.31	0.59
Observations	9	9
Pearson Correlation	0.43	
Hypothesized Mean Difference	0	
df	8	
t Stat	3.37	
P(T≤t) one-tail	0.005	
t Critical one-tail	1.86	
P(T≤t) two-tail	0.010	
t Critical two-tail	2.31	

Table 5. Equality between 2001 and 2002 densities of P. *jordani* (*P. jordani*/ha) by site. A paired t-test was used

	2001	2002
Mean	24.38	51.84
Variance	1376.37	5173.33
Observations	9	9
Pearson Correlation	0.69	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.54	
P(T<u><</u>t) one-tail	0.081	
t Critical one-tail	1.86	
P(T<u><</u>t) two-tail	0.162	
t Critical two-tail	2.31	

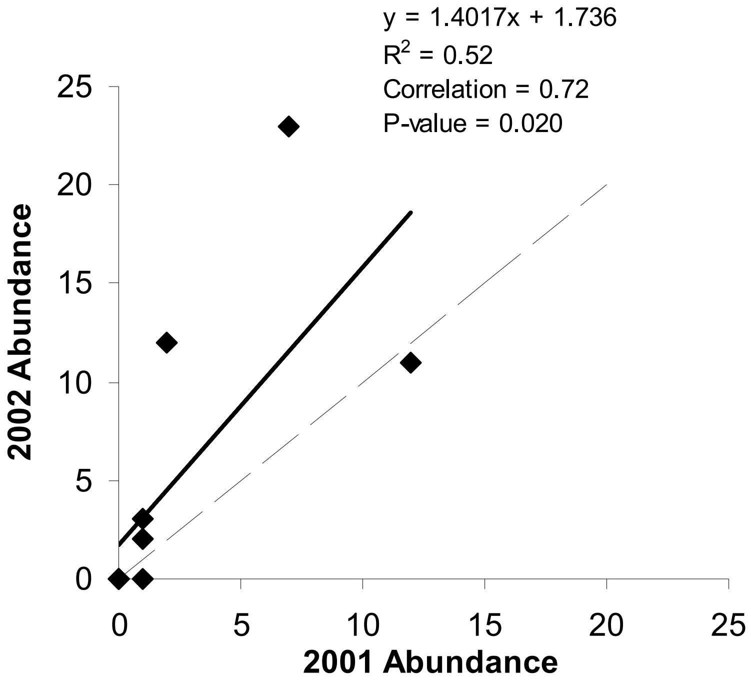


Figure 7. Correlation between abundances of *P. jordani* at sites during searches by day in 2001 with 2002. Solid line shows linear trend between 2001 day search and 2002 day search. Dashed line shows line of equality where points above the dashed line show that a greater *P. jordani* abundances were observed in 2002. Points below the dashed line indicate the 2001 season produced greater abundances of *P. jordani*.

Table 6. Equality of population composition of *P. jordani* (juveniles and adults) between 2001 and 2002. Testing equality of percent adult composition (P. jordani ≥ 45 mm SVL) at sites between 2001 and 2002 for both day and night searches. P-values presented for percent adult are the same values that would be presented for percent juveniles.

Day Searches

	2001	2002
Mean	36.71	40.40
Variance	1393.67	778.32
Observations	6	6
Hypothesized Mean Difference	0	
df	9	
t Stat	-0.19	
P(T≤t) one-tail	0.425	
t Critical one-tail	1.83	
P(T≤t) two-tail	0.850	
t Critical two-tail	2.26	

Night Searches

	2001	2002
Mean	48.65	58.44
Variance	13.31	64.60
Observations	4	3
Hypothesized Mean Difference	0	
df	3	
t Stat	-1.96	
P(T≤t) one-tail	0.072	
t Critical one-tail	2.35	
P(T≤t) two-tail	0.144	
t Critical two-tail	3.18	

Table 7. Equality of mean snout-vent-lengths (SVL) of *P. jordani* between 2001 and 2002.

Day Searches

	2001	2002
Mean	31.94	29.05
Variance	226.29	181.98
Observations	18	45
Hypothesized Mean Difference	0	
df	29	
t Stat	0.71	
P(T$\leq$t) one-tail	0.242	
t Critical one-tail	1.70	
P(T$\leq$t) two-tail	0.483	
t Critical two-tail	2.05	

Night Searches

	2001	2002
Mean	39.89	40.88
Variance	145.72	151.00
Observations	204	359
Hypothesized Mean Difference	0	
df	428	
t Stat	-0.93	
P(T$\leq$t) one-tail	0.176	
t Critical one-tail	1.65	
P(T$\leq$t) two-tail	0.352	
t Critical two-tail	1.97	

Table 8. Average densities for searches by day and combined densities for searches by night of *P. jordani*. Average day search densities and abundances are averages of 2001 and 2002 search results. Night searches only occurred once over 2001 and 2002 seasons due to lack of rain. Combined night search densities and abundances are night search results from the two years compiled into one column. Density is expressed as *P. jordani*/ha.

	Average Day Search		Combined Night Search	
Site	Density	Abundance	Density	Abundance
1	0	0	135.1	15
2	104.4	11.5	1062.0	117
3	0	0	0	0
4[a]	20.5	2	n/a	n/a
5	14.7	1.5	88.4	9
6[b]	205.7	21.5	1961.0	205
7	0	0	0	0
8	133.1	15	2192.0	247
9	65.6	7	421.6	45
10	4.9	0.5	766.6	79

[a] Site 4 was not sampled at night due to lack of rain in both 2001 and 2002 seasons

[b] Site 6 was added in 2002. Average is taken from two samples taken that year.

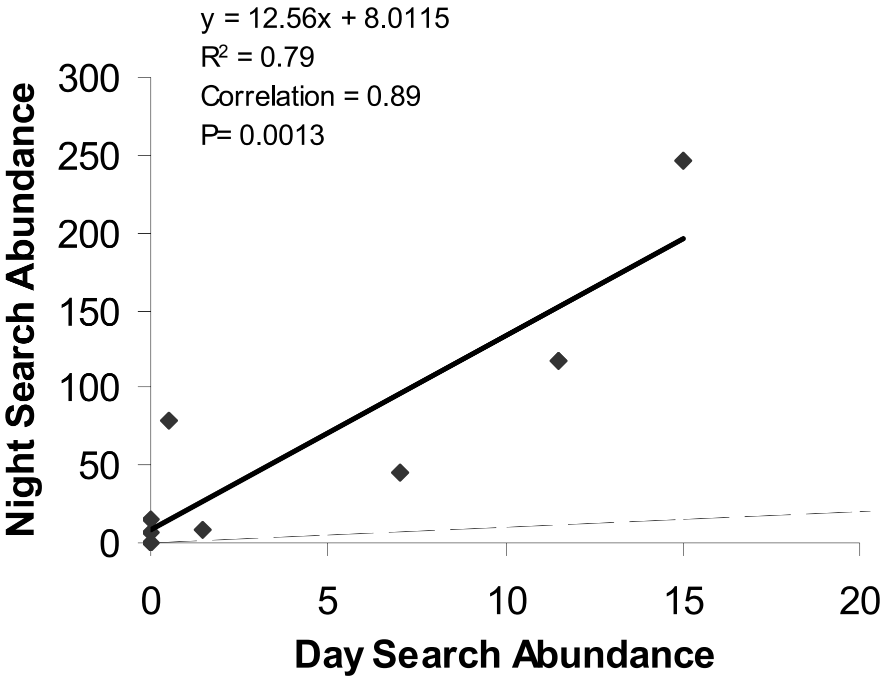


Figure 8. Correlation between abundances of *P. jordani* observed at sites during searches by day in 2001 with those observed in 2002. Solid line is linear relationship between day and night search abundances. The dashed line indicates a line of equality, where values above the dashed line depict greater abundances of *P. jordani* during night searches compared to day searches.

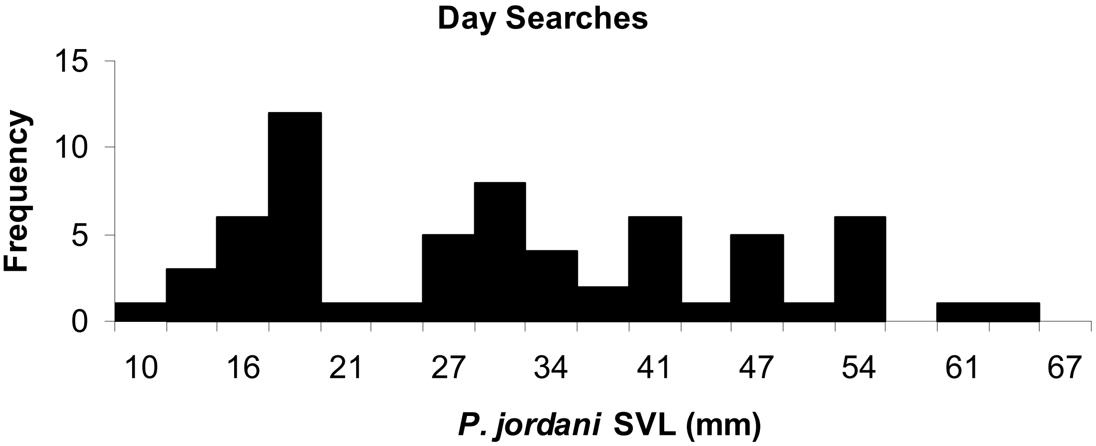
Table 9. Equality of searches by day with searches by night for population composition and mean snout-vent length (SVL) of *P. jordani*. a) testing equality of mean percent adult composition at sites between day and night sampling techniques. *P. jordani* ≥ 45 mm SVL are considered adults. Same P-values would be present if looking at percent juvenile composition, b) testing equality of mean snout-vent-length (SVL) of *P. jordani* at sites between day and night searches.

a)

	Day Search	Night Search
Mean	33.73	52.85
Variance	812.84	55.58
Observations	7	7
Hypothesized Mean Difference	0	
df	7	
t Stat	-1.72	
P(T≤t) one-tail	0.065	
t Critical one-tail	1.89	
P(T≤t) two-tail	0.130	
t Critical two-tail	2.36	

b)

	Day Search	Night Search
Mean	40.52	29.88
Variance	149.05	192.93
Observations	563	63
Hypothesized Mean Difference	0	
df	73	
t Stat	5.84	
P(T≤t) one-tail	<0.001	
t Critical one-tail	1.67	
P(T≤t) two-tail	<0.001	
t Critical two-tail	1.99	



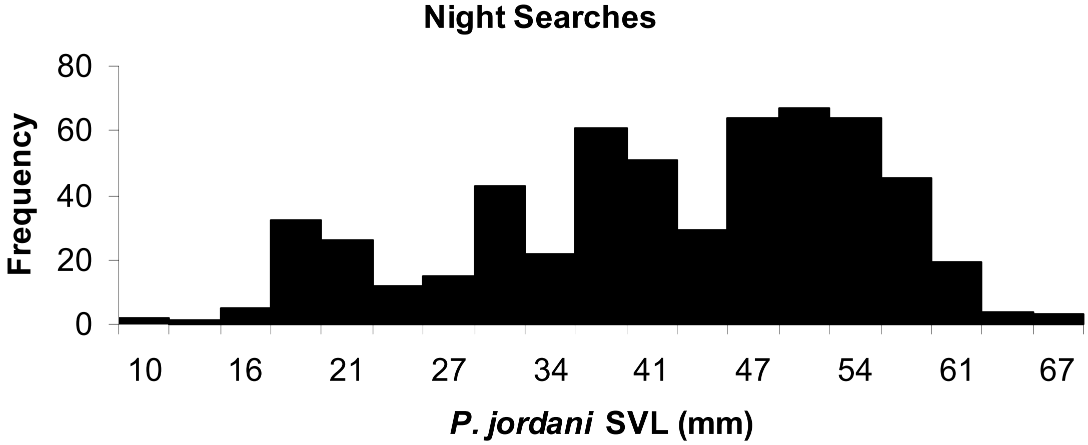


Figure 9. Size-frequency histograms for *P. jordani* during searches by day and searches by night. Day searches yielded smaller *P. jordani*, with few reaching reproductive size (SVL ≥ 45 mm). The opposite trend was seen during night searches.

Table 10. Relative efficiency of searches by day and search by night sampling methods for *P. jordani* (Pj). Adults are ≥ 45 mm in SVL.

Sampling Method	Sites Sampled	Total # of Samples	Number of P. jordani	Mean Pj per Sample	Mean SVL (mm)	Percent Juveniles	Percent Adults	Average Sample Time	Average Time to find one Pj
Day Search	10	20	91	4.6	30.1	66.3	33.7	4 hr 42 min	61.3 min
Night Search	9	9	717	79.7	40.3	47.2	52.8	6 hr 9 min	4.6 min

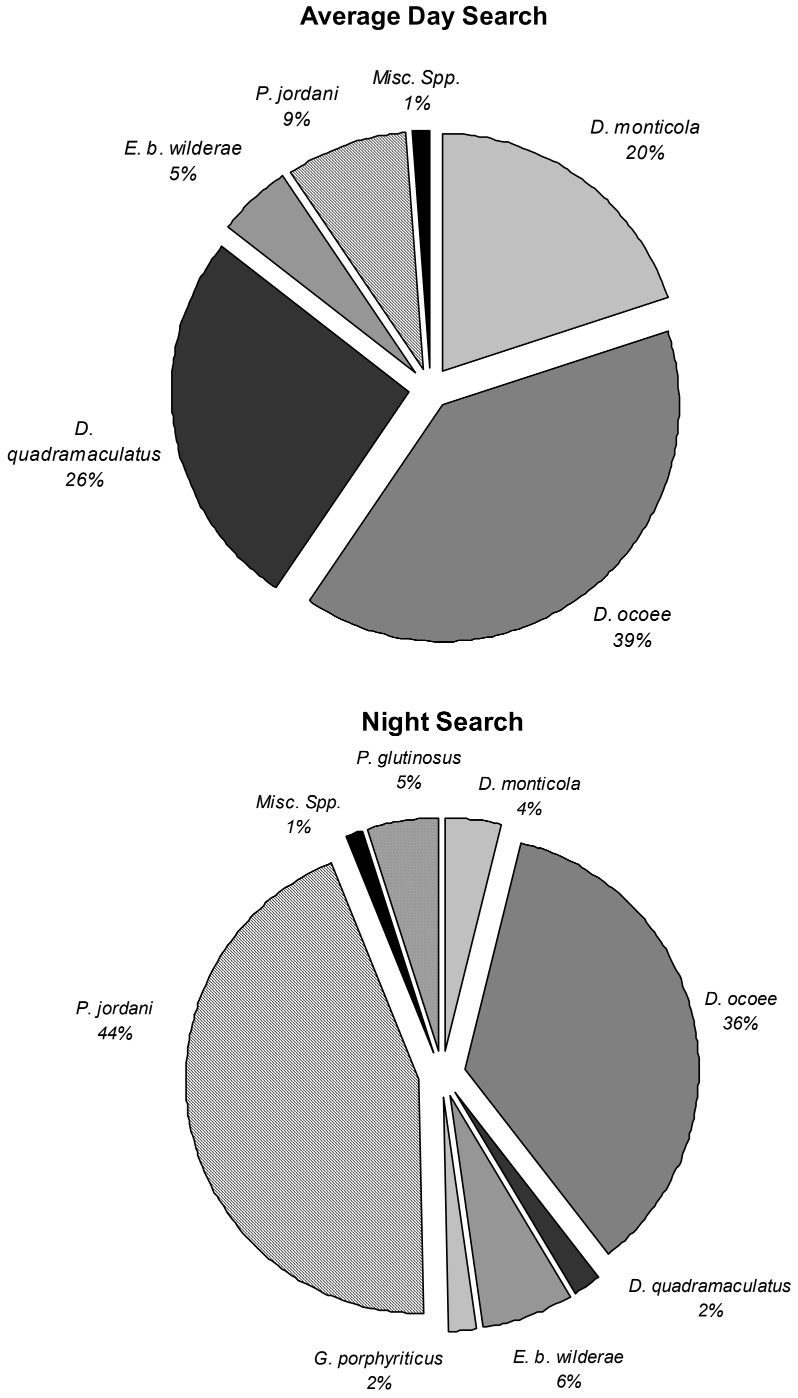


Figure 10. Percent species composition of salamanders observed at sites during searches by day and night. Sampling techniques show species-specific biases. *P. jordani* comprised only 9% of day search composition, but 44% of night search composition.

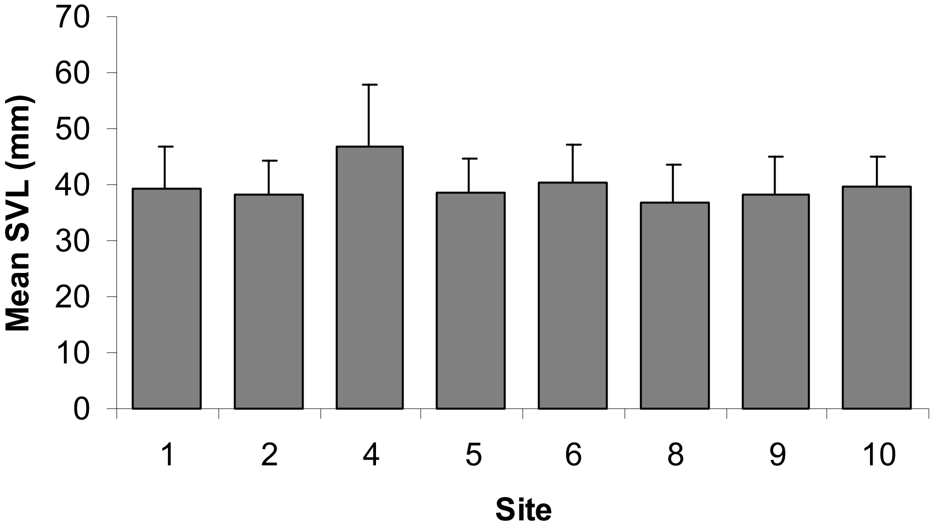


Figure 11. Mean snout-vent-length (SVL) of *P. jordani* found at each site. Mean SVL is compiled from day and night searches. There was no significant difference of mean SVL across the landscape. Note: Site 4 was only sampled during the day. *P. jordani* was not found at Site 3 or Site 7.

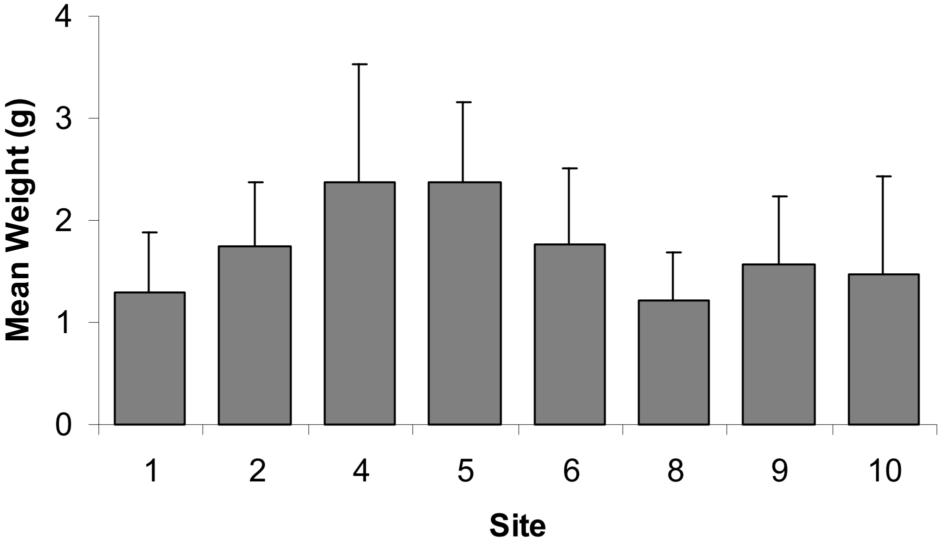


Figure 12. Mean weight (g) of *P. jordani* found at each site. Values are compiled between day and night searches. There is a significant difference between mean weights across the landscape (ANOVA). Site 4 was only sampled during the day. *P. jordani* was not found at Site 3 or Site 7.

Table 11. Association between densities of *P. jordani* with macroscale (landscape) habitat characteristics. Linear relationships of *P. jordani* density and land-form index (LFI), terrain-shape index (TSI), distance to road, elevation, and age of stand were also tested. No relationship between *P. jordani* and any macroscale habitat characteristics was seen for either day or night searches.

Landscape Parameter	**Group 1**	**Group 2**
Community Type	Dominance by Beech family	Dominance by other spp.
CISC Community Type*	Cove Hardwood (50 & 56)	Upland Hardwood (53 & 59)
Aspect	North and East Aspects	South Aspect
Rhododendron and Laurel Presence	< 5 % cover	> 5 % cover
Hemlock Presence	Hemlock Present	Hemlock Absent
Elevation	< 1066 meters	> 1066 meters
Distance from Road	< 200 meters	≥ 200 meters
Site Index	< 100	≥ 100
Slope	< 20 degrees	≥ 20 degrees

* CISC Community type and Site Index designations were provided by the USDA Forest Service.

Table 12. Habitat variables at sites which correlate with variability in densities of *P. jordani*. Thirty variables were included in test, with 100% variability in night *P. jordani* abundance at sites is explained by 7 variables. Table shows variables included in the model at 0.15 level of significance, n=9. Percent hemlock cover and number of woody debris pieces over 5 cm in diameter had negative relationships with *P. jordani* abundance.

Variable Included in Model	Partial R-Square	Model R-Square	F Value	Pr > F
Woody Debris (Size D)	0.3097	0.3097	3.14	0.1197
Average Soil Moisture	0.3054	0.6151	4.76	0.0719
Woody Debris (Size C)	0.2660	0.8811	11.19	0.0204
Percent Hemlock Cover (-)	0.1012	0.9822	22.79	0.0088
Average Leaf Litter Depth	0.0105	0.9927	4.30	0.1299
Woody Debris > 5 cm dia. (-)	0.0070	0.9997	54.15	0.0180
Woody Debris (Size E)	0.0003	1.0000	26.82	0.1214

Site Variables not included in model:
Percent Understory Cover, Percent Canopy Cover, Percent Tree Base Cover, Stand Age, Site Index, Slope, Percent Leaf Litter Cover, Average Leaf Litter Moisture, Percent Rock Cover, Percent Woody Debris Cover, Percent Rhododendron, Percent Laurel, Percent Ericacea Cover, Elevation, Total Woody Debris Pieces, Woody Debris < 5 cm in diameter, Woody Debris (Size A), Woody Debris (Size B), Woody Debris (Size F), Woody Debris Volume, Stumps, Rocks (Size C), Rocks (Size D), and Rocks (Size E).

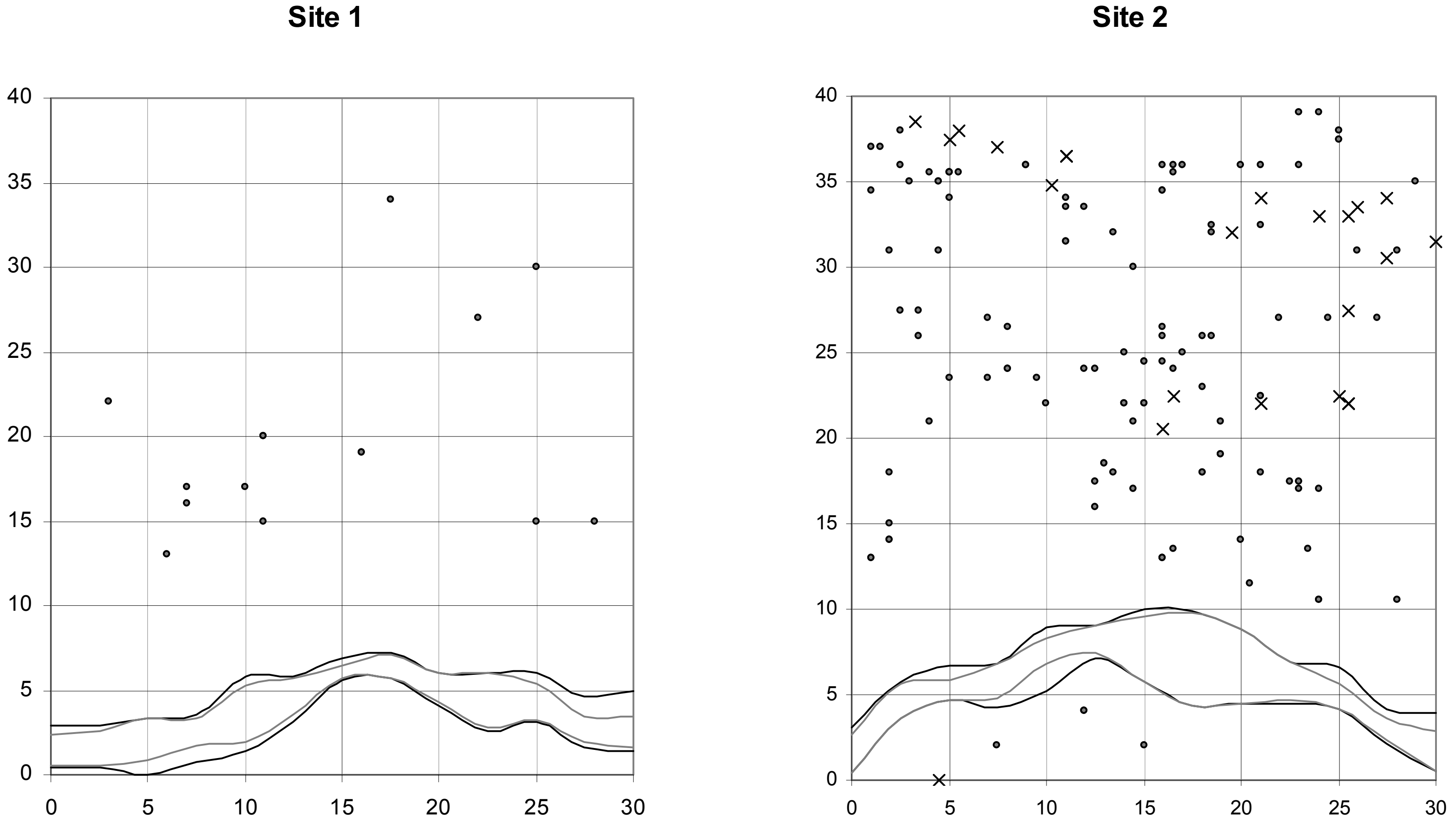
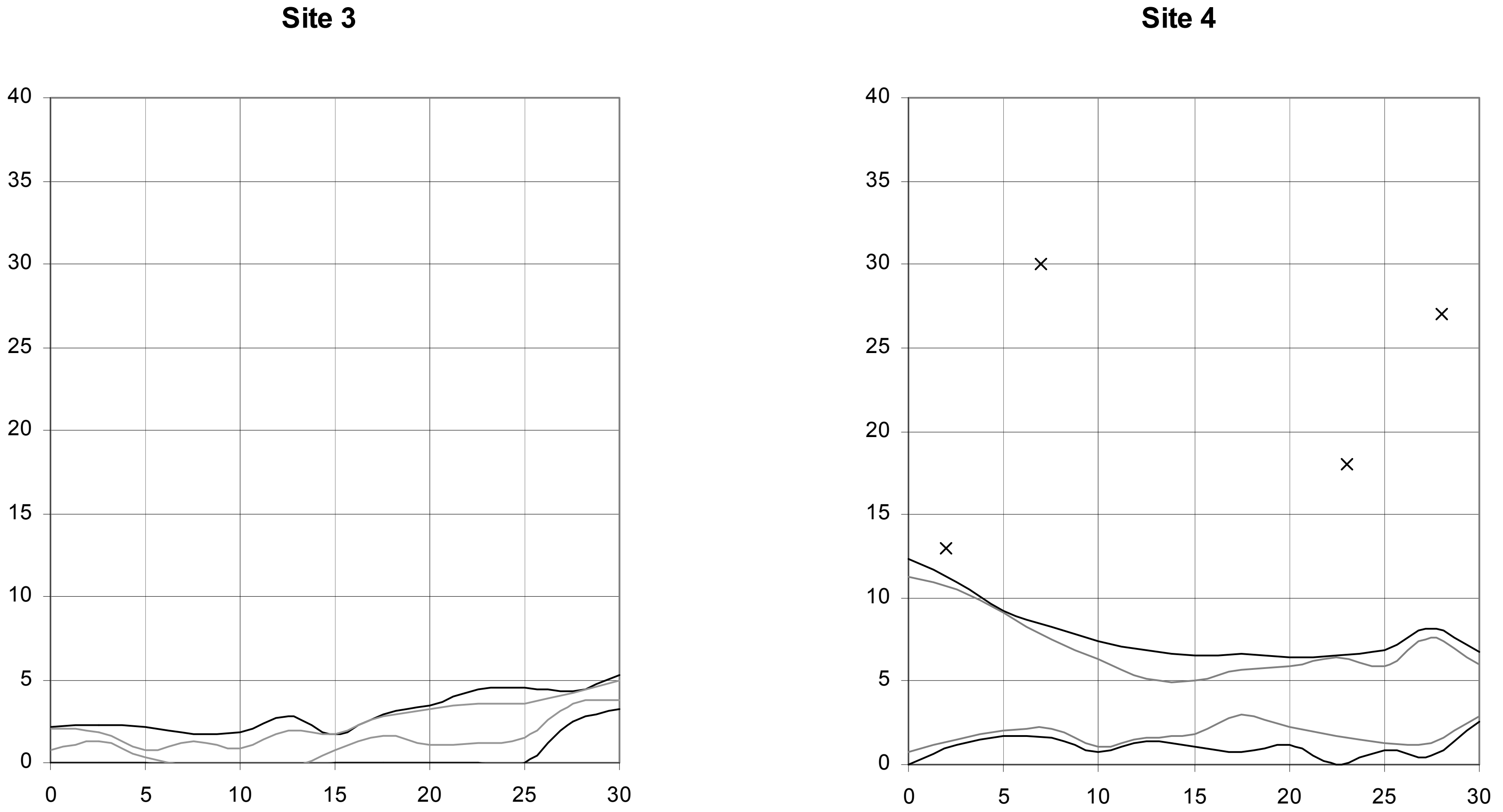
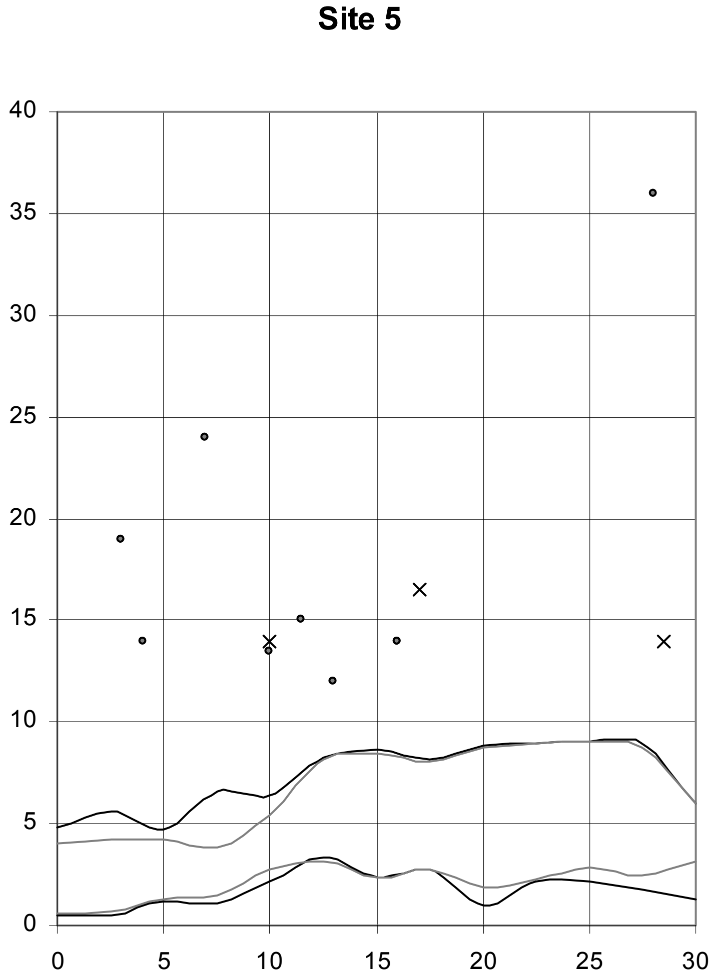


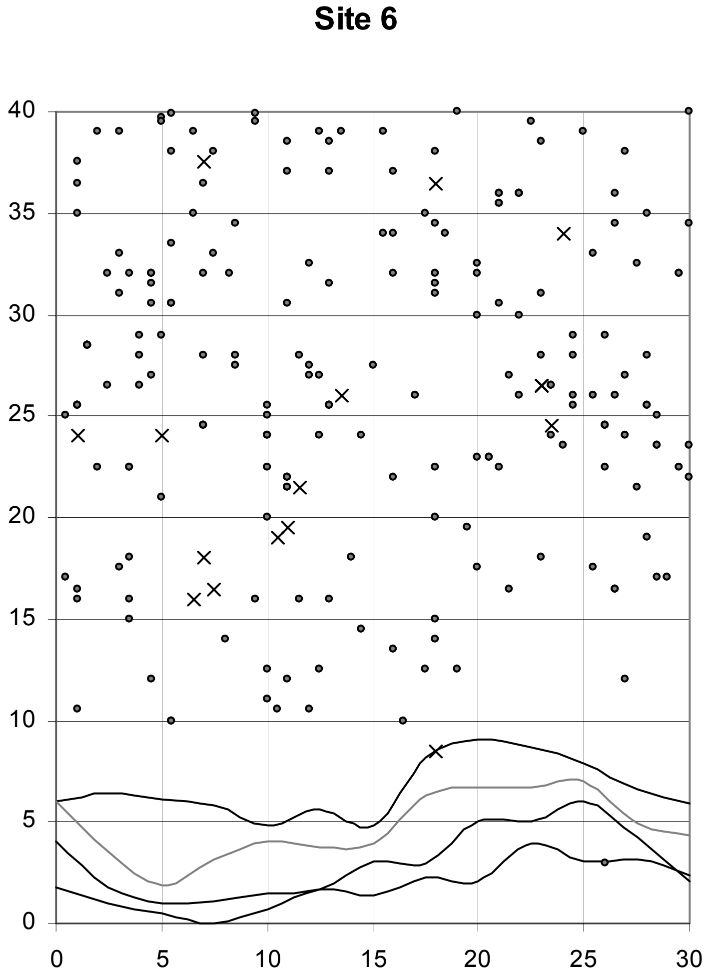
Figure 13. Distribution of *P. jordani* within each site. Solid line depicts stream bank. Dotted line depicts water. Xs indicate *P. jordan*i observed during the day with both 2001 and 2002 observations on site. Open circles represent *P. jordani* at night. Numbers along site perimeter are in meters.


Site 3

Site 4

Figure 13 continued. No *P. jordani* were observed at Site 3 during any sampling effort over 2001 and 2002. Site 4 was not sampled at night due to lack of rain.





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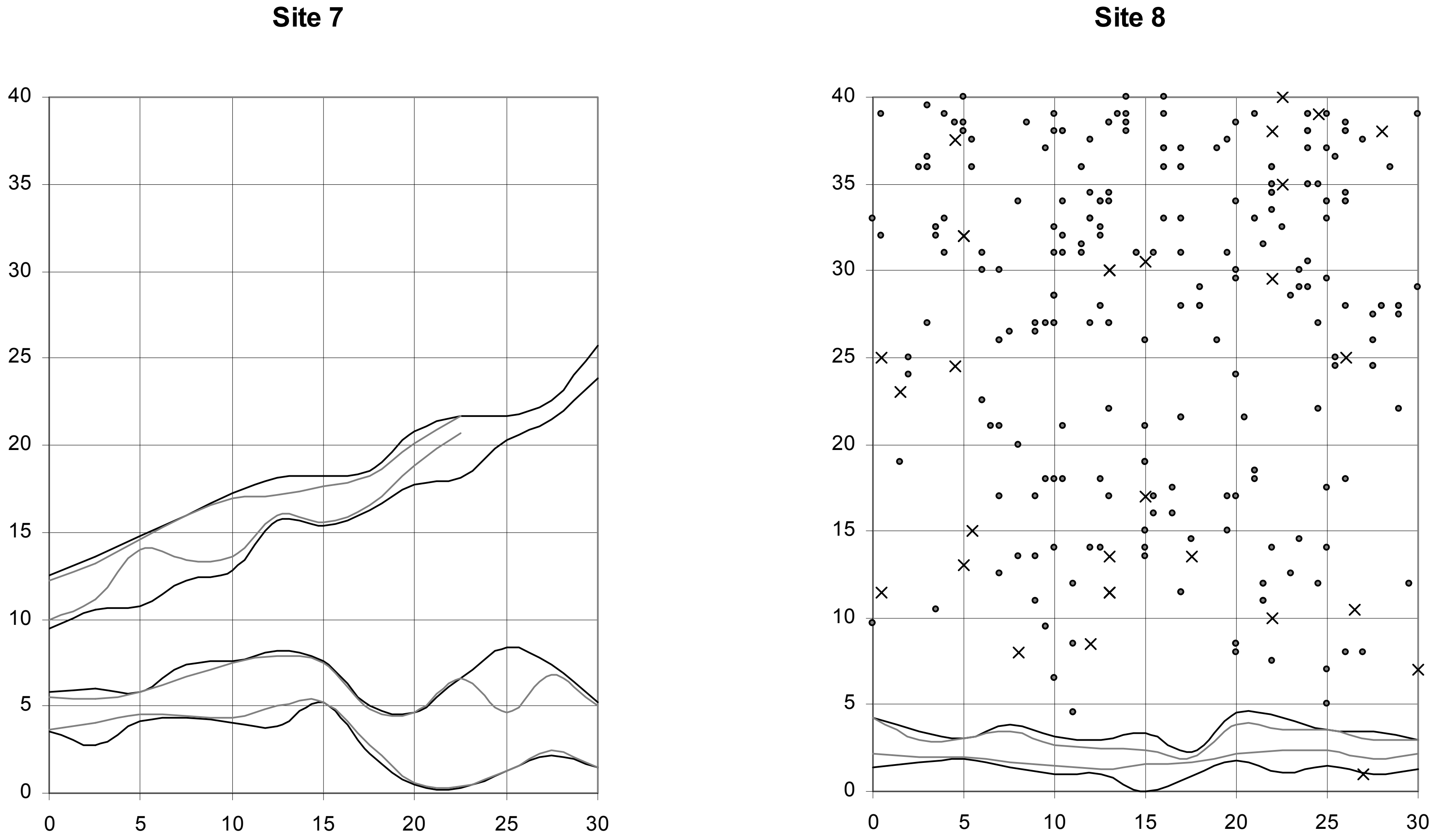
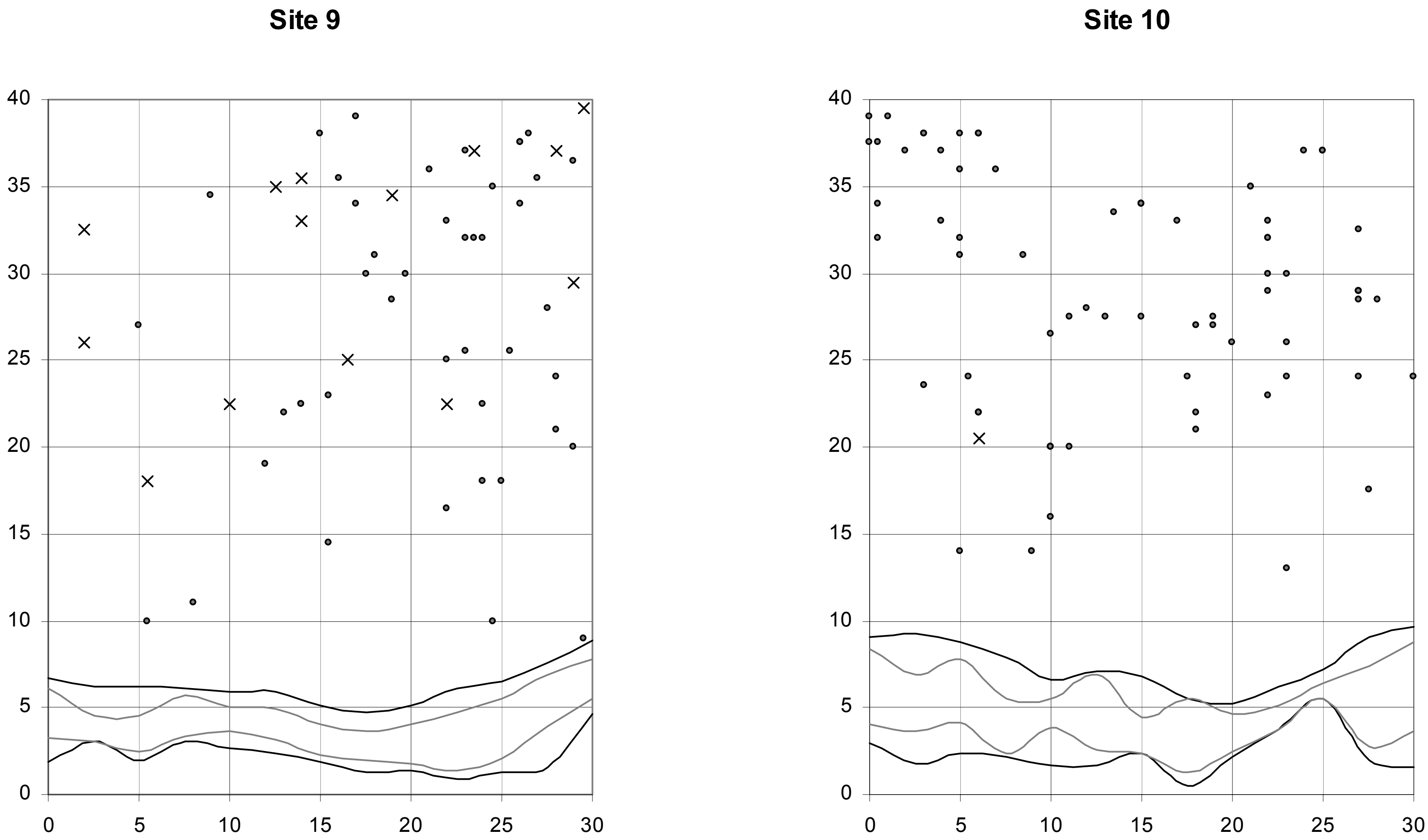


Figure 13 continued. *P. jordani* were not observed at Site 7 during any sampling effort in 2001 and 2002.



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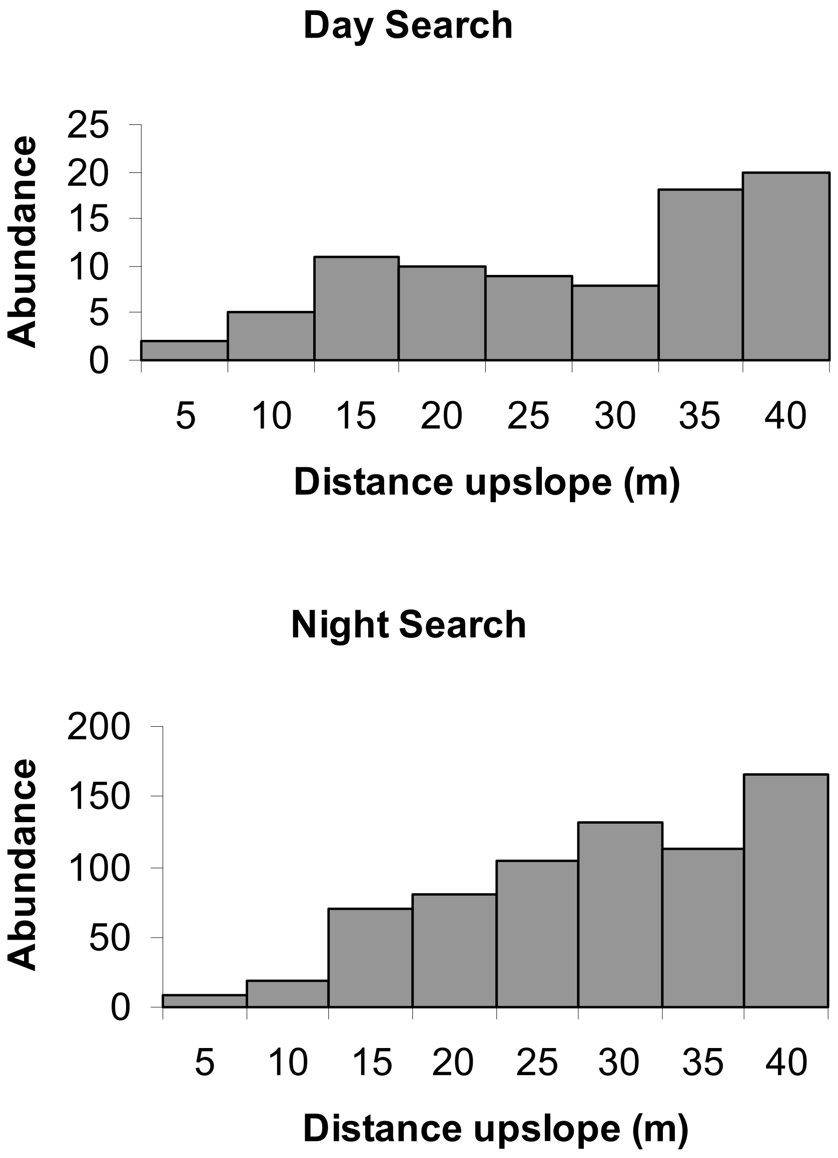


Figure 14. Distribution of abundances of *P. jordani* within each 5x30 m transect from the farthest stream edge (0 m) up slope for 40 m. Both searches by day and night showed a significant positive relationships between abundance of *P. jordani* with the distance away from stream/riparian areas.

Table 13. Habitat variables at the block level which correlate with the variability in abundance of *P. jordani* within blocks. Twenty-seven variables were included in test, with 33% of the abundance of *P. jordani* explained by 3 variables at 0.05 level of significance, n=48. Laurel presence had a negative relationship with abundance of *P. jordani*.

Variable Included in Model	Partial R-Square	Model R-Square	F Value	Pr > F
Laurel Presence	0.1470	0.1470	7.93	0.0071
Woody Debris (Size C)	0.0927	0.2398	5.49	0.0236
Volume of Woody Debris	0.0926	0.3323	6.10	0.0175

Block Variables not included in model:
Site, Percent Leaf Litter Cover, Average Leaf Litter Depth, Percent Understory Cover, Percent Canopy Cover, Percent Rock Cover, Percent Tree Base Cover, Percent Woody Debris Cover, Rhododendron Presence, Laurel Presence, Hemlock Presence, Concavity, Woody Debris <5 cm in diameter, Woody Debris (Size A), Woody Debris (Size B), Woody Debris (Size D), Woody Debris (Size E), Woody Debris (Size F), Stumps, Woody Debris Volume, Rocks (Size C), Rocks (Size D), and Rocks (Size E).

Table 14. Abundance of *P. jordani* found under rocks and woody debris during searches by day at each site in 2001 and 2002.

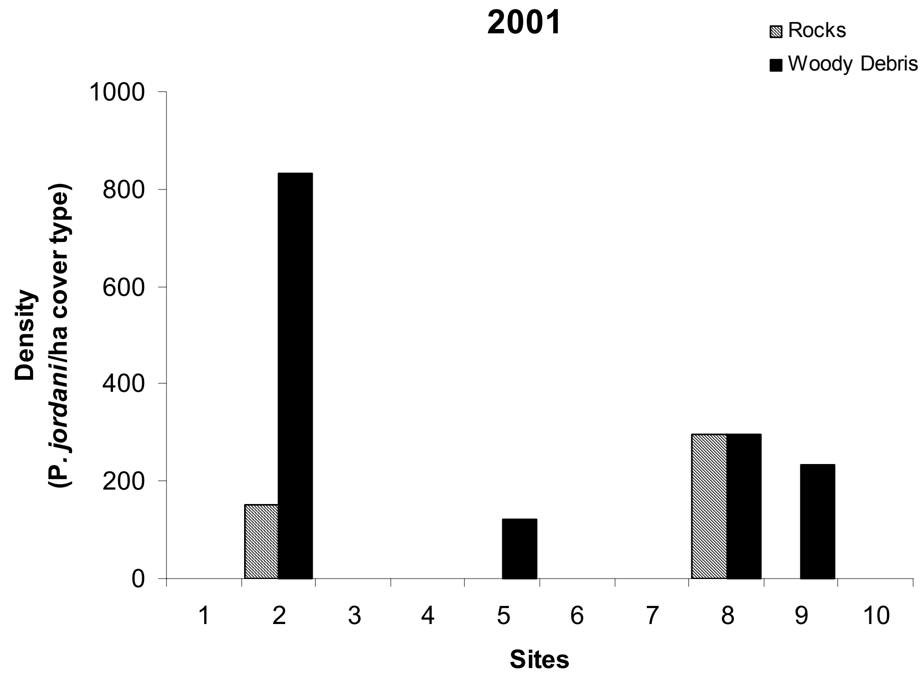
	2001		2002	
Site	Rocks	Woody Debris	Rocks	Woody Debris
1	0	0	0	0
2	1	11	0	11
3	0	0	0	0
4	0	0	0	2
5	0	1	0	2
6[a]	n/a	n/a	0	15
7	0	0	0	0
8	4	2	2	16
9	0	1	5	6
10	0	0	0	0
Total	5	15	7	52

[a] Site 6 has no 2001 data. The site was added prior to the 2002 field season.

Table 15. Density of *P. jordani* (*P. jordani*/ha of cover type) at each site found under rocks or woody debris for each sampling year.

	Area of Cover (m^2)		2001		2002	
Site	Rock	Woody Debris	Rocks	Woody Debris	Rocks	Woody Debris
1	155.5	66.6	0	0	0	0
2	66.1	132.2	151.3	832.1	0	832.1
3	66.7	100.1	0	0	0	0
4	48.8	97.7	0	0	0	204.7
5	50.92	81.5	0	122.7	0	245.4
6[a]	73.2	104.5	n/a	n/a	0	1435.4
7	127.7	68.8	0	0	0	0
8	135.2	67.6	295.9	295.9	147.9	2366.9
9	96.1	42.7	0	234.2	520.3	1405.2
10	51.5	82.4	0	0	0	0

[a] Site 6 has no 2001 data. The site was added prior to the 2002 field season.



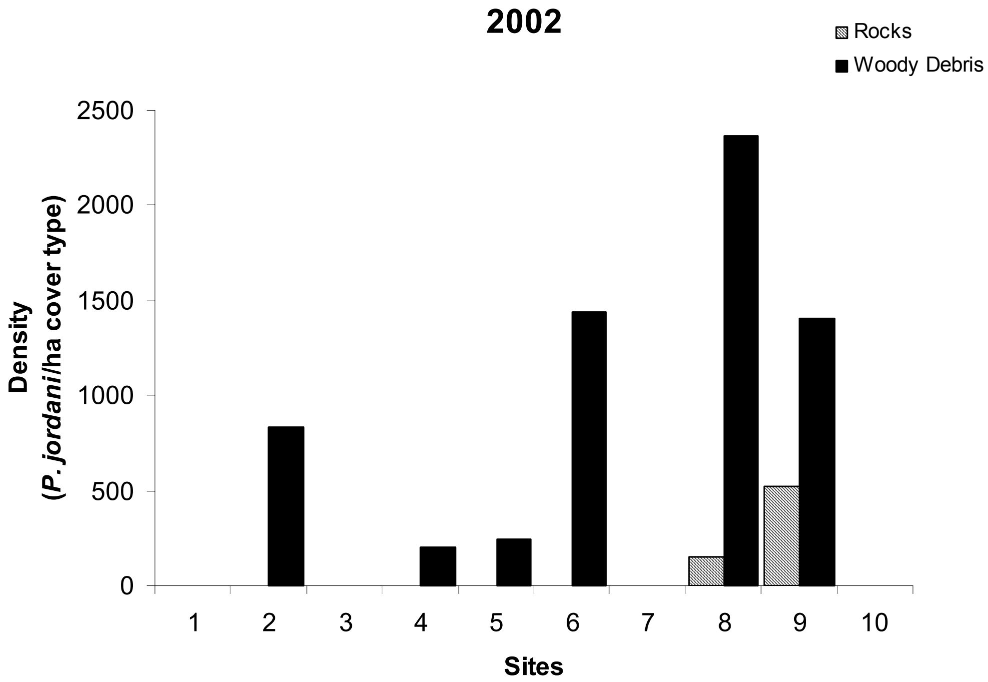
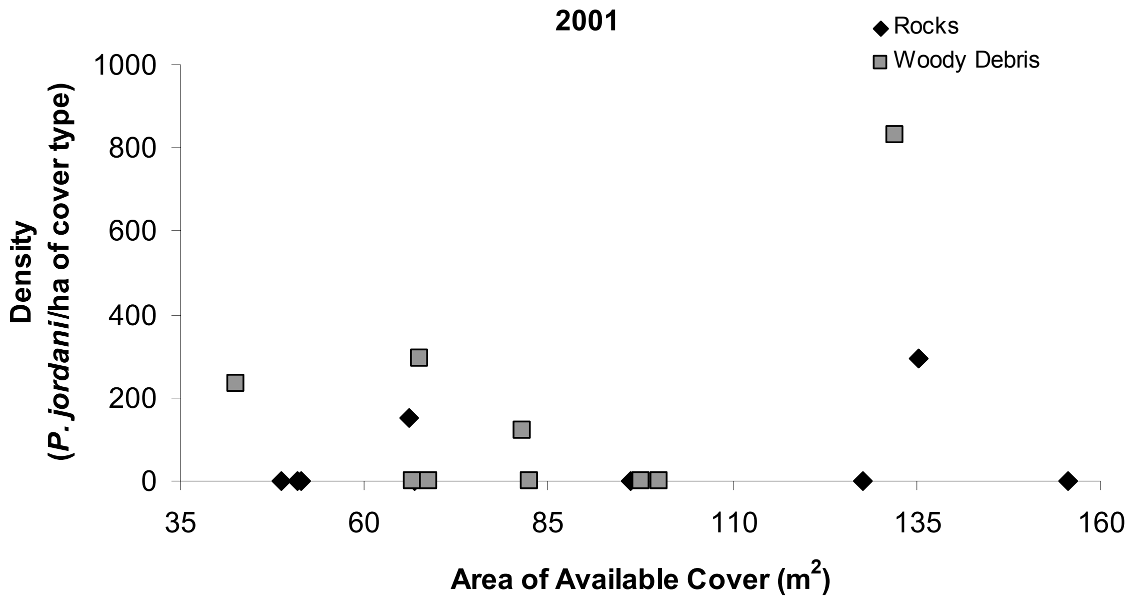


Figure 15. Distribution of use of rocks and woody debris by *P. jordani* as cover objects at sites in 2001 and 2002. Site 6 was not sampled in 2001.



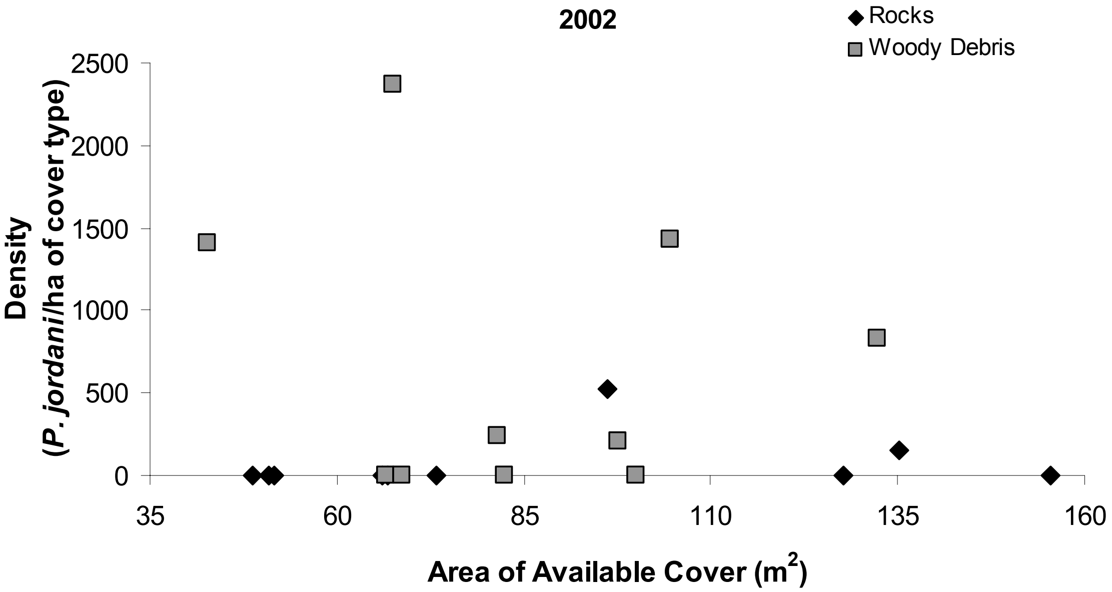


Figure 16. Correlation between area of available cover of rocks and woody debris with the density of *P. jordani* found under those cover objects at sites during the day in 2001 and 2002. There is no significant relationship between area of available cover and *P. jordani* density for either rocks or woody debris in either year.

Table 16. Equality of cover use by *P. jordani* between sampling years. Site 6 was not included in either cover type comparison because it was added in 2002.

Rocks

	2001	2002
Mean	49.68	74.25
Variance	11025.51	30371.62
Observations	9	9
Pearson Correlation	0.07	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.37	
$P(T\leq t)$ one-tail	0.359	
t Critical one-tail	1.86	
$P(T\leq t)$ two-tail	0.718	
t Critical two-tail	2.31	

Woody Debris

	2001	2002
Mean	164.98	561.58
Variance	75601.45	691580.84
Observations	9	9
Pearson Correlation	0.50	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.62	
$P(T\leq t)$ one-tail	0.072	
t Critical one-tail	1.86	
$P(T\leq t)$ two-tail	0.143	
t Critical two-tail	2.31	

Table 17. Equality of mean snout-vent length for *P. jordani* found under either rocks or woody debris between sampling years.

Rocks

	2001	2002
Mean	29.75	42.50
Variance	132.47	286.45
Observations	4	3
Hypothesized Mean Difference	0	
df	3	
t Stat	-1.12	
P(T≤t) one-tail	0.171	
t Critical one-tail	2.35	
P(T≤t) two-tail	0.343	
t Critical two-tail	3.18	

Woody Debris

	2001	2002
Mean	33.53	28.86
Variance	224.84	173.23
Observations	11	38
Hypothesized Mean Difference	0	
df	15	
t Stat	0.93	
P(T<t) one-tail	0.182	
t Critical one-tail	1.75	
P(T≤t) two-tail	0.365	
t Critical two-tail	2.13	

Table 18. Equality of cover type preference between rocks and woody for each sampling year. Site 6 was not included in 2001 analysis because the site was added in 2002. Sites 3 and 7 had no *P. jordani* present and were not included.

2001

	Rocks	Woody Debris
Mean	63.88	212.12
Variance	13642.81	89136.87
Observations	7	7
Pooled Variance	51389.84	
Hypothesized Mean Difference	0	
df	12	
t Stat	-1.22	
$P(T \leq t)$ one-tail	0.122	
t Critical one-tail	1.78	
$P(T \leq t)$ two-tail	0.245	
t Critical two-tail	2.18	

2002

	Rocks	Woody Debris
Mean	83.53	811.20
Variance	33824.47	738141.89
Observations	8	8
Pooled Variance	385983.18	
Hypothesized Mean Difference	0	
df	14	
t Stat	-2.34	
$P(T \leq t)$ one-tail	0.017	
t Critical one-tail	1.76	
$P(T \leq t)$ two-tail	0.034	
t Critical two-tail	2.14	

Table 19. Equality of mean snout-vent length (mm) of *P. jordani* found under rocks with those found under woody debris during each sampling year.

2001

	Rocks	Woody Debris
Mean	29.75	33.53
Variance	132.47	224.84
Observations	4	11
Pooled Variance	203.53	
Hypothesized Mean Difference	0	
df	13	
t Stat	-0.45	
P(T$\leq$t) one-tail	0.329	
t Critical one-tail	1.77	
P(T$\leq$t) two-tail	0.657	
t Critical two-tail	2.16	

2002

	Rocks	Woody Debris
Mean	42.50	28.86
Variance	286.45	173.23
Observations	3	38
Pooled Variance	179.04	
Hypothesized Mean Difference	0	
df	39	
t Stat	1.70	
P(T$\leq$t) one-tail	0.049	
t Critical one-tail	1.68	
P(T$\leq$t) two-tail	0.097	
t Critical two-tail	2.02	

Table 20. Relative abundances and densities of *P. jordani* observed during searches by night in 2001 and 2002. Sites 2, 3, 5, 7, 9, and 10 were sampled in 2001. Sites 1, 6, and 8 were sampled in 2002. Site 4 was never sampled at night. a) Abundance of *P. jordani* found on each substrate type during night searches at each site. b) Densities (*P. jordani*/ha of substrate type) are calculated based on the area of each substrate available at each site.

a)

Site	Leaf Litter	Rocks	Soil	Understory	Tree Trunks	Woody Debris	Total
1	8	1	0	0	0	6	15
2	76	1	1	0	21	15	114
3	0	0	0	0	0	0	0
4	n/a	n/a	n/a	n/a	n/a	n/a	0
5	3	0	0	0	2	2	7
6	94	6	0	40	33	32	205
7	0	0	0	0	0	0	0
8	126	23	0	32	20	44	245
9	26	6	1	0	6	5	44
10	37	1	0	6	15	15	74
Total	370	38	2	78	97	119	704

b)

Site	Leaf Litter	Rocks	Soil	Understory	Tree Trunks	Woody Debris
1	88.9	64.3	0	0	0	1080.5
2	884.4	151.3	907.7	0	1588.5	1945.0
3	0	0	0	0	0	0
4	n/a	n/a	n/a	n/a	n/a	n/a
5	34.3	0	0	0	245.5	178.5
6	1096.6	819.9	0	546.6	3156.7	3826.3
7	0	0	0	0	0	0
8	1491.0	1701.1	0	660.5	2958.4	4338.9
9	290.0	624.6	468.5	0	1405.4	425.9
10	443.3	194.1	0	132.3	1819.5	2426.0
Total	4328.4	3555.3	1376.2	1339.4	11173.9	14221.2

Table 21. Densities of *P. jordani* found using each substrate during searches at night for 2001, 2002, and combined years. Densities were calculated using the area of available substrate and abundance of *P. jordani* found on that substrate. Sites in which *P. jordani* were present are included in analyses. Sample size is 4, 3 and 7 for 2001, 2002, and combined year analyses, respectively.

	2001		2002		Combined Years	
Substrate	Mean Density	Std. Deviation	Mean Density	Std. Deviation	Mean Density	Std. Deviation
Understory	33.1	66.2	402.4	353.1	191.4	287.6
Soil	344.0	435.9	0	0	196.6	358.9
Rocks	242.5	268.0	861.8	819.2	507.9	607.6
Leaf Litter	413.0	356.7	892.2	723.0	618.4	550.9
Tree Trunks	1264.7	700.3	2038.3	1768.0	1596.3	1207.6
Woody Debris	1243.9	1109.5	3081.9	1752.1	2031.6	1613.7

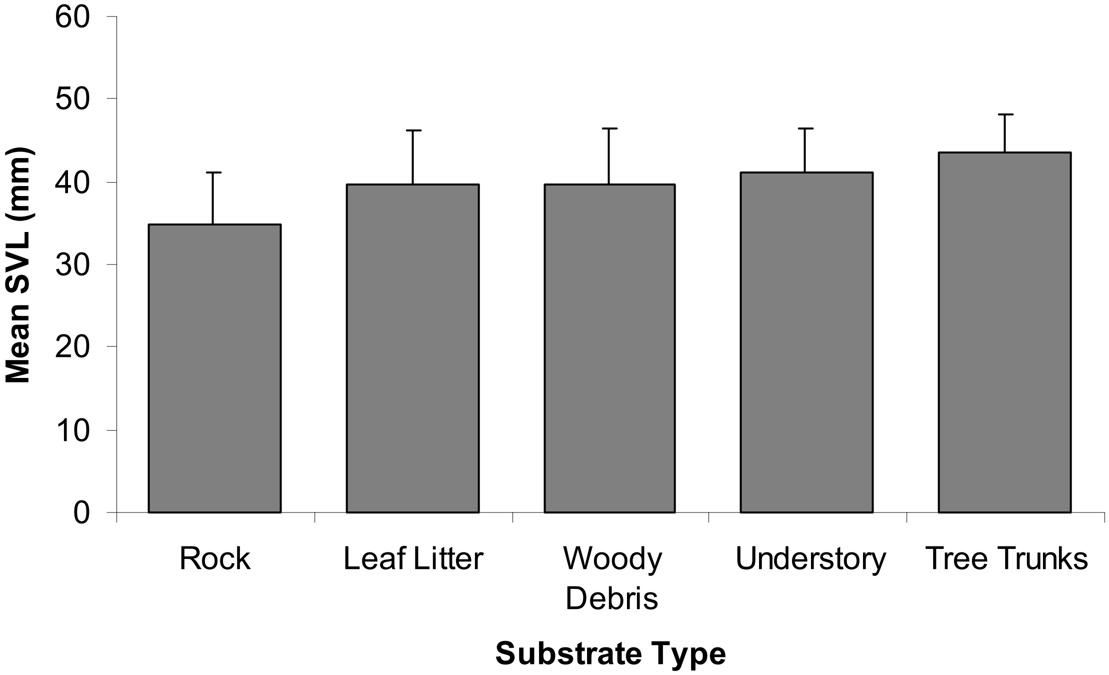


Figure 17. Mean snout-vent length (SVL in mm) of *P. jordani* observed at night for each substrate type. Two *P. jordani* were seen on soil at night, but both escaped capture and SVL was not recorded. Error bars depict standard deviation from the mean. Analyses showed a significant difference between mean SVL found on substrate types. Difference was between Tree Trunks and Rocks.

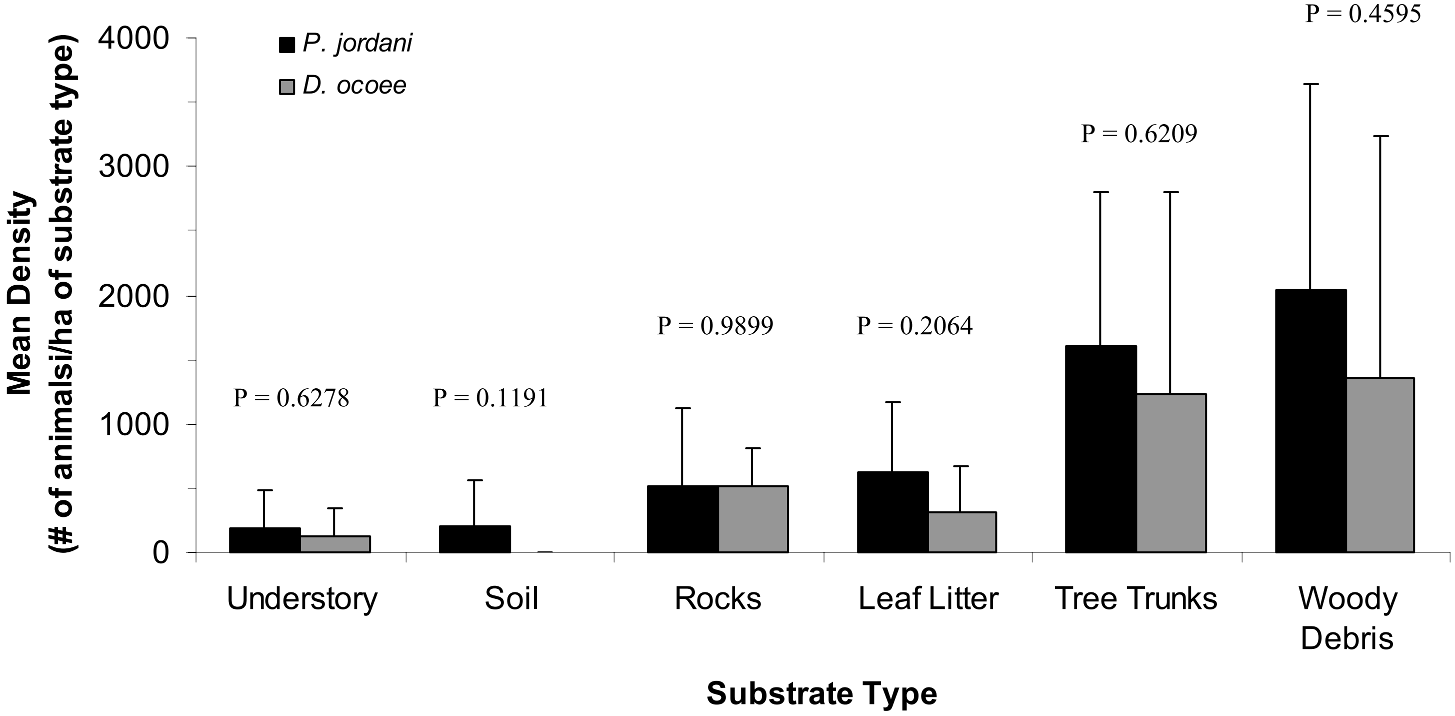


Figure 18. Mean density of *P. jordani* and *D. ocoee* found on each substrate type at night and statistical results comparing the equality of use of each substrate by the two species. *P. jordani* densities were calculated using 7 sites. *D. ocoee* density is averaged over 9 sites. Error bars depict standard deviation of the mean. P-values show comparison between *P. jordani* and *D. ocoee* mean densities for each substrate.

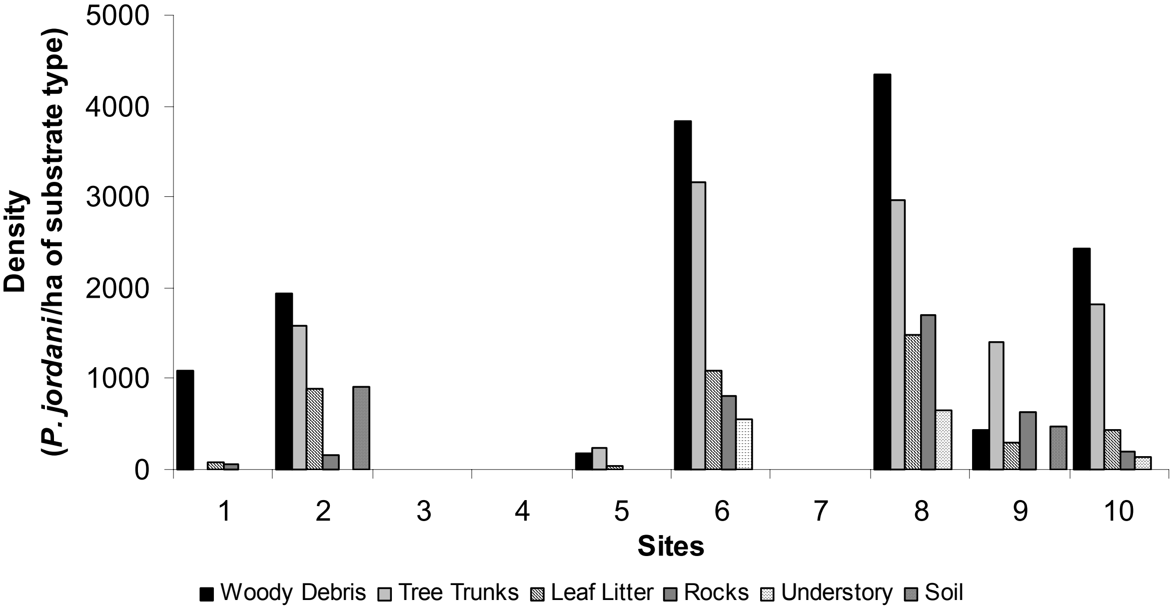


Figure 19. Variability in substrate use by *P. jordani* at night between and among sites. Site 4 was not sampled at night.

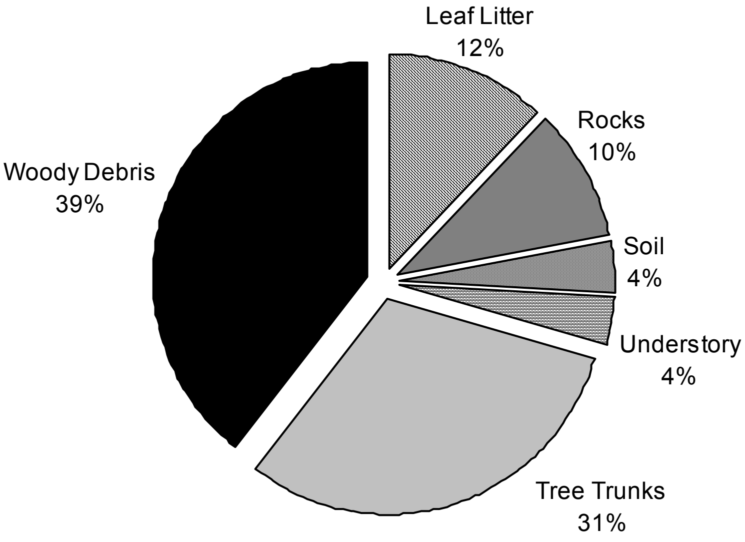


Figure 20. Percent substrate use by *P. jordani* in the Pisgah Bear Sanctuary. Percents are based on the mean *P. jordani* density (*P. jordani*/ha of substrate type) across all sites for the combined 2001 and 2002 sampling years.

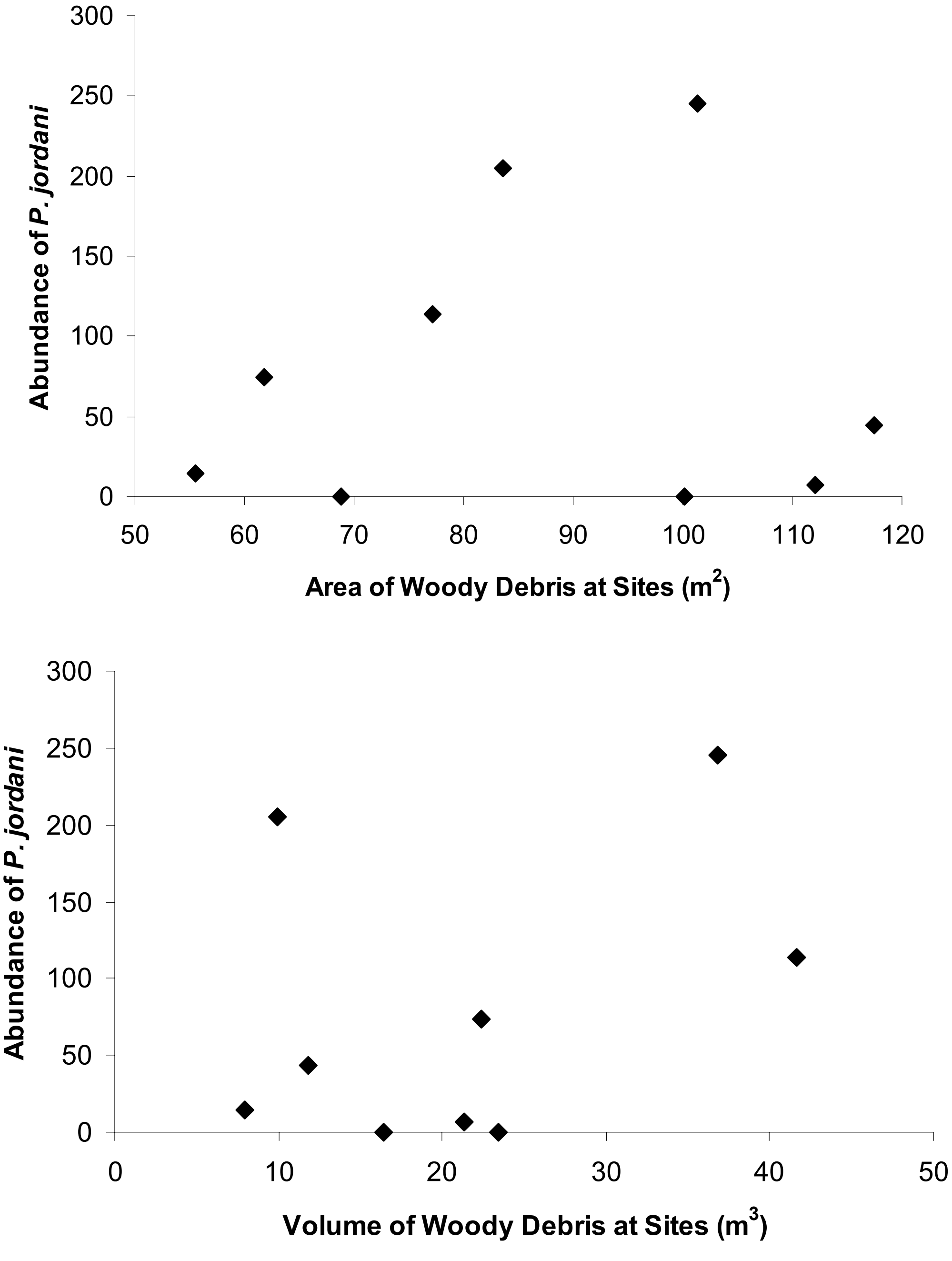


Figure 21. Correlation between abundances of *P. jordani* observed at sites with the area and volume of woody debris at those sites. No significant linear relationship was observed.

Table 22. Use of habitat characteristics by black bears and salamanders.

Black Bears	Salamanders	Citations
Roads increase human access to forests; bears are killed by automobile accidents; roads facilitate illegal poaching; bears shift home ranges away from roads	Roads can cause death from desiccation or from being run over; roads inhibit dispersal and mating migrations; roads can introduce sediments and heavy metals into streams affecting salamanders; roads enhance human collection of salamanders for pets	(Gibbs, 1998; Trombulak and Frissell, 2000; Baker and Hunter, 2002; Graham, 2002; Marsh et al., 2002)
Clearcuts provide greenbriar and some berry species to bears; minimizes shade, den trees, certain soft mast species, hard mast species; and escape cover	Salamanders have been found to disappear two years after clearcutting; populations don't rebound for decades; clearcuts affect microclimate, among other important habitat components	(Petranka 1993, 1994; Ash, 1997; Mitchell, 1997; Chen et al., 1999)
Thick areas of rhododendron and laurel provide escape cover; shade for thermoregulation; seclusion for cubs	There is little understory cover under rhododendron available for salamanders; rhododendron and laurel typically grown in acidic soils; salamanders often avoid acidic soils	(Wyman, 1988; Duffy and Meier, 1992; Zimmerman; 1992; Powell et al., 1997)
Mature forests provide for almost all the necessary habitat characteristics for bears, including hard mast, some soft mast, den areas, and escape cover	Density of salamanders increases with stand age; not necessarily correlated with stand age but factors related to stand age, such as microclimate, downed woody debris, leaf litter, and canopy cover	(Welsh, 1990; Petranka, 1994; Ash, 1997; Powell et al., 1997; Herbeck and Larsen, 1999; Welsh and Droege, 2001)
Coarse woody debris provides den sites and animal matter, particularly insects, for food	Woody debris provides nesting locations, foraging substrates, food, cover from predators, cool, moist microhabitats in dry conditions	(Miller, 1975; Hellgren, 1993; Loeb, 1993 Whiles and Grubaugh, 1993; Butts and McComb, 2000)
Bears exist on landscape scale; home ranges are large, tens of kilometers in size; bears are mobile	Home ranges are small, meters in size; salamanders are relatively restricted in movement and demonstrate site fidelity	(Powell et al., 1997; Petranka, 1998; Baker and Hunter, 2002)
Many spring foods for bears are associated with moist areas; bedding occurs in riparian areas; riparian vegetation used for cover; streams used as travel corridors and for thermoregulation	All salamanders need moisture for survival; aquatic species live exclusively in water; many salamanders reproduce in water; activity revolves around moisture	(Heatwole, 1962; Unsworth et al., 1989; Zimmerman, 1992; Petranka, 1998; Fecske et al., 2002

Table 23. Categorization of species of salamanders observed at sites for density calculations and comparison of microhabitat.

Aquatic Species
(rely heavily on flowing water)
Density (#/ha) = (abundance/stream area)*10,000

D. monticola
D. quadramaculatus

Semiaquatic Species
(rely on both aquatic and terrestrial habitats)
Density (#/ha) = (abundance/site area)*10,000

D. ocoee
E. b. wilderae
G. porphyriticus
N. viridescens
P. ruber

Terrestrial Species
(rely exclusively on terrestrial habitats)
Density (#/ha) = (abundance/terrestrial area)*10,000

D. wrighti
P. glutinosus
P. jordani
P. serratus

Table 24. Average densities (#/ha) of each salamander species observed at each site during searches by day
Site 6 average is based on two daytime samples conducted in 2002.

Site	DES_SP	DM	DO	DQ	DW	EB	GP	NV	PG	PJ	PS	PR	SAL_SP
1	8.3	111.9	79.2	671.1	0	4.2	0	0	0	0	0	4.2	29.2
2	12.5	101.7	558.3	1932.9	0	58.3	4.2	0	18.2	104.4	0	0	58.3
3	0	113.9	66.7	56.9	0	0	0	0	0	0	0	0	12.5
4	33.3	44.8	179.2	1275.7	0	20.8	0	0	0	20.5	0	0	20.8
5	37.5	55.1	83.3	1321.6	0	20.8	0	0	0	14.7	0	0	4.2
6	20.8	64.7	816.7	1002.6	100.4	41.7	4.2	0	14.3	205.7	0	0	33.3
7	50.0	46.0	283.3	850.6	0	12.5	4.17	0	0	0	5.1	0	25.0
8	20.8	136.5	316.7	1911.3	0	66.7	8.3	0	4.4	133.1	0	0	50.0
9	16.7	75.4	150.0	2449.1	0	54.2	0	0	4.7	65.6	23.4	0	16.7
10	4.2	59.0	79.2	118.0	0	4.2	0	0	0	4.9	0	0	0

DES SP = Escaped *Desmognathus* species
DM = *D. monticola*
DO = *D. ocoee*
DQ = *D. quadramaculatus*
DW = *D. wrighti*
EB = *E. b. wilderae*
GP = *G. porphyriticus*
NV = *N. viridescens*
PG = *P. glutinosus*
PJ = *P. jordani*
PS = *P. serratus*
PR = *P. ruber*
SAL SP = Escaped unidentified salamanders

Table 25. Densities (#/ha) of each salamander species observed at each site during searches by night. Site 4 was never sampled at night. Sites 2, 3, 5, 7, 9, and 10 were sampled in 2001. Sites 1, 6, and 8 were sampled in 2002.

Site	DES_SP	DM	DO	DQ	DW	EB	GP	NV	PG	PJ	PS	PR	SAL_SP
1	0	671.1	208.3	0	0	91.7	0	0	81.0	135.1	0	0	0
2	0	0	975.0	101.7	0	66.7	8.3	0	45.4	1062.0	0	0	0
3	0	455.6	50.0	113.9	0	0	66.7	0	0	0	0	0	0
5	0	385.5	50.0	275.3	0	8.3	116.7	0	29.5	88.4	0	0	25.0
6	8.3	776.2	1558.3	129.4	181.7	191.7	0	0	200.9	1961.0	0	0	0
7	25.0	1241.4	125.0	413.8	0	83.3	25.0	8.3	112.0	0	0	0	16.7
8	8.3	136.5	1383.3	682.6	0	75.0	0	0	71.0	2192.1	0	0	16.7
9	0	0	183.3	226.1	0	58.3	25.0	0	56.2	421.6	0	0	0
10	0	118.0	283.3	177.0	0	183.3	8.3	0	174.7	766.6	0	0	0

DES SP = Escaped *Desmognathus* species
DM = *D. monticola*
DO = *D. ocoee*
DQ = *D. quadramaculatus*
DW = *D. wrighti*
EB = *E. b. wilderae*
GP = *G. porphyriticus*
NV = *N. viridescens*
PG = *P. glutinosus*
PJ = *P. jordani*
PS = *P. serratus*
PR = *P. ruber*
SAL SP = Escaped unidentified salamanders

Table 26. The *HSI*, along with the species richness, density, Simpson index, and species equitability calculations at each site from searches by day and night, and from the compiled densities of searches (uses the highest density observed during day or night searches for each species at each site). Site 4 was not sampled at night and not included in the compiled search. Total density is the number of salamanders per hectare and species richness is the number of different species observed at sites during sampling events.

		Average Daytime Searches				Night Searches				Compiled Searches			
Site	New Q	Species Richness	Total Density	Simpson Index	Species Equitability	Species Richness	Total Density	Simpson Index	Species Equitability	Species Richness	Total Density	Simpson Index	Species Equitability
1	0.32	5	908.0	1.6	0.32	5	1187.2	2.7	0.53	7	1900.0	3.5	0.51
2	0.31	7	2848.8	1.9	0.27	6	2259.1	2.4	0.41	7	4262.8	3.0	0.43
3	0.32	3	250.0	2.7	0.91	4	686.1	2.1	0.52	4	715.3	2.2	0.54
4	0.40	5	1595.1	1.4	0.29	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5	0.39	5	1537.2	1.3	0.25	7	978.6	3.6	0.52	7	2108.2	2.2	0.31
6	0.40	8	2304.4	2.9	0.37	7	5007.5	3.6	0.51	8	5930.7	4.3	0.54
7	0.39	6	1276.6	1.8	0.30	7	2050.5	2.3	0.33	8	2525.7	2.6	0.33
8	0.36	7	2647.8	1.8	0.25	6	4565.6	2.9	0.48	7	5848.4	3.2	0.46
9	0.31	7	2855.7	1.3	0.19	6	970.6	3.5	0.58	8	3325.8	1.7	0.22
10	0.36	5	269.3	3.0	0.59	6	1711.3	3.8	0.63	7	1715.4	3.8	0.54

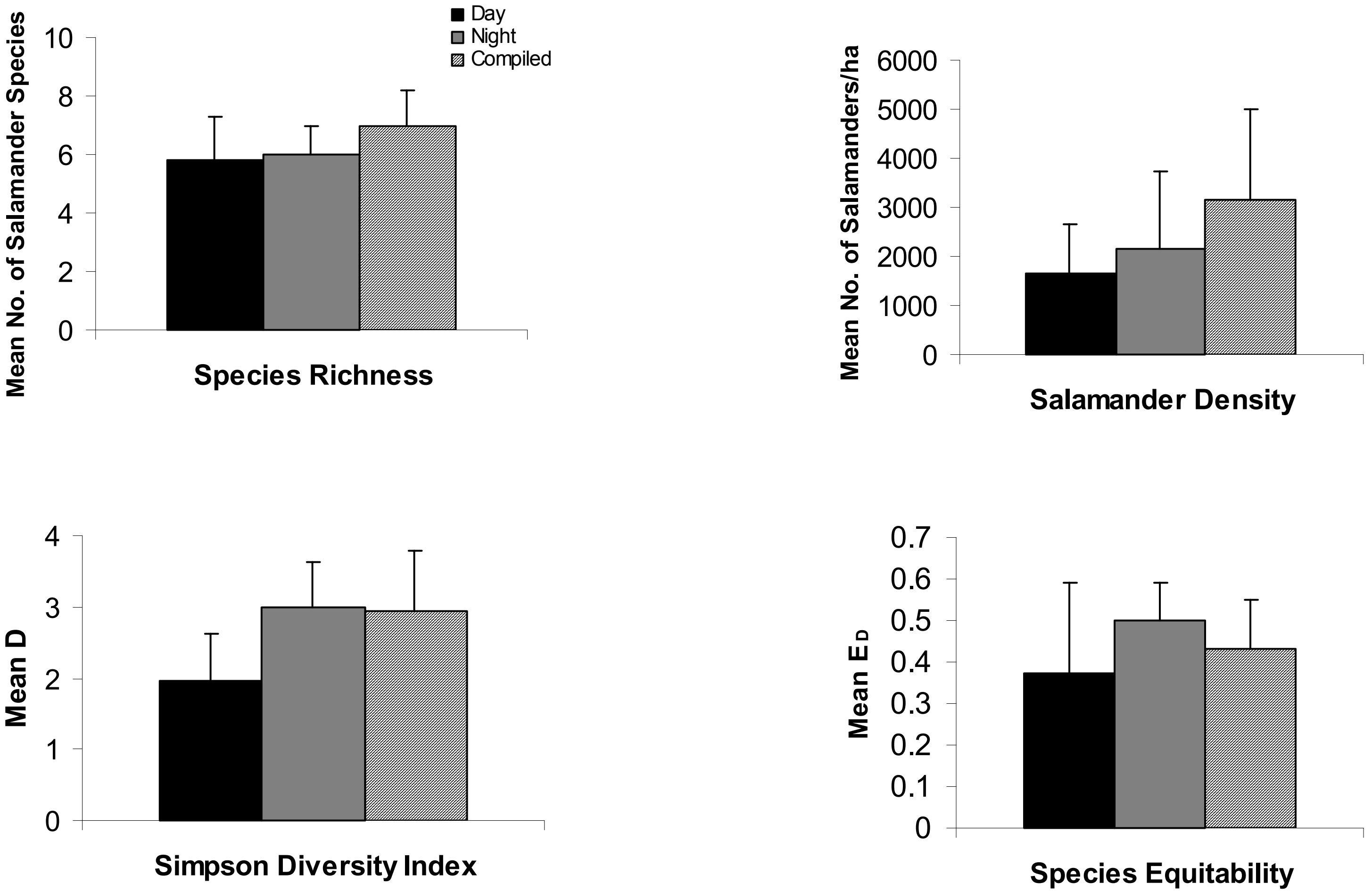


Figure 22. Variability between sampling methods and variability between sites for species richness, density, Simpson diversity index, and species equitability of salamanders.

Table 27. Linear correlations of *HSI* with multiple salamander variables. Significant P values and corresponding R-square values are in bold. Nearly significant variables at the0.05 level of significance are in italics. All correlations are positive unless otherwise indicated (-).

Salamander Variable	**Avg. Day**		**Night**		**Compiled**	
	P Value	**R-Square**	**P Value**	**R-Square**	**P Value**	**R-Square**
Total Relative Density	0.8094	0.01 (-)	0.1919	0.23	0.5132	0.07
Species Richness	0.7616	0.01	**0.0278**	**0.52**	0.3175	0.14
Simpson Diversity Index	0.9036	0	0.3111	0.15	0.3831	0.11
Species Equitability	0.6077	0.03 (-)	0.6201	0.04 (-)	0.9531	0
***Desmognathus* Density**	0.7970	0.01 (-)	*0.0822*	*0.37*	0.6347	0.03
***Plethodon* Density**	0.9730	0	0.4424	0.09	0.4424	0.09
Aquatic spp. Density	0.5678	0.04 (-)	**0.0378**	**0.48**	0.9222	0
Semiaquatic spp. Density	0.5990	0.04	0.4814	0.07	0.4651	0.08
Terrestrial spp. Density	0.6245	0.03	0.4567	0.08	0.4602	0.08
D. monticola	**0.0469**	**0.41 (-)**	0.1031	0.33	0.1307	0.30
D. ocoee	0.5459	0.05	0.5665	0.05	0.5552	0.05
D. quadramaculatus	0.6172	0.03 (-)	0.2937	0.16	0.5511	0.05 (-)
D. wrighti	0.2333	0.17	0.1668	0.25	0.1668	0.25
Eurycea b. wilderae	0.6755	0.02	0.3429	0.13	0.2953	0.16
Gyrinophilus porphyriticus	0.6700	0.02	0.6288	0.04	0.5739	0.05
Notophthalmis viridescens	-	-	0.2909	0.16	0.2909	0.16
P. glutinosus	0.5711	0.04 (-)	0.1277	0.30	0.1277	0.30
P. jordani	0.7334	0.02	0.5530	0.05	0.5530	0.05
P. serratus	0.3401	0.11 (-)	-	-	0.4135	0.10 (-)
P. ruber	0.3811	0.10 (-)	-	-	**0.0444**	**0.09 (-)**

Table 28. Reduction of black bear HSI model to better explain for variability in salamanders at sites with varying *HSI.* Variables shown correspond to individual factors from the black bear HSI model selected by multilinear stepwise regression analyses. Full model variables included all 31 factors of the black bear HSI model. Blank spaces indicate no variables of the HSI model met 0.05 significance level for entry into the model. Variable abbreviation, partial R-square, F value, and P value are presented for variables included in each model at 0.05 level of significance are presented.

Salamanders	**Day Search n=10**				**Night Search n=9**				**Compiled Search n=9**			
Dependent Variable	**Model Variable**	**Partial R^2**	**F Value**	**P Value**	**Model Variable**	**Partial R^2**	**F Value**	**P Value**	**Model Variable**	**Partial R^2**	**F Value**	**P Value**
Total Relative Density					Ff_2	0.46	5.86	0.0460				
Species Richness					LRV_E	0.59	10.04	0.0157	LRV_E	0.87	47.62	0.0002
					LRV_F	0.28	13.32	0.0107				
Diversity Index (D)					E_2	0.47	6.18	0.0418	Ff_{1a}	0.75	21.51	0.0024
					LRV_D	0.33	10.17	0.0189	Ff_3	0.22	44.82	0.0005
Species Equitability (E_D)	E_4	0.60	12.12	0.0083	Fy	0.67	14.38	0.0068	Fsu	0.54	8.23	0.0241
									Fy_{2c}	0.35	18.63	0.0050
									Fy	0.08	12.99	0.0155
Desmognathus Density					Ff_3	0.46	6.00	0.0441				
					Fy_1	0.28	6.25	0.0465				
					Fsu_1	0.21	19.58	0.0069				
					Fsu	0.04	13.60	0.0211				
Plethodon Density					Ff_{1a}	0.49	6.84	0.0346	Ff_{1a}	0.49	6.71	0.0359
Aquatic spp. Density					Fy_{2a}	0.65	13.23	0.0083	D_3	0.54	8.20	0.0242

Table 28 continued.

Salamander Variable	Model Variable	Partial R^2	F Value	P Value	Model Variable	Partial R^2	F Value	P Value	Model Variable	Partial R^2	F Value	P Value
Semiaquatic spp. Density	Ff_2	0.57	10.73	0.0113	Ff_{1a}	0.48	6.51	0.0380	Ff_{1a}	0.47	6.30	0.0404
D. monticola					Fy_{2a}	0.55	8.38	0.0232	Fy_{2a}	0.58	9.49	0.0178
D. ocoee	Ff_2	0.62	12.91	0.0071	Ff_1	0.47	6.13	0.0425	Ff_{1a}	0.46	5.95	0.0448
D. quadramaculatus					Fsp	0.46	6.04	0.0436				
D. wrighti	Ff_2	1.0	infinity	<0.0001	Ff_2	1.0	infinity	<0.0001	Ff_2	1.0	infinity	<0.0001
E. b. wilderae					Ff_3	0.56	8.79	0.0210	Ff_3	0.72	9.14	0.0193
					Ff_{1a}	0.26	8.50	0.0264	Ff_{1a}	0.15	8.21	0.0286
G. porphyriticus					Ff_{1a}	0.54	8.14	0.0246	Fsu_2	0.53	7.78	0.0270
									E_4	0.30	10.28	0.0185
									Fy_{2a}	0.15	28.43	0.0031
N. viridescens					Fy_{2a}	1.0	infinity	<0.0001	Fy_{2a}	1.0	infinity	<0.0001
P. glutinosus					Ff_3	0.72	18.17	0.0037	Ff_3	0.72	18.17	0.0037
					LRV_D	0.15	7.21	0.0363	LRV_D	0.15	7.21	0.0363
					E_4	0.08	8.71	0.0318	E_4	0.08	8.71	0.0318
					LRV_F	0.03	9.27	0.0382	LRV_F	0.03	9.27	0.0382
					LRV_D	0.01	2.83	0.1680	LRV_D	0.01	2.83	0.1680
					Fy_2	0.02	25.30	0.0073	Fy_2	0.02	25.30	0.0073
					D_3	0.00	13.48	0.0350	D_3	0.00	13.48	0.0350

Table 28 continued.

Salamander Variable	Model Variable	Partial R^2	F Value	P Value	Model Variable	Partial R^2	F Value	P Value	Model Variable	Partial R^2	F Value	P Value
P. jordani	Ff_2	0.55	9.86	0.0138	Ff_{1a}	0.47	6.18	0.0418	Ff_{1a}	0.47	6.18	0.0418
P. serratus									Fy_{2c} Fy_{2a}	0.95 0.05	142.58 infinity	<0.0001 <0.0001
P. ruber	Fy_{2b}	0.62	13.15	0.0067					Fy_{2b}	0.65	13.11	0.0085

APPENDICES

Appendix A

Abundances of salamanders found at sites during searches by day in 2001 and 2002

2001

SITE	DES_SP	DM	DO	DQ	DW	EB	GP	NV	PG	PJ	PR	PS	SAL_SP	Total
1	2	0	11	5	0	1	0	0	0	0	0	0	6	25
2	1	0	56	22	0	8	1	0	4	12	0	0	6	110
3	0	3	4	1	0	0	0	0	0	0	0	0	1	9
4	4	19	19	27	0	2	0	0	0	1	0	0	3	75
5	7	17	7	26	0	2	0	0	0	1	0	0	1	61
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	5	22	32	10	0	0	0	0	0	0	0	1	4	74
8	3	0	36	10	0	5	2	0	0	7	0	0	10	73
9	1	7	20	40	0	3	0	0	0	2	0	0	2	75
10	0	3	8	3	0	0	0	0	0	1	0	0	0	15
Total	23	71	193	144	0	21	3	0	4	24	0	1	33	517

2002

Site	DES_SP	DM	DO	DQ	DW	EB	GP	NV	PG	PJ	PR	PS	SAL_SP	Total
1	0	2	8	7	0	0	0	0	0	0	1	0	1	19
2	2	2	78	16	0	6	0	0	0	11	0	0	8	123
3	0	4	12	0	0	0	0	0	0	0	0	0	2	18
4	4	9	24	30	0	3	0	0	0	3	0	0	2	75
5	2	30	13	22	0	3	0	0	0	2	0	0	0	72
6	2	7	89	4	7	6	1	0	1	16	0	0	8	141
7	7	83	36	27	0	3	1	0	0	0	0	0	2	159
8	2	5	40	18	0	11	0	0	1	23	0	0	2	102
9	3	9	16	25	0	10	0	0	1	12	0	5	2	83
10	1	0	11	1	0	1	0	0	0	0	0	0	0	14
Total	23	151	327	150	7	43	2	0	3	67	1	5	27	806

Key

DES SP = Escaped *Desmognathus* species
DM = *D. monticola*
DO = *D. ocoee*
DQ = *D. quadramaculatus*
GP = *G. porphyriticus*
DW = *D. wrighti*
EB = *E. b. wilderae*
PJ = *P.* jordani
SAL SP = Escaped unidentified salamanders
NV = *N. viridescens*
PG = *P. glutinosus*
PS = *P. serratus*
PR = *P. ruber*

Appendix B

Abundances of salamanders found at sites during searches by night in 2001 and 2002

SITE	DES_SP	DM	DO	DQ	DW	EB	GP	NV	PG	PJ	PR	PS	SAL_SP	Total
						Sampled in 2001								
2	0	0	117	1	0	8	1	0	5	117	0	0	0	249
3	0	4	6	1	0	0	8	0	0	0	0	0	0	19
4	-	-	-	-	-	-	-	-	-	-	-	-	-	0
5	0	7	6	5	0	1	14	0	3	9	0	0	3	48
7	3	27	15	9	0	10	3	1	11	0	0	0	2	81
9	0	0	22	3	0	7	3	0	6	45	0	0	0	86
10	0	2	34	3	0	22	1	0	18	79	0	0	0	159
						Sampled in 2002								
1	0	6	25	0	0	11	0	0	9	15	0	0	0	66
6	1	12	187	2	19	23	0	0	21	205	0	0	0	470
8	1	1	166	5	0	9	0	0	8	247	0	0	2	439
Total	5	59	578	29	19	91	30	1	81	717	0	0	7	1617

Key

DES SP = Escaped *Desmognathus* species
DM = *D. monticola*
DO = *D. ocoee*
DQ = *D. quadramaculatus*
GP = *G. porphyriticus*
DW = *D. wrighti*
EB = *E. b. wilderae*
PJ = *P. jordani*
SAL SP = Escaped unidentified salamanders
NV = *N. viridescens*
PG = *P. glutinosus*
PS = *P. serratus*
PR = *P. ruber*

Appendix C

Categories used in data collection for sampling of habitat

Degree of Wetness Value	Description
1	Dry
2	Damp-Moist
3	Moist-Wet
4	Wet
5	Saturated

Rock Category	Size
A	< 2 mm
B	2-10 mm
C	1-10 cm
D	11-30 cm
E	> 30 cm
F	bedrock

Woody Debris Category	Length	Diameter
A	>30 cm, < 5 m	< 10 cm
B	< 5 m	10-50 cm
C	< 5 m	>50 cm
D	> 5 m	<10 cm
E	> 5 m	10-50 cm
F	> 5 m	> 50 cm
K	Bark	
P	Stump	

Block Topography Value	Description
0	Slope
1	Convex + Slope
2	Convex
3	Flat
4	Concave + Slope
5	Concave

Appendix D

Descriptions of individual suitability indices for each variable of the black bear habitat suitability index model (Zimmerman, 1992).

Index	Description	Measurement based on:
Fy	NONSEASONAL FOODS	
Fy_1	Number of fallen logs	Downed logs ≥ 15cm diameter (#/ha)
Fy_2	Anthropogenic foods	
Fy_{2a}	Anthropogenic food source	Amount, risk, and seasonality of food
Fy_{2b}	Distance to anthropogenic food source	Distance (km) to closest food source
Fy_{2c}	Distance between food and escape cover	Distance (m) from food source to escape cover
Fsp	SPRING FOODS	
Fsp_1	Distance to perennial water	Distance (km) to perennial water
Fsp_2	Percent cover of greenbriar	Percent cover of smilax
Fsu	SUMMER FOODS	
Fsu_1	Percent cover in berry spp.	Percent of understory berry cover and no. of genera
Fsu_2	Presence of oak spp.	Presence and dominance of oak spp.
Ff	FALL FOODS	
Ff_1	Acorns	
Ff_{1a}	Forest cover type	Dominance or co-dominance of spp.
Ff_{1b}	Age of stand	Age of stand in years
Ff_2	Number of grape vines	Grape vines (#/ha)
Ff_3	Distance to nearest road	Type of road and distance (km) to road
I_F	INTERSPERSION OF FOOD	Distance (km) bear must travel to reach all seasonal foods
LRV_F	LIFE REQUISITE VALUE FOR FOOD	Total food index
E_1, D_1	AREA OF CONTERMINOUS FOREST NOT BISECTED BY ROADS	Area of conterminous forest (ha)
E_2	PERCENT CLOSURE OF UNDERSTORY	Percent of understory cover
E_3, D_3	SLOPE OF TERRAIN	Slope (in degrees)
E_4	DISTANCE TO NEAREST ROAD	Distance from nearest road to escape cover (km)
LRV_E	LIFE REQUISITE VALUE FOR ESCAPE COVER	Total escape index
D_2	AREA OF RHODODENDRON/LAUREL SPP.	Area of contiguous rhododendron and laurel cover (in ha)
D_4	NUMBER OF LARGE TREES	Trees ≥90 cm diameter at breast height
LRV_D	LIFE REQUISITE VALUE FOR DEN	Total den index
I_{LRV}	INTERSPERSION OF HABITATS	Distance (km) bear must travel to reach all needed habitats

Appendix E

Data from Site 11. This site was not used in analyses because of recent logging activity which may have compromised the data.

Salamander Species	**Abundance by Day (2001)**	**Abundance by day (2002)**	**Abundance by night (2001)**
Escaped Des. Spp.	9	4	1
D. monticola	18	30	4
D. ocoee	4	8	7
D. quadramaculatus	18	43	4
D. wrighti	0	0	0
E. b. wilderae	1	2	15
G. porphyriticus	0	0	3
N. viridescens	0	0	0
P. glutinosus	0	0	2
P. jordani	0	0	6
P. serratus	0	0	0
P. ruber	0	0	0
Escaped Sal. Spp.	2	1	2