To the Graduate Council:

I am submitting herewith a thesis written by Raymond Clifford Mathews, Jr. entitled "Distributional Ecology of Stream-Dwelling Salamanders in the Great Smoky Mountains National Park." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

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The Graduate School

DISTRIBUTIONAL ECOLOGY OF STREAM-DWELLING SALAMANDERS IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Raymond Clifford Mathews Jr.

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DEDICATION

To My Parents

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ABSTRACT

Salamanders occupy stream environs within every conceivable microhabitat type available in the Great Smoky Mountains National Park. Patterns of abundance and biomass distributions were evident, however, in terms of watershed, elevation, season, stream size variables, stream flow and velocity, water quality, temperature, overstory and understory forest type, logging history, and stream substrate type.

Population estimates of streamside-dwelling salamanders (mean = $0.050/m^2$, range = 0 - $0.367/m^2$) were consistent with other terrestrial and streamside population estimates in the Appalachian Mountains, although stream-dwelling salamanders were much more abundant (mean = 0.153, range = 0 - 1.880) and probably represent the greatest population density of salamanders in the world. Habitat complexity effected species diversity and population density in different ways for stream and streamside-dwelling salamanders, although stream width was probably the single most overall influential parameter. Environmental impacts affecting salamander distributions in the Park include roadcuts through Anakeesta formations, acid precipitation effects, Balsam Wooly aphid parasitism of Frasier Fir, European Wild Boar rooting, and research collecting and translocation of salamanders.

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CHAPTER I

INTRODUCTION

Area Description of Great Smoky Mountains National Park

Natural Resources

The Great Smoky Mountains National Park (GRSM) is a unique area whose individual array of resources and characteristics are not duplicated in any of the other National Parks (Carpenter 1982). The designation of the GRSM as an "International Biosphere Reserve" is one indication of how the Park has come to be recognized as a unique and important natural research area (Herrmann and Bratton 1977; Johnson and Bratton 1978). The GRSM form the second highest range in the eastern United States and are part of the oldest range of mountains in the country. Extreme topography has limited access, therefore considerable amounts of virgin forest have remained intact. Floristically speaking, there are more kinds of native trees in the Smokies than in any other area of comparable size in the United States (Wright et al. 1975). The Park is a sanctuary containing unspoiled forest. It is one of the finest examples of temperate deciduous forest found anywhere in the world (U.S. Department Interior 1977). Within the Park biotic communities the Eastern Deciduous Forest attain their greatest development and diversity. Vegetation types include the cove hardwood forest where 15 species reach record proportions, the spruce-fir forest which reach their southern extension in the GRSM, and grass and heath balds (Wright et al. 1975). The Park encompasses what is

potentially one of the largest uninterrupted tracts of wilderness in the United States (U.S. Department Interior 1977). Steep slopes, deep valleys, and numerous creeks all play a part in creating an area of unique scenic grandeur and a diverse species habitat.

Salamander Fauna

The diversity of salamanders in the topographically complex region of the Southern Appalachian Mountains is high. The salamander fauna is unmatched anywhere else in the world and the region has a long history of herpetofaunal study. Surprisingly, however, little research has centered on stream-dwelling species. It is the purpose of this study to provide an inventory of species occupying streams and streamsides in the GRSM and evaluate their distributional ecology as effected by natural and disturbance aspects of the landscape, climate, vegetation, watershed, terrain slope, logging history, season, elevation, stream substrate, stream flow, stream size, and water quality. From a resource management perspective, the impacts on the stream-dwelling salamanders in the Park of greatest importance are as follows:

1. Roadcuts through Anakeesta Formations
2. Acid precipitation effects
3. Balsam Wooly Aphid parasitism of Frasier Fir
4. European wild boar rooting
5. Research collecting and translocation of salamanders

The importance of better National Park Service (NPS) management was indicated by this study.

Specific questions addressed by this study were: are the species of salamanders found in stream environs of the GRSM, and the standing crop abundance and biomass of stream and streamside salamanders influenced by elevation, watershed, stream size, stream substrate, forest type, terrain slope, temperature, season, and water quality? If so, what is the strength of these associations and what inferences can be made concerning the relationships in the population from the examination of sample data?

Topography and Geology

Between the borders of central Tennessee and North Carolina in the southern Appalachians, lies the GRSM (figure 1) of approximately 2071 km^2. The mountains reach an elevation of 2025 m (6643 ft) on Clingmans Dome, second-highest point in the eastern United States; for 58 km (36 mi) the crest of this range remains more than 1524 m (5000 ft) above sea level. The lowest point in the Park - 271 m (888 ft) above sea level - is where Abrams Creek flows into Chilhowee Lake, near the westernmost extent of the area. The rocks that make up the GRSM are intermediate in age and degree of metamorphism between the younger Paleozoic sedimentary rock of the Appalachian Valley to the northwest and the ancient metamorphic and granitic rock of the Blue Ridge to the southeast (King et al. 1968). The bedrock of the area is characterized as follows:

1. metamorphic rocks of the Precambrian basement complex (over 1 billion years old),

2. sedimentary rocks of the later Precambrian which form the great majority of the Park (1 billion to 600 million years old), and

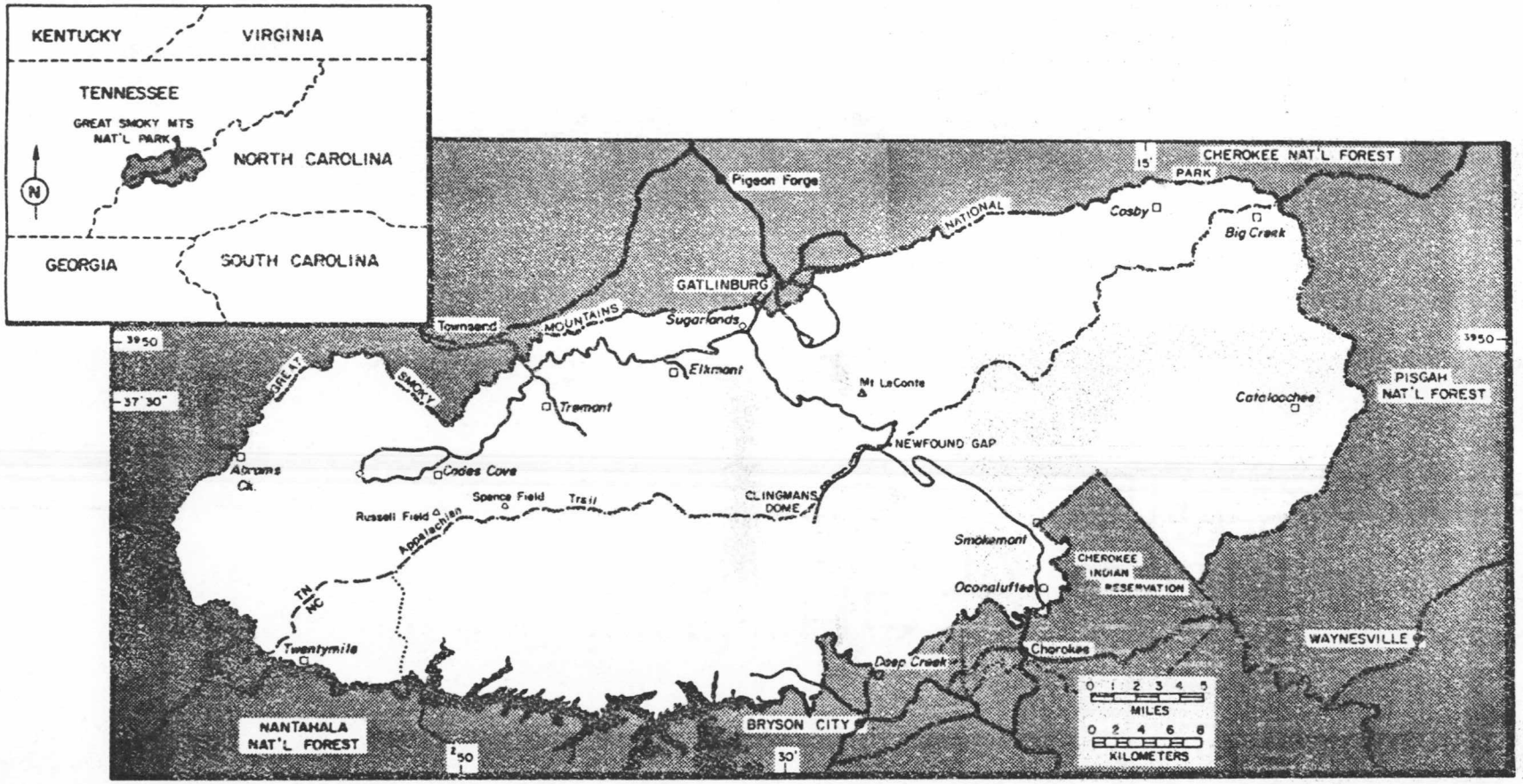


Figure 1. Location of Great Smoky Mountains National Park in the Southern Appalachians.

3. sedimentary rocks of the Appalachian Valley which were laid down in Paleozoic time (600 million to 300 million years ago) (King et al. 1968).

Although most of the bedrock is sedimentary in origin, it has been subject to folding, faulting, and low grade metamorphism. Seventeen geological formations in five major groups are recognized in the park (King et al. 1968): (1) Great Smoky group (all elevations, 60 percent of Park), (2) Anakeesta (high elevations, 8 percent of Park), (3) Walden Creek group (low elevation, 10 percent of Park), (4) Snowbird group (low elevation, 20 percent of Park), and (5) Knox group (low elevation, 2 percent of Park). The terrain of the GRSM, its soils, unconsolidated deposits, and details of terrain slope indicate a geologic history dominated by the drastic fluctuations of the ice-age climate. Although the mountains themselves were not covered with glacial ice, the climate at this latitude approached glacial conditions, and the mountaintops were occasionally above tree line (King et al. 1968). Deposits of debris that resulted from the associated erosion of hillsides during glacial intervals and the deeply weathered soils produced during the episodes of warm and humid interglacial climate are evident at many places. These climatic oscillations also controlled the flora and fauna. The complex process of adjustment of plants and animals to the prevailing climate is one of the factors that has produced their present great diversity.

Climate

In a region where the range in elevation is from 271 m (888 ft) to 2025 m (6643 ft) above sea level, climatic conditions vary considerably.

At Park Headquarters near Gatlinburg, Tennessee at 445 m (1460 ft), the annual precipitation is approximately 140 cm (55 in), but at an elevation of 1905 m (6250 ft) on Clingmans Dome the average annual precipitation is about 211 cm (83 in) (Tennessee Valley Authority 1974). Shanks (1954) reported that the precipitation at the base of the mountains is not far different from that of the adjacent valley area, but it increases sharply with elevation, and has increased by 50 percent by the time the lower limit of the spruce-fir zone is reached, at 1372-1524 m (4500-5000 ft). Altitudinal gradient affects temperature and precipitation patterns and therefore effects species distributions. The number of days of precipitation and the amount of precipitation per storm also increases with elevation (Wright et al. 1975). Likewise, the number of days between precipitation events decreases with increasing elevation. These precipitation characteristics in the GRSM and vicinity create the wettest area in the United States east of the North Cascades of Washington (Geragtly et al. 1973). Ironically, the driest area in the southeastern United States lies only about 80 km (50 mi) to the northeast of the Park in a rain shadow near Ashville, where precipitation averages less than 100 cm/yr (38 in/yr). Snowfall at low elevations in the Park is light, but like rainfall, it increases with elevation. Accumulations of more than 0.9 m (3 ft) of snow in the high spruce-fir forest are rare and short-lived.

Summer is ordinarily the season of greatest precipitation, whereas fall is usually the driest time of the year. There is a period of rapid warming during April and May; through October and November fast cooling takes place. Temperatures decrease with increase in elevation; Shanks

(1954) reported that this averages 2.23°F per 1000 ft (4.07°C per km). For the period 1922-1953, inclusive, at the Gatlinburg, Tennessee station near Park Headquarters, the average temperature for January was 39.9°F (4.39°C); for July, 74.6°F and the average annual temperature was 57.0°F (13.9°C) (Henry and Dickson 1963). In a summary of long-term climatological data of the GRSM and vicinity, Wright et al. (1975) reported that Gatlinburg's mean maximum is 70.5°F (21.4°C) and its mean minimum is 43.3°F (6.3°C). The highest temperature, 106°F (88°C), occurred in June 1936 and the lowest -13°F (-25°C) was recorded in February 1958. In comparison, Stephen (1969) reported that at Clingmans Dome the mean temperature is 42.8°F (6.0°C), mean maximum temperature 51.7°F (10.9°C), and mean minimum temperature is 36.7°F (2.6°C). Stephen (1969) further found that the lapse rate varies with season. The monthly lapse rate was greatest, 3.86°F (-15.6°C) in July and least, 1.28°F (-17.1°C) in December. Averaged over the growing season, this amounts to a climate that is 10-15°F (-17.8 to -9.4°C) cooler at higher elevations and results in a shorter growing season and a one-month delay in budbreaking conditions in the spruce-fir forest.

Broad trends in cloud cover seem apparent in the GRSM, with February, May, and October being the months with the least overall cloudiness (Wright et al. 1975). The percentage of clear and partly cloudy days decreases and the percentage of days with fog increases with elevation. The primary fog season at high elevations in the GRSM occurs between October and March, with a secondary maximum of fog cover occurring in July. During the fall months, a distinct zone or line of hoarfrost is visible on the vegetation above approximately 1310 m (4298 ft) when the

fog lifts. This zone of frost coincides roughly with the beginning of the spruce-fir forest in the GRSM and may influence the boundaries of this community, though this has not been proven. The same phenomenon has been observed in Vermont, where the spruce-fir forest and the hoarfrost appear above 762 m (2500 ft) elevation according to Wright et al. (1975). A general increase in the percent relative humidity with elevation is observed through the 1,524 m (5000 ft) level, while the mean monthly relative humidity averages over 80 percent for the Park as a whole (Wright et al. 1975). These relatively cool, moist conditions create a climatic regime ideal for salamanders.

Water Resources

The southeastern Appalachian Mountains intercepts moisture-laden winds from both the Atlantic Ocean and the Gulf of Mexico. These winds are cooled as they rise over the mountains with resulting precipitation. The region has the highest annual precipitation in the eastern United States. Precipitation in the Park as a whole averages 162 cm (64 in) annually, which amounts to some 890 billion gallons (3.37×10^9 m^3). Of this, about 500 billion gallons (1.89×10^9 m^3) are discharged from the Park during the year through the approximately 965 km (600 mi) of streams that drain the Park. The remaining 390 billion gallons (1.47×10^9 m^3) is either evaporated, transpired by plants, or seeps from the area through permeable rocks beneath the ground (McMaster and Hubbard 1970).

The streams in the Park flow outward from the central ridge line. All the streams are relatively small. None drain an area of more than 516

km^2, most are smaller than that above the point where they flow from the Park. The drainage system is characterized by a dense network of small streams flowing through steeply-sloping channels to the Tennessee River or its tributaries. Stream slopes average nearly 122 m (400 ft) per mile (196 m per km) of channel. The slopes increase to as much as 610 m (2000 ft) per mile (981 m per km) in the headwaters. Streamflow in the Park is variable with respect to both time and location. The amount of flow passing a particular point may vary by as much as a factor of 10,000 from minimum flow to maximum flood, and the low-flow yield of two basins of equal size may vary by a factor of 10 or more. Average flow varies greatly in the Park, ranging from a low of 0.039 cms in Shop Creek (Tabcat Watershed), to nearly 0.22 cms in Abrams Creek (McMaster and Hubbard 1970). Thus, some streams yield several times as much water per unit area as others, presumably because of variations in precipitation and evapotranspiration from place to place in the Park. Stream flow is usually lowest during the late summer and early fall, when rainfall is somewhat lower than usual and evapotranspiration rates are high. These streams are subject to flash flooding during summer thunderstorms and freezing during low winter stream flows. Although no permanent lakes are found within the boundaries of the GRSM, a few seasonally filled ponds which play an important role in amphibian reproductive cycles occur in and around Cades Cove.

With only a few minor exceptions, no streams in the GRSM drain areas outside the Park. Because of this, the streams are not affected directly by agricultural and commercial developments. Nevertheless, threats to the Park water quality do exist in the form of airborne

pollutants from outside the Park (Cogbill 1976; Herrmann et al. 1978; Larson et al. 1978; Wiersma et al. 1979; Mathews et al. 1979; Mathews and Larson 1980; Abernathy et al. 1984), management of historical areas within the Park (Mathews 1978; Bratton et al. 1980), development of new park facilities (Huckabee et al. 1975; Herrmann et al. 1976), exotic animals (Howe and Bratton 1976; Singer 1976; Huff 1977), and visitor use (Mathews et al. 1976; Baron and Mathews 1977; Bratton et al. 1979; Larson and Hammitt 1981).

CHAPTER II

LITERATURE REVIEW

Historical Studies - Salamander Ecology

The area which eventually became the GRSM attracted the interest of herpetologists long before it became a national park. Reports on the reptiles and amphibians of eastern Tennessee date back to observations by Rhoads (1895). Early salamander species descriptions were made by Cope (1870, 1889, 1900), Blatchley (1901), Brimley (1912), and Dunn (1916). With time, studies on their natural history and distribution were made by Dunn (1926), Pope (1924, 1928), and Noble (1927). Eventually species lists from various areas that later became the Park were compiled. McClure (1931) reported six salamander species of LeConte Creek, Weller (1931) compiled a list of 12 species for the area in general, and Necker (1934) reported seven species mostly from the vicinity of Greenbrier. The only comprehensive study of the herpetology of the GRSM to date is that of King (1939a), in which 70 species are described -- 25 salamander species. Four additional species were reported in an addendum five years later (King 1944). Huheey and Stupka (1967) compiled a survey of the amphibians and reptiles of the GRSM based upon a review of the literature and collections since King's publications, in which they list 23 species of salamanders in the Park. Several herpetofaunal checklists relating to the Park include those of Gentry (1955, 1956) for Tennessee and of DePoe et al. (1961) for North Carolina. A literature review of the reptiles and amphibians in eastern Tennessee, including distribution, habitat, and variation was summarized by Johnson (1958). Gentry (1955, 1956) and

Gentry et al. (1965) prepared an illustrated publication of the "Amphibians and Reptiles of Tennessee" which is still distributed by the Tennessee Wildlife Resources Agency, Nashville.

Since these early studies, numerous notes, articles, and publications on the salamanders of the GRSM and vicinity have occurred of too extensive a nature to cite individually here. Other biota of the Park and surrounding area have likewise been exhaustively studied. As part of a bibliographic project, a report entitled "Southern Appalachian Salamanders: An Indexed Bibliography, 1895-1932" was developed (Mathews and Pyle 1984). This bibliography provides a rapidly accessible, reference-coded source of written material relevant to salamander research in the GRSM and Southern Appalachians. Certain aspects of the literature treating salamander distribution is of importance to mention here, and thus a summarization follows.

Plethodontid Salamander Origin - Stream Salamander Evolution

The lungless salamanders of the family Plethodontidae comprise the largest and most diverse group of Park amphibians, and are the most abundant of the stream occurring species. Dunn (1926) has indicated the Appalachian highlands as the place of origin of the family Plethodontidae. This is the region where the most primitive forms are found, and where primitive species still occupy the original habitat niche--the mountain streams (Hairston 1949; Wake 1966). Since the close of the Paleozoic Era, the region has been humid continuously, and the mountain stream habitat has always been available (Braun 1955), permitting the retention of primitive forms, at the place of origin of the family. All authorities I

have reviewed in the literature to date agree that the Plethodontidae arose as forms specialized for existence in mountain streams (Wilder et al. 1920; Noble 1927; Martof 1962; Estes 1965; Wake 1966; Dunn 1926). Only those that have acquired the ability to live on land have been able to move any appreciable distance from this center; it is significant that all aquatic and semi-aquatic species are still confined to eastern North America. Likewise, the cove hardwood forest of the Southern Appalachians are similar to the widespread forest of Tertiary times (Cain 1943), which may explain the retention of certain primitive terrestrial salamander forms as well, given the homogeneity of forest cover over such a long time period.

The lungs of salamanders are hydrostatic rather than respiratory, and function in connection with the ypsiloid cartilage and muscles as a hydrostatic mechanism (Dunn 1926). This hydrostatic mechanism is obviously of advantage in still water, and of equal disadvantage in current. According to Dunn (1926) the primitive salamander was largely terrestrial, entering ponds to breed as do primitive members of unspecialized families of salamanders occurring in the Park today--the Ambystomidae and Salamandridae. These salamanders are prevalent during breeding periods in the small woodland ponds and limestone sinkholes that hold water for varying periods of time in Cades Cove (GRSM), though their range is much larger. Those forms which live or breed in mountain streams, where the swift current precludes leisurely swimming and makes crawling on the irregular bottom the safest mode of locomotion have tended to lose those hydrostatic mechanisms of their ancestors. In a current at all rapid, the buoyancy caused by the presence of lungs would be a decided

disadvantage, since the animal would be swept rapidly downstream, and would be unable thus to maintain its position even though it might habitually swim against the current. Lungless forms sink to the bottom when they cease active swimming, and however rapid the current, usually reach the bottom before being carried very far downstream. Once at the bottom, the protection from the current afforded by the shelter of the many substrate morphological irregularities enables the salamander to find its way upstream again (Wilder et al. 1920).

Horizontal Distribution: Aquatic to Terrestrial

Another objective criterion by which plethodontid salamander species have been studied is their horizontal distribution in a gradual progression from aquatic to terrestrial habitat (Hairston 1949). The maximum concentration of individuals at any point declines from 100 percent stream-dwelling in Leurognathus marmoratus through 78.6 percent for Desmognathus quadramaculatus and 54.4 percent for Desmognathus monticola to 22.5 percent in Desmognathus ochrophaeus carolinesis. Thus far up the series, the tendency towards specialization for a more terrestrial habitat has not carried with it any marked tendency towards exclusion from the original aquatic mode of life. This exclusion apparently does appear in Desmognathus wrighti, which generally occurs far from streams in the spruce-fir forest of the Park according to Hairston (1949). An important habitat partitioning was recognized through this study--the non-inundated part of the stream bed. More Desmognathus monticola were found in this location than in all others combined. In the stream bed habitat the humidity is higher and the

temperature lower than a short distance away in the forest. Organ (1961) found close agreement with the findings of Hairston, indicating the following transition during the summer: 64 percent of the Desmognathus quadramaculatus were in the streams, 88 percent of the Desmognathus monticola were in the stream bank, 83 percent of the Desmognathus ochrophaeus carolinesis were in the forest, and 100 percent of the Desmognathus wrighti were in the forest. In addition, the sampling transects revealed that Desmognathus fuscus is a stream bank form like Desmognathus monticola, with 72 percent of the specimens coming from this habitat. Seasonal variations in the ecological distribution of transformed desmognathine individuals was studied by Organ (1961). In the fall, the horizontal distribution showed the same aquatic to terrestrial trend seen in the summer. Desmognathus monticola was slightly less concentrated in the stream banks than it had been in the summer. Desmognathus fuscus was not found in the forest during the fall and was more often in the water than in the summer. Desmognathus ochrophaeus carolinesis showed a decrease in the forest and an increase in the streams and stream banks. In the spring, the horizontal distribution of most of the species was more similar to that of the fall than to that of the summer. Desmognathus monticola and Desmognathus fuscus showed a greater concentration of individuals in the water than had been seen in the other seasons. Desmognathus ochrophaeus carolinesis and Desmognathus wrighti both showed a decrease in the forest and an increase in the streams and stream banks. The horizontal transects indicated that Desmognathus ochrophaeus carolinesis and Desmognathus wrighti moved from the forest into streams and stream

banks, presumably for winter hibernation in underground seepage areas. Thus, Organ (1961) observed that Desmognathus wrighti is not so terrestrial in habitat as had been suggested previously by Hairston (1949).

Most studies of Southern Appalachian stream amphibian communities have concentrated on a single genus, Desmognathus, which as previously mentioned comprises a series of aquatic to terrestrial species showing increasing reduction of the larval phase (Organ 1961). Appalachian stream communities contain species other than Desmognathus. Eurycea bislineata is frequently the most abundant species, and Leurognathus marmoratus, Pseudotriton ruber, and Gyrinophilus porphyriticus are often common. For example, in two stream communities sampled monthly for one year Bruce (1982) recorded a total of seven species (six in each stream); five had larval periods exceeding one year, and were represented by multiple age classes in the samples.

Distribution in Streams: Elevation

Vertical distribution in salamander species is also characterized by various forms of ecological divergence (Grobman 1944; Hairston and Pope 1948; Hairston 1951; Jaeger 1971). For instance, Hairston (1949) observed that at high elevations (1372 m/4500 ft and above) Desmognathus ochrophaeus carolinesis is indiscriminate in its choice of habitat, while below this elevation it is bound to the vicinity of streams. He also found differences in habitat selection by this species (and others) in virgin and second growth forest at different elevations. In the second growth forest, it begins to spread out from the stream at 1372 m (4500 ft)

while in the virgin forest the lateral spread begins at 1066 m (3500 ft); which he suggests involves an environmental influence--the increase in humidity and decrease in temperature from second growth to virgin forest. Elevational abundance patterns and habitat preferences at various elevations have been reported on by King (1939a), Huheey (1966), and Organ (1961) among others. As an example, Huheey (1966) reports that Desmognathus quadramaculatus is more common at lower elevations, while it sometimes occupies springs and trickles at higher elevations. Desmognathus monticola is also more common at lower elevations with 66 percent of his specimens occurring between one and two thousand feet, and over 88 percent between one and three thousand feet; it is always associated with water and is widely distributed over the Park. Desmognathus ochrophaeus carolinesis ranges over a wider elevational range than any other desmognathine in the Smokies, and utilizes a wide range of habitats according to Huheey (1966). He reports that it is largely terrestrial at higher elevations. Nicholls (1949) believed that Desmognathus fuscus enters the mountains only through finger-like extensions of its range along the larger river valleys. Organ (1961), however, reported that his vertical transect studies at different seasons in the Balsam Mountains of Southwest Virginia failed to disclose any significant shift in the vertical distributions of the five species of Desmognathus. The only vertical seasonal movement he noted occurred when the aquatic and semi-aquatic species apparently followed the headwaters of the streams down the mountain after the stream levels dropped slightly during a dry period in the fall, a movement which did not exceed 31 vertical meters (100 vertical feet).

Desmognathine salamanders also differ from one another with respect to reproductive maturity which is delayed in high elevation populations relative to lower elevation populations, and in low elevation woodland populations relative to low elevation rockface populations (Organ 1961; Tilley 1973). Tilley (1973) also reports that high elevation woodland populations of Desmognathus ochrophaeus also exhibit higher adult growth rates, which in turn enhances female age-specific fecundities. Numerous investigators have reported on the size cline in desmognathine salamanders (Reynolds 1959; Huheey 1966; Highton and Henry 1970; Tilley 1973; Danstedt 1975; Hairston 1983). This is especially characteristic of Desmognathus ochrophaeus carolinesis, and carries with it some interesting implications. According to Hairston (1949) it represents a direct application of the Bergmann Rule that cold-climate members of a species tend to be larger than warm-climate ones. The difficulty is that this rule is supposed to apply inversely in the case of poikilothermic animals, whereas here the application is direct: the high elevation (cold-climate) specimens are larger than the low elevation (warm-climate) ones. In this instance, then, he believes that some factor is evidently supervening to reverse the expected condition. At high elevations in these mountains, factors other than temperature are characteristic. Two of these are forest type and a much greater rainfall. The difficulty with postulating that the vegetation is involved in the establishment and maintenance of size difference is that size change is gradual, whereas the vegetation change is relatively abrupt. The general moisture conditions, however, are gradual in their change. Moreover, moisture is sufficiently important in the lives of salamanders to reverse

the effect of temperature according to Hairston's (1949) assessment of distributional trends.

Biosystematics

Most of the biosystematic work that has been done in the Park has focused on two genera of salamanders, Plethodon and Desmognathus. Highton (1972) revised the North American salamanders of the genus Plethodon including those in the Park. In a subsequent publication Highton and Webster (1976) described another species on the western slopes of the Park--Plethodon serratus. Tilley et al. (1978) studied genetic differentiation in salamanders of the Desmognathus ochrophaeus complex using electrophoresis of general proteins, serum proteins and enzymes, which resulted in the finding of two reproductively isolated species which are broadly sympatric, Desmognathus ochrophaeus and Desmognathus imitator, which also differ in elevational distribution and microhabitat preference. As a result of electrophoretic and other studies, Tilley and Schwerdtfeger (1981) and Tilley (1981) have described a new species of dusky salamander, Desmognathus santeetlah, which they state appears to hybridize with Desmognathus fuscus in the Cosby Creek drainage on the northwestern margin of the Park. One salamander previously considered an endemic subspecies of the Park (Plethodon jordani jordani) was studied in detail by Highton and Henry (1970) which resulted in the finding that the red-cheeked form of Plethodon jordani was not a subspecies, but rather a color morph distributed in two isolates in the Park (the Gregory Bald isolate and the Great Smoky central isolate). A long-term ecological study with relevance to the biosystematics of the

genus Plethodon was conducted by Hairston (1951, 1980a, 1983), in which he reported no evidence that vegetation influenced the distribution of either Plethodon jordani or Plethodon glutinosus in the Park. He concluded that interspecies competition was responsible for the abrupt vertical limits of distribution he found in the two species.

The taxonomic status of plethodontid salamanders in the Southern Appalachians and GRSM remains an amorphic issue at present due to the considerable amount of regional differentiation that occurs in size, color pattern, reproductive isolation, hybridization along narrow zones of contact with variable amounts of gene exchange, and the fact that the recognition of species by the criterion of amount of genetic differentiation (electrophoresis technique) is somewhat arbitrary. In terms of the present literature there are 25 species of salamanders in the GRSM. Two of these are considered "In Need of Management" in Tennessee according to the Tennessee Wildlife Resources Commission Proclamation No. 75-15 (18 June 1975): Cryptobranchus alleganiensis alleganiensis and Hemidactylium scutatum.

Diversity, Density, Biomass, Nutrient Cycling

Salamanders are found in all the north temperate parts of the world including Europe, temperate Asia and North America, as well as North Africa, the mountainous regions and low elevation rainforest of South America, south at least to Bolivia, and one species is even found in Argentina. However, the United States contains more species than any other part of the world, while the Southern Appalachians and in particular the GRSM exhibit a higher concentration of both species and individuals

than any other part of the United States (Brimley 1944; Highton 1972). Seven families are found in the United States, five of which occur in the GRSM. They have invaded almost every available habitat encompassing aquatic, terrestrial, arborial, cave-dwelling, cliff-dwelling, and burrowing forms. Population estimates of salamanders are relatively rare in the literature, and most values are based on scanty evidence. Spight (1967) compiled data on terrestrial and streamside salamander population estimates and found that salamander densities of several species ranged from 0.0025 to 1.5 salamanders per m^2. A study of the role of salamander populations in ecosystem function was conducted from 1970 through 1973 in Hubbard Brook Experimental Forest, New Hampshire (Northern Appalachians). Salamanders are reportedly unimportant as agents for nutrient input or output to the forest ecosystem due to their restricted home range (Burton and Likens 1975a). The importance of salamanders in nutrient cycling may be in their role as top predators in the detritivore food web and in the maintenance of diversity of prey populations (e.g., stream macroinvertebrates). Salamanders were found to be much more efficient than birds and mammals at converting ingested energy into their own biomass (50-80 percent). Salamander tissue is also higher in protein content than that of birds and mammals and represents a source of high-quality energy for potential predators. In another study at the Hubbard Brook Experimental Forest, Burton and Likens (1975b) studied the size of the salamander populations and their biomass. Their findings are important in an ecological sense--there are more salamanders at Hubbard Brook than either birds or small mammals. Also, the biomass of salamanders is higher (2.6 times higher wet weight, 1.9 times higher dry

weight) than the biomass of birds during the peak at breeding season, and is approximately equal to the biomass of mice and shrews. The biological implications of these findings are significant as most ecologists have ignored amphibians in ecosystem energy flow and nutrient studies while considering birds and mammals in detail. Woodall and Wallace (1975) made similar findings in four small watersheds of the Southern Appalachian's Coweeta Experimental Forest and Hydrologic Station. Crayfish and salamanders were responsible for most of the standing crop biomass in the detritivore and predator mineral pathway compartments, respectively, and also account for most of the fluxes in their compartments. They are important in the nutrient flow of small streams because they form a sink in the remineralization process. On the scale of the ecosystem, the plethodontids have been shown to be an ecologically important group of animals in the GRSM. Plethodon jordani and Plethodon glutinosus, for instance, together constitute a biomass of up to 0.41 g/m^2 (4100 g/ha) according to Hairston (1982). This is more than all mammals combined, and it is probable that all salamanders combined contain more than half of the vertebrate biomass in the Southern Appalachians. The long life and exothermic nature of this group make for an unusually slow turnover, and they appear to act as a stabilizing factor keeping ecological processes more nearly in a steady state than would be the case without them (Hairston 1982).

National Park Service Policies, Threats, Management Goals, Research Perspectives

The GRSM was formally established 15 June 1934 (48 Stat. 964), and now celebrates 50 years in the National Park system. How secure are the salamander species and resource systems which support them within the bounds of the Park? What lessons in the science of preservation ecology have we learned in 50 years? Attempts to answer these questions pervade the most fundamental of conservation issues--the relative success or failure of the Park's management system in "protecting nature." The retention of native species and protection of ecosystems are basic measurements of this issue. The diversity of salamander species, other natural communities, and forested ecosystems within the GRSM certainly sheds a favorable light on Park Service's system of preservation. However, the issue is more complex than a casual glance would make one suspect. Even after the legal protection given park lands, ecological change continues to affect species and ecosystems. Changes vary from natural to human-caused, from beneficial to detrimental, and from manageable to impossible to manage (White and Bratton 1980). These changes in the GRSM range from natural (succession after prepark logging) to directly man-caused (visitor impacts); from beneficial (landslides that seem to maintain rare plant habitat) to detrimental (the loss of the American chestnut); and from manageable (fire) to impossible to manage (landslides). The spread of exotic organisms has been particularly damaging--especially the chestnut blight, balsam woolly aphid, and European wild boar (White 1980). Fire management continues to be a debated issue, but the dominant policy has been fire suppression. Prior

to the establishment of the Park, many top predators were eliminated and have not been reintroduced. Recreational impacts have increased. Road cuts through the highly pyritic and sulfide rich Anakeesta geologic formation in the Park has caused major loss of stream habitat for fish and salamanders. Poor sport fishery management policies of the past resulted in the probable extinction of the Smoky Madtom from Abrams Creek. Broad and unrelated as these ecological perturbations may appear, most and probably all of them affect the distribution of salamanders in the GRSM, several of which are discussed later in the text. Air pollution, particularly acid rain, has become a major concern. By the Act of 25 August 1916 (39 Stat. 535) the National Park Service was established to promote and regulate the use of the Federal areas known as National Parks . . . "which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Beyond this broad mandate has been the finding that as each park is unique, so are the individual management needs of each park. To this end the Service developed management policies tailored to its preservation philosophy (U.S. Department Interior 1978). These management policies dictate that the Service will gather, compile, store and analyze adequate natural, historic, social-economic, and demographic data relevant to the planning and resource management needs of each individual park. The preservationist legacy, while idealistic and philosophically attractive, has contributed to a lack of firm leadership in reserves by biologist and managers. In our relatively short term experiences in dealing with the

practicalities of resource management in parks, it is evident that dealing with ecological change requires statement of preservation goals, priorities, and clear policy on key issues; in addition, resource inventory, monitoring, and management-oriented research are required (White and Bratton 1980). Relative to the GRSM, a Wilderness Recommendation has been adopted to assure that 76 percent of the parklands perpetuate in an undeveloped state (U.S. Department Interior 1974). This land supports a remnant of this country's Tertiary forest that once extended almost unbroken from the Atlantic Ocean to beyond the Mississippi River, and will serve a scientific value as a baseline to measure the effects of man's manipulation of his environment. Such adoption led to the designation of the GRSM as a Biosphere Reserve, and an assessment and evaluation of information base and science activities in the Park by the Southern Appalachian Research/Resource Management Cooperative (SARRMC) in cooperation with Western Carolina University (McCrone et al. 1981). The National Park Service published a report entitled "State of the Parks--1980: A report to the Congress" (U.S. Department Interior 1980), which identified specific threats to the resources of individual parks, the sources of these threats, and the particular resources endangered by such threats. The GRSM reportedly ranks high among the parks facing a perplexing multitude of broad spectrum resource threats. The "State of the Parks" study found that more than 50 percent of the reported threats were attributed to sources or activities located external to the parks. A follow up study on this report specific to the GRSM entitled "Impacts and Influences on the Great Smoky Mountains National Park: An Annotated Bibliography with a Discussion and Review of Selected Findings,

Recommendations, and Conclusions" was published by the National Park Service (Carpenter 1982). The means by which these threats, impacts, influences, and other developments in the GRSM are proposed to be dealt with are discussed in the "General Management Plan, Great Smoky Mountains National Park" (U.S. Department Interior 1981) and "The Final Environmental Impact Statement, Great Smoky Mountains" (U.S. Department Interior 1982). Major developments within the Park as described in these publications include constructing new facilities at 16 locations in the Park, 47 miles of new roads, 24 miles of hiking trails, and 58 miles of bicycle paths over the next 10-15 years. Obviously, sources of impact of internal origin will continue within the GRSM, along with those of an external nature of which no management action has been designated. Each of these developments represents a habitat alteration and further intrusion of man into wilderness terrain that undoubtedly will affect the distribution and well being of salamanders among other plant and animal species. The effect of such perturbations is scarcely considered in the Park's Environmental Impact Statements and General Management Plan, and probably should be given more attention prior to such major developments and construction activities within the Park given the importance of the resource and the limited terrain remaining unspoiled.

CHAPTER III

METHODS

A comprehensive survey of stream and streamside-dwelling salamanders in 16 of the 28 watersheds in the GRSM was conducted in 1978. The watersheds selected represent a cross section of the variable size, topography, gradient, geology, and ecological features represented. The watersheds selected were as follows (figure 2):

1. Cosby Creek
2. Middle Prong Little Pigeon River
3. Dudley Creek
4. West Prong Little Pigeon River
5. Little River
6. Middle Prong Little River
7. Abrams Creek
8. Panther Creek
9. Parson's Branch
10. Eagle Creek
11. Hazel Creek
12. Noland Creek
13. Deep Creek
14. Oconaluftee River
15. Straight Fork
16. Cataloochee Creek

Sample stations were selected throughout each watershed on the basis of elevation and stream order. Relative to the size and elevational range of

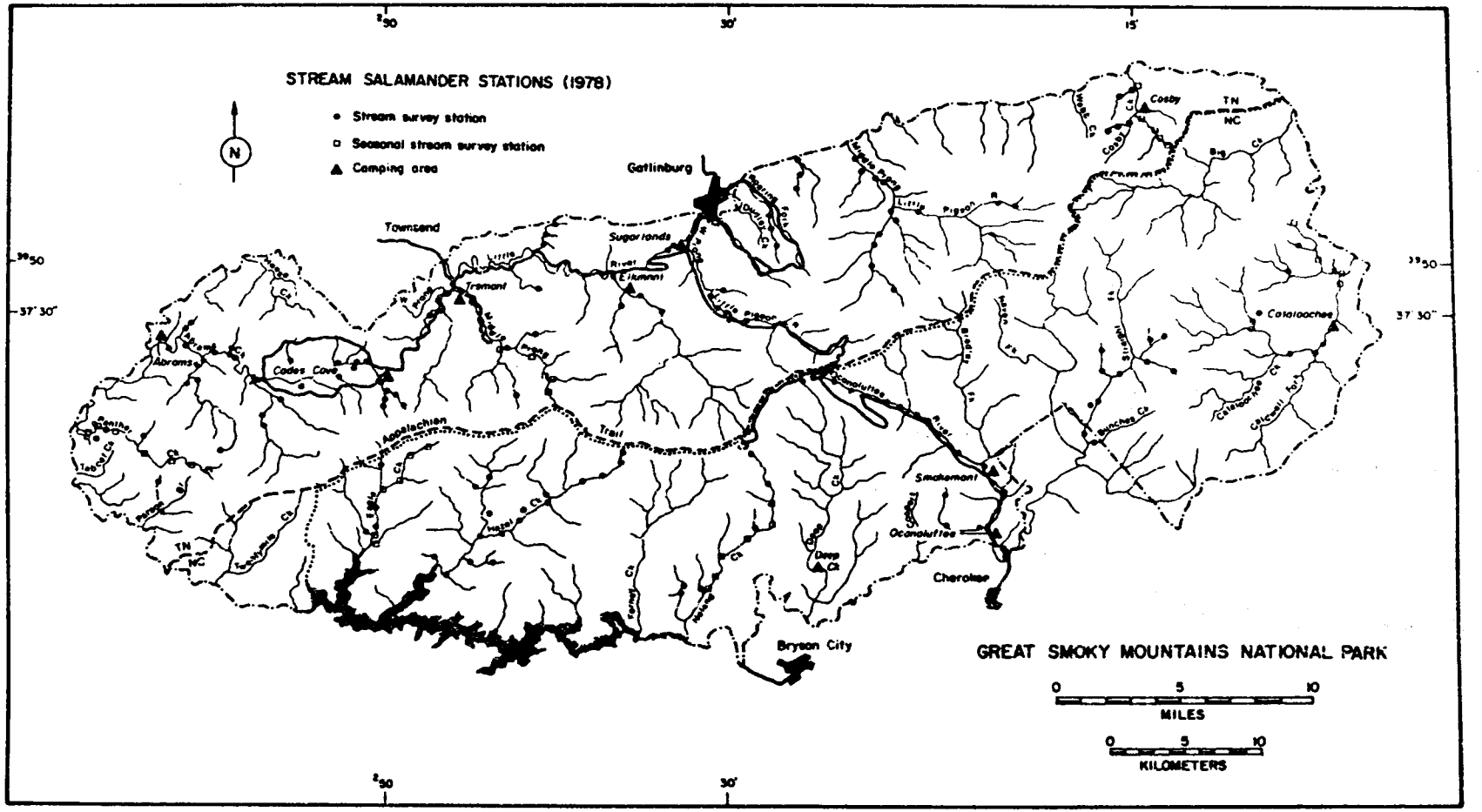


Figure 2. Watersheds of the Great Smoky Mountains National Park indicating stream sample station locations.

each watershed, a low, intermediate, and high elevation series of stations were assigned. The larger the size and greater the range of elevation of drainages in the watershed, the more stations assigned. These stations within drainages were, in addition, subdivided into size categories by stream order: first, second, third, and fourth order streams at the various elevations. Of course, not all stream orders occur at every elevation. Fourth order streams, for instance, occur only at lower elevations. Stream order is a measure of a stream in the hierarchy of tributaries (Hynes 1972). The stream order system of station distribution was used as per recent findings evaluating the extrapolation of lotic theory to stream orders in running waters (Cummins 1975). Station locations were recorded on 7.5 minute topographic, 1:125,000 scale U.S. Geologic survey maps. A series of site parameters were taken at each station (table 1) giving data on base information (e.g. watershed, elevation, date), environmental factors (e.g. water temperature, stream order, volume flow), stream bottom substrate type and composition, and chemical parameters. Overstory (forest cover, table 2) and understory (shrub cover, table 3) vegetation was also recorded at each station. The stream bottom substrate was categorized as to type(s) present (i.e., boulders, rocks, gravel, sand, salt, and bedrock) and percent composition. Before entering the stream and disturbing the water and sediments, water samples were taken in sterile polyethylene containers (1-liter unpreserved and 125-ml with nitrate stabilizer).

A General Oceanics digital flow meter, model 2030, was used for stream flow (ft^3/sec) and velocity (ft/sec) at 0.6 depth. Stream depth and width were taken along each of three transects along a 20-meter sample

Table 1. Site Codes.

I. Base Information

1 - Watershed
2 - Drainage
3 - Subdrainage
4 - Branch
5 - Sub-branch
6 - Elevation
7 - Quadrangle
8 - Date
9 - Time

II. Environmental Information

1 - Station number
2 - Latitude coordinate (UTM)
3 - Longitude coordinate (UTM)
4 - Precipitation
(None - 1, rain - 2, snow - 3, hail - 4, sleet - 5)
5 - Cloud cover
6 - Wind
(None - 1, light - 2, moderate - 3, strong - 4)
7 - Water temperature (°C)
8 - Air temperature (°C)
9 - Average stream width (meters)
10 - Average stream depth (centimeters)
11 - Stream order (1 - 4)
12 - Stream velocity (ft. per sec. and cm per sec.)
13 - Volume flow (cu. ft. per sec. and cu. m per sec.)
14 - Terrain slope (0 to >15 percent)

III. Substrate Information

Substrate type and Percent composition

1 - Boulder (percent to nearest 5 percent) - Percent
2 - Rock (percent to nearest 5 percent) - Percent
3 - Gravel (percent to nearest 5 percent) - Percent
4 - Sand (percent to nearest 5 percent) - Percent
5 - Silt (percent to nearest 5 percent) - Percent
6 - Bedrock (percent to nearest 5 percent) - Percent

IV. Chemical Parameters

1 - Dissolved oxygen (mg/l)
2 - pH (standard units)
3 - Conductivity (umhos/cm)
4 - Turbidity (JTU)

Table 1 (Continued)

5	- Alkalinity (mg/l as $CaCO_3$)
6	- Acidity (mg/l as NaOH)
7	- Hardness (mg/l as $CaCO_3$)
8	- Nitrate (mg/l as NO_3)

Table 2. Overstory Vegetation (Forest Cover) Codes.

The following lists the canopy types recognized for this survey. The classification is based largely on Whittaker's (1956) paper and on the field experience of the investigator. A three-level computer classification was used to allow easy sorting by either successional stage, major forest type, or specific forest type. All classifications are by dominance, and successional status is estimated from the size of the trees and the known history of the area.

I. Successional Codes

1 - Virgin
2 - Mature
3 - Second growth (logged)
4 - Early successional (usually after farming or fire)

II. Forest Type Codes

1. Spruce-Fir (Yellow birch)

1-1 Red Spruce - Frasier Fir (Yellow birch)
1-2 Red Spruce - Frasier Fir - Hardwood or Hemlock
1-3 Yellow birch (mature)
1-4 Heath Bald (Rhododendron or Mountain Laurel)

2. Northern Hardwoods

2-1 Beech (Gray beech gap)
2-2 Mixed northern hardwoods (Sugar maple, Beech, Yellow birch, Buckeye, Serviceberry)
2-3 Successional northern hardwoods (Yellow birch, Fire cherry, Red maple)

3. Mesic types

3-1 Mixed cove hardwoods (Tulip tree, Silverbell, Buckeye, Basswood, Beech, Sugar maple, White ash, Birches, Oak, Magnolia)
3-2 Hemlock - hardwood cove (same species as 3-1 with Hemlock co-dominant)
3-3 Mesic hardwood flats (Tulip tree, Sweet gum, Sycamore, Birch, Walnut)
3-4 Successional cove (Tulip tree, Silverbell, Red maple, Fire cherry)
3-5 Mixed sub-mesic hardwoods (Silverbell, Black gum, Magnolia, Tulip tree, predominance of Oak)
3-6 Tulip tree (dominated by small Tulip trees with successional associates)
3-7 Hemlock cove

Table 2 (Continued)

4. Xeric types

   4-1 Mixed subxeric hardwoods (Red oak, Hickories, Black locust, and some more mesic associates)
   4-2 Mixed oak (Chestnut oak, Red oak, Black oak, White oak, Sourwood, Black gum)
   4-3 White oak
   4-4 Mixed oak - Pine (including Red maple, Pine, and Sourwood - Pine, etc.)
   4-5 Mixed Pines (Virginia, Pitch, Table Mountain)
   4-6 White Pine

5. Balds, burn scars, pastures

   5-1 Grassy bald
   5-2 Burn scar
   5-3 Pastures, old fields, and artificial clearings
   5-4 Early successional shrubs (Fire cherry, Serviceberry, Hawthorn, Blueberry)
   5-5 Early successional heath (mostly ericads)

Table 3. Understory Vegetation (Shrub Cover) Codes.

1. Spruce-fir and high elevation

   1-1 Bramble-sedge-herb including Rubus and sedge and grass mixes
   1-2 Vaccinium-dominated including Vaccinium herb mixes and Viburnum types
   1-3 Spruce-fir seedling
   1-4 Rhododendron and mixed heaths
   1-5 High elevation herb including fern or moss dominated, Solidago glomerata, etc.

2. Heath balds

   2-1 Mixed heath, no trees

3. Mesic - submesic

   3-1 Mesic herbs including Laportea, Cimicifuga, ferns, etc.
   3-2 Submesic herbs including more composites, dry type sedges, New York fern, etc.
   3-3 Rhododendron, mesic heaths
   3-4 Dog hobble
   3-5 Hemlock sapling or Hemlock shrub
   3-6 Deciduous shrub sapling including Cornus-dominated

4. Xeric - subxeric

   4-1 Vaccinium-dominated including Vaccinium - sapling, Vaccinium-Smilax, etc.
   4-2 Sapling dominated including xeric shrubs like azalea
   4-3 Mountain laurel with associates
   4-4 Rhododendron - laurel
   4-5 Rhododendron with associates
   4-6 Xeric herbs

5. Early successional

   5-1 Grass - sedge
   5-2 Bramble - shrub - sapling

section, as well as at the middle, left, and right sides of the stream. Streams with variable morphology or fourth order size in addition were given flow/velocity measures at five points along each transect. Thus, such measurements were taken at from 9-15 points in each stream sample section in order to insure accuracy. These measurements were taken after salamander removal in order not to disturb their distribution within the stream.

The standard stream length sampled for salamanders was 20 meters. Sections were measured using meter tape. A Turtox long-handled bottom net (46 x 25.4 cm) with a mesh size of 1,270 microns was utilized for capturing stream-dwelling salamanders. Sampling was initiated at the lower (downstream) end of each station and then proceeded upstream so that disturbed sediments would not interfere with water clarity and stream habitat during sampling. The entire stream section was thus sampled along a systematic series of transects in all available habitats at each station. Where pool and riffle areas were both present in stream sample areas, the station was segregated into half pool and half riffle area. Most first order streams are not segregated into pool/riffle areas, but rather exist as a uniform run. Depending on flow and gradient, some second order and all third and fourth order streams had pool/riffle components. Salamanders captured were placed into plastic containers lined with moss for maintenance of body moisture and transported live to the laboratory. Streamside associated salamanders were also collected by hand or small dip nets at each station along each side of the 20 meter section for a width of three meters (60 m^2 per side, 120 m^2 total per station). Rocks, logs, leaves, and all other habitat components observed

were sampled from, and then returned to their natural position in order to effect a minimal impact sampling system. Streamside salamanders were transported to the laboratory in an identical manner as the stream salamanders. If more than three individuals of any species were found in either stream or streamside sites within a particular size class (i.e., larval, subadult, adult), then those were measured and weighed in the field using a combination of Ohaus model 8011/250-gram dial spring scale, Pescola 100-gram scale, and Pescola 50-gram scale depending upon which was most appropriate. Following other observations made on each salamander which are to be discussed, they were released where captured.

Salamanders returned to the laboratory were fixed in 10 percent buffered formalin with 1 percent glycerine for 24 hours, washed in water, and preserved in 70 percent ethyl alcohol. Each salamander was individually tagged and placed in the herpetological collection at the Uplands Field Research Laboratory, GRSM. The snout-vent length (mm), total length (mm), and wet weight (mg using a Mettler top-loading balance, model PN1210), tail autonomy (extracted, notched, regenerating, normal), and sex (male or female) were determined for each salamander before preservation (table 4). These observations were made in the field for those salamanders subsequently released. Abundance and biomass determinations were then computed for each station by species, stream-dwelling, streamside, and total standing crop in number (abundance) and weight (biomass) per hectare.

Six watersheds were surveyed seasonally in the same manner to determine the dynamics of changes in species composition, density, and biomass. The six watersheds selected were a subset of the overall survey: Panther Creek, Noland Creek, Eagle Creek, Catallochee Creek, Cosby Creek,

Table 4. Salamander Species of Great Smoky Mountains National Park.

I. Species

Leurognathus marmoratus, Shovel-nosed Salamander
Desmognathus quadramaculatus, Black-bellied Salamander
Desmognathus ochrophaeus carolinesis, Blue Ridge Mountain Salamander
Desmognathus imitator, Imitator Salamander
Desmognathus wrighti, Pigmy Salamander
Desmognathus fuscus, Dusky Salamander
Desmognathus monticola monticola, Appalachian Seal Salamander
Desmognathus santeetlah, Santeetlah Salamander
Plethodon dorsalis dorsalis, Zigzag Salamander
Plethodon glutinosus glutinosus, Slimy Salamander
Plethodon jordani, Appalachian Woodland Salamander
Plethodon serratus, Southern Redback Salamander
Hemidactylium scutatum, Four-toed Salamander
Gyrinophilus porphyriticus danielsi, Blue Ridge Spring Salamander
Pseudotriton montanus diasticus, Midland Mud Salamander
Pseudotriton ruber schencki, Black-chinned Red Salamander
Aneides aeneus, Green Salamander
Eurycea bislineata wilderae, Blue Ridge Two-lined Salamander
Eurycea longicauda longicauda, Long-tailed Salamander
Eurycea longicauda guttolineata, Three-lined Salamander
Cryptobranchus alleganiensis alleganiensis, Hellbender
Necturus maculosus maculosus, Mudpuppy
Ambystoma opacum, Marbled Salamander
Ambystoma maculatum, Spotted Salamander
Notophthalmus viridescens viridescens, Red-spotted Newt

II. Individual Character Codes

1 - Snout - vent length (millimeters)
2 - Total length (millimeters)
3 - Wet weight (grams)
4 - Sex (Male - 1, female - 2)
5 - Tail present (Yes - 1, no - 2)
6 - Tail character (Regenerating - 1, nipped or notched - 2)

and Middle Prong Little River. These watersheds were chosen due to heterogeneity among them in size, forest type, terrain slope, and their relatively even spatial distribution within the Park. Stations sampled were in the same general location as in the overall survey and thus yielded a comparative data base on the same criteria established previously, except that actual sample sites were juxtaposed slightly (20-30 m) so that previous sample site disturbance would not be a factor in salamander density.

In order to assess the relative catchability of the kick net technique on stream-dwelling salamanders of varying stream orders, a series of very intensive collections were conducted. Following standard sampling procedure in streams, a much more thorough technique was utilized. In addition, block nets (1/16 inch square mesh) were positioned at each end of the stream sample section to prevent migrates to or from areas outside the sample perimeter. Also, the sides of stream sections were blocked with seine nets (1/16 inch square mesh) at the water line on the stream bank to prevent escapement. Thus, the area was contained for purposes of these tests. Every rock and boulder was removed from the sample section, and multiple kick net transects and backpack electroshocking techniques were used in order to capture salamanders evading normal capture technique. An escapement factor was thus developed for application to abundance and biomass estimates in order to improve accuracy. In a similar manner, the streamside salamander population was contained with nets and intensive sampling technique was effected in order to derive an escapement factor. Since stream order (size) does not affect the dimension of streamside sample plots, those areas remained of constant size.

Temperature, discharge, pH, specific conductance, and dissolved oxygen measurements were made in the field, and water samples were collected in sterile 1-liter polyethylene containers for laboratory analysis. Separate 125-ml samples for nitrate determination were collected and preserved with phenylmercuric acetate (American Public Health Association 1975). Laboratory analyses were conducted as soon as possible after leaving the field--no samples were analyzed more than a week from collection. Specific conductance and pH were remeasured under laboratory conditions. Field and laboratory methods used were as follows:

pH	Orion Model 407A Specific ion/pH meter
Conductivity	YSI Model 33 Salinity-conductivity-temperature meter
Alkalinity	Titration of 50-ml sample with 0.02 N H_2SO_4 to Bromocresol Green-Methyl Red endpoint (American Public Health Association 1975)
Acidity	Titration of 50-ml sample with 0.02 N NaOH to Phenolphthalein endpoint (American Public Health Association 1975)
Dissolved Oxygen	YSI Model 54A Dissolved oxygen meter
Hardness	pH adjusted to 10.0 Titration of 50-ml sample with 0.02 N EDTA to Eriochrome Black T endpoint (American Public Health Association 1975)
Turbidity	HF Instruments Model DRT-100 nephelometric turbidimeter
Discharge	Current and flow measurements using General Oceanics Model 2030 digital flow meter
Nitrate	Orion 407A specific ion meter with nitrate electrode

CHAPTER IV

RESULTS

Introduction

Summary statistics (i.e., mean, standard deviation, minimum and maximum of numeric variables) of survey data are presented in table 5. The total number of stream-dwelling salamanders per hectare (ha) had a mean value of 1,298.2 (0.153/m^2) ranging from 0 to 9,383.8 (1.880/m^2), while that of streamside-dwelling salamanders was much lower at 491.4 per hectare (0.050/m^2) ranging from 0 to 3,669.8 (0.367/m^2). On a biomass basis, stream-dwelling salamanders had a mean value of 1,871.9 grams per ha (0.250 g/m^2), ranging from 0 to 9,223.6 (2.379 g/m^2), while again streamside-dwelling salamanders had a mean value much lower at 781.5 grams per ha (0.078 g/m^2), ranging from 0 to 5,883.0 (0.581 g/m^2). When abundances were computed together for stream and streamside-dwelling salamanders, the mean value was 744.0 salamanders per ha (0.074/m^2) ranging from 0 to 13,053.6 (2.247/m^2); while weight per ha had a mean value of 1,296.9 grams per ha (0.130 g/m^2), ranging from 0 to 15,106.6 (2.960 g/m^2). Stream sample sizes ranged from 0.0002 to 0.100 ha, with a mean of 0.012 ha, including first through fourth order streams. The elevations sampled ranged from 274.3 m (900 ft) to 1621.5 m (5,320 ft), with a mean of 803.7 m (2,636.7 ft). Although streams are found above 1621 m in the GRSM, they are intermittent (usually dry during the summer except after storms) and thus were not sampled.

Table 5. Summary Statistics (i.e., mean, standard deviation, minimum and maximum of numeric variables) of survey data. Number observations = 1719.

Parameter	Mean	Standard Deviation	Minimum	Maximum
Elevation, m	803.7	277.2	274.3	1,621.5
ft	2,636.7	909.5	900.0	5,320.0
Air Temperature, °C	14.3	7.2	-6.0	29.0
Water Temperature, °C	10.3	5.3	-1.0	22.0
pH	6.22	0.37	4.70	7.70
Conductivity, umhos/cm	11.25	6.23	0.90	82.0
Turbidity, JTU	4.01	20.22	0.20	150.0
Acidity, mg/l	5.63	2.05	0.20	31.0
Hardness, mg/l	5.07	3.67	0.30	53.0
Nitrate, mg/l	1.04	0.81	<0.01	7.10
Stream Flow, m^3/sec	1.29	3.34	0.0003	29.45
liters/sec	0.357	0.929	0.0001	8.181
ft/sec	45.41	118.03	0.01	1,040.0
Stream Velocity, cm/sec	53.9	105.8	3.0	2,023.9
ft/sec	1.77	3.47	0.01	66.4
Stream Width, m	5.7	4.6	0.1	30.6
Stream Depth, cm	18.5	14.1	0.8	83.8
Stream Order	2.4	1.1	1.0	4.0
Stream Hectares (ha)	0.012	0.013	0.0002	0.100
No. Stream Salamanders/ha	1,298.2	1,913.8	0	9,383.8
/m^2	0.153	0.302	0	1.880
Wt. Stream Salamanders/ha	1,871.9	563.2	0	9,223.6
/m^2	0.250	0.407	0	2.379
No. Streamside Salamanders/ha	491.4	563.2	0	3,669.8
/m^2	0.050	0.057	0	0.367

Table 5 (Continued)

Parameter	Mean	Standard Deviation	Minimum	Maximum
Wt. Streamside				
Salamanders/ha	781.5	1,008.4	0	5,883.0
/m^2	0.078	0.100	0	0.581
No. Stream and Streamside				
Salamanders/ha	744.0	1,467.2	0	13,053.6
/m^2	0.202	0.310	0	2.247
Wt. Stream and Streamside				
Salamanders/ha	1,296.9	3,126.8	0	15,106.6
/m^2	0.130	0.313	0	2.960
Percent Composition by Stream Substrate Type:				
Bedrock	17.9	18.2	0	100
Boulder	43.4	19.7	0	90.0
Rock	19.6	11.7	0	70.0
Gravel	11.8	10.8	0	60.0
Sand	5.3	8.6	0	95.0
Silt	2.3	10.9	0	90.0

A frequency distribution was used to analyze salamander species occurrence. A total of 13 species of salamanders were determined to dwell in stream and streamside environs (table 6). Of these Leurognathus marmoratus was the most frequent (28.3 percent of overall composition), followed in order by Desmognathus monticola (19.4 percent), Desmognathus quadramaculatus (16.3 percent), Desmognathus ochrophaeus carolinesis (16.3 percent), and Eurycea bislineata wilderae (16.1 percent). Eight other species were present, but infrequently. Forty-two stations (2.4 percent) were devoid of salamanders.

Salamander Species Distribution

Stream Versus Streamside

The distribution of stream versus streamside-dwelling salamanders among the various species was very pronounced (table 7). All the remaining data tables are given in the appendices in order to facilitate better continuity for reading this manuscript. Although Leurognathus marmoratus is considered a totally aquatic species in all the literature reviewed, 20 specimens were found on streamsides; however the great majority (466) were found in streams. Desmognathus quadramaculatus was the second most frequent species found in streams, followed by Desmognathus monticola monticola, Eurycea bislineata wilderae, Desmognathus ochrophaeus carolinesis, Desmognathus fuscus, and infrequently by the other species listed in table 7. Eurycea bislineata wilderae was the most frequently found species on the

Table 6. Frequency Distribution of Salamander Occurrence in Park Stream Environs.

Salamander Species	Frequency	Percent	Cumulative Percent
None Present	42	2.4	2.4
Leurognathus marmoratus	486	28.3	30.7
Desmognathus quadramaculatus	280	16.3	47.0
Desmognathus o. carolinesis	233	13.6	60.6
Desmognathus fuscus	19	1.1	61.7
Desmognathus m. monticola	334	19.4	81.1
Plethodon g. glutinosus	6	.3	81.4
Plethodon jordani	2	.1	81.6
Gyrinophilus p. danielsi	31	1.8	83.4
Eurycea b. wilderae	277	16.1	99.5
Eurycea l. longicauda	1	.1	99.5
Eurycea l. guttolineata	1	.1	99.6
Desmognathus santeetlah	3	.2	99.8
Desmognathus imitator	4	.2	100.0
TOTAL	1719	100.0	

Table 7. Distribution of Stream versus Streamside-Dwelling Salamanders.

Species	Sample Location		ROW* TOTAL
	Stream	Streamside	
Leurognathus marmoratus	466	20	486
			29.0
Desmognathus quadramaculatus	197	83	280
			16.7
Desmognathus o. carolinesis	46	187	233
			13.9
Desmognathus fuscus	7	12	19
			1.1
Desmognathus m. monticola	125	209	334
			19.9
Plethodon g. glutinosus		6	6
			0.4
Plethodon jordani		2	2
			0.1
Gyrinophilus p. danielsi	12	19	31
			1.8
Eurycea b. wilderae	58	220	278
			16.6
Eurycea l. longicauda	1		1
			0.1
Eurycea l. guttolineata	1		1
			0.1
Desmognathus santeetlah	2	1	3
			0.2
Desmognathus imitator	1	3	4
			0.2
COLUMN TOTAL*	916	762	1678
	54.6	45.4	100.0

*Row and column totals include frequency followed by percent.

streamside, followed by Desmognathus monticola monticola, Desmognathus ochrophaeus carolinesis, Desmognathus quadramaculatus, Leurognathus marmoratus, Gyrinophilus porphyriticus danielsi, and others infrequently as listed in table 7. Leurognathus marmoratus was the single most frequently observed species encompassing both stream and streamside environs. All of these species occupy stream and streamside environs for various residence periods in each as previously discussed. Other species found on the streamsides not discussed above are generally terrestrial types requiring a moist environment: Plethodon jordani and Plethodon glutinosus.

Watershed

The abundance of salamanders of each species varied considerably between the 16 watersheds sampled (tables 8-10, Appendix A). At elevations less than 600 m (table 8, Appendix A), Panther Creek and Abrams Creek were the most diverse, but with very different abundance patterns. Dudley Creek and Forney Creek were the least diverse. Leurognathus marmoratus was the only species present in all watersheds at all elevations though Desmognathus monticola monticola, Eurycea bislineata wilderae, Desmognathus ochrophaeus carolinesis, and Desmognathus quadramaculatus were very widespread in distributions across the different watersheds. Leurognathus marmoratus was the species most abundant at mid and high elevations in stream environs (tables 9 and 10, Appendix A), while Desmognathus monticola monticola, was the most abundant at low elevations. At high elevations, the abundance of all species was much less, although three species were

only present at high elevations: Desmognathus santeetlah, Desmognathus imitator, and Plethodon jordani. Eurycea longicauda longicauda and Eurycea longicauda guttolineata were only present at low elevations, although their abundance was rather insignificant. Whereas Eurycea longicauda longicauda is confined largely to the Tennessee side of the Park, the closely related subspecies, Eurycea longicauda guttolineata, is known only from the North Carolina side, and the specimen found during this study in Eagle Creek was the first reported collection of this species in the Park since 1965. Plethodon jordani was found on the streamside of Eagle Creek where recent wild hog rooting was apparent. There were a total of ten species of salamanders collected in stream and streamside environs at low elevations, eight at mid elevations, and nine at high elevations.

Stream Size

The influence of stream size (20 m sample section surface area) on salamander abundance by species is apparent from figure 3 (tables 11 and 12, Appendix A). The most important species in stream environs of the GRSM in terms of abundance and biomass were as follows: Leurognathus marmoratus, Desmognathus quadramaculatus, Desmognathus ochrophaeus carolinesis, Desmognathus monticola monticola, and Eurycea bislineata wilderae. These five species then are the primary focus for analytical interpretation of the overall distributional ecology of such stream environs, and their abundance and biomass dynamics are thus presented in figures throughout the remainder of this text.

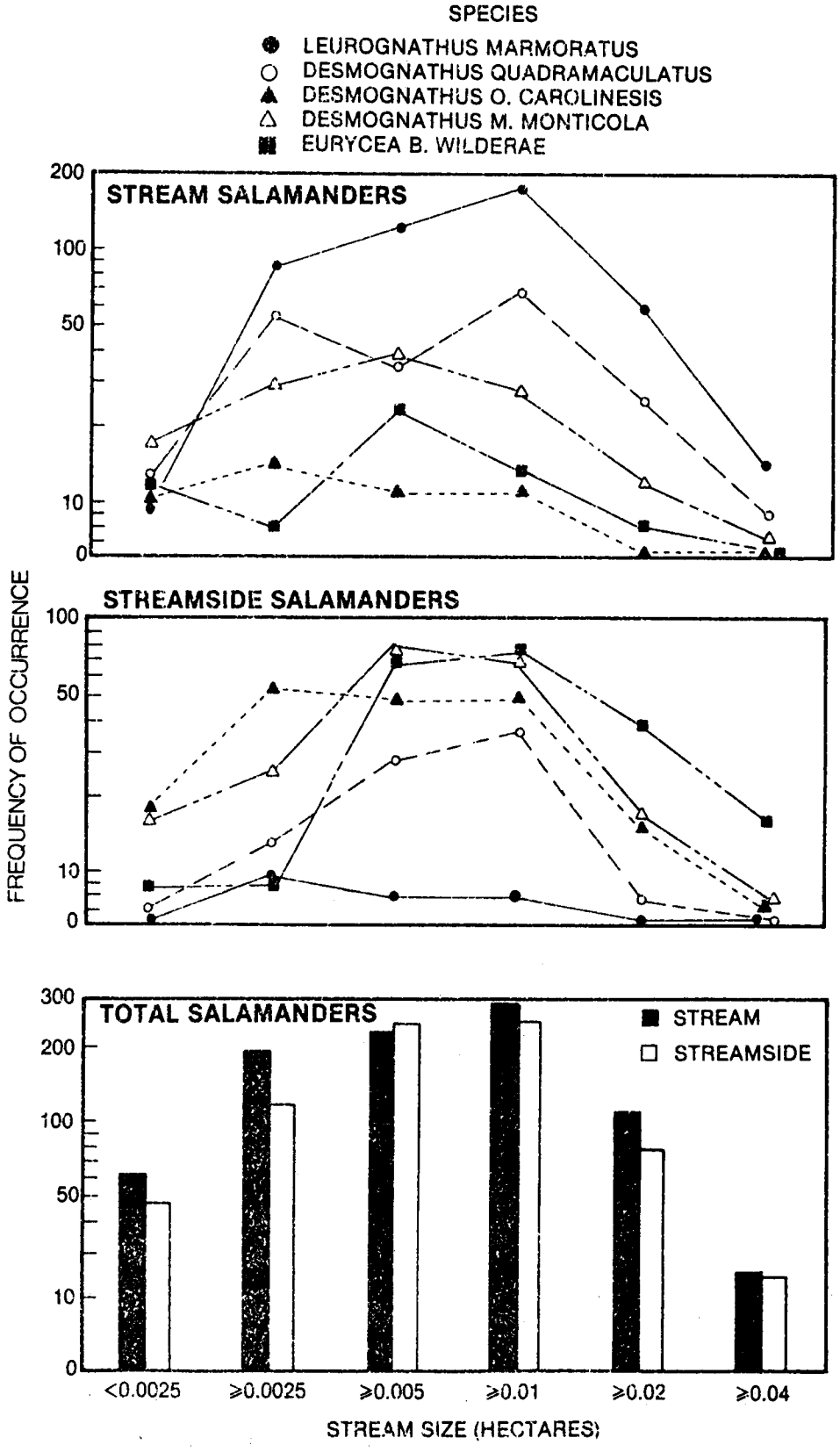


Figure 3. Stream size (surface area) in relation to salamander abundance.

The greatest species abundances of salamanders occurred within stream sample sizes ranging from 0.005 to 0.02 ha, although individual species showed preferences for different size categories. Large stream sizes were more restrictive to salamander abundance than small ones. Eurycea bislineata wilderae was the most abundant streamside-dwelling salamander in larger streams (i.e., ≥0.01 ha), while Desmognathus ochrophaeus carolinesis was the most abundant on the sides of smaller streams (i.e., <0.005 ha). Leurognathus marmoratus was the least abundant stream-dwelling salamander in very small streams (i.e., <0.0025 ha), while Desmognathus monticola monticola was the most abundant stream-dwelling salamander in that size stream. Leurognathus marmoratus dominated all other stream size regimes. Desmognathus quadramaculatus followed Leurognathus marmoratus in order of abundance within these stream sizes. In general, stream size by surface area exerted a similar effect on the total abundance patterns of both stream and streamside-dwelling salamanders.

Stream Order

The effect of stream order on the abundance of salamanders by species was very apparent on both stream and streamside salamanders (figure 4; tables 13 and 14, Appendix A). Desmognathus ochrophaeus carolinesis were found mostly in first order streams, steadily declining in abundance with larger stream orders; while on the streamside they occurred frequently within all categories, though mostly in second order. This species was four times as abundant on streamsides as in streams. Desmognathus monticola monticola was also more abundant on

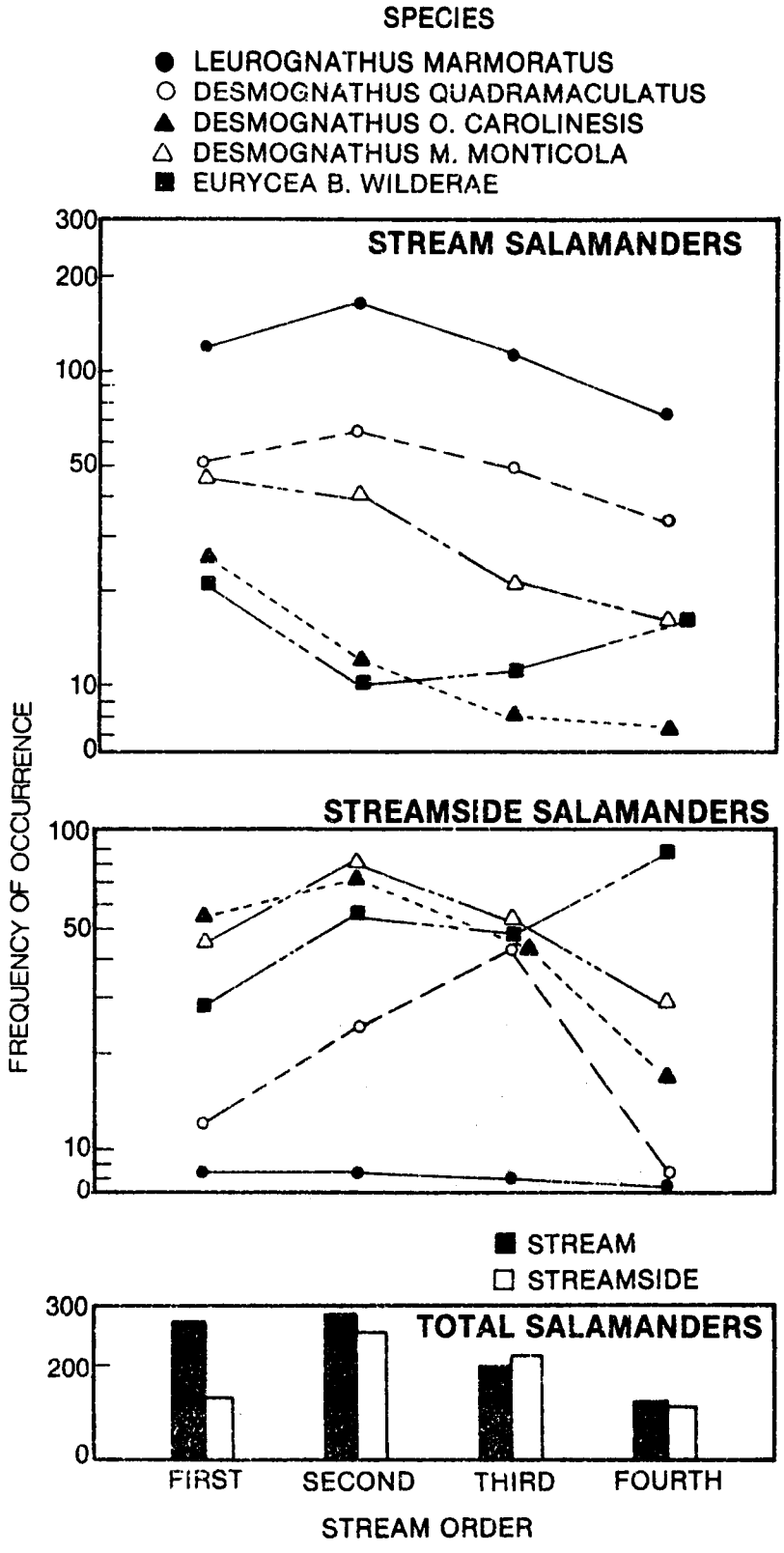


Figure 4. Stream order in relation to salamander abundance.

streamsides by a factor of about 1.7, and occurred frequently within all stream orders of both stream and streamside environs. They were, however, most abundant in first (peak abundance) and second order categories within streams, while on the streamside were most abundant on second (peak abundance) and third order categories. Eurycea longicauda longicauda and Eurycea longicauda guttolineata were present only in fourth order streams, while Desmognathus santeetlah and Desmognathus imitator were present only in first and second order streams and streamsides. Eurycea bislineata wilderae was most abundant in first order streams, while on the streamsides were most abundant on the fourth order category. They were more abundant on the streamsides by a factor of 3.8. Leurognathus marmoratus and Desmognathus quadramaculatus reached peak abundances in second order streams, while on the streamsides Leurognathus marmoratus occurred infrequently within all stream orders and Desmognathus quadramaculatus reached a peak abundance within the third order category at a much reduced level than streams.

Summarizing from tables 13 and 14 (Appendix A), the overall abundances of salamanders within stream, streamside and combined stream environs were as follows:

	Stream Order				
	1st	2nd	3rd	4th	TOTAL
Stream	275	292	198	151	916
Streamside	157	250	208	147	762
Combined	432	542	406	298	1719

The abundance order derived from these numerical profiles was then as follows:

	Stream Order			
Stream	2nd	1st	3rd	4th
Streamside	2nd	3rd	1st	4th
Combined	2nd	1st	3rd	4th

From this data, it is apparent that the intermediate abundance order profiles are reversed for the stream and streamside environs, whereas the streams encompassed a greater overall abundance and thus the combined abundance profile was the same as observed in streams. In general, the larger the stream order the more extensive the wetting action on the streamsides due to increasing stage height during storms. This increased moisture gradient may be an important component in this abundance pattern. In fourth order streams, however, the more open nature of the forest canopy results in an enhanced solar drying effect on the streamsides, thus counteracting this effect.

Stream Width and Depth

Other measures of stream size (width and depth) also effected the distribution of salamanders. The greatest abundance of salamanders was found between stream widths ranging from 1-11 m (figure 5; tables 15 and 16, Appendix A). Leurognathus marmoratus was the most abundant species across the entire array of stream widths, while Eurycea bislineata wilderae dominated the streamside abundance at stream widths $\geq$3 m and

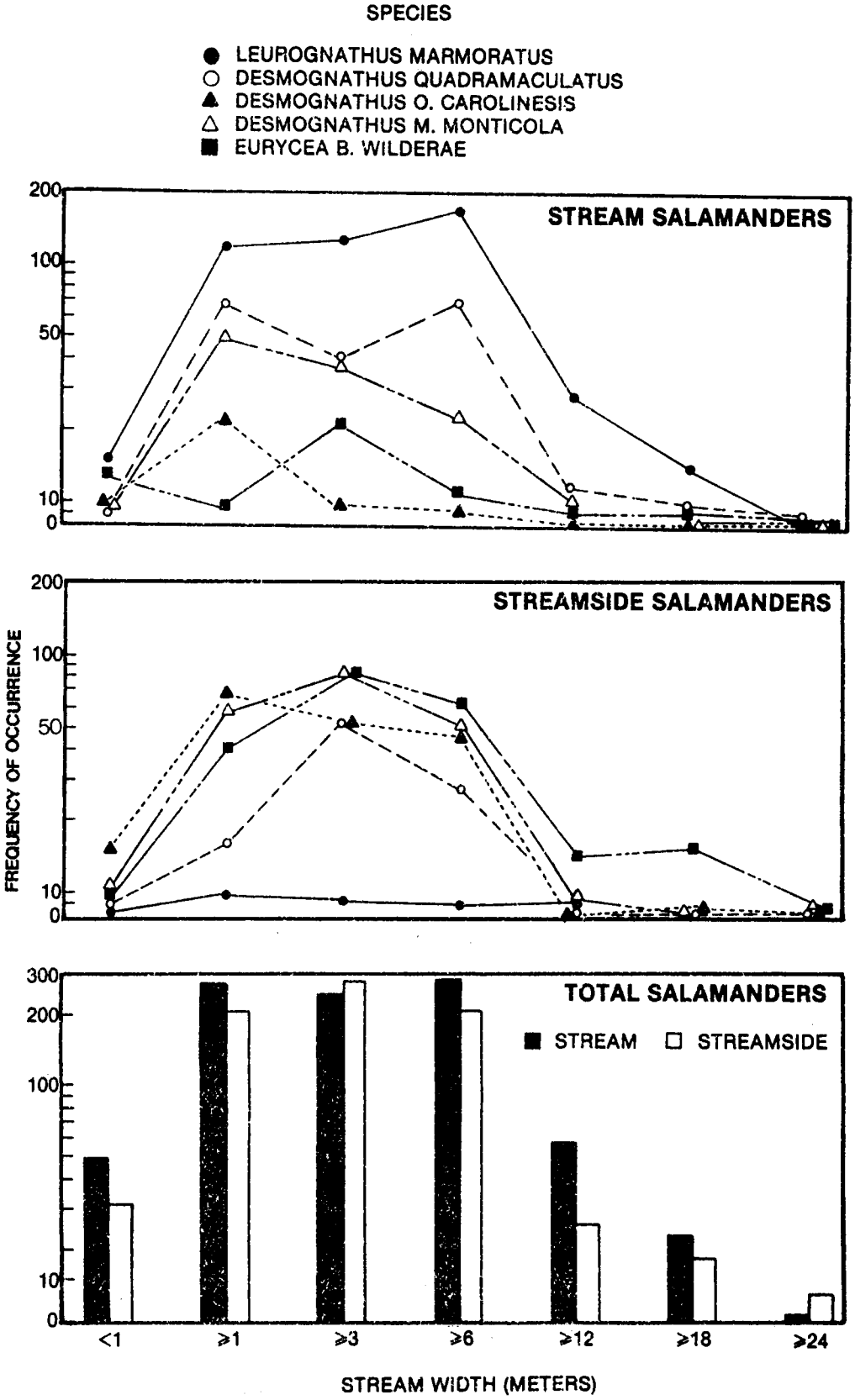


Figure 5. Stream width in relation to salamander abundance.

Desmognathus ochrophaeus carolinesis dominated in abundance at stream widths ≤1 m. The smallest stream widths (≤1 m) were more restrictive to the abundance of streamside-dwelling salamanders, while the greatest stream widths (≥24 m) were more restrictive to stream-dwelling salamanders. In the streams of the Park, Leurognathus marmoratus reached peak abundance at stream widths ranging from 6-11 m. Desmognathus quadramaculatus had bimotile abundance peaks at 1-2 m and 6-11 m stream widths, Desmognathus monticola monticola and Desmognathus ochrophaeus carolinesis reached peak abundances at 1-2 m widths and steadily declined in abundances thereafter, while Eurycea bislineata wilderae peaked out at 3-5 m widths. Generally, the stream-dwelling salamander species attained peak abundances at greater stream widths than streamside-dwelling species. For instance, on the streamsides Leurognathus marmoratus reached peak abundance represented by very few specimens at a much smaller width than when in streams of only 1-5 m, Desmognathus quadramaculatus and Desmognathus monticola monticola peaked at 3-5 m and steadily declined in abundance thereafter, Desmognathus ochrophaeus carolinesis peaked at 1-2 m but did not steadily decline in abundance until stream widths ≥6 m, while Eurycea bislineata wilderae peaked at 3 m and also did not steadily decline in abundance until stream widths ≥6 m.

Stream depth was not as important a stream habitat criterion to salamander abundance as stream surface area, stream order, stream substrate type, terrain slope, and stream width (figure 6; tables 17 and 18, Appendix A). There were some relationships, however, especially with respect to very shallow waters. Depths less than 2 cm were restrictive to

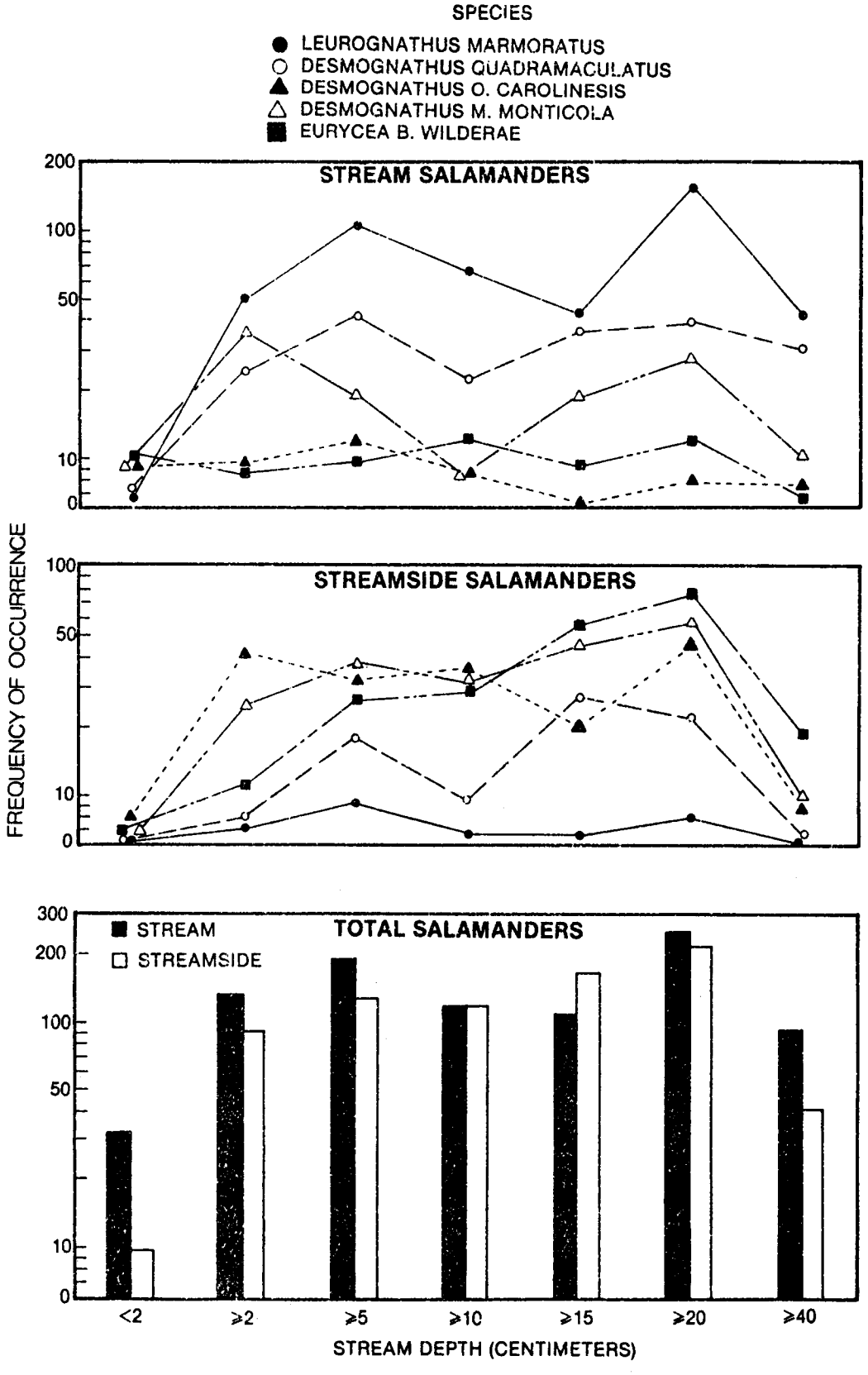


Figure 6. Stream depth in relation to salamander abundance.

both stream and streamside-dwelling salamander abundance, although much more so for streamside-dwelling salamanders. Depths ≥40 cm were related to a reduction in salamander abundance, but not nearly to the extent as with the shallow end of the depth spectrum. Depths between 5-9 cm and 20-39 cm were most abundantly populated. Leurognathus marmoratus was the least abundant of the five most important stream species depicted in figure 6, although it dominated at all other depths within streams. Desmognathus quadramaculatus was second in stream dominance at depths ≥5 cm, although Desmognathus monticola monticola was second in stream dominance at depths ranging from 2-4 cm before steadily declining in abundance at greater depths. Desmognathus ochrophaeus carolinesis was most abundant on streamsides at depths ≤4 cm and between 10-14 cm, Desmognathus monticola monticola dominated on streamsides at depths ranging from 5-9 cm, while Eurycea bislineata wilderae dominated streamsides where deeper waters occurred (i.e., ≥15 cm).

Stream Velocity and Flow

Stream velocity exerts a much greater effect on salamander abundance patterns than stream flow (figure 7; tables 19-22, Appendix A). Stream velocities between 31-90 cm/sec produced the greatest abundance of stream and streamside-dwelling salamanders, although lower stream velocities were not restrictive. Stream velocities ≥183 cm/sec were, however, very restrictive for salamanders. This effect may be related to a loss of hydrostatic control in rapid stream waters, possibly to the scouring of accumulated detritus in substrate crevasses that forms the

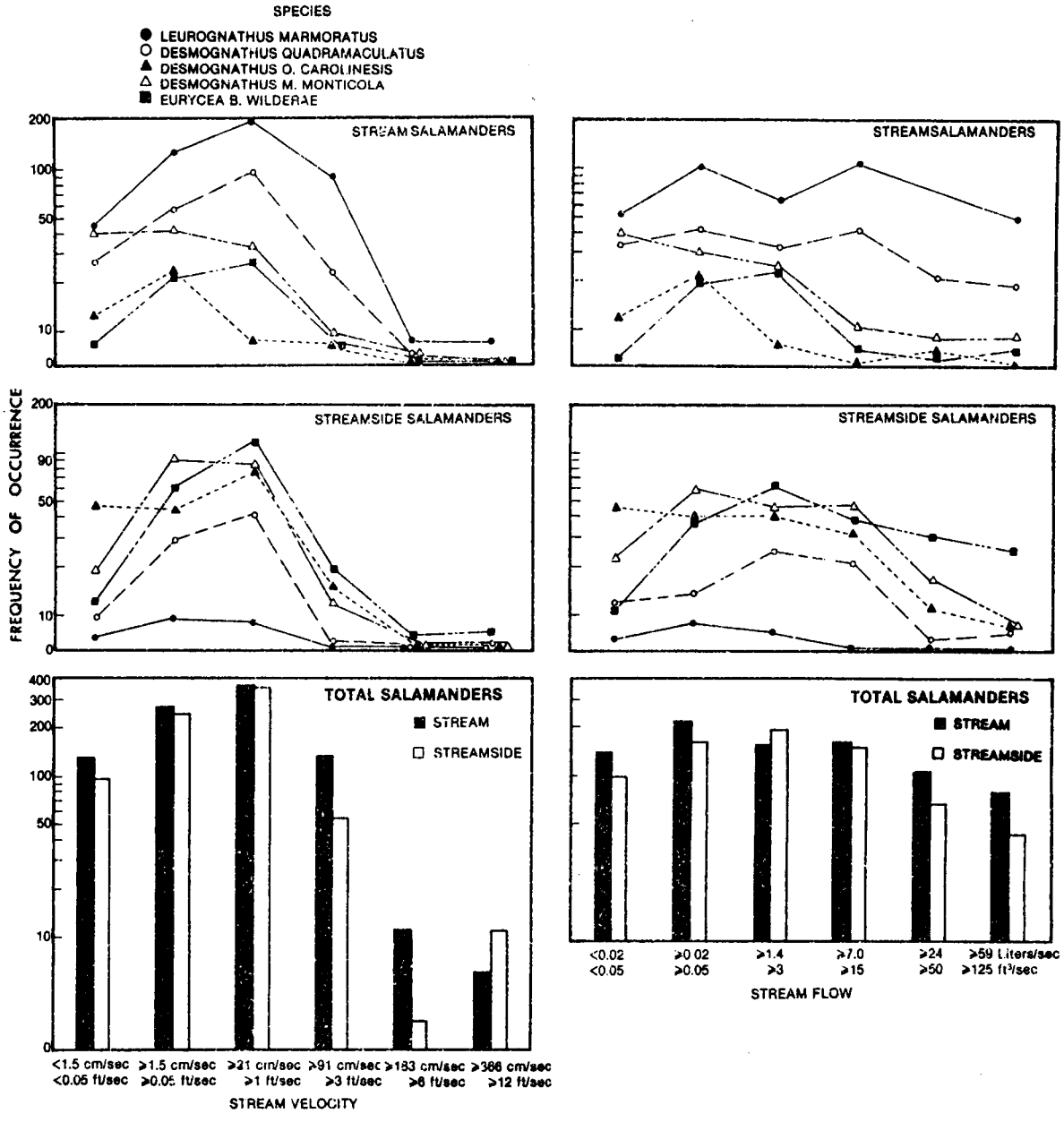


Figure 7. Stream velocity and flow in relation to salamander abundance.

base of local food webs or to the direct entrainment removal of food items (e.g., aquatic insects). Another consideration, however, is that most salamanders associated with stream environs spend several years (usually 3-4) as larvae and subadults that were generally observed during this study to seek out eddy areas of streams where quieter waters occurred. Within these segregated areas, they often existed in very densely populated microcommunities (especially around rocks and boulders). In addition, nesting sites appeared to be related to stream velocity and flow. Optimum nesting sites appeared to occur in quite to moderate stream velocities in waters where adequate substrate was available for either attachment of small egg clusters to a substrate by a pedicel (e.g., Desmognathus ochrophaeus carolinesis and Leurognathus marmoratus), attachment of large numbers of eggs singly to the lower surface of a substrate in running waters (e.g., Eurycea bislineata wilderae, Desmognathus monticola monticola, and Desmognathus quadramaculatus), or deposition in a compact mass about which the parent coils (e.g., Desmognathus fuscus). It is presumed that very rapid waters may be disruptive to these nest sites.

Salamander abundance distribution over the various flow regimes was fairly even, with a slight but steady decline in abundance for stream flows $\geq$7 l/sec. Peak abundances for stream-dwelling salamanders occurred at flows ranging from 0.02-1.3 l/sec, while that for streamside-dwelling salamanders occurred at greater flows ranging from 1.4-6 l/sec.

As a general trend, the abundance profiles over the various stream velocity and flow regimes were very similar. Leurognathus marmoratus

and Desmognathus quadramaculatus dominated within streams over all stream velocity and flow levels except at the lowest levels (i.e., <1.5 cm/sec stream velocity and <0.02 l/sec stream flow) where Desmognathus monticola monticola was more abundant than Desmognathus quadramaculatus. On the streamsides, Desmognathus ochrophaeus carolinesis was dominant at such low velocity/flow levels, then was replaced by Desmognathus monticola monticola at more rapid stream velocity/flow levels (i.e., 1.5-30 cm/sec velocity and 0.02-1.3 l/sec flow), followed for the most part by Eurycea bislineata wilderae over the remainder of the increasing levels of stream velocity and flow (i.e., ≥31 cm/sec velocity and ≥1.4 l/sec flow). This trend is interesting from the standpoint that most ecological considerations of stream organisms are based on flow, whereas in this study, velocity is obviously a more definitive criterion.

Temperature

Except for extremes of temperature, such as less than 1°C and greater than 25°C for air, and less than 2°C and greater than 18°C for water, salamanders of most species were abundant at most field temperatures to varying extents (figure 8; tables 23-26, Appendix A). The greatest abundance of salamanders in streams occurred with air temperatures between 1-21°C (Δ 20°C), and for streamside salamanders between 12-21°C (Δ9°C). Water temperatures between 4-15°C (Δ 11°C) produced the greatest abundance of stream-dwelling salamanders, while those between 8-17°C (Δ 9°C) produced the greatest abundance of streamside-dwelling salamanders. The combined optimal temperature range was 12-17°C (Δ 6°C) for air and

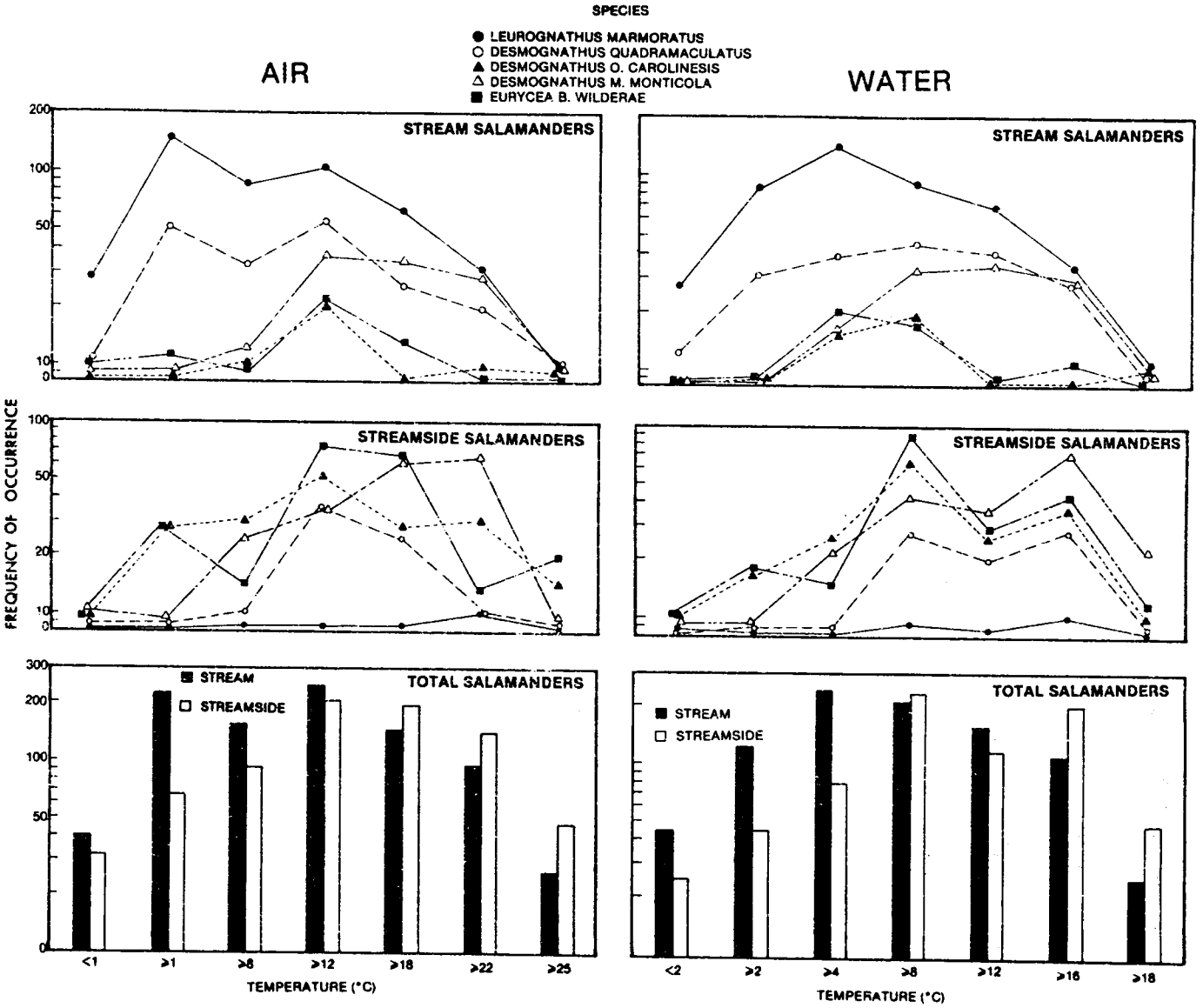


Figure 8. Air and water temperature in relation to salamander abundance.

8-11°C (Δ 4°C) for water. These abundance patterns over the range of temperatures are narrower for streamside-dwelling than for stream-dwelling salamanders. The range of water temperatures (-1 to 22°C, Δ 24°C) was narrower than air temperature (-6 to 29°C, Δ 36°C), the mean water temperature was 4°C cooler (10.3°C) than the mean air temperature (14.3°C), and the standard deviation was larger for air temperature (7.2°C) than for water temperature (5.3°C) as indicated in table 5 (page 41).

Stream-dwelling salamanders were much more abundant at colder air temperatures (i.e., $\leq$17°C), while streamside-dwelling salamanders were more abundant at warmer air temperatures (i.e., $\geq$12°C). Similarly, stream-dwelling salamanders were much more abundant at colder water temperatures (i.e., $\leq$11°C), while streamside-dwelling salamanders were much more abundant at warmer water temperatures (i.e., $\geq$8°C). An intermediate thermal zone exist for both air and water temperatures in which stream and streamside-dwelling salamanders were about equally abundant: 12-17°C (Δ 5°C) for air temperatures and 8-15°C (Δ 7°C) for water temperatures.

Leurognathus marmoratus and Desmognathus quadramaculatus were abundant at the coldest air and water temperatures in streams, while other species remained infrequent at these temperatures. On the streamsides, salamanders were also infrequent at these temperatures. Desmognathus ochrophaeus carolinesis and Eurycea bislineata wilderae were the most tolerant of colder streamside temperatures, becoming active at air temperatures $\geq$1°C. Warm temperatures, however, were much more restrictive to the abundance of stream than

streamside-dwelling salamanders. At air temperatures ≥25°C and water temperatures ≥18°C the abundance of stream-dwelling salamanders was very small, while that of streamside-dwelling species were reduced but remained moderately abundant. Eurycea bislineata wilderae and Desmognathus ochrophaeus carolinesis represented most of the streamside abundance at such warm air temperatures, while Desmognathus monticola monticola and Eurycea bislineata wilderae represented most at such warm water temperatures.

Water serves as a buffer to rapid changes in temperature yielding a thermally more stable environment than that on the streamsides and terrestrial areas. It is probably this insulation aspect of the aqueous thermal ecology that allowed for a greater overall range of stream salamander abundances across the temperature regime. Since air and water temperatures are dynamically related to elevation and season, the interpretation of temperature effects as an independent parameter is confounded.

Water Quality

The effect of water quality on salamander species abundance is indicated in tables 27-34, Appendix A. Most species showed greater abundances at alkalinity levels between 1-6 mg/l (as $CaCO_3$), total acidity levels between 4-8 mg/l (as $CaCO_3$), turbidity levels less than 3 JTU, nitrate levels between 0.5-1.5 mg/l, pH levels between 5.5-7.0, conductivity levels between 8-14 umhos/cm, and hardness levels between 3.0-10.0 mg/l (as $CaCO_3$). Strong relationships were observed particularly between salamander abundance and pH/turbidity (figures 9 and 10).

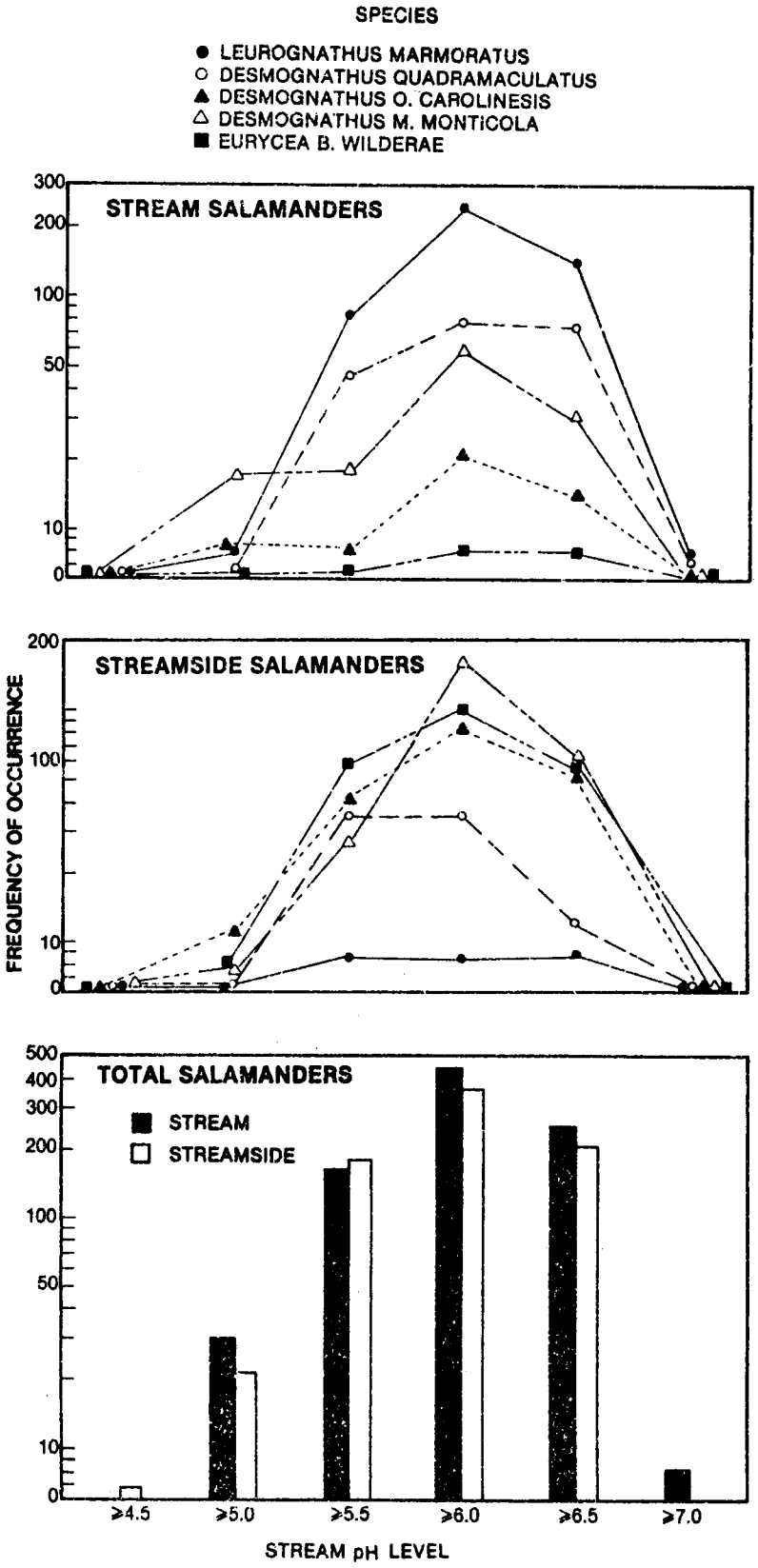


Figure 9. Stream pH level in relation to salamander abundance.

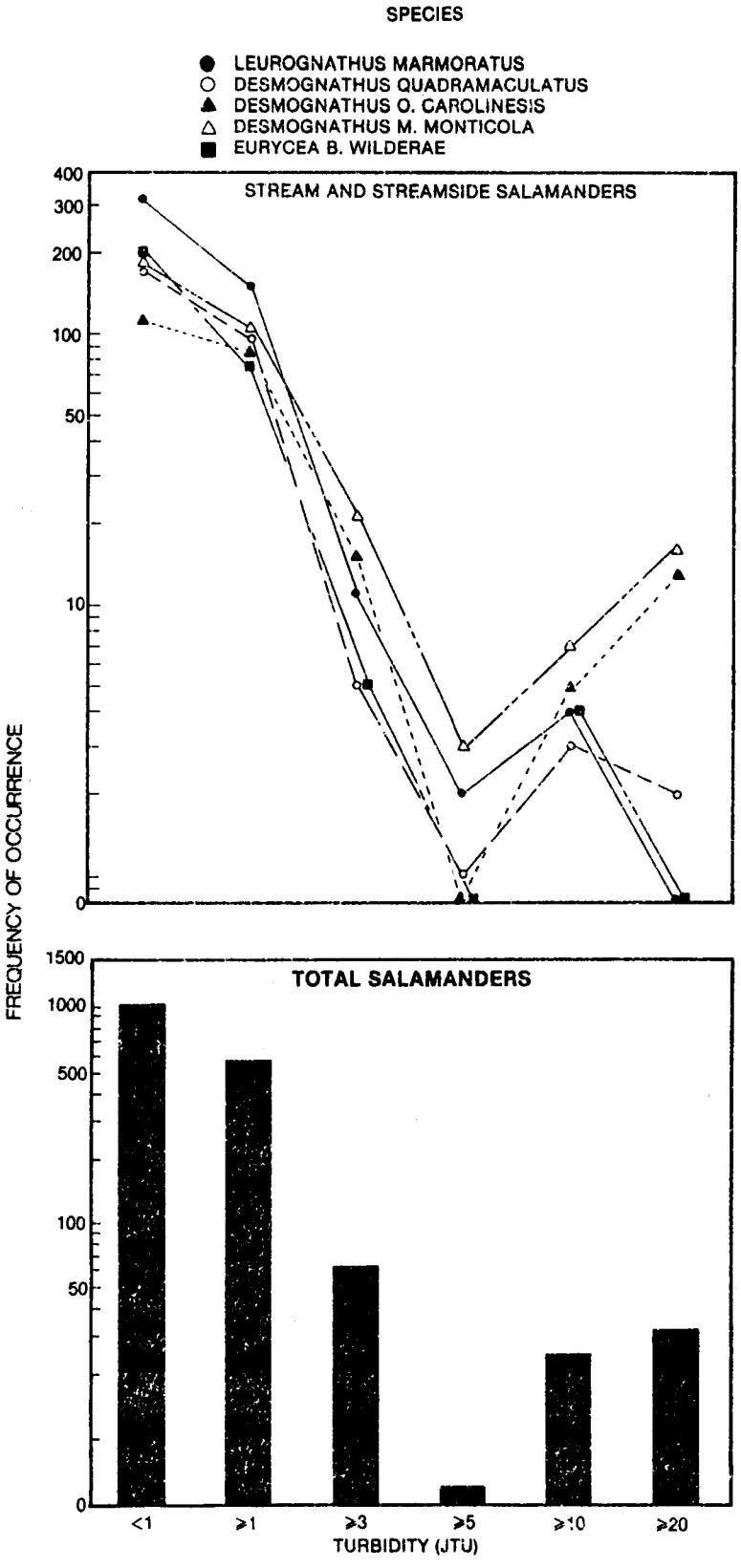


Figure 10. Stream turbidity in relation to salamander abundance.

Based on occurrence, streamside-dwelling salamanders appeared to be more tolerant of very low pH levels (i.e., 4.5-4.9), while stream-dwelling salamanders appeared to be more tolerant of slightly alkaline pH waters (i.e., 7.0-7.7). The optimum pH range for both stream and streamside-dwelling salamanders was between 6.0-6.4 based on the association of salamander abundance at a given pH level. Desmognathus monticola monticola and Desmognathus ochrophaeus carolinesis were present to a limited extent on the streamside at low pH levels (i.e., $\leq$5.4). Desmognathus monticola monticola also occurred in low pH stream waters to a limited abundance regime at pH levels ranging from 5.0-5.4. A strong relationship also exists between stream pH level and elevation in the Park, being much lower at high elevations with a mean of about 5.5 at 1600 meters and 6.6 at 300 meters. This relationship is probably due to a combination of factors: shallow soils associated with high elevations offer little buffering to acidic rainfall, short retention times for groundwater in contact with soil and bedrock allows for little geologically derived chemical buffering (Johnson et al. 1972), and coniferous forest litter decomposes more acidic than deciduous forest litter (Dochinger and Seliga 1976). The effect of this on one species at least has been that high elevation stream-dwelling Leurognathus marmoratus have been acclimated to lower stream pH levels and thus are more tolerant to the lower pH levels than low elevation specimens of the same species (Mathews and Larson 1980). This component of the chemical environment of Park streams may be related to vertical distributions of stream-dwelling salamanders, and may account for reduced abundances at higher elevations.

High turbidities were very restrictive to the abundance of salamanders, with very low abundances occurring at turbidity levels ranging from 5-9 JTU. Although not present in high numbers at high turbidity levels, Desmognathus monticola monticola and Desmognathus ochrophaeus carolinesis abundance increased as turbidity increased from 10 to ≥20 JTU for reasons not understood. Wild hog rooting in streams and cattle watering in Cades Cove historic district were responsible for much of the high turbidity loads observed in Park streams.

There appeared to be relationships between salamander abundance and all the water quality parameters measured to some degree, with the exception perhaps of dissolved oxygen. Since Park waters were almost always saturated with dissolved oxygen at the various temperatures, this variable was not limiting to salamander abundance. In the few areas where stream dissolved oxygen concentration was depressed, there was a substantial reduction in salamanders. Streams in Cades Cove are exposed to hot open fields, low flows, and organic loads with high oxygen demands during the summer that produce low dissolved oxygen concentrations and very few salamanders (Mathews 1978). Other water quality parameters appear to have trends related either to elevation (e.g., alkalinity, temperature, turbidity, and pH decrease with increasing elevation; nitrate concentrations increase with increasing elevations), logging history (e.g., nitrate, hardness, and conductivity concentrations are higher and pH levels lower in virgin forest streams), or geology (hardness, conductivity, and acidity increased while pH and alkalinity decreased in the more mineralized and pyritic type formations as exemplified by

Anakeesta, while Walden Creek and Knox geologic strata resulted in increased hardness, conductivity, pH, and alkalinity).

Elevation

Elevation had a profound effect on the distribution of salamanders, with both stream and streamside salamanders having greatest abundance by species at the mid elevations (tables 35-36, Appendix A). Eurycea longicauda guttolineata and Eurycea longicauda longicauda were found only at low elevations, while Desmognathus santeetlah, Desmognathus imitator and Plethodon jordani were found only at high elevations. Desmognathus fuscus and Gyrinophilus porphyriticus danielsi were restricted to low-mid elevations. Almost all of the Leurognathus marmoratus that were found on the streamside were at mid elevations while in streams their peak abundance was also at mid elevations. Desmognathus quadramaculatus were abundant at low and mid elevations in streams, but when found on the streamside were only abundant at mid elevations.

Slope

Closely related to elevation was terrain slope, as the higher elevations produced greater slopes (figure 11; tables 37 and 38, Appendix A). Terrain slopes greater than 10 percent were very restrictive to streamside salamanders, accounting for only 7.1 percent by abundance of the salamanders. While such slopes curtailed the abundance of stream-dwelling salamanders, terrain slopes between 10-15 percent could not be considered restrictive in that habitat, however, those greater than

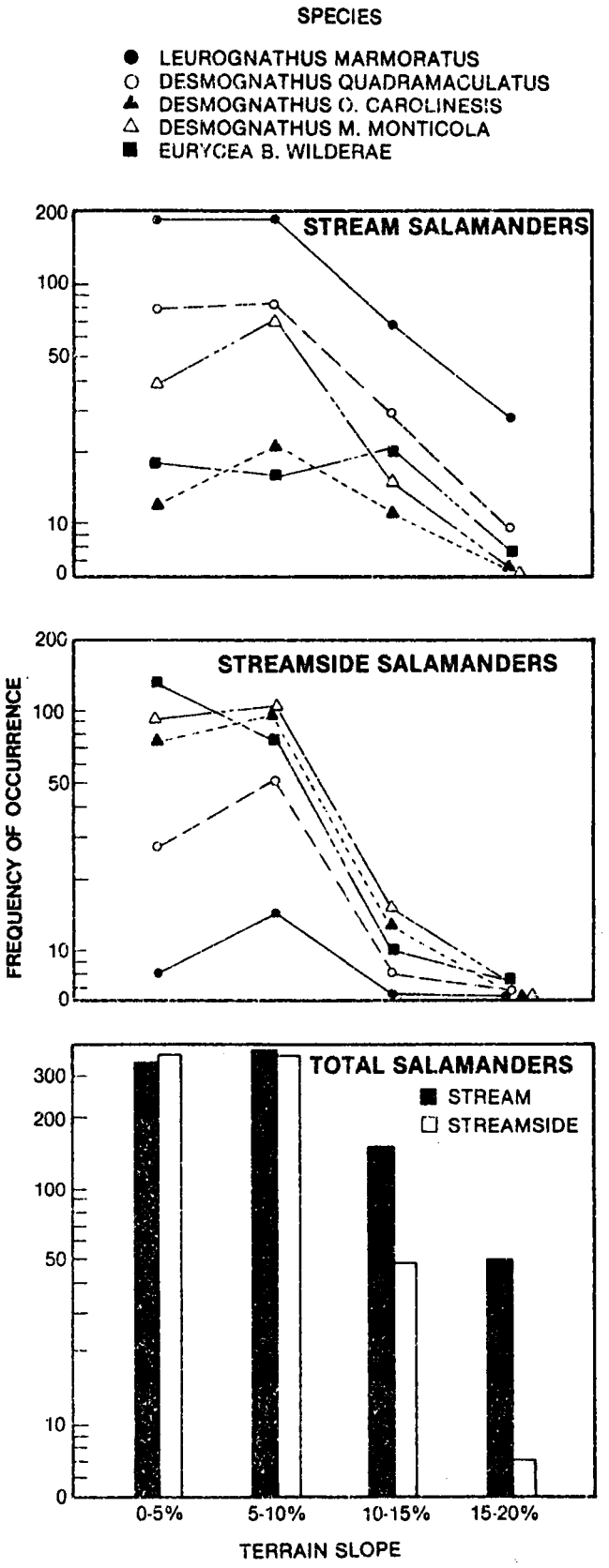


Figure 11. Terrain slope in relation to salamander abundance.

15 percent were restrictive (table 37, Appendix A). Whereas no species were observed to be highly abundant with steep slopes, several species were more abundant within 5-10 percent slopes than in the relatively flat 0-5 percent slopes (e.g., Desmognathus ochrophaeus carolinesis, Desmognathus monticola monticola, and Desmognathus quadramaculatus). Eurycea bislineata wilderae showed a strong preference for shallow sloping streamside environs. Leurognathus marmoratus and Desmognathus quadramaculatus dominated all slopes within streams, while Desmognathus ochrophaeus carolinesis was least abundant at all but the 5-10 percent slopes where Eurycea bislineata wilderae was least abundant. Desmognathus monticola monticola and Desmognathus ochrophaeus carolinesis were co-dominants of the streamside mid-range terrain slopes (i.e., 5-15 percent).

Overstory Vegetation

The complexity of the distribution of species abundances within the various overstory vegetation types of the Park is evident in tables 39-41, Appendix A. At low elevations (<600 m) second growth mesic mixed hardwood forest produced the greatest abundances. Eurycea bislineata wilderae was most abundant in mature mesic hemlock-hardwood forest. At mid elevations (600-1200 m) the second growth mesic hemlock-hardwood forest was very dominant in species abundances, followed by second growth mesic hardwood and second growth mesic mixed hardwoods. The high elevations (>1200 m) showed greatest abundances in the virgin mesic hemlock-hardwood forest, virgin mesic tulip tree forest, virgin mesic mixed hardwood forest, and virgin spruce-fir (hardwood) forest. The single most important forest

type for stream and streamside-dwelling salamanders was the second growth mesic (hemlock or hardwood) forest type. A distinct second in importance was the mature mesic hemlock-hardwood forest.

Examination of salamander distribution on a simpler overstory vegetation profile (deciduous, coniferous, or mixed forest type), showed that most species had their greatest abundance in the mixed forest type with the coniferous forest accounting for only a small relative abundance (table 42, Appendix A). Eurycea bislineata wilderae was the species most abundant in coniferous forest, Desmognathus monticola monticola and Leurognathus marmoratus were about equal in abundance dominance with deciduous forest, while Leurognathus marmoratus was most abundant in mixed forest.

Logging history also incurred an effect on the distribution of salamander species abundance as indicated in tables 43 and 44, Appendix A. Only three salamander species occurred exclusively in virgin forest--Desmognathus santeetlah, Desmognathus imitator, and Plethodon jordani. No species were endemic to second growth (pre-Park logging history). A greater abundance of salamanders occurred in the second growth forest, but more of the Park was previously logged (about 60 percent) than remains virgin. Desmognathus ochrophaeus and Eurycea bislineata wilderae were about equally distributed among cut versus virgin forest in streams, although both species were much more abundant on cut forest streamsides.

Understory Vegetation

Salamanders were distributed amongst the various understory vegetation types very differently along an elevation gradient (tables

45-47, Appendix A). For instance, at low elevations the greatest species abundance of salamanders was decisively in the xeric-submesic type dominated by rhododendron and associates. At mid elevations, however, the greatest abundance occurred much less decisively in the mesic-submesic type dominated by rhododendron and mesic heaths, while mesic-submesic type deciduous shrub sapling including Cornus dominated and Hemlock sapling or shrub dominated also encompassed abundant salamander populations. The high elevation areas of the Park were less diverse in understory vegetation types along stream environs. Spruce-fir type bramble-sedge-herb including Rubus and sedge and grass mixes, and spruce-fir type with Rhododendron and mixed heaths were co-dominant in salamander species abundances, with mesic-submesic type with mesic herbs including Laportea, Cimicifuga, ferns, etc. as a close subdominant.

Season

Samples taken at the same general site on a seasonal basis indicated abundance patterns that were not expected (figure 12; tables 48 and 49, Appendix A). Fall was the season of greatest species abundance for both stream and streamside-dwelling salamanders, followed by winter, summer, and spring for stream salamanders and summer, winter, and spring for streamside salamanders. During the fall Eurycea bislineata wilderae were very abundant on the streamside, while present much less frequently during the other seasons, especially spring. Leurognathus marmoratus were very abundant in streams during the winter, though much less abundant in the spring and summer. Desmognathus monticola monticola was very abundant in the summer in both streams and on streamsides although not very abundant in the winter. Desmognathus

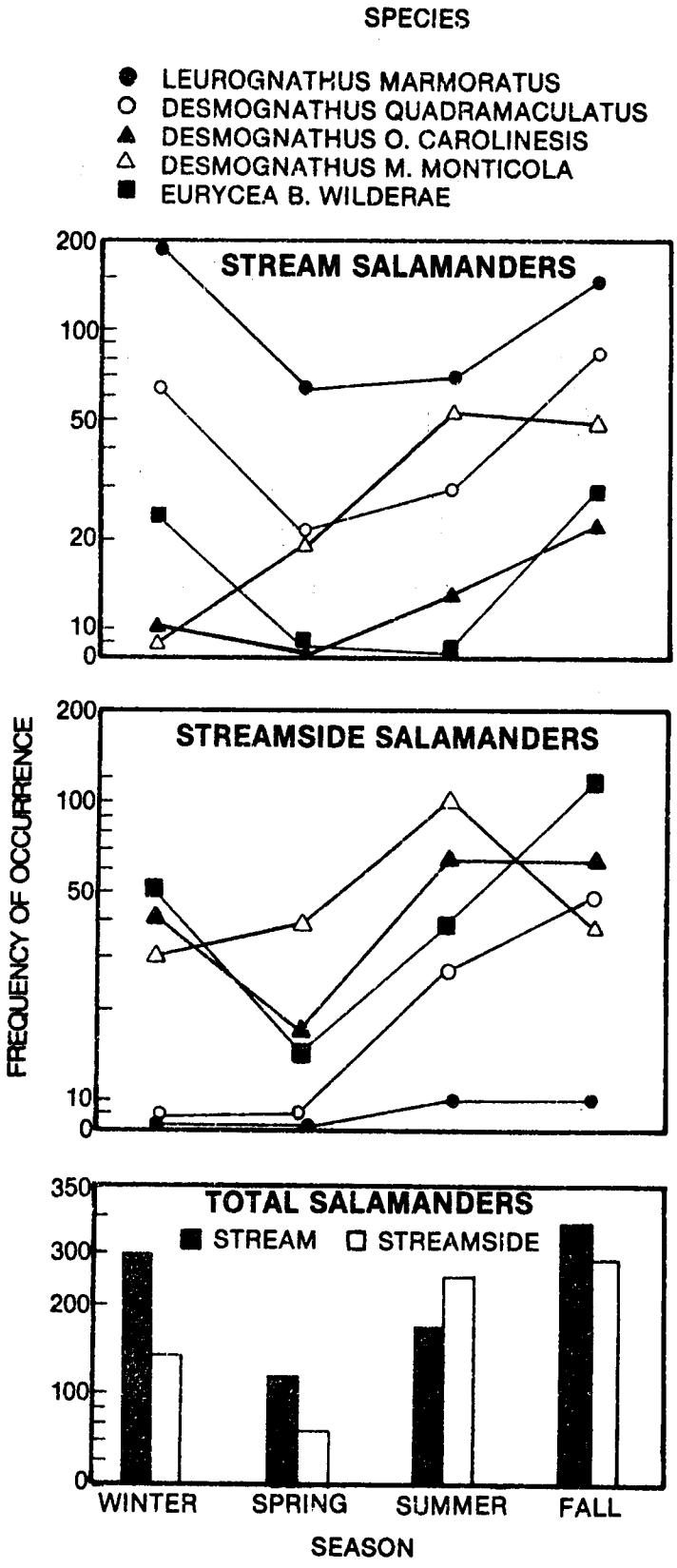


Figure 12. Seasonal variations in the abundance of salamanders.

quadramaculatus was most abundant in the fall, and was rather scarce during spring and winter on streamsides. Spring was the season when salamander abundance in stream associated environs (i.e., stream and streamside) was least.

During the summer, streamside-dwelling salamanders were more abundant than stream-dwelling salamanders. Then in fall, the trend was reversed as stream-dwelling salamanders nearly doubled their abundance from summer and tripled their abundance from spring. Similarly, the streamside-dwelling salamander abundance was more than tripled in just one seasonal shift from spring to summer, while only a slight increase in abundance occurred from summer to fall. During the period from winter through spring, both stream and streamside-dwelling salamander abundances were reduced by nearly half.

The extensive increase in the abundance of Desmognathus monticola monticola from winter through summer in both stream and streamside environs was uncharacteristic of the abundance profiles of the other salamander species. The dominance of this species on streamsides during the spring and summer was responsible for much of the overall salamander abundance during such periods, and also strongly influenced the stream salamander abundance during those seasons.

Stream Substrate

The role of stream substrate in the distribution of salamanders was evident from figure 13 and tables 50-54, Appendix A. For purposes of arraying the species distribution by substrate type in a simplistic manner for cross tabulation technique, the substrate composition at each site was categorized into dominant binary substrate types by elevation range as

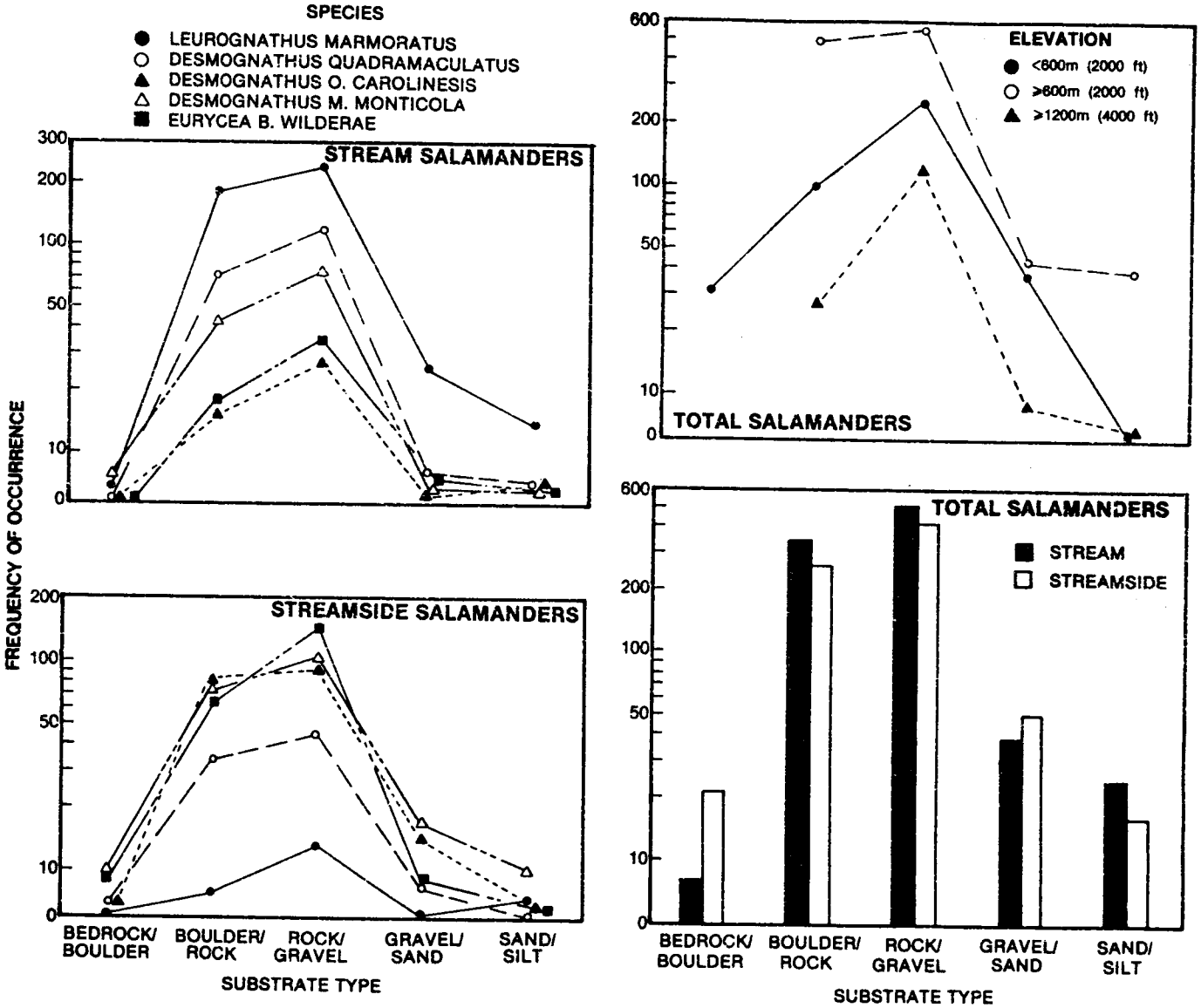


Figure 13. Stream substrate in relation to salamander abundance.

indicated in tables 50-52, Appendix A. The rock/gravel dominant composition resulted in the greatest abundance by species of salamanders at all elevations. Sand/silt substrate produced the least abundance. The bedrock/boulder dominant substrate composition exists only at lower elevations in the Park and produced a low level of species abundance, although Desmognathus monticola monticola was the most abundant species associated with this substrate composition. The bedrock/boulder substrate offers little microhabitat potential and little protection from fish predators also associated with low elevations. Boulder/rock substrate was much more important in relation to species abundance at mid elevations than either low or high elevations. An almost sterile salamander (and stream insect) environment was produced by the sand/silt substrate at low and high elevations, although at mid elevations Leurognathus marmoratus and Desmognathus monticola monticola were present in relatively small numbers. The gravel/sand composition was also not abundantly populated with salamanders, especially at high elevations. At low elevations, Desmognathus monticola monticola were the predominant species occupying gravel/sand substrates, while at mid elevations Leurognathus marmoratus predominated. The rock/gravel substrate was the only type in which salamanders were abundant at high elevations (i.e., $\geq$1200 m).

Segregating stream from streamside salamander species abundance by substrate type produced a similar profile (figure 13; tables 53 and 54, Appendix A), although the individual species abundances were more variable over the various substrate types. The bedrock/boulder substrate type was almost sterile for stream-dwelling salamanders. Rock/gravel and

boulder/rock substrate types were the most abundantly populated. Desmognathus ochrophaeus carolinesis were more abundant on streamsides than in streams where boulder/rock substrates were present. Eurycea bislineata wilderae, Desmognathus quadramaculatus, and Desmognathus ochrophaeus carolinesis were not present in streams where bedrock/boulder substrates were present. Few species occurred where fine substrate types were dominant (i.e., gravel/sand and sand/silt). In the few instances where Leurognathus marmoratus emerged onto the streamside, the rock/gravel substrate was dominant. A casual direct relationship appeared to exist between rock size and salamander size: the larger the rocks in the substrate, the larger the salamanders. This seemed especially evident where large rocks were clumped in piles that formed mini-cascades/waterfalls, which also functioned well in concentrating allochthonous detritus and aquatic insect communities. Leurognathus marmoratus were often observed foraging for entrained insects in areas between rocks that carried insect drift within their grasp (a very bioenergetically efficient feeding strategy).

Salamander Abundance and Biomass Distributions

Watershed

The abundance and biomass of salamanders dwelling in stream associated environs varied widely among the various Park watersheds, elevations, forest types, stream substrate types, stream sizes, and water quality. With reference to salamander distribution by watershed, Cosby Creek was the most productive watershed in terms of abundance of

stream-dwelling salamanders followed by Eagle Creek, Cataloochee Creek, and the Middle Prong Little River (table 55, Appendix B). Parson's Branch, Middle Prong Little Pigeon River, Forney Creek, and Little River were the least abundant. In terms of biomass of stream-dwelling salamanders, Cataloochee Creek, Eagle Creek, and Cosby Creek were the most productive (table 56, Appendix B), while Parson's Branch, Dudley Creek, and Middle Prong Little Pigeon River were least productive. Cataloochee Creek was considerably more abundant in streamside-dwelling salamanders than any of the other watersheds, although Cosby Creek and Eagle Creek were both more productive in terms of biomass than Cataloochee Creek (tables 57 and 58, Appendix B).

Elevation

The difference in salamander abundance and biomass for stream and streamside-dwelling salamanders was very profound on an elevational gradient (figures 14-17; tables 59-62, Appendix B). High densities (i.e., abundance and biomass) of salamanders occurred in high elevation streams but not streamside environs. Both stream and streamside-dwelling salamanders were most dense at the mid elevations, and these distribution profiles were the most variable as well (figures 14-17). Low elevation salamander densities were somewhat greater than those for high elevations, although they more closely resembled high elevation density profiles than such for mid elevations. Salamanders most frequently occurred within the $\geq$800/ha category, while on the streamside were most frequently encountered in lesser abundances within the $\geq$500/ha category. In terms of peak biomass, the stream salamanders were most frequent for the biomass

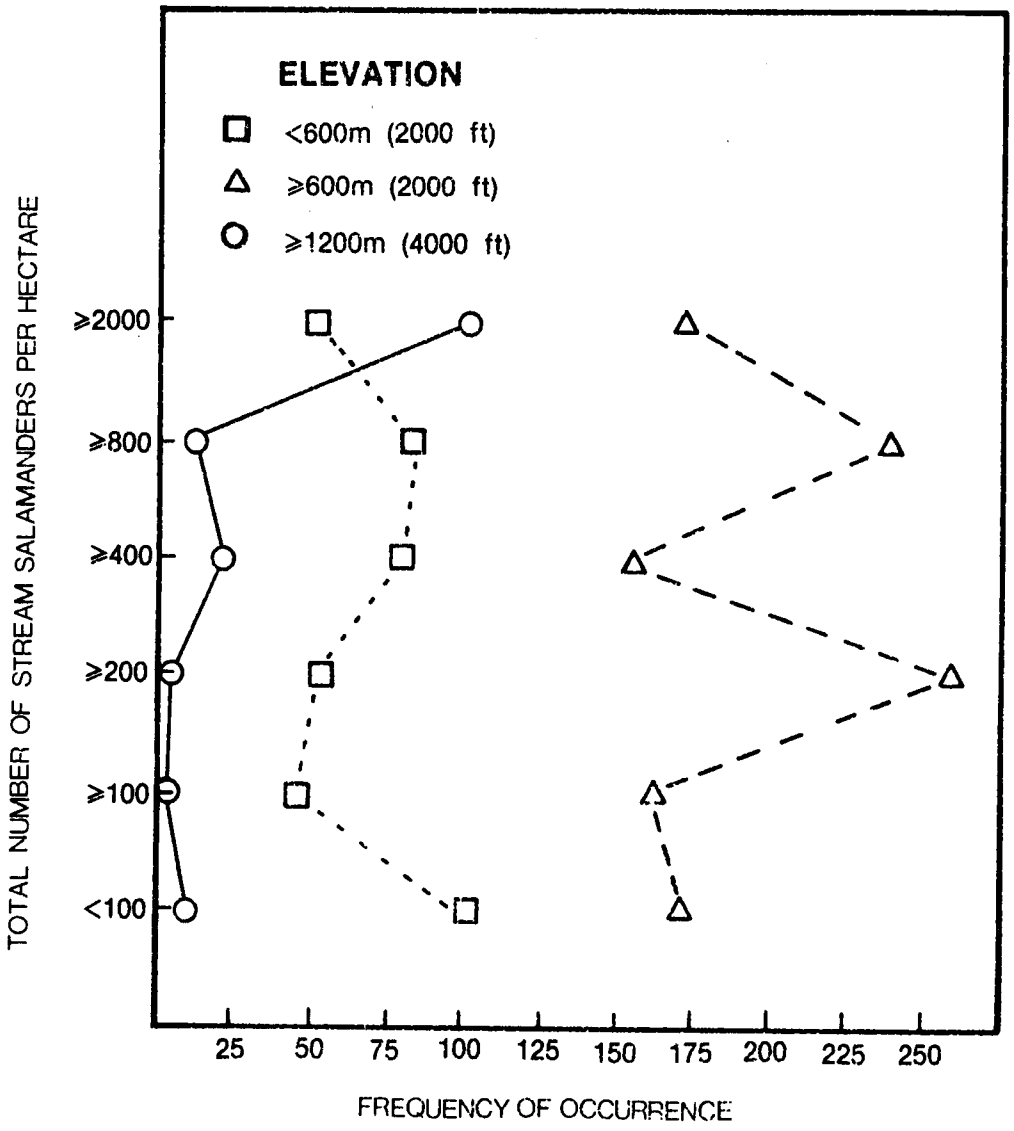


Figure 14. Stream salamander abundance in relation to elevation.

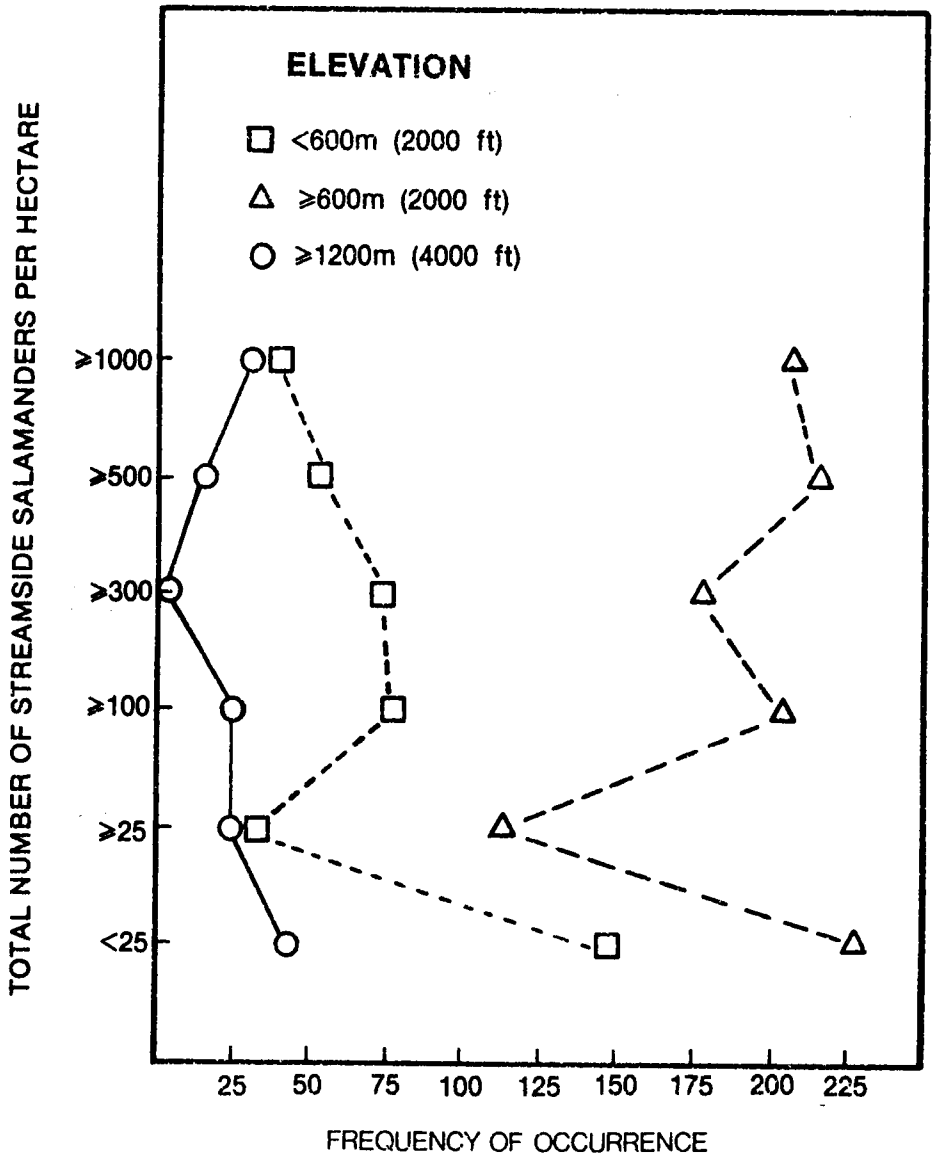


Figure 15. Streamside salamander abundance in relation to elevation.

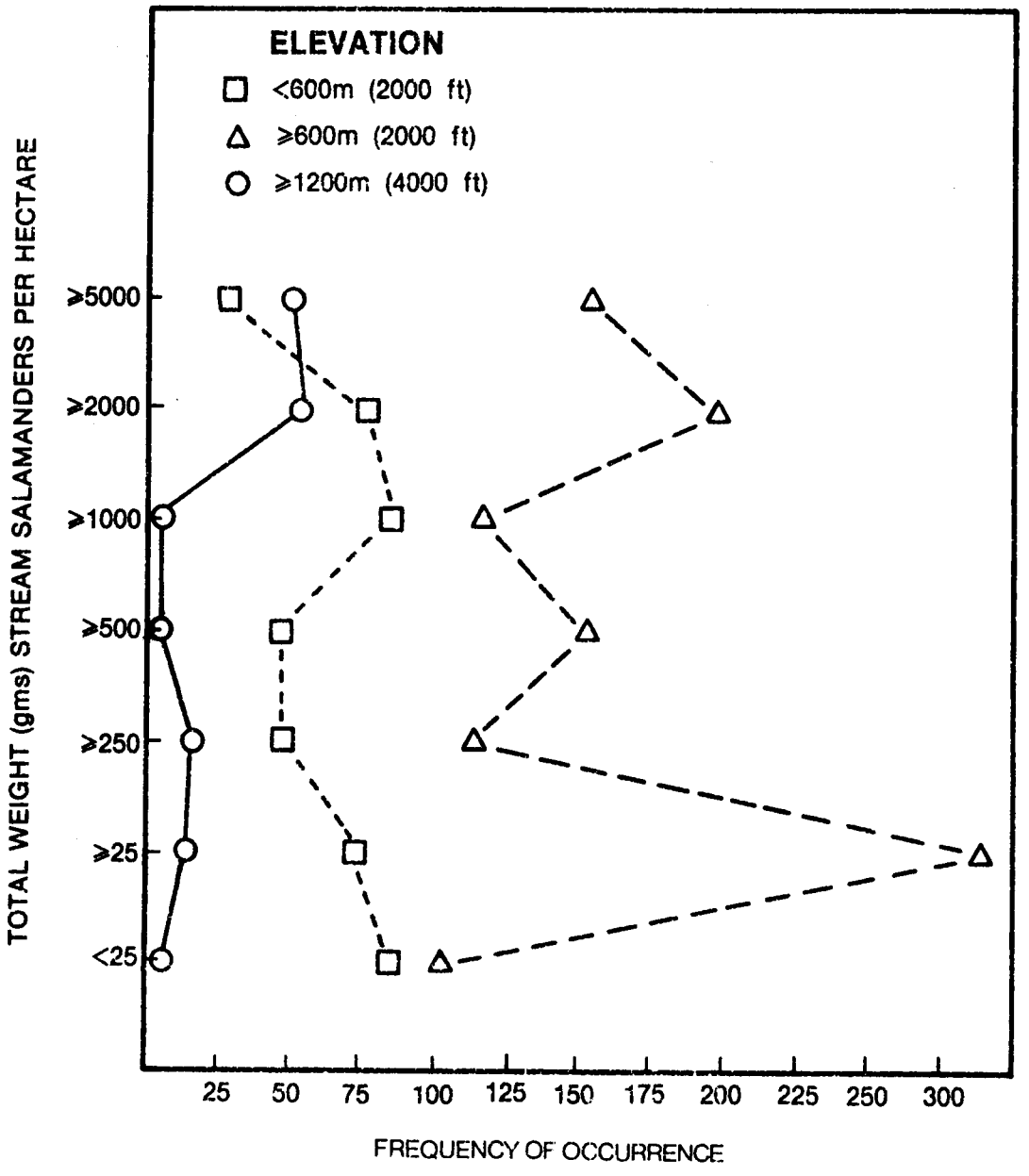


Figure 16. Stream salamander biomass in relation to elevation.

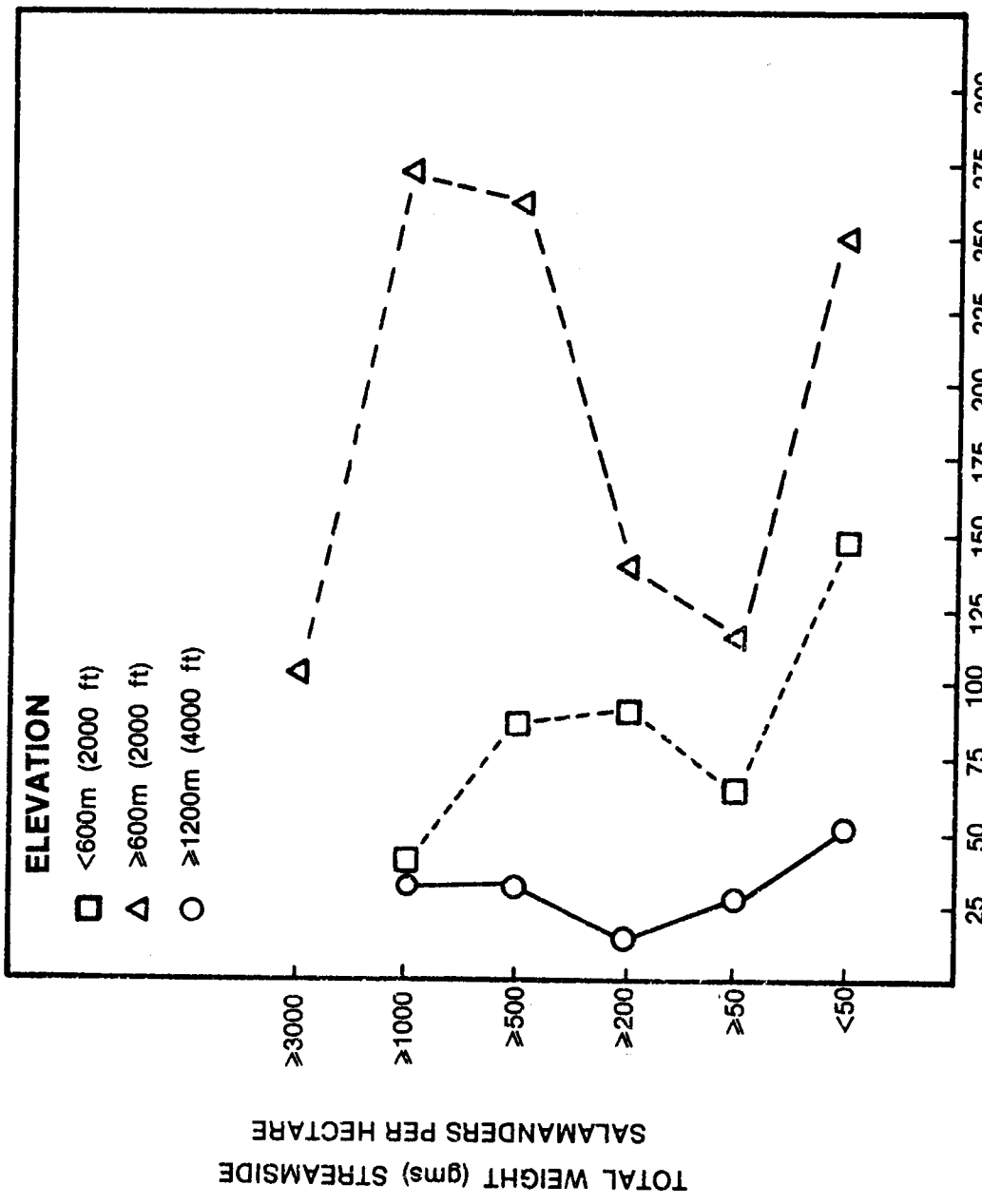


Figure 17. Streamside salamander biomass in relation to elevation.

category of ≥25 gms/ha closely followed by ≥2000 gms/ha, while on the streamside the most frequently encountered biomass category was <50 gms/ha (tables 60 and 62, Appendix B).

Overstory Vegetation

The distribution of salamanders amongst the various overstory vegetation types was highly differentiated. The second growth mesic hemlock-hardwood forest produced the most abundantly populated stream-dwelling salamander environ (table 63, Appendix B). Other abundantly populated forest types included the second growth mesic mixed hardwood forest, mature mesic hemlock-hardwood forest, virgin mesic tulip tree forest, virgin mesic mixed hardwood forest, and virgin spruce-fir (hardwood) forest. Biomass distributions were somewhat differently distributed for stream-dwelling salamanders, although the second growth mesic hemlock-hardwood forest type also produced the greatest biomass (table 64, Appendix B). Other forest types producing high biomass levels included virgin mesic tulip tree forest, virgin mesic hemlock-hardwood forest, second growth mesic mixed hardwood forest, second growth mesic hardwood forest, and early successional mesic hemlock-hardwood forest. The streamside-dwelling salamanders were similarly distributed among the various forest types with the second growth mesic hemlock-hardwood forest again producing the greatest density (tables 65 and 66, Appendix B). The relationship between salamander density and overstory vegetation type appeared moderately strong for both stream and streamside-dwelling salamanders.

Logging History

The effect of logging history on the density of salamanders was very definitive (figures 18 and 19; tables 67-70, Appendix B). In terms of abundance, streams located in areas that had been previously logged contained the greatest number of salamanders followed by streamsides in previously logged forest areas. These two ecosystems appeared to show a close relationship (figure 18). The least abundant system was the streamside in virgin forest areas closely followed by streams in virgin forest stands. A close relationship also existed between these two ecosystems (figures 18 and 19), such that the two pairs of related systems appeared polarized as to their density relationships with logging history and stream environ type. This was especially evident for salamander abundance profiles. There was considerable variability in the biomass profiles in logged watersheds (figure 19), perhaps resulting from the ecological instability inherent to recovering ecosystems. Summarizing from tables 67-70 (Appendix B), the order of salamander abundance and biomass for these parameters are as follows (greatest---->smallest):

Abundance:

logged/stream--->logged/streamside--->virgin/stream--->virgin/streamside

Biomass:

logged/stream--->logged/streamside--->virgin/stream--->virgin/streamside

These density profiles show clearly that salamanders thrive well in stream environs of old growth previously logged forest and that the logged side of the biomass relationship is characterized by a relatively high degree of variance.

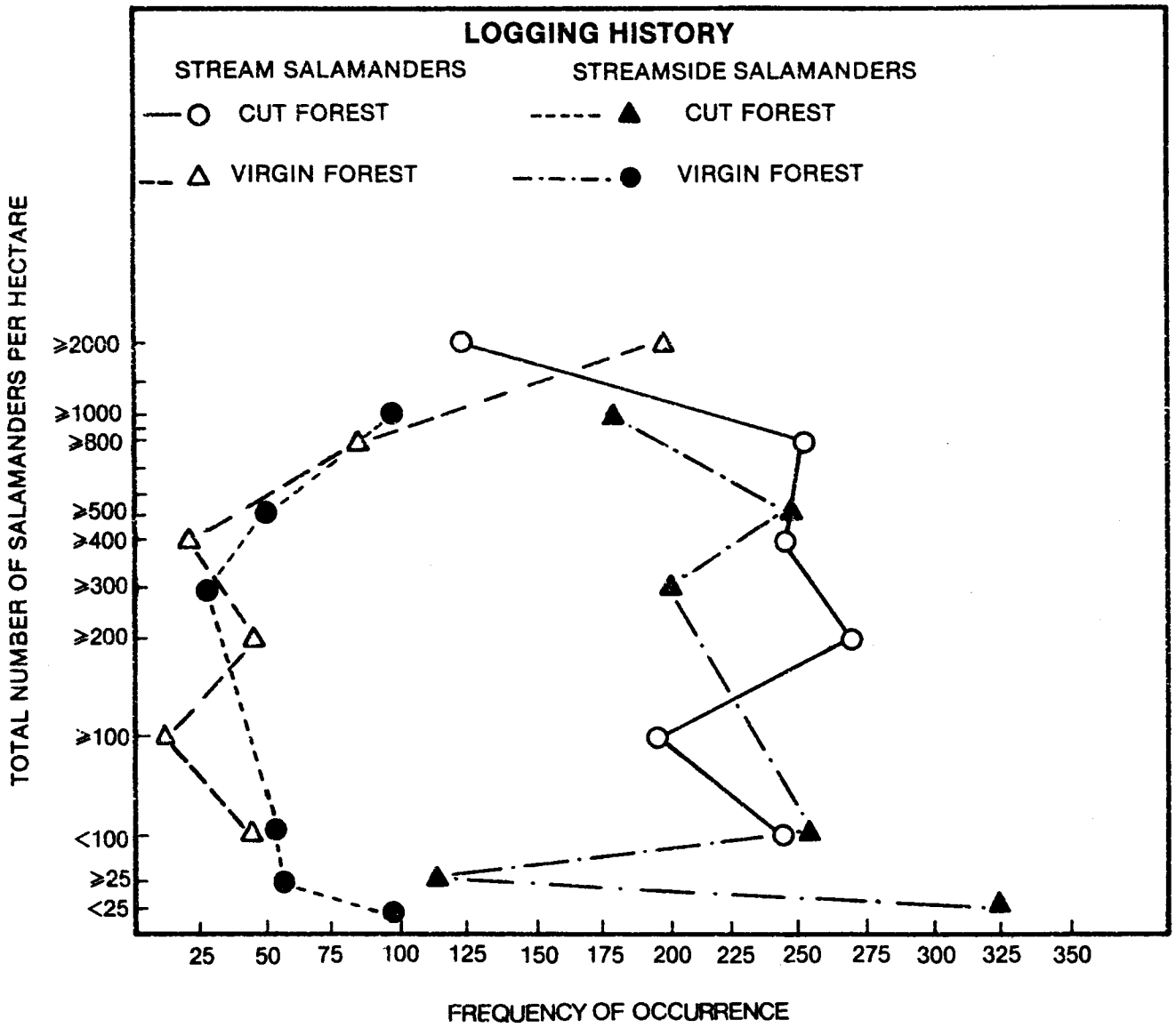


Figure 18. Salamander abundance in relation to logging history.

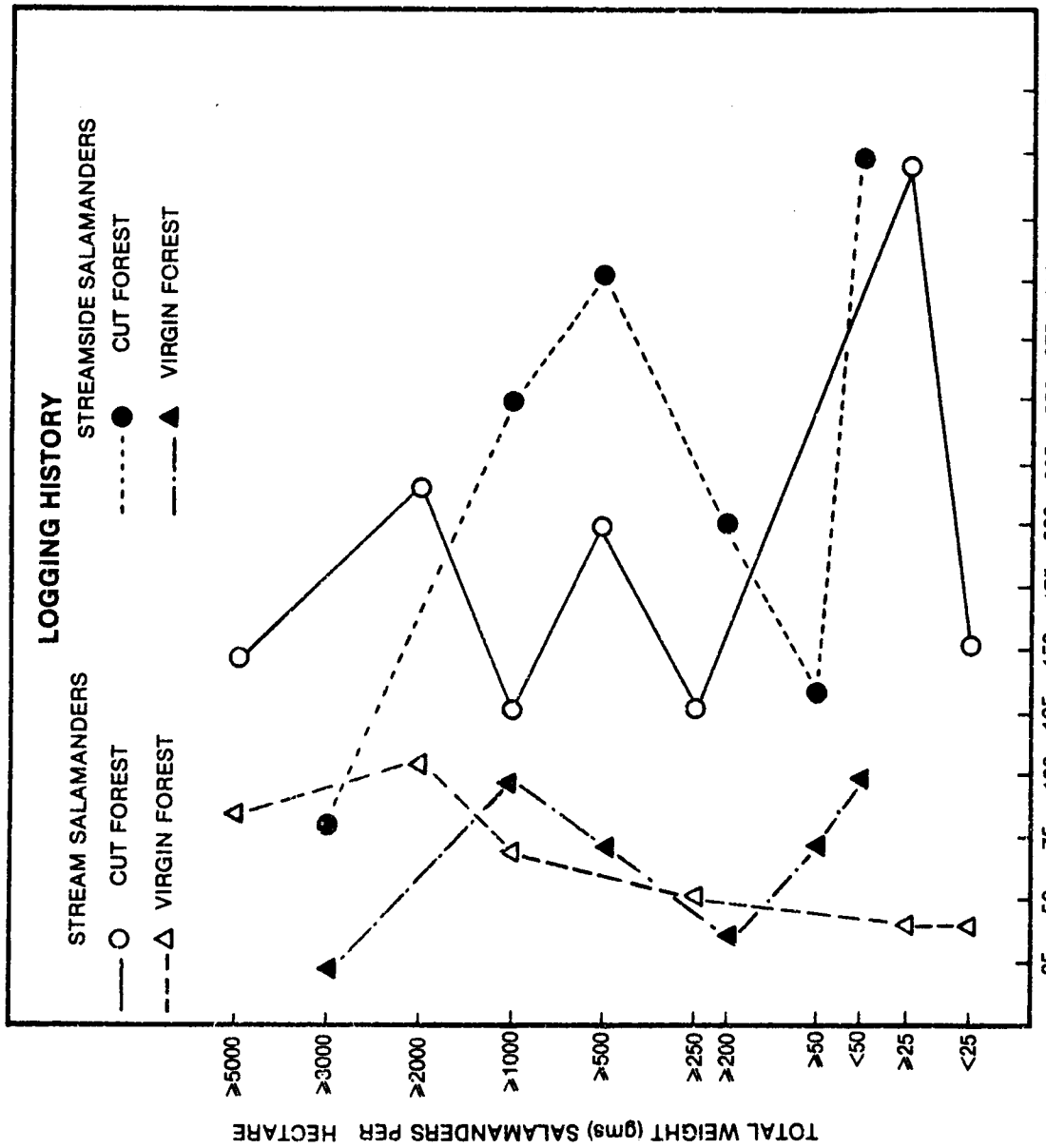


Figure 19. Salamander biomass in relation to logging history.

CHAPTER V

DISCUSSION

Salamanders occupy stream environs within every conceivable microhabitat type available in the GRSM. Patterns of abundance and biomass distribution were evident, however, in terms of watershed, elevation, season, stream size variables, stream flow and velocity, water quality, temperature, overstory and understory forest type, logging history, and stream substrate type. Population estimates of streamside salamanders (mean = 0.050/m^2, range = 0-0.367/m^2) were about average within the range (0.0025-1.5/m^2) presented by Spight (1967) in his review of terrestrial and streamside salamander populations. However, stream-dwelling salamanders were much more abundant (mean = 0.153, range = 0-1.880) and the upper end of the range presented by Spight was exceeded by a fairly large margin. Since stream population estimates of salamanders have apparently not been investigated previous to this study, it is not possible to comparatively analyze stream populations of salamanders in other areas or even to historical studies within the GRSM. It is evident, however, that stream salamander populations in the Park are greater than any other salamander population estimates reviewed in the literature, and thus may represent the habitat type and terrain where salamanders attain their greatest population density. It was also observed that in Park stream environs that adjacent localities (streamside) may support salamander faunas differing markedly in species diversity and population density, with different relationships to

environmental and habitat variables. Variation in species diversity in other kinds of vertebrates has been correlated with variation in habitat complexity (MacArthur and MacArthur 1961; Pianka 1967). Measures of habitat complexity for this study were rather basic since the entire Park was involved in the survey.

Habitat complexity and environmental variables effected species diversity, population abundance and biomass in different ways. Air and water temperature, for example, were important environmental parameters effecting species diversity, although these parameters were not strongly related to stream salamander abundance, and were only weakly related to stream salamander biomass. Air and water temperature strongly influenced streamside salamander biomass, however. Stream width was probably the single most important habitat parameter in this study effecting both salamander diversity and population density. Closely related to stream width, stream order was also an important factor. About 85 percent of all stream miles in the United States are first to third order streams (Cummins 1975), which constitutes the majority of stream orders in the GRSM. The transition in organic inputs and plant growth represent the basis of changing overall community structure and function. The headwaters are characteristically heavily dependent upon terrestrial contributions of particulate organic matter, especially coarse particles such as leaf litter, with little or no photosynthetic production of organic matter in the stream. Coarse particulate organic matter feeding invertebrates (shredders) and detritivores feeding on fine particulate organic matter (collectors) are thus the dominant macroconsumers (Cummins 1975) while salamanders which feed on these invertebrates are responsible

for most of the standing crop abundance and biomass in the predator compartment of these stream ecosystems (Woodall and Wallace 1975). Second order streams were more densely populated with both stream and streamside-dwelling salamanders, while the series of first through third order streams in the Park were more populous than fourth order streams. Fourth order streams are less dependent upon direct terrestrial inputs and more on organic production by photosynthesizing algae and vascular hydrophytes along with the input of fine particulate organic matter from upstream (Cummins 1975). Along with these changes in the functional aspects of ecosystem structure in streams, the fishery component increases in larger streams of the Park (King 1937, 1939b; Lennon 1967; Jones 1975). Evidence indicates that larvae of some salamanders are restricted to the upper portions of breeding streams because of fish predation (Petranka 1983). Tail autonomy has been used as a measure of predation on salamanders (Ducey and Brodie 1983) and among the stream salamanders surveyed it was observed to markedly increase in fourth order streams where fish predators are abundant. Thus, it seems probable that a combination of changes in the food web structure of streams and increased predation are related to reduced salamander diversity and population density observed within larger streams of the Park. The effect of introduced game fish (Rainbow and Brown Trout) that have resulted in the loss of the native species (Brook Trout) has probably effected salamander distributions through alterations in predatory-prey relationships although I was unable to assess these effects.

The high elevation headwater streams were not, however, as productive as those within mid elevations and this occurrence may be

related to forest type and other characteristics of high elevation terrains (e.g., steep gradient of terrain slope and low pH stream waters). The second growth mesic hemlock-hardwood forest was very favorable to salamander density; and wherever Rhododendron occurred in the understory, salamander densities were usually high. These vegetation types are not as structurally diverse as other forest types (e.g., cove hardwoods) and suggest that salamander diversity and population density along a vegetative diversity gradient are not well related. However, strong relationships between salamander species and overstory/understory vegetation types, and between population densities and forest types were observed. Goldman and Kangas (1976) found high terrestrial salamander species diversity and abundance in the GRSM where there were many plants less than three feet tall, which suggest that salamander species diversity might increase in locations with high primary productivity. High productivity may allow salamanders to partition food more finely in these authors' assessment. Vertebrate species frequently avoid stringent competition by partitioning food and space resources.

Logging history effected the diversity and density of salamanders in stream environs of the Park, although not in the manner generally reported in the literature. The population density of salamanders in the Park was clearly greater in second growth forest, although three species were indemic to virgin forest stands. Bury (1983) reported that amphibian populations had more individuals and greater biomass, and different species composition on the old growth sites than on logged plots in the Redwood National Park, California. Similarly, in South Carolina, Bennett et al. (1980) found a higher number of amphibians in natural oak-hickory

habitat than in nearby managed pine habitats. The difference in my findings is probably attributable to the difference in age of cut stands which are ≥50 years old in the case of the GRSM, while in the previous studies such stands average only 6-7 years. Thus, the logged stands in the GRSM have matured considerably more than those involved in the Redwoods and South Carolina studies. Logging creates vegetational diversity (e.g., edges and openings) and thus is generally beneficial to game because it promotes increased growth of herbaceous and shrubby foods that many game species require (Teague 1968; Noble 1974; Umber and Harris 1974; Costa et al. 1976). But game may constitute only a small fraction of forest wildlife (Bury et al. 1980), as obviously is the case in small Appalachian Mountain watersheds (Burton and Likens 1975b; Woodall and Wallace 1975). Leaf litter appeared to offer better microhabitat conditions in deciduous and mixed forests than conifer needles did in coniferous forest of the Park, which may be a prime reason for the reduced population densities observed at high elevations.

The decline of the Frasier Fir forest due to parasitism by the Balsam Wooly Aphid may also be related to reduced salamander densities observed in high elevation areas of Park watersheds. The loss of this forest has many of the same effects as logging, as dead and dying fir trees result in an opening in the forest canopy. I suggest a scenario of events that may have resulted in the reduced salamander population densities where Frasier Fir dominant stands exist. The increased light penetration on the forest floor leads to increased soil temperatures and, in turn, greater evaporative water loss from the soil and understory. Opened areas also are subject to greater daily fluctuations in temperature

and humidity than areas under forest canopy. Erosion of the organic top soil and humus, which occurs rapidly in an area receiving such high amounts of rainfall. Also, the decline of the Frasier Fir probably alters the nutrient cycle and reduces needle litter that serves as microhabitat for salamanders. Stream nitrate concentrations (an important nutrient) were higher in virgin forest sections of watersheds, which is probably attributable to a conservation of nutrients in the second growth forest biomass, resulting in reduced export through stream systems. The effect of this increase, however, did not produce a higher level of salamander production (i.e., as indicated by standing crop biomass) in virgin forest watersheds.

The microdistribution of stream insects is related to current velocity, substratum particle size, silt, and detritus according to Rabeni and Minshall (1977). They reported that the reduction of current velocity alone accounted for reductions in the numbers of several species, while the addition of a light coating of silt significantly reduced the numbers of only a few species. While stream salamanders are dependent upon the dynamics of the food resources provided by stream insects, they were also observed to be strongly influenced by stream velocity and flow. Silt exerted a strong negative effect on the biomass of salamanders, however. Stream insects colonize small (1.0-3.5 cm) substrata (gravel/rock) perhaps because these serve as a better food collecting device than do larger (or smaller) substrata, and manipulation of the substratum (as for instance by hog rooting) may alter the productivity of a stream through an influence on its detritus storage capacity (Rabeni and Minshall 1977).
Stream-dwelling salamanders showed a preference for rock/gravel and

boulder/rock substrates, perhaps as bioenergetic efficient feeding zones paralleling insect distributions. The fact that turbidity was strongly negatively related to stream and streamside salamander densities, indicates the probable effect of hog rooting where this activity produces high turbidity loads. Cattle watering in Cades Cave also produces high turbidity/silt loads (Mathews 1978; Bratton et al. 1980); however, this occurrence is at least isolated to a specific managed area of the Park, whereas exotic wild hogs presently occur over three-fourths of the Park and attempts to eliminate or significantly reduce their population has proved futile.

The lowest pH levels (4.7), highest conductance (92.0), acidity (31.0), and hardness (53.0) observed in this study occurred in Beech Flats Creek where road construction of U.S. Highway 441 in 1963 near Newfound Gap eliminated stream-dwelling salamanders for approximately 8 km downstream of the roadcut and fill areas (Mathews and Morgan 1982). Salamander mortality in this study was attributed to acidic heavy metal leachate formed through redox processes associated with the pyritic content of the Anakeesta Formation roadfill bedrock. The highly mineralized component structure characterizing most of the geologic formations in the Park may effect other stream salamander populations where eroded rock exposures exist. The strong effects on salamander diversity and population density of hardness and conductance gives hint of such relationship. Acidic precipitation is also a phenomena occurring in the Park (Mathews et al. 1979; Mathews and Larson 1980) which may also accelerate the leachate of metals from such geologic exposures. Mushinsky (1975) has demonstrated that selection of substrate pH is a factor related to geographic and interspecific variation in some salamander species.

Although the effects of research collecting and translocation of salamanders was not a study area of this research endeavor, it is an area of potential effect on the distribution of Park salamanders given the extensive amount of collecting and recently the translocation of selected species. In one experiment, for instance, red cheeked morphs of Plethodon jordani were translocated from one area of the Park to another in order to study its competitive interactions with Plethodon glutinosus (Hairston 1980b; Mathews and Echternacht 1984). A persistent unnatural population persist today with some hybridization. The effects of this in the long term within the Park could parallel the problems associated with introduced exotic organisms.

The geographic variation in salamander populations in stream environs of the GRSM is complex and is probably effected as much by the influence of environmental and habitat elements as by competition which was not investigated during this study. Evolutionary theory as it applies to interspecific competition hold that ecologically equivalent species in contact will evolve to become different by an amount specified by their positions on the resource spectrum. Hairston (1980a) found that two species of terrestrial salamanders have different distributional relationships on different mountain ranges in the southern Appalachians, and that the two species are in intense competition where they overlap narrowly and is much reduced where the vertical overlap is wide. In stream environs of the GRSM there appears to be two distinct broad zones of overlap between salamander species: (1) between low and mid elevations involving Desmognathus fuscus, Gyrinophilus porphyriticus danielsi, Eurycea longicauda longicauda, Eurycea

longicauda guttolineata, and the remainder of the Leurognathus-Desmognathus series which distributions are continuous across all elevational zones in the Park (i.e., Leurognathus marmoratus, Desmognathus quadramaculatus, Desmognathus ochrophaeus carolinesis, and Desmognathus monticola monticola) and Eurycea bislineata wilderae which is also present at all elevational zones in the Park, and (2) between mid and high elevations involving Desmognathus santeetlah, Desmognathus imitator, Plethodon jordani, and again the elevationally ubiquitous species previously described in the Leurognathus-Desmognathus series and Eurycea bislineata wilderae. Where one of two species begins to evolve a superior competitive mechanism, whether by increased efficiency at obtaining the resources for which they are competing or by some interference mechanism, the other species must evolve in a similar direction or be displaced. In stream environs of the GRSM, this displacement has involved not only vertical distributions but also a partitioning of the horizontal dimension across boundaries of aquatic and terrestrial zones (ecotone), which probably influences the great diversity present in the Park. Such species specific traits as differences between Plethodon glutinosus and Plethodon cinereus in reaction and susceptibility to dry air have long since been correlated to differences in their geographic distribution (Shelford 1913, 1914; Noble 1927), and Burger (1935) and Littleford et al. (1947) have shown differences in resistance to water loss between several salamander species which they have correlated to ecological distribution. Tilley (1973) has shown that maturity is delayed in high elevation populations relative to low

elevation populations, and in low elevation woodland populations relative to low elevation rockface populations in the vicinity of Mt. Mitchell, North Carolina. This delayed maturity results in individuals being larger at maturity and may be responsible for the altitudinal size clines noted in several salamander species during this study, which may also have influenced the population density variances observed along an altitudinal gradient in the Park. Theory predicts that delayed maturity should be adaptive in relatively stable environments, and where it occurs is accompanied by increased survivorship and fertility (Tilley 1973). Such conditions may be met in high elevation remote stream environs of the GRSM within forest types other than Frasier Fir. In some respects, streams are more stable than terrestrial environments; specifically they are buffered from rapid changes in temperature and wind blown drying effects. Seasonal changes in salamander populations in stream environs of the Park were dynamic, although season was not nearly as influential on salamander population density as other variables examined. While terrestrial salamanders were burrowing and otherwise seeking refuge during winter, stream-dwelling salamanders were active. The ecological effects of this extended activity level in stream environs of the Park may have extensive influence on the distribution of salamanders.

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APPENDICES

APPENDIX A

SALAMANDER SPECIES ABUNDANCE DISTRIBUTION

Abbreviation Legend for Salamander Species

Abbreviation	Salamander Species
L.M.	*Leurognathus marmoratus*
D.Q.	*Desmognathus quadramaculatus*
D.O.C.	*Desmognathus ochrophaeus carolinesis*
D.F.	*Desmognathus fuscus*
D.M.M.	*Desmognathus monticola monticola*
P.G.G.	*Plethodon glutinosus glutinosus*
P.J.	*Plethodon jordani*
G.P.D.	*Gyrinophilus porphyriticus danielsi*
E.B.W.	*Eurycea bislineata wilderae*
E.L.L.	*Eurycea longicauda longicauda*
E.L.G.	*Eurycea longicauda guttolineata*
D.S.	*Desmognathus santeetlah*
D.I.	*Desmognathus imitator*

Table 8. Salamander Species Abundance by Watershed at Elevations <600 m (2000 ft).

Species	Watershed											ROW* TOTAL
	Cosby Creek	Mid. Prong Lt. Pigeon River	Dudley Creek	West Prong Lt. Pigeon River	Little River	Mid. Prong Little River	Abrams Creek	Panther Creek	Eagle Creek	Forney Creek	Noland Creek	
None		4		1	2	5	9	2	1	2		26 6.1
L.M.	11	5	1	6	10	2	40	8	2	4	2	91 21.5
D.Q.	4	1			6	9	30	11	1		1	63 14.9
D.O.C.	2		8		4	3	3	15			1	36 8.5
D.F.						1	1	2	1			5 1.2
D.M.M.	6	13		3	9	10	14	21	18	2	9	105 24.8
P.G.G.	1											1 0.2
G.P.D.		4	1		4	1	1	1			2	14 3.3
E.B.W.	15	4	1	3	3	5	3	40		4	2	80 18.9
E.L.L.								1				1 0.2
E.L.G.									1			1 0.2
COLUMN* TOTAL	39 9.2	31 7.3	11 2.6	13 3.1	38 9.0	36 8.5	101 23.9	101 23.9	24 5.7	12 2.8	17 4.0	423 100.0

*Row and column totals include frequency followed by percent.

Table 9. Salamander Species Abundance by Watershed at Elevations between 600-1200 m (2000-4000 ft).

Species	Watershed														
	Cosby Creek	Mid. Prong Lt. Pigeon River	Dudley Creek	Little River	Mid. Prong Little River	Abrams Creek	Panther Creek	Parsons Branch	Eagle Creek	Forney Creek	Noland Creek	Oconaluftee River	Straight Fork	Cataloochee Creek	ROW* TOTAL
None	1	1		3					2	2	2	1	1		13
															1.1
L.M.	66	7	39	10	43	12	18	1	23	7	36	8	27	60	375
															31.3
D.Q.	41		9		28	5	10		29	4	22	7	13	34	202
															17.7
D.O.C.	21		5	4	21	1	27	3	6	7	10	9	4	44	162
															14.2
D.F.	1			1	6		2		2				1	1	14
															1.2
D.M.M.	41			1	29	5	22	2	34	7	17	16	6	14	194
															17.0
P.G.G.	2											1		1	4
															0.4
G.P.D.			2	4	1		1				1	1		7	17
															1.5
E.B.W.	19		8	16	16	2	15	1	4	10	14	1	3	69	178
															15.6
COLUMN*	192	8	63	39	144	25	95	7	100	37	102	44	55	230	1141
TOTAL	16.8	0.7	5.5	3.4	12.6	2.2	8.3	0.6	8.8	3.2	8.9	3.9	4.8	20.2	100.0

*Row and column totals include frequency followed by percent.

Table 10. Salamander Species Abundance by Watershed at Elevations >1200 m (4000 ft).

Species	Watershed								ROW* TOTAL
	Mid. Prong Lt. Pigeon River	West Prong Lt. Pigeon River	Abrams Creek	Eagle Creek	Forney Creek	Noland Creek	Deep Creek	Oconaluftee River	
None	1		1			1			3 1.9
L.M.				3		16		19	38 24.5
D.Q.				5	4	1		5	15 9.7
D.O.C.		8		23	1			3	35 22.6
D.M.M.		3		24		3		5	35 22.6
P.G.G.				1					1 0.6
P.J.				2					2 1.3
E.B.W.		8		3		4	2	2	19 12.3
D.S.		1		1		1			3 1.9
D.I.								4	4 2.6
COLUMN* TOTAL	1 0.6	20 12.9	1 0.6	62 40.0	5 3.2	26 16.8	2 1.3	38 24.5	155 100.0

*Row and column totals include frequency followed by percent.

Table 11. Stream-Dwelling Salamander Species Abundance by Stream Size.

Species	Stream Hectares <0.0025	>=0.0025	>=0.005	>=0.01	>=0.02	>=0.04	ROW* TOTAL
Leurognathus marmoratus	9	86	121	177	59	14	466 50.9
Desmognathus quadramaculatus	12	52	34	67	25	7	197 21.5
Desmognathus o. carolinesis	10	14	11	11			46 5.0
Desmognathus fuscus	1	1	3	2			7 0.8
Desmognathus m. monticola	17	29	38	28	12	1	125 13.6
Gyrinophilus p. danielsi	1	3	1		5	2	12 1.3
Eurycea b. wilderae	11	5	23	13	5	1	58 6.3
Eurycea l. longicauda			1				1 0.1
Eurycea l. guttolineata					1		1 0.1
Desmognathus santeetlah	1	1					2 0.2
Desmognathus imitator				1			1 0.1
COLUMN TOTAL*	62 6.8	191 20.9	232 25.3	299 32.6	107 11.7	25 2.7	916 100.0

*Row and column totals include frequency followed by percent.

Table 12. Streamside-Dwelling Salamander Species Abundance by Stream Size.

Species	Stream Hectares <0.0025	>=0.0025	>=0.005	>=0.01	>=0.02	>=0.04	ROW* TOTAL
Leurognathus marmoratus		9	5	5	1		20 2.6
Desmognathus quadramaculatus	2	13	28	36	4		83 10.9
Desmognathus o. carolinensis	18	54	49	49	15	3	188 24.6
Desmognathus fuscus	1		1	7	2	1	12 1.6
Desmognathus m. monticola	16	25	79	68	17	4	209 27.4
Plethodon g. glutinosus	1	1		4			6 0.8
Plethodon jordani		2					2 0.3
Gyrinophilus p. danielsi	1		8	8	2		19 2.5
Eurycea b. wilderae	7	8	73	77	38	16	219 28.7
Desmognathus santeetlah			1				1 0.1
Desmognathus imitator	1	2					3 0.4
COLUMN TOTAL*	47 6.2	114 15.0	245 32.1	254 33.3	79 10.4	24 3.1	762 100.0

*Row and column totals include frequency followed by percent.

Table 13. Stream-Dwelling Salamander Species Abundance by Stream Order.

Species	Stream Order				ROW* TOTAL
	First	Second	Third	Fourth	
Leurognathus marmoratus	120	163	111	72	466
					50.9
Desmognathus quadramaculatus	51	64	49	33	197
					21.5
Desmognathus o. carolinesis	26	12	5	3	46
					5.0
Desmognathus fuscus	2	3		2	7
					0.8
Desmognathus m. monticola	48	40	21	16	125
					13.6
Gyrinophilus p. danielsi	4		1	7	12
					1.3
Eurycea b. wilderae	21	10	11	16	58
					6.3
Eurycea l. longicauda				1	1
					0.1
Eurycea l. guttolineata				1	1
					0.1
Desmognathus santeetlah	2				2
					0.2
Desmognathus imitator	1				1
					0.1
COLUMN TOTAL*	275	292	198	151	916
	30.0	31.9	21.6	16.5	100.0

*Row and column totals include frequency followed by percent.

Table 14. Streamside-Dwelling Salamander Species Abundance by Stream Order.

Species	Stream Order				ROW* TOTAL
	First	Second	Third	Fourth	
Leurognathus marmoratus	6	6	5	3	20 2.6
Desmognathus quadramaculatus	12	24	42	5	83 10.9
Desmognathus o. carolinesis	55	70	44	17	188 24.5
Desmognathus fuscus	1	3	7	1	12 1.6
Desmognathus m. monticola	46	81	53	29	209 27.4
Plethodon g. glutinosus	2	1	1	2	6 0.8
Plethodon jordani	2				2 0.3
Gyrinophilus p. danielsi	1	8	8	2	19 2.5
Eurycea b. wilderae	28	55	48	88	219 28.7
Desmognathus santeetlah	1				1 0.1
Desmognathus imitator	3				3 0.4
COLUMN TOTAL*	157 20.6	250 32.8	208 27.3	147 19.3	762 100.0

*Row and column totals include frequency followed by percent.

Table 15. Stream-Dwelling Salamander Species Abundance by Stream Width.

Species	Stream Width (m) <1	>=1	>=3	>=6	>=12	>=18	>=24	ROW* TOTAL
Leurognathus marmoratus	15	118	122	169	28	14		466 50.9
Desmognathus quadramaculatus	5	68	41	68	9	5	1	197 21.5
Desmognathus o. carolinesis	9	22	8	7				46 5.0
Desmognathus fuscus		2	3	2				7 0.8
Desmognathus m. monticola	6	49	38	23	9			125 13.6
Gyrinophilus p. danielsi		4	1		5	2		12 1.3
Eurycea b. wilderae	13	8	21	11	4	1		58 6.3
Eurycea l. longicauda			1					1 0.1
Eurycea l. guttolineata					1			1 0.1
Desmognathus santeetlah	1	1						2 0.2
Desmognathus imitator				1				1 0.1
COLUMN TOTAL*	49 5.3	272 29.7	235 25.7	281 30.7	56 6.1	22 2.4	1 0.1	916 100.0

*Row and column totals include frequency followed by percent.

Table 16. Streamside-Dwelling Salamander Species Abundance by Stream Width.

Species	Stream Width (m) <1	>=1	>=3	>=6	>=12	>=18	>=24	ROW* TOTAL
Leurognathus marmoratus		9	6	4	1			20
								2.6
Desmognathus quadramaculatus	2	16	38	27				83
								10.9
Desmognathus o. carolinesis	15	70	52	45	3	1	2	188
								24.6
Desmognathus fuscus	1		2	8		1		12
								1.6
Desmognathus m. monticola	7	60	83	50	6	1	3	210
								27.5
Plethodon g. glutinosus	1	1	2	2				6
								0.8
Plethodon jordani		2						2
								0.3
Gyrinophilus p. danielsi	1	4	6	7	1			19
								2.5
Eurycea b. wilderae	4	40	83	62	14	15	1	219
								28.7
Desmognathus santeetlah		1						1
								0.1
Desmognathus imitator		3						3
								0.4
COLUMN TOTAL*	31	206	272	205	25	18	6	762
	4.1	27.0	35.7	26.9	3.3	2.4	0.8	100.0

*Row and column totals include frequency followed by percent.

Table 17. Stream-Dwelling Salamander Species Abundance by Stream Depth.

Species	Stream Depth (cm) <2	>=2	>=5	>=10	>=15	>=20	>=40	ROW* TOTAL
Leurognathus marmoratus	2	51	105	67	44	154	43	466 50.9
Desmognathus quadramaculatus	3	24	42	22	36	40	30	197 21.5
Desmognathus o. carolinesis	8	9	12	7	1	5	4	46 5.0
Desmognathus fuscus		1	1	2	1	1	1	7 0.8
Desmognathus m. monticola	8	36	19	6	19	27	10	125 13.6
Gyrinophilus p. danielsi		1	1			8	2	12 1.3
Eurycea b. wilderae	9	7	8	12	8	12	2	58 6.3
Eurycea l. longicauda				1				1 0.1
Eurycea l. guttolineata						1		1 0.1
Desmognathus santeetlah	2							2 0.2
Desmognathus imitator		1						1 0.1
COLUMN TOTAL*	32 3.5	130 14.2	188 20.5	117 12.8	109 11.9	248 27.1	92 10.0	916 100.0

*Row and column totals include frequency followed by percent.

Table 18. Streamside-Dwelling Salamander Species Abundance by Stream Depth.

Species	Stream Depth (cm) <2	>=2	>=5	>=10	>=15	>=20	>=40	ROW* TOTAL
Leurognathus marmoratus		3	8	2	2	5		20 2.8
Desmognathus quadramaculatus		5	18	9	27	22	2	83 10.9
Desmognathus o. carolinesis	5	42	32	36	20	46	7	188 24.6
Desmognathus fuscus			1		3	7	1	12 1.6
Desmognathus m. monticola	1	25	38	31	46	58	10	209 27.4
Plethodon g. glutinosus		1	1	1	1	1	1	6 0.8
Plethodon jordani	1	1						2 0.3
Gyrinophilus p. danielsi		2	2	7	5	2	1	19 2.5
Eurycea b. wilderae	2	11	26	29	57	75	19	219 28.7
Desmognathus santeetlah			1					1 0.1
Desmognathus imitator				3				3 0.4
COLUMN TOTAL*	9 1.2	90 11.8	127 16.7	119 15.6	161 21.1	216 28.3	41 5.4	762 100.0

*Row and column totals include frequency followed by percent.

Abbreviation Legend for Salamander Species

Abbreviation	Salamander Species
L.M.	*Leurognathus marmoratus*
D.Q.	*Desmognathus quadramaculatus*
D.O.C.	*Desmognathus ochrophaeus carolinesis*
D.F.	*Desmognathus fuscus*
D.M.M.	*Desmognathus monticola monticola*
P.G.G.	*Plethodon glutinosus glutinosus*
P.J.	*Plethodon jordani*
G.P.D.	*Gyrinophilus porphyriticus danielsi*
E.B.W.	*Eurycea bislineata wilderae*
E.L.L.	*Eurycea longicauda longicauda*
E.L.G.	*Eurycea longicauda guttolineata*
D.S.	*Desmognathus santeetlah*
D.I.	*Desmognathus imitator*

Table 19. Stream-dwelling Salamander Species Abundance by Stream Velocity.

Species	Stream Velocity (cm/sec and ft/sec) <1.5 cm/sec (<0.05 ft/sec)	>=1.5 cm/sec (>=0.05 ft/sec)	>=31 cm/sec (>=1 ft/sec)	>=91 cm/sec (>=3 ft/sec)	>=183 cm/sec (>=6 ft/sec)	>=366 cm/sec (>=12 ft/sec)	ROW* TOTAL
L.M.	44	125	196	89	6	6	466 50.9
D.Q.	26	55	93	22	1		197 21.5
D.O.C.	12	22	7	5			46 5.0
D.F.	1	2	3	1			7 0.8
D.M.M.	40	41	33	8	3		125 13.6
G.P.D.	1	5	4	2			12 1.3
E.B.W.	5	21	26	5	1		58 6.3
E.L.L.			1				1 0.1
E.L.G.			1				1 0.1
D.S.	1	1					2 0.2
D.I.		1					1 0.1
COLUMN* TOTAL	130 14.2	273 29.8	364 39.7	132 14.4	11 1.2	6 0.7	916 100.0

*Row and column totals include frequency followed by percent.

Table 20. Streamside-dwelling Salamander Species Abundance by Stream Velocity.

Species	Stream Velocity (cm/sec and ft/sec) <1.5 cm/sec (<0.05 ft/sec)	>=1.5 cm/sec (>=0.05 ft/sec)	>=31 cm/sec (>=1 ft/sec)	>=91 cm/sec (>=3 ft/sec)	>=183 cm/sec (>=6 ft/sec)	>=366 cm/sec (>=12 ft/sec)	ROW* TOTAL
L.M.	3	9	8				20
							2.6
D.Q.	8	29	41	1		4	83
							10.9
D.O.C.	47	45	79	15		1	187
							24.5
D.F.		3	5	4			12
							1.6
D.M.M.	19	92	86	12		1	210
							27.5
P.G.G.	1	2	1	2			6
							0.8
P.J.	2						2
							0.3
G.P.D.		4	14	1			19
							2.5
E.B.W.	12	61	119	19	3	5	219
							28.7
D.S.	1						1
							0.1
D.I.		1	2				3
							0.4
COLUMN*	93	246	355	54	3	11	762
TOTAL	12.2	32.3	46.6	7.1	0.4	1.4	100.0

*Row and column totals include frequency followed by percent.

Table 21. Stream-dwelling Salamander Species Abundance by Stream Flow.

Species	Stream Flow (liters/sec and ft^3/sec) >0.02 l/sec (<0.05 ft^3/sec)	>=0.02 l/sec (>=0.05 ft^3/sec)	>=1.4 l/sec (>=3 ft^3/sec)	>=7 l/sec (>=15 ft^3/sec)	>=24 l/sec (>=50 ft^3/sec)	>=59 l/sec (>=125 ft^3/sec)	ROW* TOTAL
L.M.	53	106	67	112	75	53	466
							50.9
D.Q.	34	43	34	44	22	20	197
							21.5
D.C.C.	12	22	6	2	4		46
							5.0
D.F.	1	1	3	1	1		7
							0.8
D.M.M.	41	31	25	11	8	9	125
							13.6
G.P.D.	1	3	4		2	2	12
							1 3
E.B.W.	2	20	24	5	3	4	58
							6.3
E.L.L.			1				1
							0.1
E.L.G.					1		1
							0.1
D.S.	1	1					2
							0.2
D.I.		1					1
							0.1
COLUMN*	145	228	164	175	116	88	916
TOTAL	15.8	24.9	17.9	19.1	12.7	9.6	100.0

*Row and column totals include frequency followed by percent.

Table 22. Streamside-dwelling Salamander Species Abundance by Stream Flow.

Species	Stream Flow (liters/sec and ft^3/sec) <0.02 l/sec (<0.05 ft^3/sec)	>=0.02 l/sec (>=0.05 ft^3/sec)	>=1.4 l/sec (>=3 ft^3/sec)	>=7 l/sec (>=15 ft^3/sec)	>= 24 l/sec (>=50 ft^3/sec)	>=59 l/sec (>=125 ft^3/sec)	ROW* TOTAL
L.M.	3	8	6	2	1		20 2.6
D.Q.	12	14	26	22	3	6	83 10.9
D.O.C.	48	42	44	35	12	7	188 24.6
D.F.	1		3	4	3	1	12 1.6
D.M.M.	23	62	49	50	18	7	209 27.4
P.G.G.	1	2	1	1	1		6 0.8
P.J.	2						2 0.3
G.P.D.	1	3	9	4	2		19 2.5
E.B.W.	11	39	67	42	33	27	219 28.7
D.S.	1						1 0.1
D.I.		1	2				3 0.4
COLUMN* TOTAL	103 13.5	171 22.4	207 27.2	160 21.0	73 9.6	48 6.3	762 100.0

*Row and column totals include frequency followed by percent.

Table 23. Stream-Dwelling Salamander Species Abundance by Air Temperature.

Species	Air Temperature (°C) <1	>=1	>=8	>=12	>=18	>=22	>=25	ROW* TOTAL
Leurognathus marmoratus	28	148	85	104	62	32	7	466
								50.9
Desmognathus quadramaculatus	9	50	32	54	25	19	8	197
								21.5
Desmognathus o. carolinesis		5	10	20	2	8	1	46
								5.0
Desmognathus fuscus		1	1	2	3			7
								0.8
Desmognathus m. monticola	1	7	12	36	34	28	7	125
								13.6
Gyrinophilus p. danielsi			3	1	4	4		12
								1.3
Eurycea b. wilderae	2	11	7	22	13	1	2	58
								6.3
Eurycea l. longicauda					1			1
								0.1
Eurycea l. guttolineata						1		1
								0.1
Desmognathus santeetlah				1			1	2
								0.2
Desmognathus imitator			1					1
								0.1
COLUMN TOTAL*	40	222	151	240	144	93	26	916
	4.4	24.2	16.5	26.2	15.7	10.2	2.8	100.0

*Row and column totals include frequency followed by percent.

Table 24. Streamside-Dwelling Salamander Species Abundance by Air Temperature.

Species	Air Temperature (°C) <1	>=1	>=8	>=12	>=18	>=22	>=25	ROW* TOTAL
Leurognathus marmoratus			3	3	3	10	1	20
								2.6
Desmognathus quadramaculatus	1	1	10	35	24	10	2	83
								10.9
Desmognathus o. carolinesis	7	28	30	51	28	30	14	188
								24.6
Desmognathus fuscus		1			6	5		12
								1.6
Desmognathus m. monticola	8	7	24	35	62	65	8	209
								27.4
Plethodon g. glutinosus			2		2	2		6
								0.8
Plethodon jordani				1			1	2
								0.3
Gyrinophilus p. danielsi	8	1	4	2	2	1	1	19
								2.5
Eurycea b. wilderae	8	28	14	73	64	13	19	219
								28.7
Desmognathus santeetlah			1					1
								0.1
Desmognathus imitator			3					3
								0.4
COLUMN TOTAL*	32	66	91	200	191	136	46	762
	4.2	8.7	11.9	26.2	25.1	17.8	6.0	100.0

*Row and column totals include frequency followed by percent.

Table 25. Stream-Dwelling Salamander Species Abundance by Water Temperature.

Species	Water Temperature (°C) <2	>=2	>=4	>=8	>=12	>=16	>=18	ROW* TOTAL
Leurognathus marmoratus	27	88	143	92	70	35	11	466
								50.9
Desmognathus quadramaculatus	12	31	39	45	40	28	2	197
								21.5
Desmognathus o. carolinesis	1		15	19	2	3	6	46
								5.0
Desmognathus fuscus			2	1	1	3		7
								0.8
Desmognathus m. monticola	2		21	33	35	29	5	125
								13.6
Gyrinophilus p. danielsi			2	5	4		1	12
								1.3
Eurycea b. wilderae	3	2	20	17	5	11		58
								6.3
Eurycea l. longicauda						1		1
								0.1
Eurycea l. guttolineata							1	1
								0.1
Desmognathus santeetlah				1		1		2
								0.2
Desmognathus imitator			1					1
								0.1
COLUMN TOTAL*	45	121	243	213	157	111	26	916
	4.9	13.2	26.5	23.3	17.1	12.1	2.8	100.0

*Row and column totals include frequency followed by percent.

Table 26. Streamside-Dwelling Salamander Species Abundance by Water Temperature.

Species	Water Temperature (°C) <2	>=2	>=4	>=8	>=12	>=16	>=18	ROW* TOTAL
Leurognathus marmoratus				6	3	10	1	20 2.6
Desmognathus quadramaculatus		1	4	28	20	28	2	83 10.9
Desmognathus o. carolinesis	8	17	26	65	26	37	9	188 24.6
Desmognathus fuscus		1			1	7	3	12 1.6
Desmognathus m. monticola	7	6	22	43	36	72	23	209 27.4
Plethodon g. glutinosus			1	1	3	1		6 0.8
Plethodon jordani				1		1		2 0.3
Gyrinophilus p. danielsi		1	11	4		3		19 2.5
Eurycea b. wilderae	10	18	15	90	30	44	12	219 28.7
Desmognathus santeetlah		1						1 0.1
Desmognathus imitator			2	1				3 0.4
COLUMN TOTAL*	25 3.3	45 5.9	81 10.6	239 31.4	119 15.6	203 26.6	50 6.6	762 100.0

*Row and column totals include frequency followed by percent.

Table 27. Salamander Species Abundance by Stream Alkalinity Level.

Species	Alkalinity (mg/l as $CaCO_3$) <1	>=1	>=3	>=6	>=12	ROW* TOTAL
None	3	13	18	2	6	42 2.4
Leurognathus marmoratus	31	203	131	66	55	486 28.3
Desmognathus quadramaculatus	3	120	96	45	16	280 16.3
Desmognathus o. carolinesis	4	71	106	44	8	233 13.6
Desmognathus fuscus	1	8	9	1		19 1.1
Desmognathus m. monticola	8	139	145	35	7	334 19.4
Plethodon g. glutinosus		3	1	1	1	6 0.3
Plethodon jordani		2				2 0.1
Gyrinophilus p. danielsi		9	13	9		31 1.8
Eurycea b. wilderae	4	92	118	51	12	277 16.1
Eurycea l. longicauda			1			1 0.1
Eurycea l. guttolineata			1			1 0.1
Desmognathus santeetlah	1	1	1			3 0.2
Desmognathus imitator				3	1	4 0.2
COLUMN TOTAL*	55 3.2	661 38.5	640 37.2	257 15.0	106 6.2	1719 100.0

*Row and column totals include frequency followed by percent.

Table 28. Salamander Species Abundance by Stream Acidity Level.

Species	Acidity (mg/l as NaOH) <3	>=3	>=4	>=5	>=6	>=8	>=11	ROW* TOTAL
None	4	1	16	8	11	1	1	42
								2.4
Leurognathus marmoratus	16	54	136	115	115	39	11	486
								28.3
Desmognathus quadramaculatus	8	14	62	107	73	11	5	280
								16.3
Desmognathus o. carolinesis	12	13	30	76	76	23	3	233
								13.6
Desmognathus fuscus	1	1	1	2	10	4		19
								1.1
Desmognathus m. monticola	12	15	33	84	157	32	1	334
								19.4
Plethodon g. glutinosus	1		1	2	2			6
								0.3
Plethodon jordani						2		2
								0.1
Gyrinophilus p. danielsi	1	2	5	10	10	1	2	31
								1.8
Eurycea b. wilderae	10	9	87	114	48	8	1	277
								16.1
Eurycea l. longicauda				1				1
								0.1
Eurycea l. guttolineata					1			1
								0.1
Desmognathus santeetlah	1			1		1		3
								0.2
Desmognathus imitator				1	2		1	4
								0.2
COLUMN TOTAL*	66	109	371	521	505	122	25	1719
	3.8	6.3	21.6	30.3	29.4	7.1	1.5	100.0

*Row and column totals include frequency followed by percent.

Table 29. Salamander Species Abundance by Stream Turbidity Levels.

Species	Turbidity (JTU) <1	>=1	>=3	>=5	>=10	>=30	ROW* TOTAL
None	22	17	3				42
							2.4
Leurognathus marmoratus	319	150	11	2	4		486
							28.3
Desmognathus quadramaculatus	172	97	5	1	3	2	280
							16.3
Desmognathus o. carolinesis	112	88	15		5	13	233
							13.6
Desmognathus fuscus	9	9	1				19
							1.1
Desmognathus m. monticola	180	107	21	3	7	16	334
							19.4
Plethodon g. glutinosus	4	2					6
							0.3
Plethodon jordani					1	1	2
							0.1
Gyrinophilus p. danielsi	20	10	1				31
							1.8
Eurycea b. wilderae	186	82	5		4		277
							16.1
Eurycea l. longicauda		1					1
							0.1
Eurycea l. guttolineata		1					1
							0.1
Desmognathus santeetlah	2				1		3
							0.2
Desmognathus imitator	4						4
							0.2
COLUMN TOTAL*	1030	564	62	6	25	32	1719
	59.9	32.8	3.6	0.3	1.5	1.9	100.0

*Row and column totals include frequency followed by percent.

Table 30. Salamander Species Abundance by Stream Nitrate Concentration.

Species	Nitrate (mg/l as NO_3) <0.25	>=0.25	>=0.5	>=1.0	>=1.5	>=2.0	ROW* TOTAL
None	3	6	9	7	5	12	42 2.4
Leurognathus marmoratus	48	46	135	122	88	47	486 28.3
Desmognathus quadramaculatus	25	34	90	61	38	32	280 16.3
Desmognathus o. carolinesis	29	26	73	28	52	25	233 13.6
Desmognathus fuscus		3	2	7	1	6	19 1.1
Desmognathus m. monticola	32	54	84	70	55	39	334 19.4
Plethodon g. glutinosus	1		2			3	6 0.3
Plethodon jordani					2		2 0.1
Gyrinophilus p. danielsi	10	6	8	1	6		31 1.8
Eurycea b. wilderae	38	59	101	24	43	12	277 16.1
Eurycea l. longicauda			1				1 0.1
Eurycea l. guttolineata				1			1 0.1
Desmognathus santeetlah	1				2		3 0.2
Desmognathus imitator			1	3			4 0.2
COLUMN TOTAL*	187 10.9	234 13.6	506 29.4	324 18.8	292 17.0	176 10.2	1719 100.0

*Row and column totals include frequency followed by percent.

Table 31. Stream-Dwelling Salamander Species Abundance by Stream pH Level.

Species	pH Level >=5.0	>=5.5	>=6.0	>=6.5	>=7.0	ROW* TOTAL
Leurognathus marmoratus	5	82	239	138	2	466
						50.9
Desmognathus quadramaculatus	2	45	77	72	1	197
						21.5
Desmognathus o. carolinensis	6	5	21	14		46
						5.0
Desmognathus fuscus		1	5	1		7
						0.8
Desmognathus m. monticola	17	18	59	31		125
						13.6
Gyrinophilus p. danielsi		2	5	5		12
						1.3
Eurycea b. wilderae		8	35	13	2	58
						6.3
Eurycea l. longicauda			1			1
						0.1
Eurycea l. guttolineata			1			1
						0.1
Desmognathus santeetlah		1	1			2
						0.2
Desmognathus imitator			1			1
						0.1
COLUMN TOTAL*	30	162	445	274	5	916
	3.3	17.7	48.6	29.9	0.5	100.0

*Row and column totals include frequency followed by percent.

Table 32. Streamside-Dwelling Salamander Species Abundance by Stream pH Level.

Species	pH Level >=4.5	>=5.0	>=5.5	>=6.0	>=6.5	ROW* TOTAL
Leurognathus marmoratus			7	6	7	20
						2.6
Desmognathus quadramaculatus		1	35	35	12	83
						10.9
Desmognathus o. carolinesis		11	41	83	53	188
						24.6
Desmognathus fuscus				9	3	12
						1.6
Desmognathus m. monticola	1	4	27	116	61	209
						27.4
Plethodon g. glutinosus			1	3	2	6
						0.8
Plethodon jordani		1	1			2
						0.3
Gyrinophilus p. danielsi			1	6	12	19
						1.8
Eurycea b. wilderae		4	59	100	56	219
						28.7
Desmognathus santeetlah			1			1
						0.1
Desmognathus imitator	1		2			3
						0.4
COLUMN TOTAL*	2	21	175	358	206	762
	0.3	2.8	23.0	47.0	27.0	100.0

*Row and column totals include frequency followed by percent.

Table 33. Salamander Species Abundance by Stream Conductivity Level.

Species	Conductivity (umhos/cm) <5	>=5	>=8	>=11	>=14	>=20	ROW* TOTAL
None	1	5	12	13	6	5	42
							2.4
Leurognathus marmoratus	16	68	221	95	50	36	486
							28.3
Desmognathus quadramaculatus		47	106	73	43	11	280
							16.3
Desmognathus o. carolinesis	1	24	89	74	41	4	233
							13.6
Desmognathus fuscus		4	10	4	1		19
							1.1
Desmognathus m. monticola	1	71	116	109	29	8	334
							19.4
Plethodon g. glutinosus	1			3	2		6
							0.3
Plethodon jordani		1		1			2
							0.1
Gyrinophilus p. danielsi			15	9	6	1	31
							1.8
Eurycea b. wilderae	3	11	113	67	74	9	277
							16.1
Eurycea l. longicauda				1			1
							0.1
Eurycea l. guttolineata			1				1
							0.1
Desmognathus santeetlah		1	1		1		3
							0.2
Desmognathus imitator						4	4
							0.2
COLUMN TOTAL*	23	232	684	449	253	78	1719
	1.3	13.5	39.8	26.1	14.7	4.5	100.0

*Row and column totals include frequency followed by percent.

Abbreviation Legend for Salamander Species

Abbreviation	Salamander Species
L.M.	*Leurognathus marmoratus*
D.Q.	*Desmognathus quadramaculatus*
D.O.C.	*Desmognathus ochrophaeus carolinesis*
D.F.	*Desmognathus fuscus*
D.M.M.	*Desmognathus monticola monticola*
P.G.G.	*Plethodon glutinosus glutinosus*
P.J.	*Plethodon jordani*
G.P.D.	*Gyrinophilus porphyriticus danielsi*
E.B.W.	*Eurycea bislineata wilderae*
E.L.L.	*Eurycea longicauda longicauda*
E.L.G.	*Eurycea longicauda guttolineata*
D.S.	*Desmognathus santeetlah*
D.I.	*Desmognathus imitator*

Table 34. Salamander Species Abundance by Stream Hardness Level.

Species	Hardness (mg/l as $CaCO_3$) <1	>=1.5	>=2.0	>=2.5	>=3.0	>=5.0	>=10.0	>=15.0	ROW* TOTAL
None	1	1	4	2	13	17		4	42 2.4
L.M.	13	4	29	79	155	182	19	5	486 28.3
D.Q.	3	3	24	27	99	116	4	4	280 16.3
D.O.C.	1	1	26	26	82	90	5	2	233 13.6
D.F.	1			5	9	4			19 1.1
D.M.M.	6	8	37	53	102	121	4	3	334 19.4
P.G.G.						6			6 0.3
P.J.			2						2 0.1
G.P.D.		2		1	13	12	3		31 1.8
E.B.W.	2	2	4	19	86	156	3	5	277 16.1
E.L.L.						1			1 0.1
E.L.G.					1				1 0.1
D.S.			1	1		1			3 0.2
D.I.						1		3	4 0.2
COLUMN* TOTAL	27 1.6	21 1.2	127 7.4	213 12.4	560 32.6	707 41.1	38 2.2	26 1.5	1719 100.0

*Row and column totals include frequency followed by percent.

Table 35. Stream-Dwelling Salamander Species Abundance by Elevation.

Species	Elevation (m and ft) <600 m (<1200 ft)	>=600 m (>=1200 ft)	>=1200 m (>=4000 ft)	ROW* TOTAL
Leurognathus marmoratus	90	338	38	466 50.9
Desmognathus quadramaculatus	56	130	11	197 21.5
Desmognathus o. carolinesis	7	23	16	46 5.0
Desmognathus fuscus	3	4		7 0.8
Desmognathus m. monticola	39	60	26	125 13.6
Gyrinophilus p. danielsi	6	6		12 1.3
Eurycea b. wilderae	15	30	13	58 6.3
Eurycea l. longicauda	1			1 0.1
Eurycea l. guttolineata	1			1 0.1
Desmognathus santeetlah			2	2 0.2
Desmognathus imitator			1	1 0.1
COLUMN TOTAL*	218 23.8	591 64.5	107 11.7	916 100.0

*Row and column totals include frequency followed by percent.

Table 36. Streamside-Dwelling Salamander Species Abundance by Elevation.

Species	Elevation (m and ft) <600 m (<1200 ft)	>=600 m (>=1200 ft)	>=1200 m (>=4000 ft)	ROW* TOTAL
Leurognathus marmoratus	1	19		20 2.6
Desmognathus quadramaculatus	7	72	4	83 10.9
Desmognathus o. carolinesis	29	139	20	188 24.6
Desmognathus fuscus	2	10		17 1.6
Desmognathus m. monticola	66	134	9	209 27.4
Plethodon g. glutinosus	1	4	1	6 0.8
Plethodon jordani			2	2 0.3
Gyrinophilus p. danielsi	8	11		19 2.5
Eurycea b. wilderae	65	148	6	219 28.7
Desmognathus santeetlah			1	1 0.1
Desmognathus imitator			3	3 0.4
COLUMN TOTAL*	179 23.5	537 70.5	46 6.0	762 100.0

*Row and column totals include frequency followed by percent.

Table 37. Stream-Dwelling Salamander Species Abundance by Terrain Slope.

Species	Terrain Slope 0-5%	5-10%	10-15%	>15%	ROW* TOTAL
Leurognathus marmoratus	184	186	68	28	466
					50.9
Desmognathus quadramaculatus	79	81	29	8	197
					21.5
Desmognathus o. carolinensis	12	21	11	2	46
					5.0
Desmognathus fuscus	4	2	1		7
					0.8
Desmognathus m. monticola	39	70	15	1	125
					13.6
Gyrinophilus p. danielsi	3	2	1	6	12
					1.3
Eurycea b. wilderae	18	16	20	4	58
					6.3
Eurycea l. longicauda	1				1
					0.1
Eurycea l. guttolineata		1			1
					0.1
Desmognathus santeetlah		1	1		2
					0.2
Desmognathus imitator			1		1
					0.1
COLUMN TOTAL*	340	380	147	49	916
	37.1	41.5	16.0	5.3	100.0

*Row and column totals include frequency followed by percent.

Table 38. Streamside-Dwelling Salamander Species Abundance by Terrain Slope.

Species	Terrain Slope 0-5%	5-10%	10-15%	>15%	ROW* TOTAL
Leurognathus marmoratus	5	14	1		20 2.6
Desmognathus quadramaculatus	27	50	5	1	83 10.9
Desmognathus o. carolinesis	76	96	13	1	188 24.6
Desmognathus fuscus	4	8			12 1.6
Desmognathus m. monticola	92	101	15	1	209 27.4
Plethodon g. glutinosus	1	4		1	6 0.8
Plethodon jordani		2			2 0.3
Gyrinophilus p. danielsi	16	3			19 2.5
Eurycea b. wilderae	131	75	10	3	219 28.7
Desmognathus santeetlah	1				1 0.1
Desmognathus imitator			3		3 0.4
COLUMN TOTAL*	353 46.3	355 46.6	47 6.2	7 0.9	762 100.0

*Row and column totals include frequency followed by percent.

Abbreviation Legend for Salamander Species

Abbreviation	Salamander Species
L.M.	*Leurognathus marmoratus*
D.Q.	*Desmognathus quadramaculatus*
D.O.C.	*Desmognathus ochrophaeus carolinesis*
D.F.	*Desmognathus fuscus*
D.M.M.	*Desmognathus monticola monticola*
P.G.G.	*Plethodon glutinosus glutinosus*
P.J.	*Plethodon jordani*
G.P.D.	*Gyrinophilus porphyriticus danielsi*
E.B.W.	*Eurycea bislineata wilderae*
E.L.L.	*Eurycea longicauda longicauda*
E.L.G.	*Eurycea longicauda guttolineata*
D.S.	*Desmognathus santeetlah*
D.I.	*Desmognathus imitator*

Abbreviation Legend for Overstory Vegetation Type

Abbreviation and Code No.	Description
VSFY, 1111	Virgin Spruce-Fir (Yellow Birch)
VSFH, 1121	Virgin Spruce-Fir-Hardwood or Hemlock
VYBM, 1131	Virgin Yellow Birch (Mature)
VNHM, 1221	Virgin Mixed Northern Hardwood
VMMH, 1311	Virgin Mesic Mixed Cove Hardwoods
VMHH, 1321	Virgin Mesic Hemlock-Hardwood Cove
VMHF, 1331	Virgin Mesic Hardwood Flats
VMT, 1361	Virgin Mesic Tulip Tree dominated
VXMP, 1451	Virgin Xeric Mixed Pines
MNHB, 2211	Mature Northern Hardwoods - Beech Gap
MNHM, 2221	Mature Mixed Northern Hardwoods
MMMH, 2311	Mature Mesic Mixed Cove Hardwoods
MMHH, 2321	Mature Mesic Hemlock-Hardwood Cove
MMHF, 2331	Mature Mesic Hardwood Flats
MMMM, 2351	Mature Sub-Mesic Hardwoods
MXMD, 2441	Mature Xeric Mixed Oak-Pine
MXWP, 2461	Mature Xeric White Pine
SNHB, 3211	Second Growth Northern Hardwoods - Beech Gap
SNHM, 3221	Second Growth Mixed Northern Hardwoods
SNHS, 3231	Second Growth Successional Northern Hardwoods
SMMH, 3311	Second Growth Mesic Mixed Cove Hardwoods
SMHH, 3321	Second Growth Mesic Hemlock-Hardwood Cove
SMH, 3331	Second Growth Mesic Hardwood Flats
SMS, 3341	Second Growth Mixed Sub-xeric Hardwoods
SMMS, 3351	Second Growth Mesic Mixed Sub-mesic Hardwoods
SMT, 3361	Second Growth Mesic Tulip Tree dominated
SXMS, 3411	Second Growth Mixed Sub-xeric Hardwoods
SXMO, 3421	Second Growth Xeric Mixed Oak
SXOP, 3441	Second Growth Mixed Sub-xeric Hardwoods
SXMP, 3451	Second Growth Xeric Mixed Pines
SXWP, 3461	Second Growth Xeric White Pine
ENHM, 4221	Early Successional Northern Hardwoods - Beech Gap
EMMH, 4311	Early Successional Mesic Mixed Cove Hardwoods
EMHH, 4321	Early Successional Mesic Hemlock - Hardwood Cove
EMHF, 4331	Early Successional Mesic Hardwood Flats
EMSC, 4341	Early Successional Mesic Cove
EMMS, 4351	Early Successional Mixed Sub-mesic Hardwoods
EMT, 4361	Early Successional Mesic Tulip Tree dominated
EMHC, 4371	Early Successional Mesic Hemlock Cove
EXMS, 4411	Early Successional Mixed Sub-xeric Hardwoods
EXWP, 4461	Early Successional White Pine
EPAF, 5531	Early Successional Pastures-Fields-Clearings

Table 39. Salamander Species Abundance by Overstory Vegetation at Elevations <600 m (2000 ft).

Species	Overstory Vegetation Type																									
	VMHH 1321	MMMH 2311	MHHH 2321	MHHF 2331	MHHM 2351	MXMO 2441	MXWP 2461	SNHM 3221	SMMH 3311	SMHH 3321	SMH 3331	SMS 3341	SMMS 3351	SMT 3361	SXMS 3411	SXMO 3421	SXOP 3441	EMMH 4311	EMHH 4321	EMHF 4331	EMSC 4341	EMMS 4351	EXWP 4461	EPAF 5531	ROW* TOTAL
None			2				1		2	14	1						1	1	1	2				1	26
																									6.1
L.M.	1	1	2	2					21	36	1				4		1		16	2	1			3	91
																									21.5
D.Q.			2	2		1		1	18	22	1		1		4		3			8					63
																									14.9
D.O.C.		5	5		2				6	4	7	1					1					4	1		36
																									8.5
D.F.			1						1	2				1											5
																									1.2
D.M.M.	4	1	8	5				1	19	36	4	1	8	1	3	2	10				2				105
																									24.8
P.G.G.									1																1
																									0.2
G.P.D.				1					6	4	1		2												14
																									3.3
E.B.W.	2	1	27	2				3	23	10	1		2		1		4				3	1			80
																									18.9
E.L.L.			1																						1
																									0.2
E.L.G.																	1								1
																									0.2
COLUMN*	7	8	48	12	2	1	1	5	97	128	16	2	13	2	12	2	21	1	17	12	6	5	1	4	423
TOTAL	1.7	1.9	11.3	2.8	0.5	0.2	0.2	1.2	22.9	30.3	3.8	0.5	3.1	0.5	2.8	0.5	5.0	0.2	4.0	2.8	1.4	1.2	0.2	0.9	100.0

*Row and column totals include frequency followed by percent.

Table 40. Salamander Species Abundance by Overstory Vegetation Type at Elevations between 600-1200 m (2000-4000 ft).

Species	Overstory Vegetation Type																																ROW* TOTAL
	VMHH 1311	VMHH 1321	VMHF 1331	VXHP 1451	XSSN 2221	MMHH 2311	MMHH 2321	MMHF 2331	SMMB 3211	SMHM 3221	SMHS 3231	SMHH 3311	SMHH 3321	SMH 3331	SMS 3341	SMMS 3351	SMT 3361	SXMS 3411	SXMO 3421	SXOP 3441	SXHP 3451	SXHP 3461	EMHH 4221	EMHH 4311	EMHH 4321	EMHF 4331	EMMS 4351	EMT 4361	EMHC 4371	EXMS 4411	EXHP 4461		
None	1	1										1	5				1			1				1	1		1						13
	0.1																																1.1
L.M.		12	5	5	9	4	34	10		4	1	45	158	25		5	3	2		9	2		2	4		6	7			3	2		357
		1.0																															31.3
O.Q.		5	2	2	4	2	16	3		1		25	96	13	3	4		1		6			3	3	3		2	3	1		2		202
																																	17.7
O.O.C.			1		7	13	3	2	2	18		12	62	13	5	7	1					4		1	2	3		3	2	1			162
																																	14.2
O.F.												4	8		1							1											14
																																	1.2
D.M.M.		2	1			9	22		2	4	3	12	97	16	4	1	2	1		2	1			2	2	7	2	1				1	194
																																	17.0
P.G.G.						1							2												1								4
																																	0.4
G.P.D.								2					5	1	3				1			1				4							17
																																	1.5
E.B.W.			2	2		3	3	1		1	2	12	71	52	5		2	2		1	2	1		1	1	3	1		8		2		178
																																	15.6
COLUMN* TOTAL	1	20	11	9	20	32	80	18	4	28	6	111	504	120	21	17	9	6	1	19	5	7	5	12	10	23	13	7	11	4	7		1141
	0.1	1.8	1.0	0.8	1.8	2.8	7.0	1.6	0.4	2.5	0.5	9.7	44.2	10.5	1.8	1.5	0.8	0.5	0.1	1.7	0.4	0.6	0.4	1.1	0.9	2.0	1.1	0.6	1.0	0.4	0.6		100.0

*Row and column totals include frequency followed by percent.

Table 41. Salamander Species Abundance by Overstory Vegetation Type at Elevations >1200 (4000 ft).

	Overstory Vegetation Type									
Species	VSFY 1111	VSFH 1121	VYBM 1131	VNHM 1221	VMMH 1311	VMHH 1321	VMT 1361	MNHB 2211	SNHM 3221	ROW* TOTAL
None		1				2				3 1.9
L.M.	5	7	4		19	3				38 24.5
D.Q.			1		3	3	2	4	2	15 9.7
D.O.C.		8		1	1	10	13	1	1	35 22.6
D.M.M.	1	3	2	1	3	9	16			35 22.6
P.G.G.						1				1 0.6
P.J.						1	1			2 1.3
E.B.W.	1	11	2		2	3				19 12.3
D.S.	1	1				1				3 1.9
D.I.				2	1	1				4 2.6
COLUMN* TOTAL	8 5.2	31 20.0	9 5.8	4 2.6	29 18.7	34 21.9	32 20.6	5 3.2	3 1.9	155 100.0

*Row and column totals include frequency followed by percent.

Table 42. Salamander Species Abundance by Forest Type.

Species	Forest Type			ROW* TOTAL
	Deciduous	Coniferous	Mixed	
None	7	5	30	42 2.4
Leurognathus marmoratus	118	27	341	486 28.3
Desmognathus quadramaculatus	84	14	182	280 16.3
Desmognathus o. carolinesis	64	12	157	233 13.6
Desmognathus fuscus	9	1	9	19 1.1
Desmognathus m. monticola	117	9	208	334 19.4
Plethodon g. glutinosus	2		4	6 0.3
Plethodon jordani	2			2 0.1
Gyrinophilus p. danielsi	5	3	23	31 1.8
Eurycea b. wilderae	38	34	205	277 16.1
Eurycea l. longicauda			1	1 0.1
Eurycea l. guttolineata			1	1 0.1
Desmognathus santeetlah	1		2	3 0.2
Desmognathus imitator			4	4 0.2
COLUMN TOTAL*	447 26.0	105 6.1	1167 67.9	1719 100.0

*Row and column totals include frequency followed by percent.

Table 43. Streamside-Dwelling Salamander Species Abundance by Logging History.

Species	Logging History: Cut Forest	Logging History: Virgin Forest	ROW* TOTAL
Leurognathus marmoratus	19	1	20 2.6
Desmognathus quadramaculatus	65	19	83 10.9
Desmognathus o. carolinesis	146	42	188 24.6
Desmognathus fuscus	12		12 1.6
Desmognathus m. monticola	164	45	209 27.4
Plethodon g. glutinosus	4	2	6 0.8
Plethodon jordani		2	2 0.3
Gyrinophilus p. danielsi	19		19 2.5
Eurycea b. wilderae	188	31	219 28.7
Desmognathus santeetlah		1	1 0.1
Desmognathus imitator		3	3 0.4
COLUMN TOTAL*	617 81.0	145 19.0	762 100.0

*Row and column totals include frequency followed by percent.

Table 44. Stream-Dwelling Salamander Species Abundance by Logging History.

Species	Logging History		ROW* TOTAL
	Cut Forest	Virgin Forest	
Leurognathus marmoratus	353	113	466
			50.9
Desmognathus quadramaculatus	165	32	197
			21.5
Desmognathus o. carolinesis	22	24	46
			5.0
Desmognathus fuscus	6	1	7
			0.8
Desmognathus m. monticola	88	37	125
			13.6
Gyrinophilus p. danielsi	9	3	12
			1.3
Eurycea b. wilderae	28	30	58
			6.3
Eurycea l. longicauda		1	1
			0.1
Eurycea l. guttolineata	1		1
			0.1
Desmognathus santeetlah		2	2
			0.2
Desmognathus imitator		1	1
			0.1
COLUMN TOTAL*	672	244	916
	73.4	26.6	100.0

*Row and column totals include frequency followed by percent.

Abbreviation Legend for Salamander Species

Abbreviation	Salamander Species
L.M.	*Leurognathus marmoratus*
D.Q.	*Desmognathus quadramaculatus*
D.O.C.	*Desmognathus ochrophaeus carolinesis*
D.F.	*Desmognathus fuscus*
D.M.M.	*Desmognathus monticola monticola*
P.G.G.	*Plethodon glutinosus glutinosus*
P.J.	*Plethodon jordani*
G.P.D.	*Gyrinophilus porphyriticus danielsi*
E.B.W.	*Eurycea bislineata wilderae*
E.L.L.	*Eurycea longicauda longicauda*
E.L.G.	*Eurycea longicauda guttolineata*
D.S.	*Desmognathus santeetlah*
D.I.	*Desmognathus imitator*

Abbreviation Legend for Understory Vegetation Type

Abbreviation and Code No.	Description
SFBS, 111	Spruce-Fir Bramble-Sedge-Herb
SFV, 121	Spruce-Fir, *Vaccinium*-dominated
SFS, 131	Spruce-Fir Seedling
SFRM, 141	Spruce-Fir Rhododendron and Mixed Heaths
SFHD, 151	Spruce-Fir High Elevation Herb - Fern or Moss dominated
MSHF, 311	Mesic-Herbs-Ferns
MSHS, 321	Sub-mesic Herbs-Composites, Sedges
MSRH, 331	Rhododendron, Mesic Heaths
MSDH, 341	Dog Hobble
MSHH, 351	Hemlock Sapling or Shrub
MSDS, 361	Deciduous Shrub Sapling - *Cornus* dominated
XSVD, 411	Xeric-Sub-xeric - *Vaccinium* dominated
XSSD, 421	Xeric-Sub-xeric - Sapling dominated
XSML, 431	Mountain Laurel with Associates
XSRL, 441	Rhododendron Laurel
XSR, 451	Rhododendron with Associates
XSXH, 461	Xeric Herbs
ESGS, 511	Early Successional Grass-Sedge
ESBS, 521	Early Successional Bramble-Shrub-Sapling

Table 45. Salamander Species Abundance by Understory Vegetation Type at Elevation <600 m (2000 ft).

Species	Understory Vegetation Type															ROW* TOTAL
	SFRM 141	MSHF 311	MSHS 321	MSRH 331	MSDH 341	MSHH 351	MSDS 361	XSVD 411	XSSD 421	XSML 43i	XSRL 441	XSR 451	XSXH 461	ESGS 511	ESBS 521	
None			2	2	2	1	1			1	3	7	1	4	2	26 6.1
L.M.	1	2		2	1	8	4	1	3		1	60		6	2	91 21.5
D.Q.				2	1	3	3		9		4	40			1	63 14.9
D.O.C.		1		3	4	13	1		2			11	1			36 8.5
D.F.				1	1							3				5 1.2
D.M.M.	4	4	1	11	7	6	4		15		2	45			6	105 24.8
P.G.G.													1			1 0.2
G.P.D.			1	1		3						5			4	14 3.3
E.B.W.	2	2	1		7	6	1		7		1	49	2	1	1	80 18.9
E.L.L.												1				1 0.2
E.L.G.															1	1 0.2
COLUMN* TOTAL	7 1.7	9 2.1	5 1.2	22 5.2	23 5.4	40 9.5	14 3.3	1 0.2	36 8.5	1 0.2	11 2.6	221 52.2	5 1.2	11 2.6	17 4.0	423 100.0

*Row and column totals include frequency followed by percent.

Table 46. Salamander Species Abundance by Understory Vegetation Type at Elevations between 600-1200 m (2000-4000 ft).

Species	Understory Vegetation Type													ROW* TOTAL
	SFS 131	MSHF 311	MSHS 321	MSRH 331	MSDH 341	MSHH 351	MSDS 361	XSVD 411	XSSD 421	XSRL 441	XSR 451	XSXH 461	ESGS 511	
None				5			3			1	4			13 1.1
L.M.		8	38	89	4	51	57			56	39	5	10	357 31.3
D.Q.		6	14	48		19	51		1	27	20	10	6	202 17.7
D.O.C.	2	6	4	65	4	17	33		2	9	17	2	1	162 14.2
D.F.			3	1		2		2		2		1	3	14 1.2
D.M.M.	2	1	17	75	9	22	26	3		13	15	6	5	194 17.0
P.G.G.				1	1		1					1		4 0.4
G.P.D.				7		2	6			1	1			17 1.5
E.B.W.		2	14	59	3	29	23		19	4	11	9	5	178 15.6
COLUMN* TOTAL	4 0.4	23 2.0	90 7.9	350 30.7	21 1.8	142 12.4	200 17.5	5 0.4	22 1.9	113 9.9	107 9.4	34 3.0	30 2.6	1141 100.0

*Row and column totals include frequency followed by percent.

Table 47. Salamander Species Abundance by Understory Vegetation Type at Elevations >1200 (4000 ft).

	Understory Vegetation Type									
Species	SFBS 111	SFV 121	SFS 131	SFRM 141	SFHD 151	MSHF 311	MSRH 331	MSDH 341	MSDS 361	ROW* TOTAL
None			1	2						3 1.9
L.M.	1	7	5	19	4				2	38 24.5
D.Q.	2			5	1	2		4	1	15 9.7
D.O.C.	13			3		13	1	1	4	35 22.6
D.M.M.	9		1	5	2	16			2	35 22.6
P.G.G.									1	1 0.6
P.J.	1					1				2 1.3
E.B.W.	12	1	1	2	2				1	19 12.3
D.S.	2		1							3 1.9
D.I.				4						4 2.6
COLUMN* TOTAL	40 25.8	8 5.2	9 5.8	40 25.8	9 5.8	32 20.6	1 0.6	5 3.2	11 7.1	155 100.0

*Row and column totals include frequency followed by percent.

Table 48. Stream-Dwelling Salamander Species Abundance by Season.

Species	Season				ROW* TOTAL
	Winter	Spring	Summer	Fall	
Leurognathus marmoratus	189	64	69	144	466
					50.9
Desmognathus quadramaculatus	64	21	29	83	197
					21.5
Desmognathus o. carolinesis	10	1	13	22	46
					5.0
Desmognathus fuscus	1		2	4	7
					0.8
Desmognathus m. monticola	5	19	52	49	125
					13.6
Gyrinophilus p. danielsi	2	7	2	1	12
					1.3
Eurycea b. wilderae	24	3	2	29	58
					6.3
Eurycea l. longicauda	1				1
					0.1
Eurycea l. guttolineata			1		1
					0.1
Desmognathus santeetlah			1	1	2
					0.2
Desmognathus imitator				1	1
					0.1
COLUMN TOTAL*	296	115	171	334	916
	32.3	12.6	18.7	36.5	100.0

*Row and column totals include frequency followed by percent.

Table 49. Streamside-Dwelling Salamander Species Abundance by Season.

Species	Season				ROW* TOTAL
	Winter	Spring	Summer	Fall	
Leurognathus marmoratus			10	10	20
					2.6
Desmognathus quadramaculatus	4	5	27	47	83
					10.9
Desmognathus o. carolinesis	41	17	65	65	188
					24.6
Desmognathus fuscus	1	1	10		12
					1.6
Desmognathus m. monticola	30	39	102	38	209
					27.4
Plethodon g. glutinosus			2	4	6
					0.8
Plethodon jordani			2		2
					0.3
Gyrinophilus p. danielsi	11		1	7	19
					2.5
Eurycea b. wilderae	50	14	38	117	219
					28.7
Desmognathus santeetlah	1				1
					0.1
Desmognathus imitator				3	3
					0.4
COLUMN TOTAL*	138	76	257	291	762
	18.1	10.0	33.7	38.2	100.0

*Row and column totals include frequency followed by percent.

Table 50. Salamander Abundance by Substrate Type at Elevations <600 m (2000 ft).

Species	Substrate Type: Bedrock/ Boulder	Boulder/ Rock	Rock/ Gravel	Gravel/ Sand	Sand/ Silt	ROW* TOTAL
None	2	12	10	1	1	26 6.1
Leurognathus marmoratus	2	17	64	7	1	91 21.5
Desmognathus quadramaculatus	2	14	46	1		63 14.9
Desmognathus o. carolinesis	2	13	15	6		36 8.5
Desmognathus fuscus	2	1	2			5 1.2
Desmognathus m. monticola	12	21	55	17		105 24.8
Plethodon g. glutinosus			1			1 0.2
Gyrinophilus p. danielsi	2	5	5	2		14 3.3
Eurycea b. wilderae	7	16	54	3		80 18.9
Eurycea l. longicauda			1			1 0.2
Eurycea l. guttolineata				1		1 0.2
COLUMN TOTAL*	31 7.3	99 23.4	253 59.8	38 9.0	2 0.5	423 100.0

*Row and column totals include frequency followed by percent.

Table 51. Salamander Species Abundance by Substrate Type at Elevations between 600-1200 m (2000-4000 ft).

Species	Substrate Type: Boulder/ Rock	Rock/ Gravel	Gravel/ Sand	Sand/ Silt	ROW* TOTAL
None	7	6		6	13 1.1
Leurognathus marmoratus	160	164	17	16	357 31.3
Desmognathus quadramaculatus	87	104	8	3	202 17.7
Desmognathus o. carolinesis	81	68	8	5	162 14.2
Desmognathus fuscus	5	9			14 1.2
Desmognathus m. monticola	90	91	1	12	194 17.0
Plethodon g. glutinosus	3	1			4 0.4
Gyrinophilus p. danielsi	5	8	4		17 1.5
Eurycea b. wilderae	60	109	6	3	178 15.6
COLUMN TOTAL*	498 43.6	560 49.1	44 3.9	39 3.4	1141 100.0

*Row and column totals include frequency followed by percent.

Table 52. Salamander Species Abundance by Substrate Type at Elevations >1200 m (4000 ft).

Species	Substrate Type: Boulder/ Rock	Rock/ Gravel	Gravel/ Sand	Sand/ Silt	ROW* TOTAL
None	2			1	3 1.9
Leurognathus marmoratus	16	20	2		38 24.5
Desmognathus quadramaculatus	1	13	1		15 9.7
Desmognathus o. carolinesis		34	1		35 22.6
Desmognathus m. monticola	3	31	1		35 22.6
Plethodon g. glutinosus			1		1 0.6
Plethodon jordani		2			2 1.3
Eurycea b. wilderae	4	14	1		19 12.3
Desmognathus santeetlah	1	2			3 1.9
Desmognathus imitator		4			4 2.6
COLUMN TOTAL*	27 17.4	120 77.4	7 4.5	1 0.6	155 100.0

*Row and column totals include frequency followed by percent.

Table 53. Stream Salamander Abundance by Substrate Type.

Species	Substrate Type: Bedrock/ Boulder	Boulder/ Rock	Rock/ Gravel	Gravel/ Sand	Sand/ Silt	ROW* TOTAL
Leurognathus marmoratus	2	189	235	26	14	466 50.9
Desmognathus quadramaculatus		70	119	5	3	197 21.5
Desmognathus o. carolinesis		15	27	1	3	46 5.0
Desmognathus fuscus	1	1	5			7 0.8
Desmognathus m. monticola	4	42	75	2	2	125 13.6
Gyrinophilus p. danielsi	1	7	4			12 1.3
Eurycea b. wilderae		18	35	3	2	58 6.3
Eurycea l. longicauda			1			1 0.1
Eurycea l. guttolineata				1		1 0.1
Desmognathus santeetlah			2			2 0.2
Desmognathus imitator			1			1 0.1
COLUMN TOTAL*	8 0.9	342 37.3	504 55.0	38 4.1	24 2.6	916 100.0

*Row and column totals include frequency followed by percent.

Table 54. Streamside Salamander Abundance by Substrate Type.

Species	Substrate Type: Bedrock/ Boulder	Boulder/ Rock	Rock/ Gravel	Gravel/ Sand	Sand/ Silt	ROW* TOTAL
Leurognathus marmoratus		4	13		3	20 2.6
Desmognathus quadramaculatus	2	32	44	5		83 10.9
Desmognathus o. carolinesis	2	80	90	14	2	188 24.6
Desmognathus fuscus	1	5	6			12 1.6
Desmognathus m. monticola	8	72	102	17	10	209 27.4
Plethodon g. glutinosus		3	2	1		6 0.8
Plethodon jordani			2			2 0.3
Gyrinophilus p. danielsi	1	3	9	6		19 2.5
Eurycea b. wilderae	7	62	142	7	1	219 28.7
Desmognathus santeetlah		1				1 0.1
Desmognathus imitator			3			3 0.4
COLUMN TOTAL*	21 2.8	262 34.4	413 54.2	50 6.6	16 2.1	762 100.0

*Row and column totals include frequency followed by percent.

APPENDIX B

SALAMANDER ABUNDANCE AND BIOMASS DISTRIBUTIONS

Table 55. Stream Salamander Abundance by Watershed.

Watershed	Total No. Stream Salamanders/ha						ROW* TOTAL
	<100	>=100	>=200	>=400	>=800	>=2000	
Cosby Creek	25	10	18	38	53	87	231
							13.4
Mid. Prong, Lt. Pigeon River	7	7	3		23		40
							2.3
Dudley Creek	11	3	2	18	22	18	74
							4.3
West Prong, Lt. Pigeon River	7			6		20	33
							1.9
Little River	28	5	13	19	12		77
							4.5
Mid. Prong, Little River	47	39	24	10	26	34	180
							10.5
Abrams Creek	17	12	31	44	7	16	127
							7.4
Panther Creek	31	38	42	20	65		196
							11.4
Parson's Branch		7					7
							0.4
Eagle Creek	26	17	50	29		64	186
							10.8
Forney Creek	15	10	17	12			54
							3.1
Noland Creek	14	23	34	43	16	15	145
							8.4
Deep Creek						2	2
							0.1
Oconaluftee River	10	10	22	3	8	29	82
							4.8
Straight Fork	1	10	3	6	22	13	55
							3.2
Cataloochee Creek	44	14	51	17	78	26	230
							13.4
COLUMN TOTAL*	283	205	310	265	332	324	1719
	16.5	11.9	18.0	15.4	19.3	18.8	100.0

*Row and column totals include frequency followed by percent.

Table 56. Stream Salamander Biomass by Watershed.

Watershed	Total Wt. (gms) Stream Salamanders/ha <25	>=25	>=250	>=500	>=1000	>=2000	>=5000	ROW* TOTAL
Cosby Creek	17	32		25	56	75	26	231
								13.4
Mid. Prong, Lt. Pigeon River	8	6	3	7	7	9		40
								2.3
Dudley Creek	11	3	20	17	5		18	74
								4.3
West Prong, Lt. Pigeon River	7			6		20		33
								1.9
Little River	5	44	5	11	12			77
								4.5
Mid. Prong, Little River	36	53	17	4	10	31	29	180
								10.5
Abrams Creek	16	18	12	4	36	14	27	127
								7.4
Panther Creek	28	53	39	21	28	11	16	196
								11.4
Parson's Branch	7							7
								0.4
Eagle Creek	11	36	13	32	3	41	50	186
								10.8
Forney Creek	9	16		3	9	17		54
								3.1
Noland Creek	12	36	36	21	20	20		145
								8.4
Deep Creek				2				2
								0.1
Oconaluftee River	10	4	13	11	7	37		82
								4.8
Straight Fork	1	5	5	13	3	25	3	55
								3.2
Cataloochee Creek	16	78	18	30		25	63	230
								13.4
COLUMN TOTAL*	194	384	181	207	196	325	232	1719
	11.3	22.3	10.5	12.0	11.4	18.9	13.5	100.0

*Row and column totals include frequency followed by percent.

Table 57. Streamside Salamander Abundance by Watershed.

Watershed	Total No. Streamside Salamanders/ha						ROW* TOTAL
	<25	>=25	>=100	>=300	>=500	>=1000	
Cosby Creek	23	40		66	47	55	231
							13.4
Mid. Prong, Lt. Pigeon River	33	7					40
							2.3
Dudley Creek	58		5	11			74
							4.3
West Prong, Lt. Pigeon River	7	20			6		33
							1.9
Little River	5	17	6	13	13	23	77
							4.5
Mid. Prong, Little River	19	20	73	40	28		180
							10.5
Abrams Creek	86	4	23	7	7		127
							7.4
Panther Creek	16	3	55	25	42	55	196
							11.4
Parson's Branch					7		7
							0.4
Eagle Creek	26	5	31	26	66	32	186
							10.8
Forney Creek	7	3	32	12			54
							3.1
Noland Creek	33	16	43	8	32	13	145
							8.4
Deep Creek	2						2
							0.1
Oconaluftee River	37	19	8	9	9		82
							4.8
Straight Fork	40	8	7				55
							3.2
Cataloochee Creek	29	15	24	25	36	101	230
							13.4
COLUMN TOTAL*	421	177	307	242	293	279	1719
	24.5	10.3	17.9	14.1	17.0	16.2	100.0

*Row and column totals include frequency followed by percent.

Table 58. Streamside Salamander Biomass by Watershed.

Watershed	Total Wt. (gms) Streamside Salamanders/ha <50	>=50	>=200	>=500	>=1000	>=3000	ROW* TOTAL
Cosby Creek	29	25	37	46	57	37	231 13.4
Mid. Prong, Lt. Pigeon River	33	7					40 2.3
Dudley Creek	58		5	11			74 4.3
West Prong, Lt. Pigeon River	7	20			6		33 1.9
Little River	5	16	8	35	13		77 4.5
Mid. Prong, Little River	22	13	42	26	77		180 10.5
Abrams Creek	87	9	15	16			127 7.4
Panther Creek	16	36	25	55	49	15	196 11.4
Parson's Branch				7			7 0.4
Eagle Creek	31	6	13	56	47	33	186 10.8
Forney Creek	10	14	25		5		54 3.1
Noland Creek	33	31	30	28	23		145 8.4
Deep Creek	2						2 0.1
Oconaluftee River	39	7	5	31			82 4.8
Straight Fork	48		7				55 3.2
Cataloochee Creek	29	25	24	64	67	21	230 13.4
COLUMN TOTAL*	449 26.1	209 12.2	236 13.7	375 21.8	344 20.0	106 6.2	1719 100.0

*Row and column totals include frequency followed by percent.

Table 59. Stream Salamander Abundance by Elevation.

Total No. Stream Salamanders/ha	Elevation <600 m (<2000 ft)	Elevation >=600 m (>=2000 ft)	Elevation >=1200 m (>=4000 ft)	ROW* TOTAL
<100	101	173	9	283 16.5
>=100	44	159	2	205 11.9
>=200	55	249	6	310 18.0
>=400	82	162	21	265 15.4
>=800	90	226	16	332 19.3
>=2000	51	172	101	324 18.8
COLUMN TOTAL*	423 24.6	1141 66.4	155 9.0	1719 100.0

*Row and column totals include frequency followed by percent.

Table 60. Stream Salamander Biomass by Elevation.

Total Wt. (gms) Stream Salamanders/ha	Elevation <600 m (<2000 ft)	Elevation >=600 m (>=2000 ft)	Elevation >=1200 m (>=4000 ft)	ROW* TOTAL
<25	79	106	9	194 11.3
>=25	70	302	12	384 22.3
>=250	46	118	17	181 10.5
>=500	45	156	6	207 12.0
>=1000	81	108	7	196 11.4
>=2000	75	196	54	325 18.9
>=5000	27	155	50	232 13.5
COLUMN TOTAL*	423 24.6	1141 66.4	155 9.0	1719 100.0

*Row and column totals include frequency followed by percent.

Table 61. Streamside Salamander Abundance by Elevation.

Total No. Streamside Salamanders/ha	Elevation <600 m (<2000 ft)	>=600 m (>=2000 ft)	>=1200 m (>=4000 ft)	ROW* TOTAL
<25	146	226	49	421 24.5
>=25	35	115	27	177 10.3
>=100	76	206	25	307 17.9
>=300	73	165	4	242 14.1
>=500	56	219	18	293 17.0
>=1000	37	210	32	279 16.2
COLUMN TOTAL*	423 24.6	1141 66.4	155 9.0	1719 100.0

*Row and column totals include frequency followed by percent.

Table 62. Streamside Salamander Biomass by Elevation.

Total Wt. (gms) Streamside Salamanders/ha	Elevation <600 m (<2000 ft)	>=600 m (>=2000 ft)	>=1200 m (>=4000 ft)	ROW* TOTAL
<50	148	250	51	449 26.1
>=50	67	115	27	209 12.2
>=200	84	138	14	236 13.7
>=500	83	261	31	375 21.8
>=1000	41	271	32	344 20.0
>=3000		106		106 6.2
COLUMN TOTAL*	423 24.6	1141 66.4	155 9.0	1719 100.0

*Row and column totals include frequency followed by percent.

Abbreviation Legend for Overstory Vegetation Type

Abbreviation and Code No.	Description
VSFY, 1111	Virgin Spruce-Fir (Yellow Birch)
VSFH, 1121	Virgin Spruce-Fir-Hardwood or Hemlock
VYBM, 1131	Virgin Yellow Birch (Mature)
VNHM, 1221	Virgin Mixed Northern Hardwood
VMMH, 1311	Virgin Mesic Mixed Cove Hardwoods
VMHH, 1321	Virgin Mesic Hemlock-Hardwood Cove
VMHF, 1331	Virgin Mesic Hardwood Flats
VMT, 1361	Virgin Mesic Tulip Tree dominated
VXMP, 1451	Virgin Xeric Mixed Pines
MNHB, 2211	Mature Northern Hardwoods - Beech Gap
MNHM, 2221	Mature Mixed Northern Hardwoods
MMMH, 2311	Mature Mesic Mixed Cove Hardwoods
MMHH, 2321	Mature Mesic Hemlock-Hardwood Cove
MMHF, 2331	Mature Mesic Hardwood Flats
MMMM, 2351	Mature Sub-Mesic Hardwoods
MXMD, 2441	Mature Xeric Mixed Oak-Pine
MXWP, 2461	Mature Xeric White Pine
SNHB, 3211	Second Growth Northern Hardwoods - Beech Gap
SNHM, 3221	Second Growth Mixed Northern Hardwoods
SNHS, 3231	Second Growth Successional Northern Hardwoods
SMMH, 3311	Second Growth Mesic Mixed Cove Hardwoods
SMHH, 3321	Second Growth Mesic Hemlock-Hardwood Cove
SMH, 3331	Second Growth Mesic Hardwood Flats
SMS, 3341	Second Growth Mixed Sub-xeric Hardwoods
SMMS, 3351	Second Growth Mesic Mixed Sub-mesic Hardwoods
SMT, 3361	Second Growth Mesic Tulip Tree dominated
SXMS, 3411	Second Growth Mixed Sub-xeric Hardwoods
SXMO, 3421	Second Growth Xeric Mixed Oak
SXOP, 3441	Second Growth Mixed Sub-xeric Hardwoods
SXMP, 3451	Second Growth Xeric Mixed Pines
SXWP, 3461	Second Growth Xeric White Pine
ENHM, 4221	Early Successional Northern Hardwoods - Beech Gap
EMMH, 4311	Early Successional Mesic Mixed Cove Hardwoods
EMHH, 4321	Early Successional Mesic Hemlock - Hardwood Cove
EMHF, 4331	Early Successional Mesic Hardwood Flats
EMSC, 4341	Early Successional Mesic Cove
EMMS, 4351	Early Successional Mixed Sub-mesic Hardwoods
EMT, 4361	Early Successional Mesic Tulip Tree dominated
EMHC, 4371	Early Successional Mesic Hemlock Cove
EXMS, 4411	Early Successional Mixed Sub-xeric Hardwoods
EXWP, 4461	Early Successional White Pine
EPAF, 5531	Early Successional Pastures-Fields-Clearings

Table 63. Stream Salamander Abundance by Overstory Vegetation Type.

Overstory Vegetation Type	Total No. Stream Salamanders/ha						ROW* TOTAL
	<100	>=100	>=200	>=400	>=800	>=2000	
VSFY, 1111					8		8 0.5
VSFH, 1121	1				8	22	31 1.8
VYBM, 1131				9			9 0.5
VNHM, 1221	4						3 0.2
VMMH, 1311	1					29	30 1.7
VMHH, 1321	10	5	21	7		18	61 3.5
VMHF, 1331					11		11 0.6
VMT, 1361						32	32 1.9
VXMP, 1451			9				9 0.5
MNHB, 2211				5			5 0.3
MNHM, 2221					7	13	20 1.2
MMMH, 2311	10				13	17	40 2.3
MMHH, 2321	8	16	5		35	64	128 7.4
MMHF, 2331	1		5		6	18	30 1.7
MMMM, 2351	2						2 0.1
MXMO, 2441	1						1 0.1
MXWP, 2461	1						1 0.1
SNHB, 3211				4			4 0.2
SNHM, 3221				8	28		36 2.1
SNHS, 3231			6				0 0.3
SMMH, 3311	33	28	26	39	51	31	208 12.1
SMHH, 3321	122	101	130	123	119	37	632 26.8

Table 63 (Continued)

Overstory Vegetation Type	Total No. Stream Salamanders/ha						ROW* TOTAL
	<100	>=100	>=200	>=400	>=800	>=2000	
SMH, 3331	39	9	59	13	16		136
							7.9
SMS, 3341	3	2	18				23
							1.3
SMMS, 3351			7	13		10	30
							1.7
SMT, 3361	5		6				11
							0.6
SXMS, 3411	2	9			7		18
							1.0
SXMO, 3421	3						3
							0.2
SXOP, 3441	15	3		7	6	9	40
							2.3
SXMP, 3451		5					5
							0.3
SXWP, 3461					7		7
							0.4
ENHM, 4221					5		5
							0.3
EMMH, 4311	4	4			5		13
							0.8
EMHH, 4321	4	1	6			16	27
							1.6
EMHF, 4331	6		5	24			35
							2.0
EMSC, 4341		6					6
							0.3
EMMS, 4351	6	4				8	18
							1.0
EMT, 4361		7					7
							0.4
EMHC, 4371				11			11
							0.6
EXMS, 4411		2		2			4
							0.2
EXWP, 4461	1	3	4				8
							0.5
EPAF, 5531	1		3				4
							0.2
COLUMN TOTAL*	283	205	310	265	332	324	1719
	16.5	11.9	18.0	15.4	19.3	18.8	100.0

*Row and column totals include frequency followed by percent.

Table 64. Stream Salamander Biomass by Overstory Vegetation Type.

Overstory Vegetation Type	Total Wt. (gms) Stream Salamanders/ha							ROW* TOTAL
	<25	>=25	>=250	>=500	>=1000	>=2000	>=5000	
VSFY, 1111			8					8 0.5
VSFH, 1121	1		8	2		20		31 1.8
VYBM, 1131		4			5			9 0.5
VNHM, 1221	4							4 0.2
VMMH, 1311	1					29		30 1.7
VMHH, 1321	10	15	8	4	6		18	61 3.5
VMHF, 1331					11			11 0.6
VMT, 1361							32	32 1.9
VXMP, 1451		9						9 0.5
MNHB, 2211						5		5 0.3
MNHM, 2221				7			13	20 1.2
MMMH, 2311	10				13	17		40 2.3
MMHH, 2321	8	11	32	2	23	35	17	128 7.4
MMHF, 2331	1				11		18	30 1.7
MMMM, 2351	2							2 0.1
MXMO, 2441	1							1 0.1
MXWP, 2461	1							1 0.1
SNHB, 3211					4			4 0.2
SNHM, 3221		3		5		8	20	36 2.1
SNHS, 3231		6						6 0.3
SMMH, 3311	19	60	6	33	26	45	19	208 12.1
SMHH, 3321	82	136	83	116	63	100	52	632 36.8

Table 64 (Continued)

Overstory Vegetation Type	Total Wt. (gms) Stream Salamanders/ha							ROW* TOTAL
	<25	>=25	>=250	>=500	>=1000	>=2000	>=5000	
SMH, 3331	14	67	9	23	7		16	136 7.9
SMS, 3341	3		2		5	13		23 1.3
SMMS, 3351			4		3	23		30 1.7
SMT, 3361	3	2				6		11 0.6
SXMS, 3411	2	9			7			18 1.0
SXMO, 3421	1	2						3 0.2
SXOP, 3441	11	13	3		7	6		40 2.3
SXMP, 3451		5						5 0.3
SXWP, 3461						7		3 0.4
ENHM, 4221						5		5 0.3
EMMH, 4311	4		4		5			13 0.8
EMHH, 4321	2	3		4		2	16	27 1.6
EMHF, 4331	6	18					11	35 2.0
EMSC, 4341		6						6 0.3
EMMS, 4351	6		8	4				18 1.0
EMT, 4361				7				7 0.4
EMHC, 4371		11						11 0.6
EXMS, 4411		4						4 0.2
EXWP, 4461	1		3			4		8 0.5
EPAF, 5531	1		3					4 0.2
COLUMN* TOTAL	194 11.3	384 22.3	181 10.5	207 12.0	196 11.4	325 18.9	232 13.5	1719 100.0

*Row and column totals include frequency followed by percent.

Table 65. Streamside Salamander Abundance by Overstory Vegetation Type.

Overstory Vegetation Type	Total No. Streamside Salamanders/ha						ROW* TOTAL
	<25	>=25	>=100	>=300	>=500	>=1000	
VSFY, 1111			8				8 0.5
VSFH, 1121	11	20					31 1.8
VYBM, 1131		4	5				9 0.5
VNHM, 1221				4			4 0.2
VMMH, 1311	30						30 1.7
VMHH, 1321	25		11		25		61 3.5
VMHF, 1331		11					11 0.6
VMT, 1361						32	32 1.9
VXMP, 1451		9					9 0.5
MNHB, 2211			5				5 0.3
MNHM, 2221			7	13			20 1.2
MMMH, 2311	6		8		9	17	40 2.3
MMHH, 2321	7	14	5	37	17	48	128 7.4
MMHF, 2331	18	1	11				30 1.7
MMMM, 2351			2				2 0.1
MXMO, 2441		1					1 0.1
MXWP, 2461	1						1 0.1
SNHB, 3211			4				4 0.2
SNHM, 3221		3	8	5		20	36 2.1
SNHS, 3231				6			6 0.3
SMMH, 3311	49	26	61	44	14	14	208 12.1
SMHH, 3321	192	51	67	98	171	53	632 36.8

Table 65 (Continued)

Overstory Vegetation Type	Total No. Streamside Salamanders/ha						ROW* TOTAL
	<25	>=25	>=100	>=300	>=500	>=1000	
SMH, 3331	1	6	47	6	16	60	136 7.9
SMS, 3341	2	5	3			13	23 1.3
SMMS, 3351	3	3	11			13	30 1.7
SMT, 3361	3		2	6			11 0.6
SXMS, 3411	5		6	7			18 1.0
SXMO, 3421	1	2					3 0.2
SXOP, 3441	15		7		9	9	40 2.3
SXMP, 3451			5				5 0.3
SXWP, 3461			7				7 0.4
ENHM, 4221			5				5 0.3
EMMH, 4311	7		6				13 0.8
EMHH, 4321	19	6		2			27 1.6
EMHF, 4331	12	5		5	13		35 2.0
EMSC, 4341			6				6 0.3
EMMS, 4351	5			5	8		18 1.0
EMT, 4361		7					7 0.4
EMHC, 4371					11		11 0.6
EXMS, 4411	2	2					4 0.2
EXWP, 4461	3	1		4			8 0.5
EPAF, 5531	4						4 0.2
COLUMN TOTAL*	421 16.5	177 11.9	307 18.0	242 15.4	293 19.3	279 18.8	1719 100.0

*Row and column totals include frequency followed by percent.

Table 66. Streamside Salamander Biomass by Overstory Vegetation Type.

Overstory Vegetation Type	Total Wt. (gms) Streamside Salamanders/ha						ROW* TOTAL
	<50	>=50	>=200	>=500	>=1000	>=3000	
VSFY, 1111				8			8 0.5
VSFH, 1121	11	20					31 1.8
VYBM, 1131		4	5				9 0.5
VNHM, 1221	4						4 0.2
VMMH, 1311	30						30 1.7
VMHH, 1321	23		11	23	4		61 3.5
VMHF, 1331		11					11 0.6
VMT, 1361					32		32 1.9
VXMP, 1451		9					9 0.5
MNHB, 2211			5				5 0.3
MNHM, 2221			20				20 1.2
MMMH, 2311	6		8	17	9		40 2.3
MMHH, 2321	7	24	2	24	48	23	128 7.4
MMHF, 2331	18	11	1				30 1.7
MMMM, 2351			2				2 0.1
MXMO, 2441			1				1 0.1
MXWP, 2461	1						1 0.1
SNHB, 3211		4					4 0.2
SNHM, 3221		3	5	28			36 2.1
SNHS, 3231				6			6 0.3
SMMH, 3311	56	18	50	33	37	14	208 12.1
SMHH, 3321	203	36	59	155	110	69	632 36.8

Table 66 (Continued)

Overstory Vegetation Type	Total Wt. (gms) Streamside Salamanders/ha <50	>=50	>=200	>=500	>=1000	>=3000	ROW* TOTAL
SMH, 3331	6	9	19	32	70		136
							7.9
SMS, 3341	2			8	13		23
							1.3
SMMS, 3351	3	10	4	13			30
							1.7
SMT, 3361	3		8				11
							0.6
SXMS, 3411	5	11		2			18
							1.0
SXMO, 3421	1	2					3
							0.2
SXOP, 3441	15	9	13	3			40
							2.3
SXMP, 3451			5				5
							0.3
SXWP, 3461		7					7
							0.4
ENHM, 4221				5			5
							0.3
EMMH, 4311	7		2	4			13
							0.8
EMHH, 4321	21		2	4			27
							1.6
EMHF, 4331	12		5	5	13		35
							2.0
EMSC, 4341			6				6
							0.3
EMMS, 4351	5			5	8		18
							1.0
EMT, 4361		4	3				7
							0.4
EMHC, 4371		11					11
							0.6
EXMS, 4411	2	2					4
							0.2
EXWP, 4461	4	4					8
							0.5
EPAF, 5531	4						4
							0.2
COLUMN TOTAL*	449	209	236	375	344	106	1719
	26.1	12.2	13.7	21.8	20.0	6.2	100.0

*Row and column totals include frequency followed by percent.

Table 67. Stream Salamander Abundance by Logging History.

Total No. Stream Salamanders/ha	Logging History		ROW* TOTAL
	Cut Forest	Virgin Forest	
<100	243	40	283
			16.5
>=100	191	14	205
			11.9
>=200	270	40	310
			18.0
>=400	244	21	265
			15.4
>=800	251	81	332
			19.3
>=2000	124	200	324
			18.8
COLUMN TOTAL*	1323	396	1719
	77.0	23.0	100.0

*Row and column totals include frequency followed by percent.

Table 68. Stream Salamander Biomass by Logging History.

Total Wt. (gms) Stream Salamanders/ha	Logging History		ROW* TOTAL
	Cut Forest	Virgin Forest	
<25	155	39	194
			11.3
>=25	345	39	384
			22.3
>=250	129	52	181
			10.5
>=500	201	6	207
			12.0
>=1000	127	69	196
			11.4
>=2000	219	106	325
			18.9
>=5000	147	85	232
			13.5
COLUMN TOTAL*	1323	396	1719
	77.0	23.0	100.0

*Row and column totals include frequency followed by percent.

Table 69. Streamside Salamander Abundance by Logging History.

Total No. Streamside Salamanders/ha	Logging History		ROW* TOTAL
	Cut Forest	Virgin Forest	
<25	324	97	421
			24.5
>=25	117	60	177
			10.3
>=100	252	55	307
			17.9
>=300	206	36	242
			14.1
>=500	242	51	293
			17.0
>=1000	182	97	279
			16.2
COLUMN TOTAL*	1323	396	1719
	77.0	23.0	100.0

*Row and column totals include frequency followed by percent.

Table 70. Streamside Salamander Biomass by Logging History.

Total Wt. (gms) Streamside Salamanders/ha	Logging History		ROW* TOTAL
	Cut Forest	Virgin Forest	
<50	350	99	449
			26.1
>=50	135	74	209
			12.2
>=200	201	35	236
			13.7
>=500	303	72	375
			21.8
>=1000	251	93	344
			20.0
>=3000	83	23	106
			6.2
COLUMN TOTAL*	1323	396	1719
	77.0	23.0	100.0

*Row and column totals include frequency followed by percent.

VITA

Raymond Clifford Mathews, Jr., was born in Houston, Texas, on August 11, 1946. He graduated from Bellaire High School in June, 1965. After spending a tour of duty in the Texas Maritime Academy (merchant marine training academy) he entered Texas Wesleyan College where he received a Bachelor of Science degree in Biology. He then worked for the Fort Worth Zoological Zoo (herpetarium) where he participated in a research expedition to the cloud forest of Oaxaca, Mexico, to study tree frogs. A year later he went to work for the Texas A & M University Oceanography Department, and two years later accepted a staff biologist position with Woodward-Envicon Environmental Consultant Co. where he worked until 1973.

Following this position, he entered graduate school at Tennessee Technological University, Cookeville, under a research assistantship awarded through the U.S. Fish and Wildlife Service Cooperative Fishery Research Unit. He received a Master's degree in Biology in August, 1975. He then worked as a fisheries and environmental biologist for the Tennessee Wildlife Resources Agency. After two years, he accepted a research biologist position with the Uplands Field Research Laboratory of the Great Smoky Mountains National Park where he worked for six years and concurrently attended the University of Tennessee, Knoxville, for additional graduate study. A Master's degree in Ecology was awarded August, 1984.

The author is a member of Sigma Xi, Beta Beta Beta, Ecological Society of America, American Society of Ichthyologist and Herpetologist, American Fisheries Society, National Speological Society, and the Society

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