TERRESTRIAL SALAMANDERS IN SOUTHERN APPALACHIAN HARDWOOD FORESTS: RELATIVE ABUNDANCE, NUTRITIONAL CONDITION, AND RESPONSE TO SILVICULTURAL PRACTICES

by

Douglas N. Harpole

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APPROVED:

Carola A. Haas, Chair

Roy L. Kirkpatrick

Richard G. Oderwald

Henry M. Wilbur

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Fisheries and Wildlife Sciences

(ABSTRACT)

We compared techniques for assessing nutritional condition in 3 groups of terrestrial salamanders. We measured variability in species richness and relative abundance before harvest at 5 sites in the Jefferson National Forest of southwest Virginia and compared the effects of 7 silvicultural treatments on terrestrial salamander richness and relative abundance at 1 site.

Mass/SVL was the most efficient and precise index of nutritional condition. Mass to length ratios were not useful for predicting total body fat for individuals within groups. There was a significant difference in total body fat ($p < 0.001$) and mass/SVL ($p < 0.001$) among the 3 salamander groups we tested.

The number of species encountered on the 5 sites sampled ranged from 4 to 12. Mean densities of animals captured ranged from 0.01 to 0.74 individuals

per m^2. Relative abundance differed significantly among 2-ha treatment plots within a 15-ha site on 2 study sites ($p = 0.01$ and $p = 0.07$).

We compared species richness and relative abundance before and after treatments (control, understory removal, group selection, 2 shelterwoods, leavetree, and clearcut) at 1 study site. Treatments consisted of a control, an understory removal, a group selection, 2 shelterwoods, a leavetree, and a clearcut. There was no change in species richness after harvest. There was a significant difference ($p = 0.02$) in relative abundance among treatment plots after harvest but not before ($p = 0.95$). Relative abundance declined after treatment on all plots except the control and understory removal.

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CHAPTER 1

COMPARISONS OF TECHNIQUES FOR ASSESSING NUTRITIONAL CONDITION OF SALAMANDERS

INTRODUCTION

Terrestrial salamanders are restricted to cool, moist environments and foraging success increases during and after periods of rain (Jaeger 1980). Assimilation efficiency in terrestrial salamanders is inversely related to temperature, but metabolic rate is directly correlated with temperature (Bobka et al. 1981). During warm, dry periods, access to prey becomes limited and salamanders may experience difficulty in maintaining a positive energy balance because of lower food intake and assimilation efficiency, and an increased metabolic rate (Bobka et al. 1981).

There is no standard method for assessing the nutritional condition of salamanders. Regressions of body length on mass provide an index of condition (Dupuis et al. 1995, Ng and Wilbur 1995), but are subject to high variability because of allometric variation (Smith 1984), variation in fullness of the digestive tract, reproductive status, degree of hydration, and prior tail autotomy. Morphological measurements can also have high variability because of the difficulty in immobilizing live salamanders. Captured salamanders can be immobilized on a flat surface using firm pressure, but animals can contort torsos and tails, making precise measurements difficult and increasing the time required to measure each animal.

Salamanders store lipids in fat bodies near the gonads and in the tail (Duellman and Trueb 1986). Lipid stores, primarily triglycerides, are important for reproduction and metabolic maintenance during dormancy (Fitzpatrick 1976). Scott and Fore (1995) found that female marbled salamanders (*Ambystoma opacum*) maintained on high-food diets maintained larger body size, higher lipid levels, and produced larger clutches than animals maintained on less food. Fraser (1980) studied the relationship between condition and oocyte maturation in red-backed salamanders (*Plethodon cinereus*). He derived an index of condition using volume displacement of salamander tails and found a significant correlation between volume displacement of tails and both the amount of food ingested and body weight (Fraser 1980). Increased volume of the tail indicated increased fat storage and nutritional condition. Jaeger (pers. commun.) used tail width (TW) at the posterior end of the cloaca as a measure of condition in plethodontid salamanders. Anthony (pers. commun.) used tail width as a condition index in assessing the effects of parasites on the Rich Mountain salamander (*P. ouachitae*)and the western slimy salamander (*P. albagula*). Caudal fat stores are important to salamander reproductive success. Fitzpatrick (1976) and Maiorana (1977) found that tail autotomy in gravid females can cause reproductive failure.

Measurements of volume displacement and tail width may provide an indication of lipid storage in the tail, but the primary site of lipid deposition is in fat bodies near the gonads (Duellman and Trueb 1986). Measuring tail width may provide an index of condition and does not require sacrificing the animal, but it only assesses tail lipids. An accurate method of assessing condition in salamanders should address all lipid stores. Ether extraction of total body lipids provides a precise means of quantifying lipid stores in an organism, and is used as an index of nutritional condition in small mammals (e.g. Fleharty et al. 1973), birds (e.g. Johnson et al. 1985, Blem and Shelor 1986), and fish (e.g. Neumann and Murphy 1992). However, unlike morphological measurements, lipid extraction requires sacrificing the animal.

OBJECTIVES

The purpose of this study was to evaluate measures of salamander nutritional condition. The specific objectives were 1) to compare precision and efficiency of 2 methods of immobilizing salamanders to measure snout to vent length (SVL), tail length (TL) and TW; 2) to compare efficiency of calculating 3 condition indices (mass/SVL, TW/SVL, and volume/SVL); and 3) to compare condition indices with total body lipids.

METHODS

PRECISION AND EFFICIENCY

In July of 1995 we hand-captured 12 adult red-backed salamanders from Giles County (longitude 80^0 28', latitude 37^0 17'), Virginia (scientific collecting permit #SCP9526). Animals were individually maintained in sealed plastic bags with moistened leaf litter from the capture site. We measured SVL, TW, and TL (Figure 1.1) 10 times for each animal using 2 common techniques for immobilizing salamanders: 1) plastic bag, and 2) press (Wise and Buchanan 1992)(Figure 1.2). All measurements were taken by one individual. Salamanders were presented to the measurer unmarked and in random sequence to reduce bias from familiarity with individual animals. We took multiple measurements of each animal over a 3-day period to avoid measurer fatigue and changes in salamander behavior. We calculated coefficients of variation for each type of measurement using both immobilization techniques for each salamander. We determined the sample size required to achieve a desired precision using the formula:

$$\hat{N} = \frac{t^2 CV^2}{A^2}$$

Where $\hat{N}$ = sample size required for given significance level, t = test statistic for desired significance level (t = 1.96), CV = coefficient of variation, and A = level of variability allowed (5%). To compare precision, we calculated the mean sample size required for each measurement using both immobilization techniques. A precise technique of measurement requires no more than 1 measurement of a particular parameter to reach the desired level of precision.

An efficient measurement technique requires the least amount of time to conduct relative to alternate methods. To assess efficiency, we used an

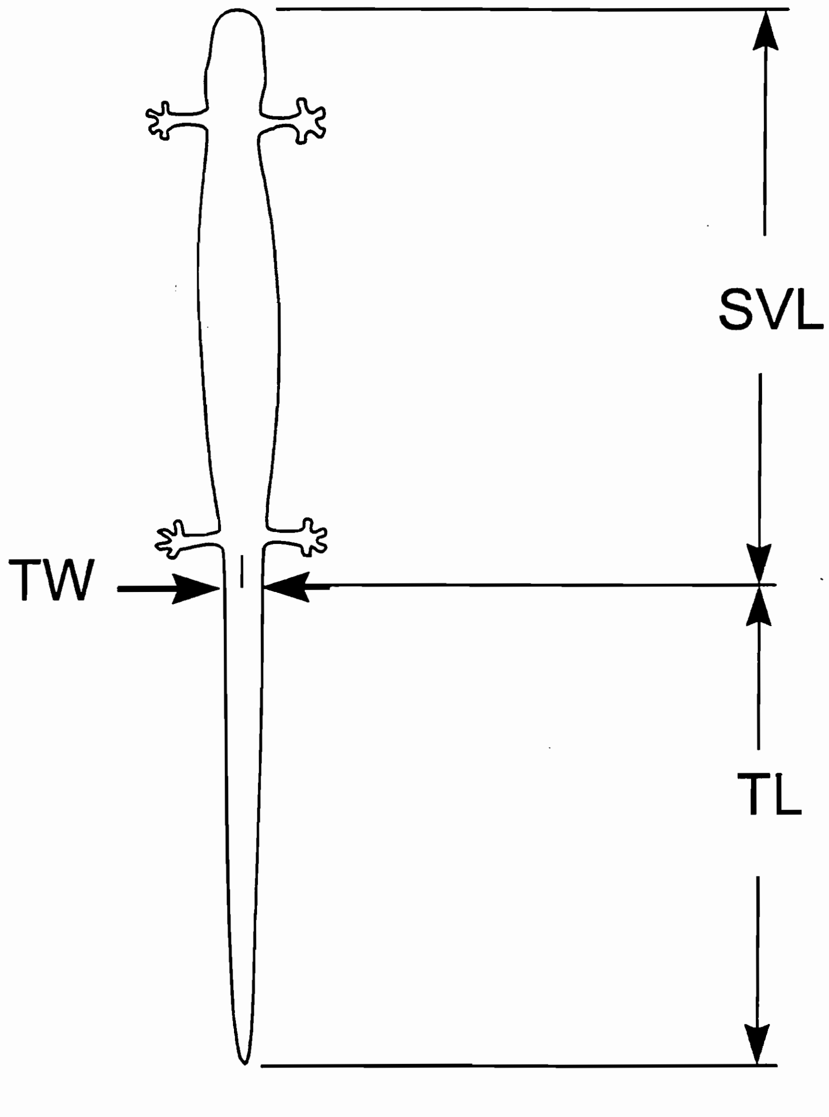

Figure 1.1. Locations for measuring snout-vent length (SVL), tail length (TL), and tail width (TW).

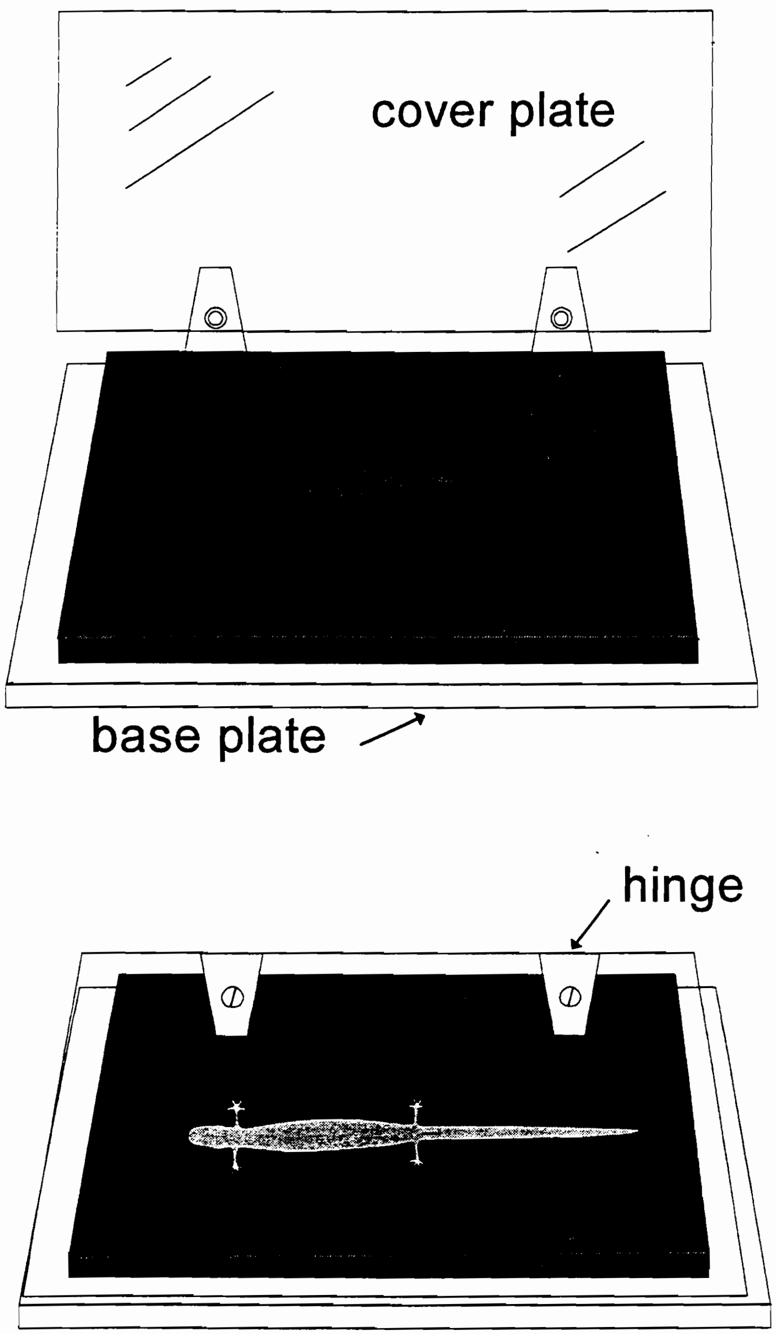

Figure 1.2. Illustration of press adapted from Wise and Buchanan (1992).

electronic stopwatch to record the time required to measure mass, volume displacement, SVL, and TW on the salamanders used for the nutritional condition study (see *Nutritional Condition*). We also recorded the time required to measure SVL, TW on the salamanders in the precision study using the press. We added time to measure SVL to each of the times it took to measure mass, volume, and TW to calculate total time required to obtain an index of salamander nutritional condition. We then tested for differences in time required for each condition index using a Kruskal-Wallis one-way test. We compared times for SVL and TW between bags and press using a two-tailed two-sample t-test. We used Minitab 10.0 for all statistical analyses (Minitab 1995). Significance was defined as $P \leq 0.10$ for all statistical inference. Nonparametric tests were used on data sets where $n \leq 30$.

NUTRITIONAL CONDITION

During May and June of 1995 we hand-captured 66 adult male red-backed salamanders in Montgomery County (longitude 80^0 28', latitude 37^0 16') and Giles County (longitude 80^0 28', latitude 37^0 17'), VA (scientific collecting permit #SCP9526). Only adult male animals (> 32 SVL) were used in order to eliminate bias that could result from including both gravid and non-gravid females. During field capture, we chose only those animals that appeared to have no more than 30% of the tail missing.

Each animal was individually housed on wet filter paper in plastic 2.5 x 15 cm numbered petri dishes on a diet of either ad libitum fruit flies (*Drosophila* *melanogaster*) or fasting. Spotila (1972) determined mean preferred temperature of redbacks in captivity to be 16.2° C. Jaeger (1980) calculated daily caloric requirements for redbacks to maintain body mass at various temperatures. Given that metabolic rate for salamanders increases with temperature, we maintained the animals at 18° C on 14:10 hrs light:dark to ensure that the fasted group would be on a negative energy budget and therefore deplete energy stores (lipids). Animals in the other group were fed ad libitum to ensure they would either maintain or increase mass.

Prior to the experiment, captured salamanders were fed a diet of live, wingless fruit flies ad libitum. All salamanders were held in captivity at least 3 days to acclimate them to captivity and the fly diet. Throughout captivity, all animals were checked daily, and filter paper was changed when it was soiled from uneaten flies or fecal material. Both the filter paper and salamander were wetted daily using a squirt bottle and deionized water.

In order to reduce bias that could result from initial differences in the size of animals, we stratified assignment of animals into 2 groups containing an equal number of animals with approximately the same body mass, SVL, tail length, and length of time in captivity. We randomly assigned the groups to one of the 2 diets. There was no significant difference between groups in initial mean SVL ($\bar{X}$ = 41.2, 42.4, $t = -0.88$, $p = 0.38$) or TL ($\bar{X}$ = 1.27, 1.12, $t = -2.57$, $p = 0.13$). Salamanders in the ad libitum diet group had slightly higher initial mean mass than the fasting diet group ($\bar{X}$ = 0.94, 1.00 (fasting, ad libitum), $t = -1.76$, p =

0.084). Three salamanders from the ad libitum diet group and 1 from the fasting diet group died during the experiment.

We withheld food to all specimens for 3 days before initiation of treatments to void the digestive tract (Bobka et al. 1981). After 3 days, we 1) weighed all salamanders on an electronic balance to the nearest 0.01 g; 2) measured SVL with a dial caliper to the nearest 0.1 mm; 3) measured length of tail to the nearest 0.1 mm; and 4) measured tail width at the posterior end of the cloaca to the nearest 0.1 mm. We recorded the time required to complete each measurement using a stopwatch. Prior to weighing, all animals were fully hydrated in petri dishes by filling the dish with enough deionized water to float the salamander, and blotted dry on a cloth towel.

We maintained the salamanders on the 2 diets for 30 days, again withheld food for 3 days to void the digestive tract, and then repeated all pre-experiment measurements. We also determined volume of each animal by measuring the amount of water displaced to the nearest 0.1 ml by submerging the salamander head first in a 10 ml graduated cylinder filled to a known level. We removed water with a 2 ml 1/100 graduated pipette until the meniscus returned to the original level and recorded volume as the amount of water removed.

We euthanized the salamanders in a chlorotone solution (hydrous chlorobutanol, 1,1,1-trichloro-2-methyl-2-propanol) based on the guidelines of the Society for the Study of Amphibians and Reptiles (Simmons 1987) and as approved by the Virginia Tech Animal Care Committee (proposal # 93-085-F&W). We placed salamanders in individually numbered aluminum taring pans and freeze-dried them for 24 hrs using a LabConCo® Freeze Dryer 8. We measured salamander dry mass to the 0.0001 g using a Mettler electronic balance. To determine body fat, we extracted total body lipids in a Soxhlet apparatus using ethyl ether for 24 hrs (Harder and Kirkpatrick 1994). Animals were aerated under a positive flow vent hood for 8 hrs, and freeze-dried again following the same procedure. We calculated total mass of non-polar body lipids expressed in grams of fat (g fat) as the difference between dry mass before and after ether extraction (Harder and Kirkpatrick 1994). Lean mass was the difference between dry mass after extraction and grams of fat.

Because mass, TW and volume are correlated with length in salamanders, we standardized these measures of condition by dividing each parameter by SVL. We generated regressions of mass on SVL (mass/SVL), TW on SVL, and volume on SVL. Ratios form a binomial distribution and tend to have heterogeneous variances (Zar 1974, Ott 1993). We tested each data set for normal distribution using a Kolmogorov-Smirnov one sample goodness of fit test (Minitab 1995). All three condition indices were normally distributed ($p > 0.15$ for each) and data were not transformed. Based on results from Precision and Efficiency experiments (see below), we only compared the relationship between mass/SVL and total body lipids. We regressed mass/SVL against the grams of fat per gram of lean dry mass (g fat/g lean mass) for both diet groups.

We determined total body fat of 12 recently captured red-backed salamanders captured from Giles County, VA, in June 1995. We held these animals for 3 days to void the digestive tract, and followed the same procedures for determining body fat and regressing mass/SVL on total body lipids. For between-group comparisons, we also plotted the mean mass/SVL on the mean g fat/g lean dry mass for each diet group.

RESULTS

PRECISION AND EFFICIENCY

The press and bag provide acceptable levels of precision for measuring SVL and TL ($N \leq 1$ measurement) (Table 1.1). Neither technique provided an acceptable level of precision for measuring TW ($N > 1$) (Table 1.1). Because of the high variability, we excluded TW measurements from condition index analyses.

There was no significant difference in time required to measure SVL ($p = 0.46$) or TW ($p = 0.89$) using the bag or press (Table 1.2). There was a significant difference in the amount of time required to calculate condition indices ($p < 0.001$, $H = 37.10$, $df = 2$)(Table 1.2). Tail width and mass measurements were the most efficient (requiring the least time), whereas measuring volume required the most time.

NUTRITIONAL CONDITION

Salamanders in both diet groups lost mass during the experiment (Table 1.3). The fasting group lost significantly more mass ($t = -2.42$, $p = 0.02$) and had

Table 1.1. Sample size required ($\hat{N}$) for given level of precision and mean coefficient of variation (C.V.) for measuring salamanders in bag and press.

immobilization method	SVL		TL		TW	
	$\hat{N}$	CV	$\hat{N}$	CV	$\hat{N}$	CV
bag	1.0	2.58	0.9	2.29	4.5	5.12
press	0.7	1.94	0.9	2.08	4.1	4.69

Table 1.2. Time required in seconds to measure SVL and TW using bag and press.

immobilization method	SVL $\bar{x}$ (SE)	TW $\bar{x}$ (SE)
bag	36.0 (3.1)	10.3 (1.8)
press	29.3 (2.5)	9.4 (0.52)

Table 1.3. Measurements of 2 groups of salamanders after 30-day feeding trials and a group of animals measured 3 days after capture from field. Volume, mass, and SVL taken before ether extraction. Mean change in mass ($\bar{X}\Delta$) during feeding experiment. Values presented are means ± SE. Minimum and maximum values given in parentheses.

	fasting diet	ad libitum diet	recently captured	P value
sample size (n)	32	30	12	
volume (ml)	0.81 ± 0.02	0.98 ± 0.02	not measured	
$\bar{X}\Delta$ in mass (g)	-0.13	-0.08	not measured	0.020[a]
mass (g)	0.81 ± 0.03 (0.39 - 1.12)	0.94 ± 0.03 (0.62 - 1.20)	1.15 ± 0.08 (0.72 - 1.54)	<0.001[b]
SVL (mm)	41.3 ± 0.58 (33.5 - 46.6)	42.6 ± 0.59 (34.7 - 48.6)	43.1 ± 0.84 (37.7 - 47.0)	0.179[b]
mass/SVL	0.019 ± 0.006 (0.012 - 0.025)	0.022 ± 0.004 (0.018 - 0.026)	0.026 ± 0.001 (0.019 - 0.033)	<0.001[b]
total body lipids (g)	0.02 ± 0.00 (0.01 - 0.05)	0.03 ± 0.00 (0.02 - 0.05)	0.06 ± 0.01 (0.04 - 0.09)	<0.001[b]

[a] - t-test between fasting and ad libitum diets

[b] - ANOVA for all groups

significantly less total body fat ($t = 1.67$, $p = 0.05$) than the group on the ad libitum diet (Table 1.3). Volume displacement was not significantly different from mass ($t = -1.37$, $p = 0.18$) (Table 1.3) and took significantly more time to measure than mass, therefore, we excluded volume from subsequent analyses.

Regression analysis revealed no significant relationship between mass/SVL and grams of fat per gram of lean dry mass for animals on the fasting diet ($r^2 = 0.10$), ad libitum diet ($r^2 = 0.18$), or the wild caught animals ($r^2 = 0.01$) (Figure 1.3).

DISCUSSION

PRECISION AND EFFICIENCY

Based on previous experience and personal communication with other researchers, we were concerned about the precision of salamander morphological measurements using various techniques. On a routine night of sampling, researchers may encounter 200 salamanders. An efficient method of sampling is therefore important to reduce the time required to obtain data from each salamander. The objective of this section was to identify a precise and efficient method of assessing salamander nutritional condition by using only field measurements.

The bag and press both provide an acceptable level of precision for measuring SVL and TL and there was no significant difference in the time required to obtain SVL or TL using either technique. Most researchers hold captured salamanders temporarily in plastic bags. Bags offer an advantage over

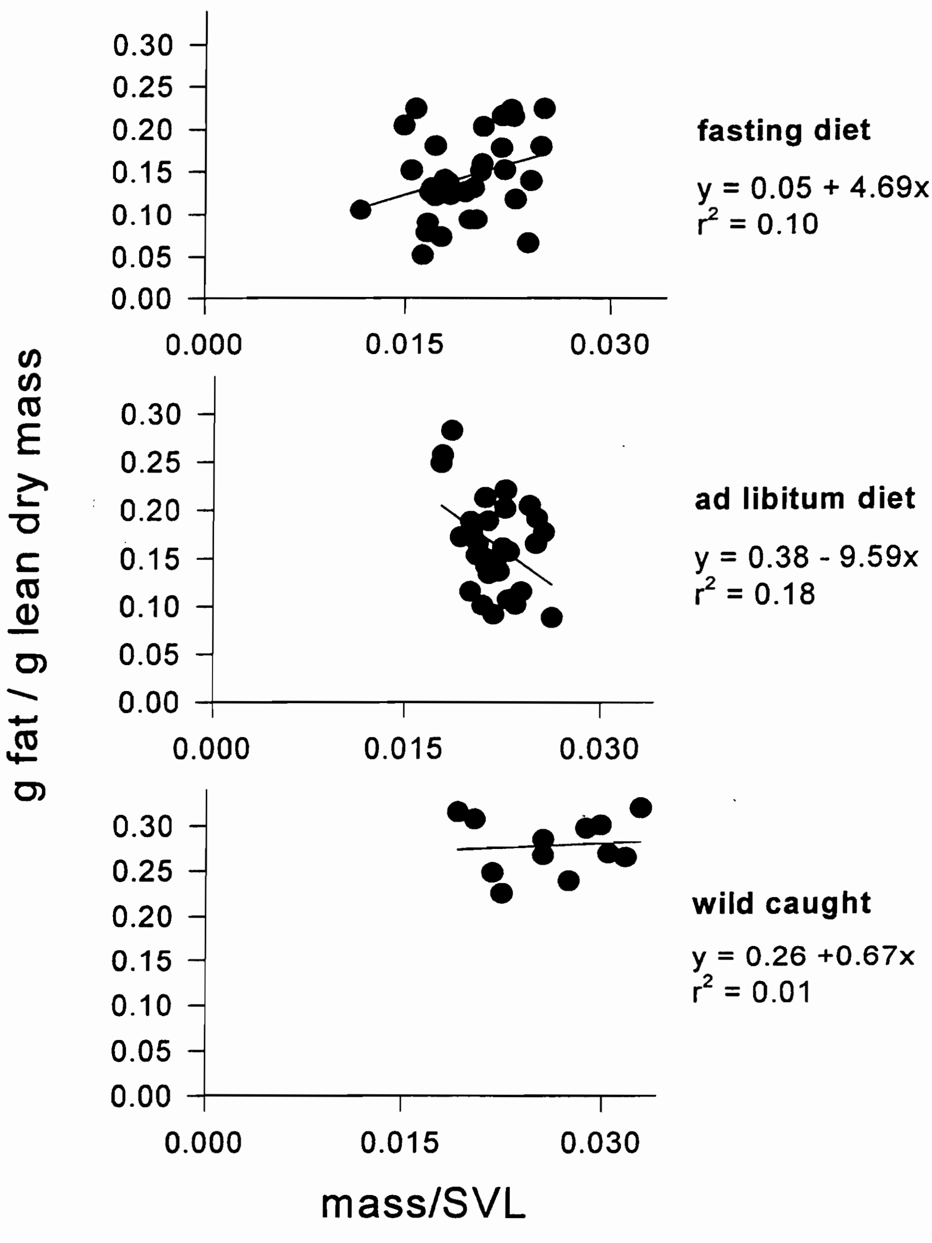

Figure 1.3. Regressions of mass/SVL and g fat/g lean dry mass for fasting diet (n=32), ad libitum diet (n=30), and recently captured (n=12) group.

the press for sex determination of salamanders. Sex can be determined on some salamander species based on external secondary sex characteristics. For species which can be sexed only by viewing the gonads, bags are useful to immobilize the animal while holding them up to a light source. If animals are to be measured in the same bag, this can cut down on handling time between bags and a press.

Tail width was highly variable using both the bag and the press. More than 4 measurements were required at the 10% rate of error we set as acceptable. High variability is probably due to the scale of measurement and the softness and compressibility of the salamander tails. Our salamander TW in bags ranged from 3.3-4.7 mm (4.0 ± 0.12 , $\bar{x} \pm$ SE). We measured each TW with a dial caliper to the nearest 0.1 mm. At this level, slight pressure from the caliper or immobilizing device can easily distort the width a few millimeters, increasing between-measure variability and decreasing the precision. Fraser (1980) found a significant relationship between tail volume and the amount of food ingested in red-backed salamanders. Because the tail is a primary site of fat deposition in salamanders, it remains plausible that measuring tail width with a greater precision may be an effective means of assessing nutritional condition. Immobilizing and measuring TW without distorting width may be possible by photographing salamanders on a measurable grid or by using pressure sensitive calipers, but these may not be feasible for field measurements or with large sample sizes.

Tail width measurements may be useful with larger salamander species. C. D. Anthony (pers. commun.) found a significant relationship between tail width and mass/SVL in Rich Mountain and western slimy salamanders. Both Rich Mountain and western slimy salamanders are larger than redbacks (total length 100-120.5 mm, 121-172 mm, and 57-100 mm respectively). An acceptable level of precision may be obtainable when measuring salamanders with wider tails.

Based on the lack of precision using a bag or press, we would recommend against using TW as a measure of nutritional condition for small salamanders. Precise measurement of SVL and TL can be achieved using a bag or press.

NUTRITIONAL CONDITION

Because of the low precision in measuring TW on red-backed salamanders, TW is not useful in assessing condition or predicting total body lipids. Measuring volume provides no additional information over mass and takes significantly more time to calculate, making it less useful for field use. Precision of these measuring techniques would probably improve if salamanders were anesthetized. However, this would also greatly increase handling time.

While no relationship was detected between mass/SVL measurements and total body fat for any of the 3 groups, between-group comparison reveals a trend in the relationship between mass/SVL and fat content (Figure 1.4). The group that was feeding under natural conditions (maintained in lab 3 days) had significantly greater mass ($H = 16.52$, $p < 0.001$), total body fat ($H = 20.33$, $p <$

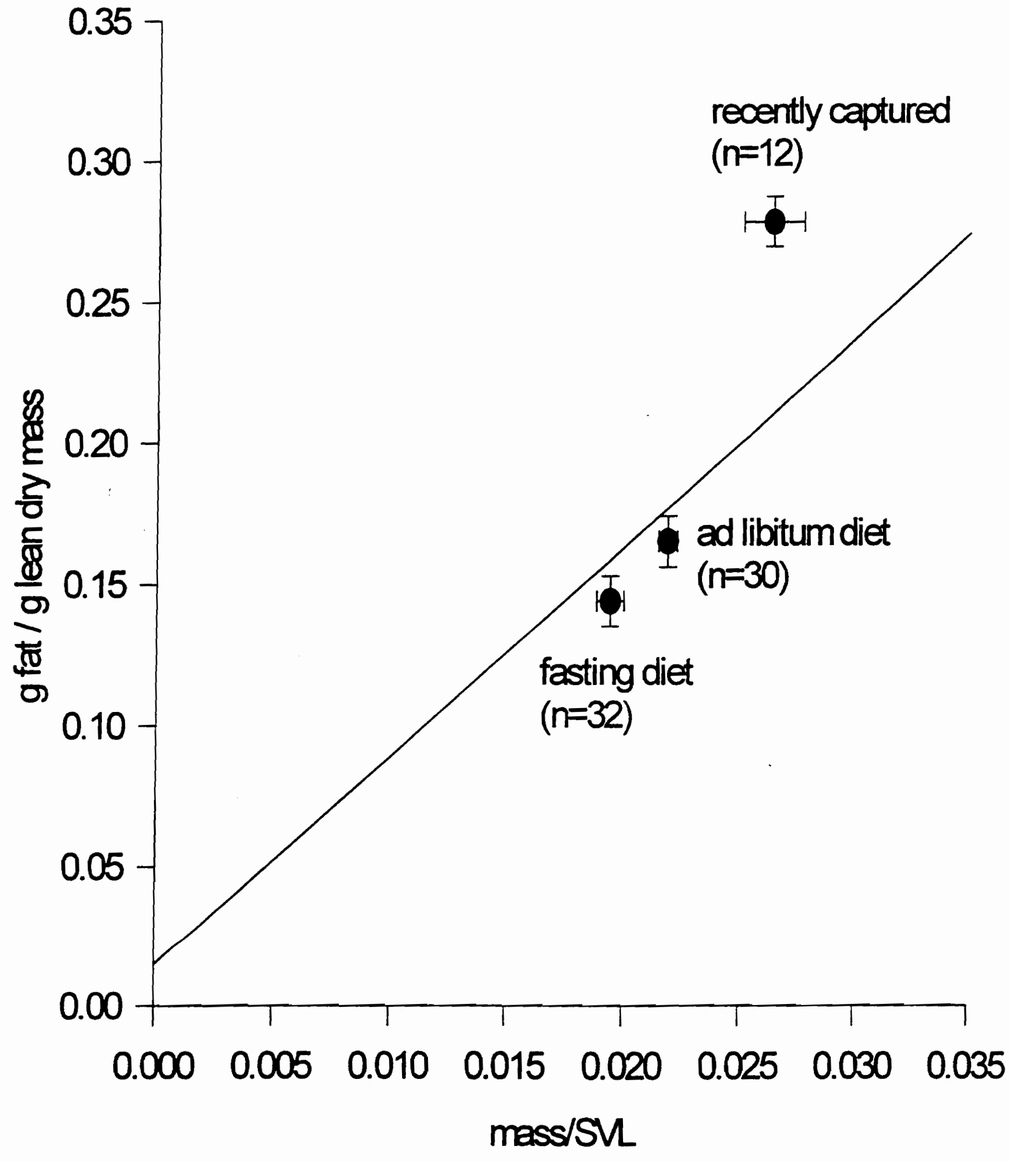

Figure 1.4. Plot of mean (± SE) mass/SVL on g fat / g lean dry mass for fasting diet, ad libitum diet, and recently captured groups.

0.001), and mass/SVL (H = 29.54, $p < 0.001$) than the fasting and ad libitum diet animals (Table 1.3). The group that was most stressed (captive and fasting at high temperature), had the least mass, g fat/g lean mass, and mass/SVL (Table 1.3). There was no significant difference in SVL (H = 3.45, $p = 0.179$) among the 3 groups (Table 1.3).

Scott and Fore (1995) found that female marbled salamanders (*Ambystoma opacum*) maintained at 16^0C on high-food diets had higher lipid levels than animals maintained on less food. We maintained our study animals at 18^0C to increase metabolic rate and ensure that the fasting group would decrease energy stores. As a result, both diet groups lost mass. The average decrease in mass for the ad libitum diet group was probably because all the salamanders didn't ingest enough calories to compensate for the increased metabolic rate. Although we didn't count the number of flies eaten by each animal, there were apparent behavioral differences. We provided more flies than we thought an individual could eat in 24 hrs (based on observations from a preliminary study), but occasionally some petri dishes would still have all the flies after 24 hrs, and others would be emptied. We also recorded the number of fecal pellets deposited by each group as an indication of feeding. The ad libitum diet group averaged 10.8 (± 0.75) pellets/30 days (min-max 1-19). Only 6 individuals deposited pellets in the fasting group during the experiment.

Measurement error could also mask any potentially observable relationship between size and amount of fat. Salamander mass ranged from

0.39 g final mass in the fasting group to 1.54 g for an animal in the wild caught group. We addressed error (precision) in our length measurements, but did not address error in collecting mass data, which could contribute to experimental error.

Mass/SVL may reflect body lipid stores at a population level, but individual variability could mask the relationship within small or relatively homogeneous populations. Most physiological variables vary allometrically with body size (Smith 1984). Scaling variables by using ratios such mass/SVL assumes an isometric relationship (Packard and Boardman 1988). Scaling mass by length in salamanders could produce misleading results because the ratio of mass/SVL may not change isometrically. We selected only adult male red-backed salamanders for our feeding experiment. Using a larger sample size and animals of different sizes, age classes, or sexes may reveal a significant relationship between body size and total body fat.

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CHAPTER 2

SPECIES RICHNESS AND RELATIVE ABUNDANCE OF TERRESTRIAL SALAMANDERS FROM SELECTED SITES IN SOUTHWEST VIRGINIA

INTRODUCTION

There is mounting public concern over suspected adverse effects of silvicultural manipulations used in national forests on biological diversity in general (Salwasser et al. 1992). The National Forest Management Act of 1976 mandated the US Forest Service to maintain biological diversity on the 76 million ha National Forest system. While numerous studies have been conducted on salamander distribution, behavior, and ecology (Hairston 1949, 1987), we know of no studies that systematically document variability in salamander richness and abundance on National Forest land.

Recent studies have shown that terrestrial salamander populations decline after timber harvests. While most studies on the impacts of silviculture on terrestrial salamanders include the basic experimental design principles of control and replication, rarely do they contain pre- and post-treatment data (deMaynadier and Hunter 1995). We measured species richness and relative abundance of terrestrial salamanders at 5 sites in the Jefferson National Forest in southwest Virginia as part of on ongoing joint study with the Department of Forestry entitled "Biodiversity in the Southern Appalachians: Impacts of Silviculture" (Cooperative Research Agreement number 29-1033). The sites are scheduled for harvest during 1995-97 according to guidelines described in Chapter 3.

OBJECTIVES

The objective of this study was to determine preharvest variation in species richness and relative abundance at five study sites in the Jefferson National Forest of southwest Virginia. These data will provide baseline data for an ongoing, long-term, replicated study to compare the effects of seven silvicultural treatments on the species richness and relative abundance of terrestrial salamanders.

STUDY SITES

Five study sites were located in the Newcastle, Blacksburg, Wythe, and Clinch ranger districts of the Jefferson National Forest of southwest Virginia (Figure 2.1). The Clinch district is located in the Allegheny Plateau physiographic province and contains 2 study sites. The remaining districts contain 1 site each and are located in the Ridge and Valley physiographic province. Study sites were selected based on criteria established by Dr. D. Wm. Smith in the Virginia Tech Department of Forestry. Selection criteria included slope, aspect, elevation (Table 2.1), uniformity in timber stand composition within

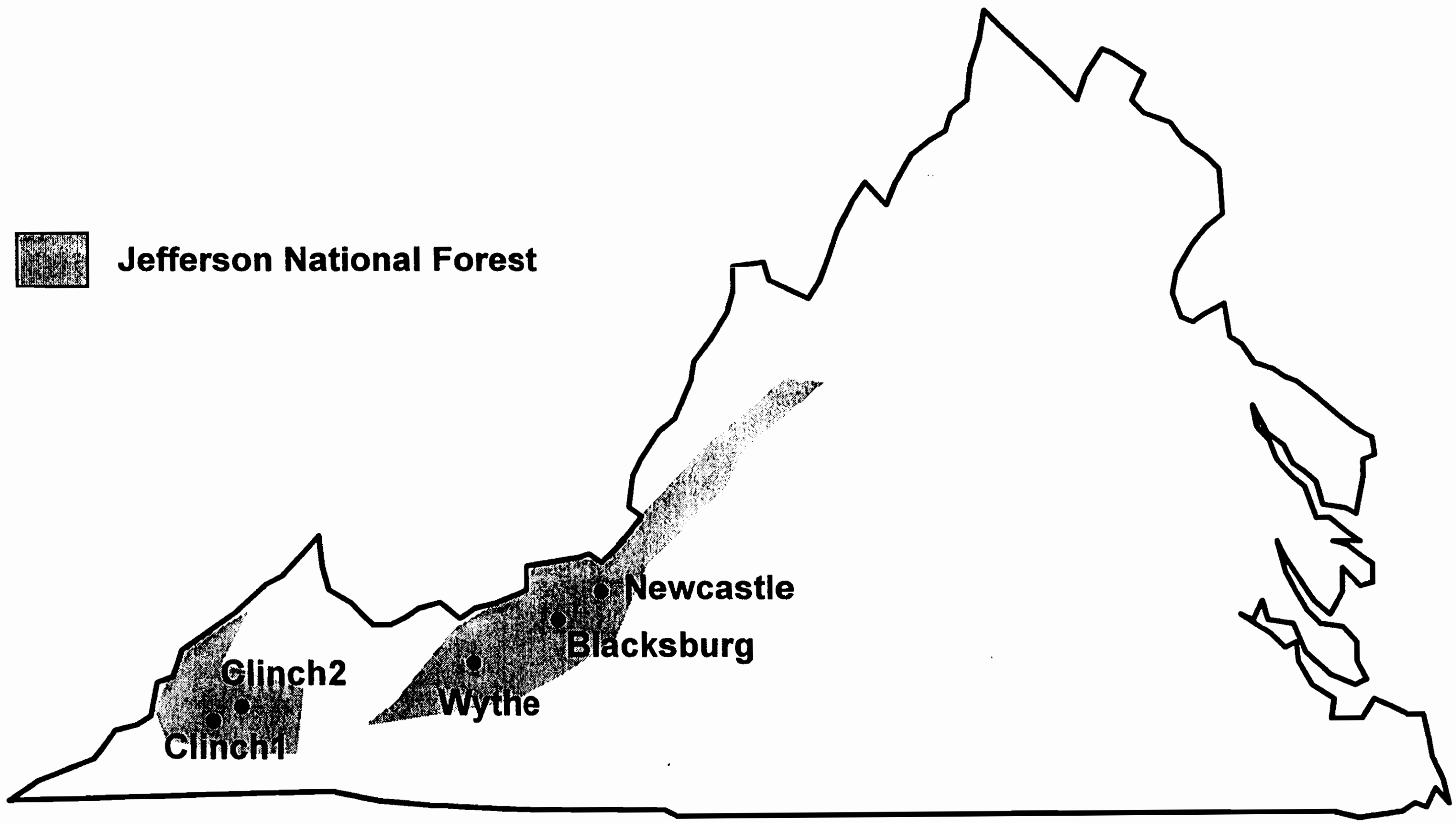

Figure 2.1. Location of study sites in Jefferson National Forest of Virginia.

Table 2.1. County (VA), range of slope, and approximate longitude, latitude, aspect, and elevation for the 5 study sites sampled before harvest in 1994.

	Blacksburg	Clinch 1	Clinch 2	New Castle	Wythe
County	Montgomery	Scott	Wise	Craig	Bland
Slope	8-35.5^0	12-35^0	5-33^0	8-27^0	6-44^0
Longitude	80^0 27'	82^0 36'	82^0 33'	80^0 23'	81^0 06'
Latitude	37^0 17'	36^0 52'	36^0 53'	37^0 26'	37^0 02'
Aspect	120^0	150^0	115^0	170^0	160^0
Elevation	685 m	1080 m	1050 m	670 m	820 m

the site, and site index (around SI_{50} 70 for white oak *Quercus alba*). Sites selected within each district had to be able to accommodate 7 square 2-ha treatment plots. Sites are typical of mid-elevation (600-1050 m) southern Appalachian hardwood forests and are dominated by red and white oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.).

METHODS

SPECIES RICHNESS

We determined species richness by identifying all salamanders encountered during nighttime area-constrained searches. We also list any species encountered during preparation of night transects and trails, during time spent returning captured animals to transects, and during periodic searches in and around drainages and natural cover objects located on each treatment but not on transects.

RELATIVE ABUNDANCE

The long-term goal of this study was to monitor the effects of different silviculture practices on terrestrial salamander richness and abundance over many years. Therefore, we selected sampling techniques that were repeatable and would not introduce bias to sampling in future years because of increased mortality of salamanders or destruction of habitat. Our primary sampling method for determining relative abundance consisted of nighttime surveys of 2 x 15 m transects. All surveys were conducted during or after rain events so that the forest floor was wet. In order to reduce bias from observer searching effort, we captured only animals visible on the forest floor. No cover objects were disturbed to search for animals unless an animal was initially visible on the surface but escaped under a cover object. We conducted preharvest sampling from April through October of 1994. We conducted postharvest sampling from April through June 1995 at the Blacksburg site.

Nine transects were evenly spaced on a grid in each treatment and marked using stakes and string (Figure 2.2). Because all transects were sampled at night using headlamps to locate salamanders, we marked a system of trails using color-coded reflective tape to facilitate locating the transects. We placed transects in a grid rather than in random locations to facilitate finding transects at night in the rain. The grid was centered on each treatment allowing for a 30 m buffer zone (no sampling) around the perimeter to reduce edge effects from adjacent treatments (Petranka et al. 1994)(Figure 2.2).

Intermittent and permanent streams transect each study site. However, not all treatments on each study site have streams. Densities of some salamander species (e.g. *Desmognathus* spp.) encountered during sampling and during other searches of the sites are directly correlated with stream habitats. Because all treatment plots do not have streams, we concentrated on those species which are completely terrestrial and made no effort to adjust

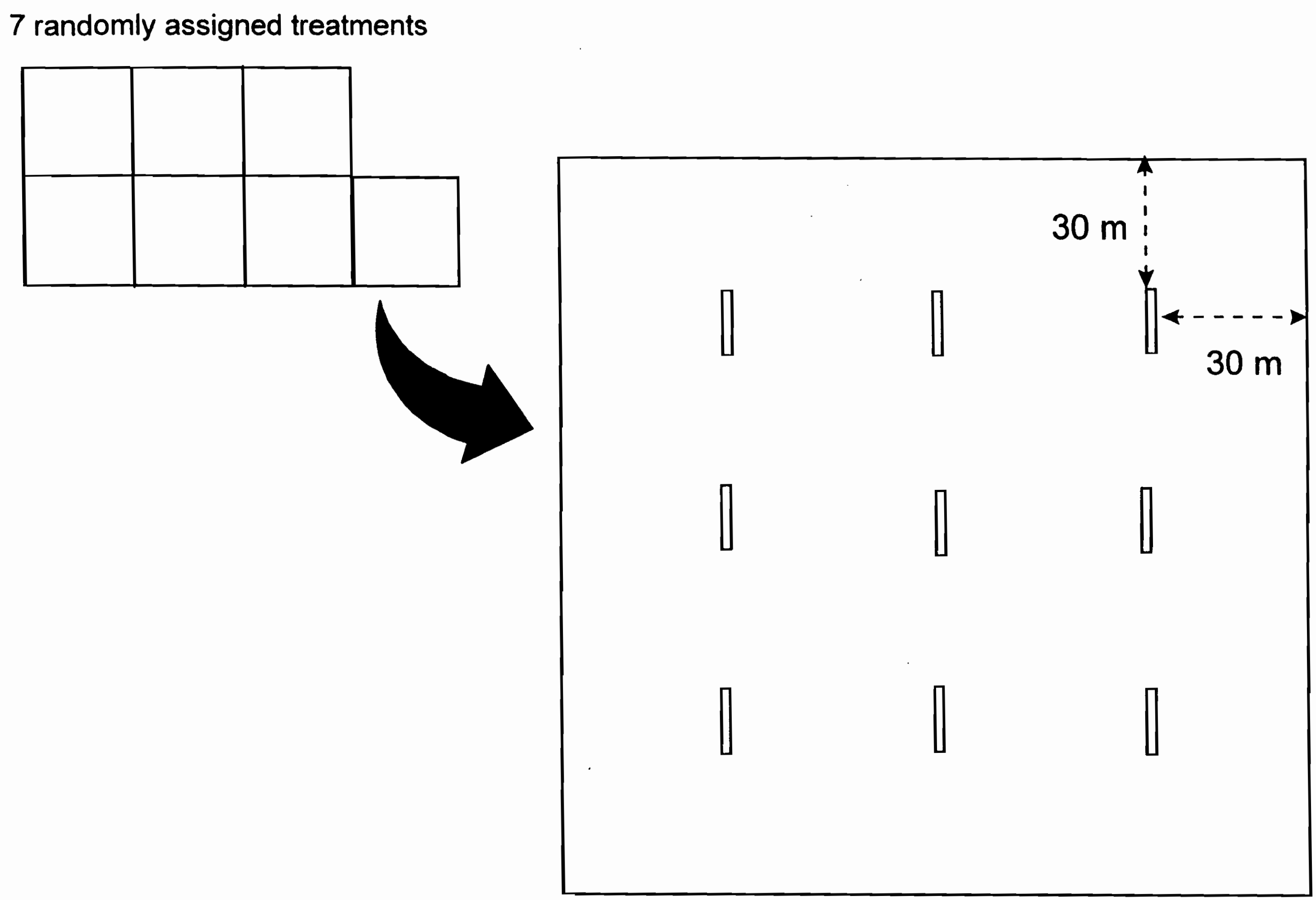

Figure 2.2. Location of 2 x15 m transects and 30 m buffer zone within each 2 ha treatment plot.

sampling procedures for stream habitat. Therefore, if transects randomly fell in or across a stream, we made no effort to relocate them.

On a given sample night, 1 transect was randomly chosen and sampled from each treatment plot for a total of 30 m^2 sampled per treatment per sample night. We sampled each transect once per sampling season. Sampling began approximately 1 hr. after sunset to ensure maximum darkness and continued until one transect on every treatment had been sampled. Each transect required a minimum of 20 minutes to sample if no animals were encountered and visibility was good (little understory vegetation) and a maximum of 50 minutes if we encountered large numbers of animals. We chose 2-m wide transects to allow 2-3 searchers to crawl adjacent to each other and adequately cover the entire area. On several occasions, 4 searchers were available and we searched each transect with 2 persons starting from opposite ends and meeting in the middle. Some evidence suggests that salamander activity peaks at certain periods during the night (Holomuzki 1980, Keen 1984). In order to avoid potential biases associated with these activity peaks, we randomized the order in which we searched treatment plots. We randomly selected 1 of the 7 treatments (without replacement) each sample night as a starting point and moved to the next treatment in clockwise order. We chose 15 m long transects to allow enough time to sample and travel between all 7 treatments in a single night. Total time required to sample all 7 treatments ranged from 3.5 to 5.0 hours per night.

We hand captured all salamanders observed (Virginia Scientific Collection Permit # SCP9527) and placed them in numbered plastic baggies. We added wet leaf litter to keep specimens from dehydrating and to reduce the possibility of accidentally crushing the animal. Because many of the species we captured are territorial, we returned all animals after data collection to the exact site of capture within 24 hours. We placed numbered flags at the site of each captured salamander and recorded the baggie and flag number to facilitate returning the animal.

We recorded mass, snout-vent length (SVL), total length (TL), tail width at the posterior end of the cloacal opening (TW), sex, age class, reproductive status of females (gravid or non-gravid), and description of tail (intact or in regeneration) on all salamanders captured. We measured mass by rinsing debris off of specimens with distilled water, blotting excess water with a towel, and weighing the animal on an electronic balance to the nearest 0.01 g. We immobilized salamanders by holding them in an empty moistened plastic baggie, and measured SVL, TL, and TW to the nearest 0.1 mm using a dial caliper. We determined sex of specimens by holding them in front of a fiber optic light and viewing the gonads, or by the presence of secondary sex characteristics (e.g. mental gland under the mandible or swollen cirri on nasolabial grooves on males, or sexually dimorphic shape of the snout). We classified all salamanders as either young of the year (YOY), juvenile, or adult based on SVL. Data on temperature, humidity, and litter condition during sampling, sex, age class, and reproductive status were not analyzed in this study.

We began sampling in April during or after rain and when temperatures were above 7^0 C at night. In order to standardize for sampling conditions, we sampled only after enough rain fell so that the forest floor was wet. We had no means of continuously monitoring actual rainfall on the site, therefore, we classified litter condition into 3 categories to reflect apparent moisture: Class 1 - litter on surface of forest floor (O_i and O_e layers) and forest floor (O_a and A layers) were wet; Class 2 - litter on surface of forest floor wet, forest floor dry; and Class 3 - litter on surface of forest floor dry, forest floor wet. Class 1 reflects ample recent or current rainfall. Class 2 indicates recent rainfall, but not sufficient to soak into the forest floor soil. Class 3 indicates recent rainfall, but some drying has occurred. We did not sample if both the surface litter and forest floor layers were dry.

We compared the number of salamanders captured on each treatment plot to test for variation in relative abundance among treatment plots before harvest. We combined data from all species captured on all transects within a treatment plot and tested for within-site differences in relative abundance using a Kruskal-Wallis one-way layout (Minitab 1995).

RESULTS

SPECIES RICHNESS

Our ability to sample each site was limited by rainfall and availability of volunteer labor when classes were in session. We sampled the Blacksburg site 8 times from April through October of 1994. We sampled Wythe once in May, twice in June, and once in July of 1994. Both Clinch sites were sampled 5 times from June through August of 1994. For the Blacksburg, Wythe, and Clinch sites, the number of species captured on night transects varied from 3 to 10. When we include the number of species found on the study area, but not captured on the transects, species richness increases to 7 to 12.

We sampled night transects twice at the Newcastle site in June of 1994. On both nights it had been raining for at least 24 hours prior to the sample night, and the leaf litter and soil layer were wet. Only 6 white-spotted slimy salamanders (*Plethodon cylindraceus)* were captured on transects during 18 personhours of sampling (mean density of 0.01 salamanders/m^2). In addition, we only found 4 white-spotted slimy and 1 red eft (*Notophthalmus viridescens*) by turning rocks and logs during approximately 18 personhours of site preparation. We observed northern dusky (*Desmognathus fuscus*) and black-bellied salamanders (*D. quadramaculatus*) in one of the drainages on the site. Because of the low number of salamanders found, limited availability of volunteer labor to survey the site, and delays in getting the site harvested during this study period, we elected to discontinue sampling the Newcastle site during the 1994 field season.

We found 3 species on night transects at the Blacksburg site and 5 additional species off-transects (Table 2.2). We captured red-backed and white-spotted slimy salamanders on all 7 treatment plots. Northern dusky salamanders were regularly seen in drainages away from most transects and were only caught during night transect sampling on those treatments which had transects passing near or through streams (4 of 7 treatments).

We captured 10 species on night transects at the Wythe site (Table 2.3). The only terrestrial species found on all treatments during night transect sampling was the northern slimy salamander (*Plethodon glutinosus*). We also found ravine (*P. richmondi*) and mountain dusky salamanders (*D. ochrophaeus*) in upland habitat away from streams on some of the treatment plots. All other species encountered were located in or near streams.

We found 6 salamander species on night transects at both Clinch sites (Table 2.4 and 2.5). The dominant species were mountain dusky, ravine, and northern slimy salamanders and all 3 species were regularly captured on all 7 treatments of both sites. We also observed Cumberland plateau salamanders (*P. kentucki*), two-lined salamanders, and red efts on Clinch 1 transects, and Cumberland plateau, red efts and northern dusky salamanders on Clinch 2 transects. We identified 5 additional species away from transects in or near

Table 2.2. Number of salamanders, by species, caught on transects at the Blacksburg site, April-October 1994. Species listed with an asterisk in the number column are species observed on the study site, but not caught on transects.

Species	Common Name	Number	% Total
Plethodon cinereus	red-backed salamander	468	92.3
P. cylindraceus	white-spotted slimy salamander	25	4.9
Desmognathus fuscus	northern dusky salamander	14	2.7
Eurycea cirrigera	two-lined salamander	*	
D. monticola	seal salamander	*	
Notophthalmus viridescens	red-spotted newt	*	
Gyrinophilus porphyriticus	spring salamander	*	
Pseudotriton ruber	northern red salamander	*	
TOTAL		507	

Table 2.3. Number of salamanders, by species, caught on transects at the Wythe site, May-July 1994.

Species	Common Name	Number	% Total
Plethodon glutinosus	slimy salamander	26	33.4
Desmognathus monticola	seal salamander	14	18.2
D. ochrophaeus	mountain dusky salamander	14	18.2
D. fuscus	northern dusky salamander	8	10.4
D. quadramaculatus	black-bellied salamander	4	5.2
Eurycea cirrigera	two-lined salamander	3	3.9
Gyrinophilus porphyriticus	spring salamander	3	3.9
Pseudotriton ruber	northern red salamander	2	2.6
Plethodon richmondi	ravine salamander	2	2.6
Notophthalmus viridescens	red-spotted newt	1	1.3
TOTAL		77	

Table 2.4. Number of salamanders, by species, caught on transects at the Clinch 1 site, June-August 1994. Species listed with an asterisk in the number column are species observed on the study site, but not caught on transects.

Species	Common Name	Number	% Total
Desmognathus ochrophaeus	mountain dusky salamander	498	64.4
Plethodon richmondi	ravine salamander	172	22.1
P. glutinosus	slimy salamander	78	10.1
P. kentucki	Cumberland Plateau salamander	12	1.6
Eurycea cirrigera	two-lined salamander	7	0.9
Notophthalmus viridescens	red-spotted newt	6	0.7
Desmognathus fuscus	northern dusky salamander	*	
D. monticola	seal salamander	*	
D. quadramaculatus	black-bellied salamander	*	
D. welteri	black mountain salamander	*	
Gyrinophilus porphyriticus	spring salamander	*	
TOTAL		773	

Table 2.5. Number of salamanders, by species, caught on transects at the Clinch 2 site, June-August 1994. Species listed with an asterisk in the number column are species observed on the study site, but not caught on transects.

Species	Common Name	Number	% Total
Desmognathus ochrophaeus	mountain dusky salamander	383	59.1
P. richmondi	ravine salamander	178	27.5
P. glutinosus	slimy salamander	62	9.6
P. kentucki	Cumberland Plateau salamander	13	2.0
Notophthalmus viridescens	red-spotted newt	7	1.1
Desmognathus fuscus	northern dusky salamander	5	0.8
D. monticola	seal salamander	*	
D. quadramaculatus	black-bellied salamander	*	
D. welteri	black mountain salamander	*	
Gyrinophilus porphyriticus	spring salamander	*	
Eurycea cirrigera	two-lined salamander	*	
Pseudotriton ruber	northern red salamander	*	
TOTAL		648	

streams at the Clinch 1 site and 3 additional species off transects on the Clinch 2 site.

RELATIVE ABUNDANCE

There was no significant difference in relative abundance of salamanders among treatment plots (all species combined) on the Blacksburg site ($n = 8$, $p = 0.949$). We captured 507 salamanders during 8 sample nights (mean density of 0.30 salamanders/m^2) (Table 2.2). Mean number of salamanders observed on treatment plots ranged from 6.0 to 10.2 per transect (Figure 2.3). Red-backed salamanders accounted for 92 % of all captures.

There was no significant difference in among-treatment plot relative abundance of salamanders (all species combined) on the Wythe site (Figure 2.4, $n = 4$, $p = 0.706$). We captured 77 salamanders during 4 sample nights (mean density of 0.09 salamanders/m^2)(Table 2.3).

Relative abundance of salamanders differed significantly among treatment plots at the Clinch 1 ($n = 5$, $p = 0.014$) and Clinch 2 sites ($n = 5$, $p = 0.069$). Mean number of salamanders observed on treatment plots ranged from 10.8 to 34.6 per transect on Clinch 1 (Figure 2.5). We captured 773 salamanders during 5 sample nights (mean density of 0.74 salamanders/m^2). Mountain dusky salamanders accounted for 64.4% of all captures (Table 2.4).

Mean captures per treatment plot ranged from 14.8 to 25.0 salamanders per transect on the Clinch 2 site (Figure 2.6). We observed 648 salamanders

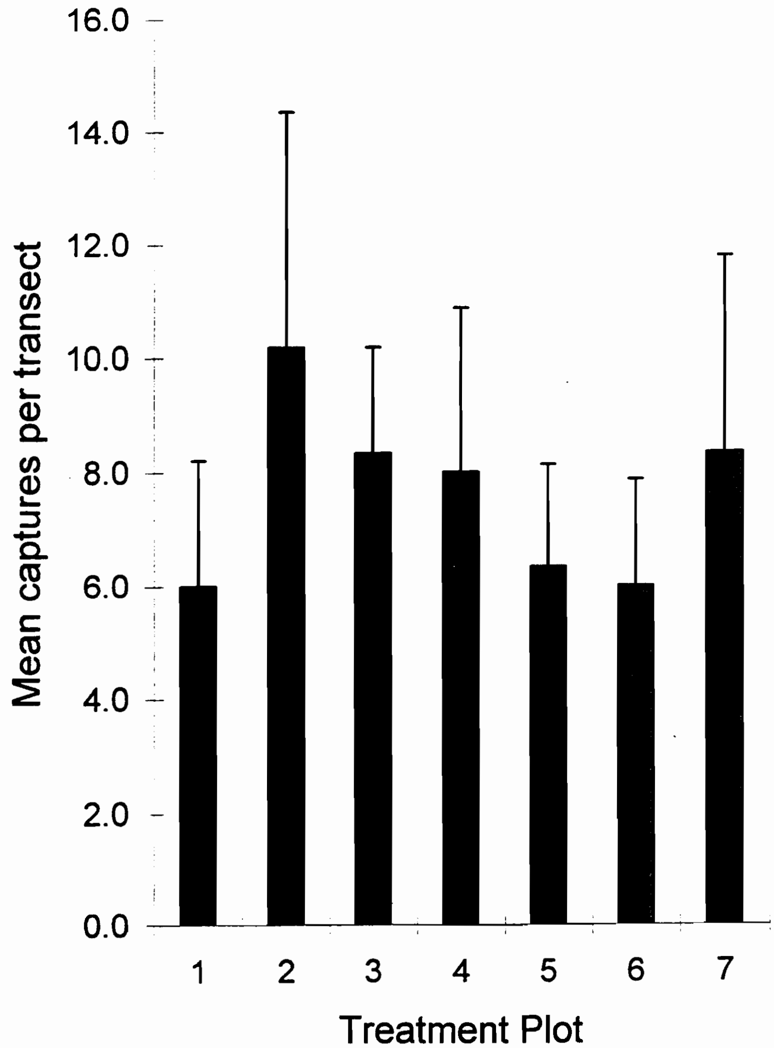

Figure 2.3. Mean (SE) number of salamanders captured per transect per sample night on Blacksburg study site, 1994.

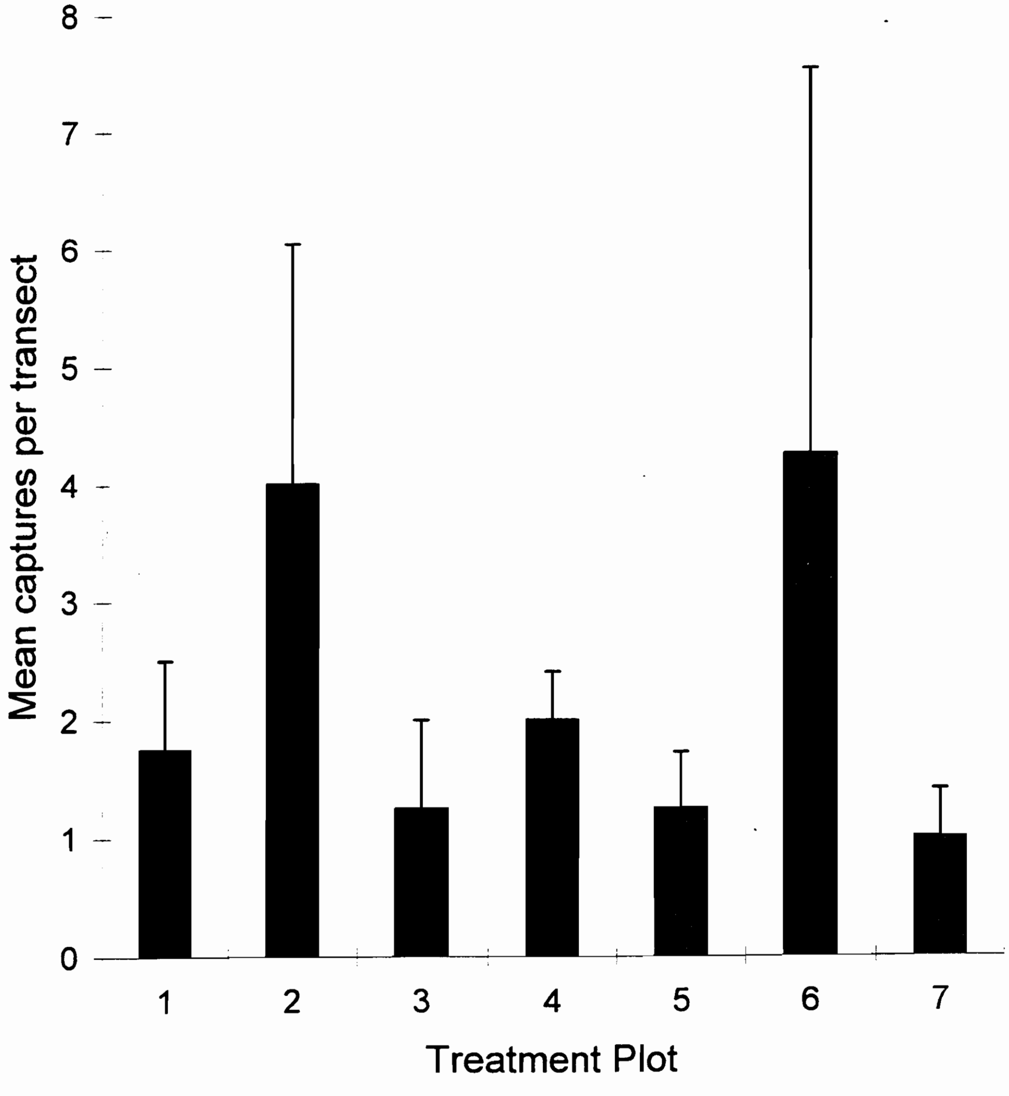

Figure 2.4. Mean (SE) number of salamanders captured per transect per sample night on Wythe study site, 1994.

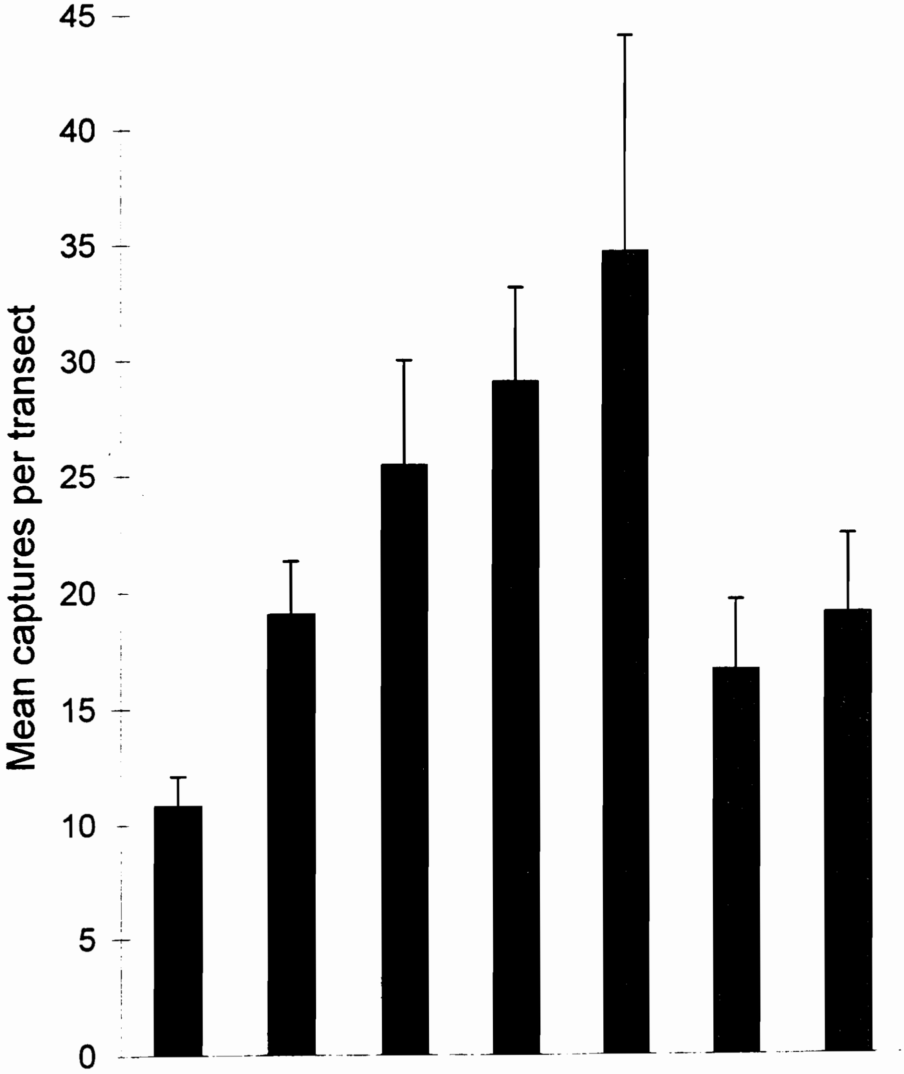

Figure 2.5. Mean (SE) number of salamanders captured per transect per sample night on Clinch 1 study site, 1994.

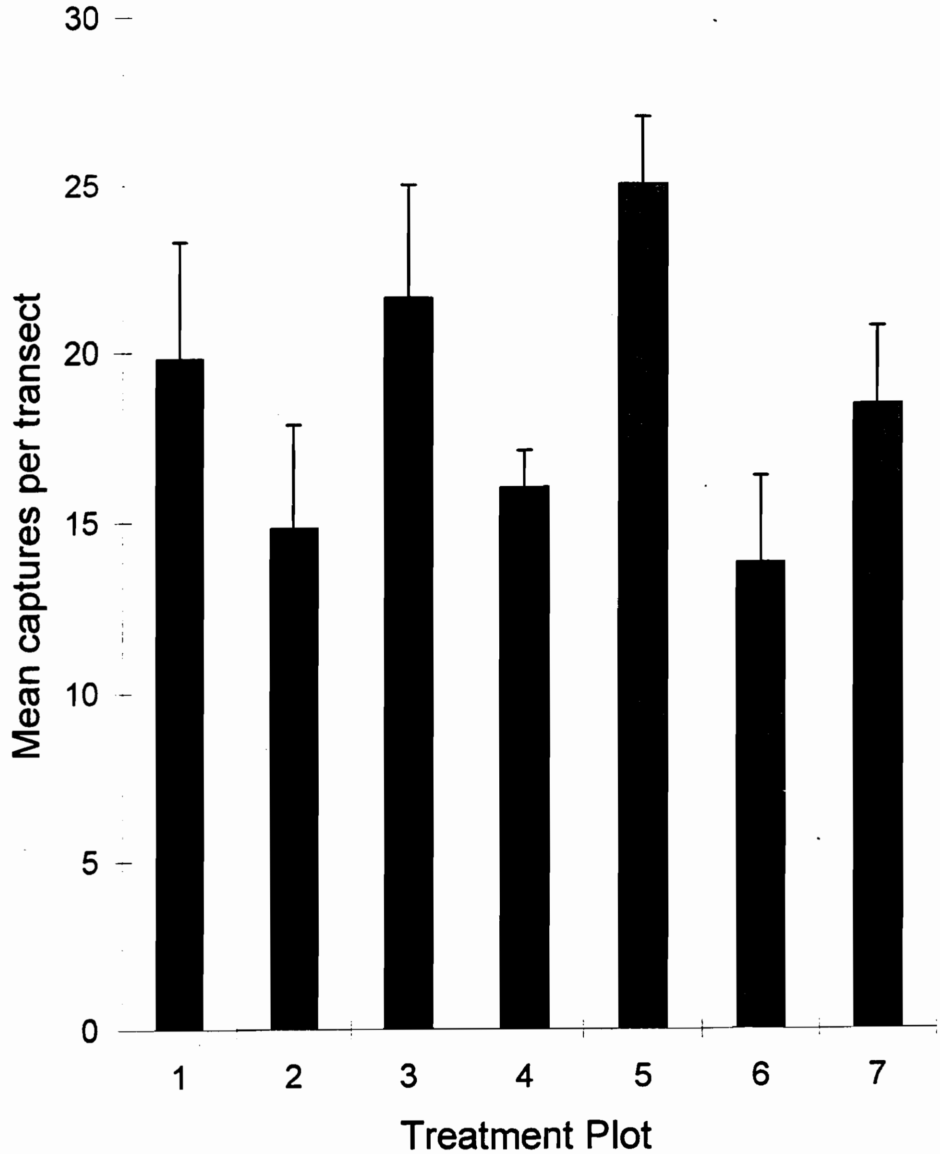

Figure 2.6. Mean (SE) number of salamanders captured per transect per sample night on Clinch 2 study site, 1994.

during 5 sample nights (mean density of 0.62 salamanders/m^2). Mountain dusky salamanders constituted 59.1% of all captures (Table 2.5).

DISCUSSION

SPECIES RICHNESS

Species richness varied both within and among study sites. We observed the fewest species at our northernmost sites (Newcastle and Blacksburg) and the most species at the southernmost sites (Clinch 1 and 2). In general, salamander diversity increases towards the southern Appalachians (Hairston 1987). Salamander diversity is also influenced by habitat diversity. Study sites that have permanent streams (Wythe, Clinch 1 and 2) have increased species richness because of the higher number of species occurring in the stream and streamside habitat (e.g. *Desmognathus* spp.). The dominant species on each site were found on all treatment plots of those sites. Additional species found on each site were usually associated with streams or were a less abundant species located on a single treatment plot (e.g. spring salamanders on Blacksburg and northern red salamanders on Clinch 2 site).

Species lists for all sites could potentially increase with increased sampling effort. For example, we encountered spotted salamanders (*Ambystoma maculatum*) less than 200 m from the Clinch 2 site during 1996 sampling. Mole salamanders (*Ambystoma* spp.) could potentially be located on all sites if sampling coincided with annual breeding. However, we concentrated primarily on woodland salamanders and most of our sampling was conducted outside the breeding season for mole salamanders. Species richness at Newcastle would probably increase with greater sampling effort in drainages. The Newcastle site is well-drained and we spent the least amount of effort sampling it relative to other sites (see *Relative Abundance* section). Higher species richness at the Wythe site relative to other sites was due to a permanent stream bisecting several of the treatment plots. This stream is from diverted groundwater from the nearby (approximately 100 m from one treatment) Big Walker Mountain tunnel on Interstate 77. This stream contributes to the presence of 8 of the 10 species found on the study site. The higher species richness at the Clinch sites is probably because of more moisture and cooler climate. Clinch 1 and 2 have more intermittent and permanent streams bisecting treatment plots. Clinch 1 and 2 are also in the Allegheny Plateau physiographic region, are approximately 350 m higher in elevation, and receive more rainfall than the other study sites.

RELATIVE ABUNDANCE

Relative abundance varied both within and among study sites. Mean density of salamanders was higher on Clinch 1 and 2 than other study sites. The differences in relative abundance might be partially a result of the greater species richness farther south, and perhaps less intense competitive interactions among species than within species. However, differences in relative abundance can be better explained as a consequence of differences in microhabitat. Although all sites were chosen for their similar site characteristics, the Newcastle and Blacksburg sites are very well-drained, while the Clinch sites are slightly higher in elevation and tend to remain cool and moist during the summer months even long after a rain event.

Relative abundance of dominant salamander species differed significantly among treatment plots only on the Clinch 1 and 2 study sites. The mountain dusky salamander was the dominant species on Clinch 1 and 2. Although mountain dusky salamanders are commonly found upland and are among the most terrestrial salamanders in the genus, they require streams for reproduction and distribution is influenced by proximity to streams (Organ 1961). Relative abundance varied among treatment plots on Clinch 1 and 2 probably because of differences in distribution of streams. If we remove mountain duskys from the analysis and compare only completely terrestrial species, there was no significant difference in relative abundance among the treatments on Clinch 1 ($p = 0.746$, $n = 7$, $H = 3.48$) or Clinch 2 ($p = 0.292$, $n = 7$, $H = 7.34$).

Red-backed salamanders (the dominant species on the Blacksburg site) are completely terrestrial and do not require streams or ponds for reproduction. Thus, we would not expect distribution to be strongly influenced by standing water. There was no difference in relative abundance among treatment plots prior to timber harvest on the Blacksburg site. Although there was no significant difference in relative abundance among preharvest treatment plots on the Wythe site, results are inconclusive. We caught very few animals on any treatments making analysis difficult.

We were unable to equally sample the 5 sites during spring, summer, and fall because of weather conditions and lack of searchers. Therefore, we were unable to compare seasonal variability in relative abundance within and among sites. Total salamanders captured per sample night and mean captures per site are presented in the Appendix (Figures A1 through A5).

We are currently continuing to sample the 5 sites discussed in this study and they are scheduled for future harvesting. In addition, several other sites have been identified and scheduled for sampling and harvesting during 1996-98. Variability in local abundance (as observed with mountain dusky salamanders on our Clinch 1 site) emphasizes the importance of pre-treatment sampling in studies examining the effects of habitat manipulation on salamander populations. Pre-treatment sampling, monitoring of controls, replication of this study design, and long-term data collection on the study sites will enable us to assess the effects of the different silvicultural practices on terrestrial salamander species richness and abundance.

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CHAPTER 3

EFFECTS OF 7 SILVICULTURAL TREATMENTS ON TERRESTRIAL SALAMANDERS

INTRODUCTION

Salamanders are an important ecological component of Appalachian deciduous forests and can occur in densities such that total salamander biomass in a given area can exceed that of other small vertebrate species (Burton and Likens 1975, Hairston 1987). Terrestrial salamanders feed on prey that are too small for birds or mammals and serve as prey for snakes, birds, small mammals, and other salamanders (Brodie and Howard 1973, Brodie et al. 1979, Pough 1980). Species distributions vary according to moisture and elevation gradients throughout the southern Appalachians (Hairston 1987). Terrestrial salamanders forage in the forest floor litter primarily at night, after rainfall or during periods of high humidity. Previous studies have shown that salamander populations decline after clearcut timber harvesting (Ash 1988, Pough et al. 1987, Petranka et al. 1993, Petranka et al. 1994). Clearcutting increases the surface temperature and leads to drying of the litter layer (Johnson et al. 1985) limiting salamander surface activity (Fraser 1976, Jaeger 1980). Although the effects of clearcut timber harvesting on terrestrial salamander populations have been documented, few studies have compared the effects of other silvicultural practices on terrestrial salamander populations in eastern deciduous forests of the United States (but see preliminary work by Bennett et al. 1980, Pough et al. 1987).

In 1994 we measured species richness and relative abundance of terrestrial salamanders at 5 sites in the Jefferson National Forest in southwest Virginia (see table 2.1). Dr. D. Wm. Smith in the Virginia Tech Department of Forestry selected these sites as part of on ongoing joint study with the Department of Fisheries and Wildlife Sciences entitled "Biodiversity in the Southern Appalachians: Impacts of Silviculture" (Cooperative Research Agreement number 29-1033)(See Chapter 2, Study Sites section for site descriptions) . Sites were scheduled for harvest during winter of 1994-95, however, only one site was harvested.

OBJECTIVES

The purpose of this study was to compare the effects of seven silvicultural treatments on species richness and relative abundance of terrestrial salamanders. The specific objectives were 1) to compare the effects of seven silvicultural treatments on species richness and abundance at one harvested site; 2) to correlate salamander abundance with microhabitat variables, and 3) to compare the effects of 7 silvicultural treatments on salamander nutritional condition.

STUDY SITE AND SILVICULTURAL TREATMENTS

Our study site was located in the Blacksburg Ranger District of the Jefferson National Forest in southwest Virginia (See Figure 2.1 and Study Sites section of Chapter 2). The site is located in the Ridge and Valley physiographic province and was selected based on criteria described in the Study Sites section in Chapter 2.

We randomly assigned 1 of 7 silvicultural treatments to each 2-ha plot. Treatments included an herbicide removal of understory woody vegetation, group selection, clearcut, leave tree, 2 shelterwoods, and an unharvested control. Timber was marked for sale by U. S. Forest Service personnel according to guidelines as described below. Timber was placed for bid and scheduled to be harvested by private contractors according to Forest Service guidelines.

Herbicide removal of understory consisted of a thin-line individual stem (basal) application of Garlon 4® herbicide (Triclopyr butoxyethyl ester). Herbicide treatment was intended to remove nondesirable understory woody vegetation to reduce competition with species desired for timber production. Group selection harvest removed 2-3 groups of trees within the treatment plot and produced an uneven-aged timber stand. Total tree removal from each group selection was about 0.5 ha per 2-ha treatment plot. Group size and number was based on tree height. Groups were round or elliptical and had diameters between 1.5 to 2.0 times the adjacent tree height. Remaining uncut trees will be harvested in groups on an approximately 20 year rotation. The clearcut harvest removed all merchantable trees and stems down to 5 cm dbh from the treatment plot during a single harvest and resulted in an even-aged timber stand. Some mast, snag, and cull trees were left for wildlife, but total remaining trees did not exceed 6 per ha. The leave tree harvest (previously called a deferment cut) consisted of a single harvest in which between 3-4 m^2 of basal area (BA) was retained per hectare. A maximum of 16 trees per ha were retained resulting in an uneven-aged stand. The 2 shelterwood cuts consisted of an initial partial harvest in which the prescribed BA was retained and the residual overstory will be removed 5-10 years later. One shelterwood treatment retained 4-7 m^2 BA per ha and one retained 12-14 m^2 BA (this treatment actually retained 15 m^2 BA during 1995 sampling, with the remainder to be harvested at a later date). The schedule for secondary removal of timber will depend on regeneration rate of desired species. One plot was maintained as an unharvested control plot in which no silvicultural treatment was applied.

METHODS

SALAMANDER SAMPLING

Species Richness

We determined species richness before and after harvest as described in methods section of Chapter 2.

Relative Abundance

We determined relative abundance using nighttime area-constrained searches (described in methods section of Chapter 2) and artificial cover objects. We combined data from all area-constrained searches in each plot and calculated the mean number of salamanders captured per treatment to identify changes in preharvest and postharvest relative abundance. We tested for within-site differences in preharvest and postharvest relative abundance using Kruskal-Wallis one-way layout tests (Minitab 1995).

Our artificial coverboard sampling consisted of 50, 5 x 30 x 90 cm rough-cut poplar (*Liriodendron tulipifera*) boards placed in a grid pattern on each 2-ha treatment plot (Figure 3.1). We evenly spaced coverboards (approximately 10 m apart) over each treatment plot, leaving a 30 m buffer zone around the perimeter of each treatment to avoid any edge effects from adjacent treatments (Figure 3.1). Boards were placed on each site and allowed to weather for at least 1 month prior to sampling. All coverboards were oriented in the same direction, but placement was modified for some boards to ensure full contact with the ground. We removed leaf litter from under each coverboard to increase board-to-ground contact and to allow for greater visibility of salamanders. We planned to check coverboards every 2 weeks during the postharvest sampling season, but we observed that soil under boards dried out and boards were not used between rains. Therefore, we sampled boards every 2-3 weeks after enough rainfall to dampen the soil under the boards. We waited 1-2 days after rainfall until the surrounding leaf litter dried to sample boards. We sampled coverboards

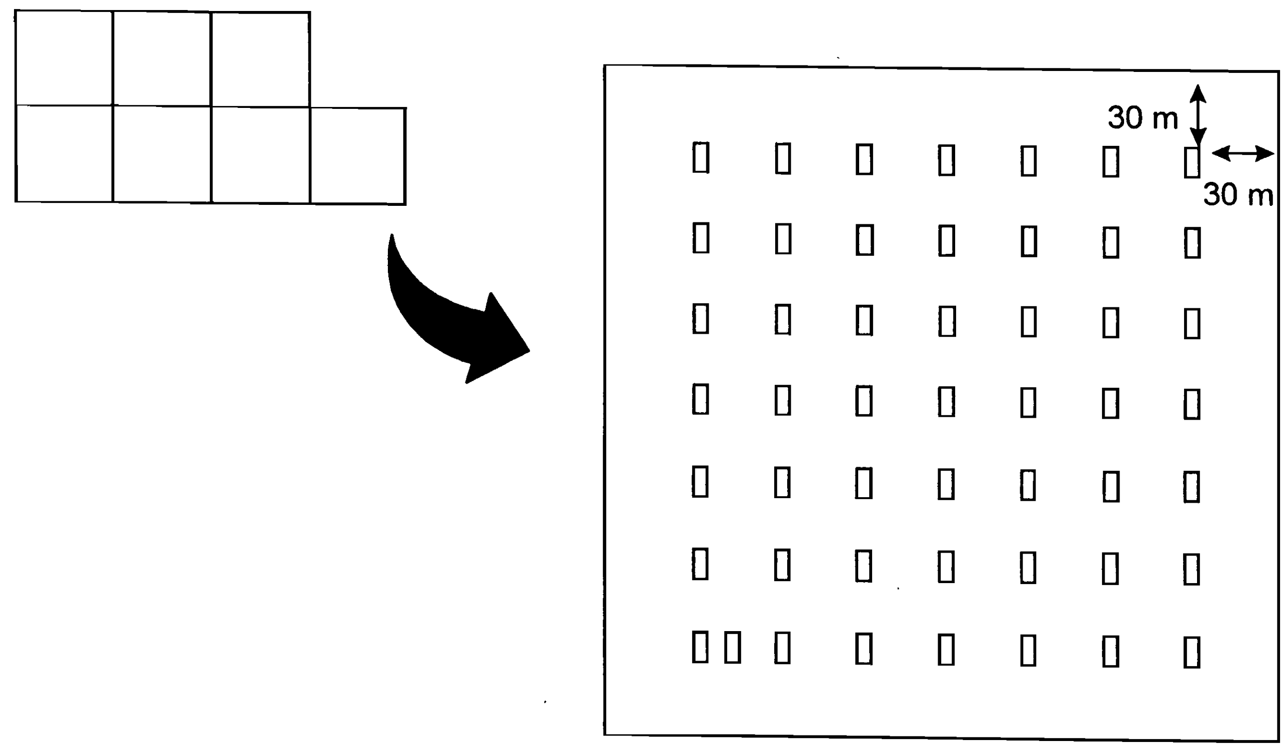

Figure 3.1. Grid placement of 50 coverboards on each treatment plot.

until we did not find any salamanders under any boards on consecutive sample dates. Because we did not want to disturb any potentially brooding female salamanders, we counted animals, recorded species and sex, and did not remove any salamanders from the sites for further data collection.

We began sampling in the morning on a randomly selected treatment plot, and checked all coverboards in that treatment before moving to the next treatment plot. We sampled all treatment plots in sequence to minimize travel time between treatments. In order to avoid any time of day sampling bias, we began sampling subsequent treatment plots at another randomly chosen plot (excluding previously chosen treatments), and all plots were sampled in the same sequence. We sampled coverboards at the Blacksburg site from April through July 1995.

We tested for among-treatment differences in the number of salamanders found under coverboards using a Kruskal-Wallis one-way layout (Minitab 1995). We compared relative abundance estimated from night sampling with boards to identify trends.

MICROHABITAT VARIABLES

We measured 6 microhabitat variables on each treatment plot in July and August 1995 after treatments were applied: soil moisture, soil temperature, leaf litter biomass, leaf litter moisture, leaf litter ground coverage, and canopy coverage. Our initial objective was to correlate salamander abundance and nutritional condition with these microhabitat variables, but because we lack replication, these variables are presented for descriptive purposes only.

We gravimetrically measured soil moisture by collecting soil samples using a 2 cm diameter tube soil sampling probe. We collected 24 samples from each treatment plot at a depth of 10 cm (3 per transect x 8 transects). Samples were collected in zip-lock type plastic bags, weighed the same day of collection, dried in an oven for 48 hours, and weighed again. Percent soil moisture was calculated as the difference between wet and dry mass divided by dry mass. Samples were pooled within treatments and the mean (± SE) was calculated for each treatment.

We measured soil temperature at 2.5 and 10 cm depth using a Taylor® soil thermometer. We collected temperatures 4 times during July and August of 1995. Each sample included 2 measurements at each depth on each transect. We averaged the 2 samples at each depth for each transect, pooled means at each depth for the 8 transects on each treatment, and calculated the mean (± SE) for each treatment at each depth.

We determined leaf litter biomass by collecting 40 leaf litter samples (5 per transect x 8 transects) from each treatment. We collected samples using a 0.25 m^2 PVC frame placed at 3 m intervals beginning at one end of each transect. All litter and woody debris (< 1 cm) were placed in zip-lock type plastic bags, weighed the same day of collection, dried in an oven for 48 hours, and weighed again. We recorded the mean (± SE) dry biomass (final dry weight) for comparisons between treatments.

We compared the leaf litter moisture and drying rate by collecting 10 litter samples per day (using methods described above) on each treatment for 3 consecutive days after a rain event. Samples were collected off of transects at randomly chosen locations on each treatment plot. Estimated rainfall the day before sampling was >2.5 cm based on the local weather report. We gravimetrically determined percent moisture for each sample for comparisons between treatments.

We measured leaf litter ground coverage by categorizing estimated percent coverage per 1 m^2 in each transect. We divided the 8 transects into 30 units using a 1 m^2 PVC frame. We categorized the estimated percent ground coverage using 0 - bare ground (< 5% coverage), 1 - 6-25% coverage, 2 - 26-50% coverage, 3 - 51-75% coverage, 4 - 76-95% coverage, and 5 - >95 % coverage. We pooled scores for transects within treatments and calculated the mean score for each treatment.

We measured canopy coverage of each treatment plot by using a 5-cm ocular tube with cross-hairs. The canopy above each transect was viewed through the tube and assigned a variable of 0 through 5 based on the presence of vegetation in the quadrants: 0 - no vegetation visible, 1-4 some vegetation visible in 1, 2, 3, or 4 quadrants, and 5 - no sky visible through any portion of the tube. We took readings at 1 meter intervals (total of 15 per transect) in each of the 8 transects on each treatment. We pooled scores for transects within treatments and calculated the mean score for each treatment.

NUTRITIONAL CONDITION

We used data collected from each captured animal to compare nutritional condition. We initially planned on using TW as an indicator of nutritional condition, but as reported in Chapter 1 results, we elected to use ratios of mass to SVL. We compared within-site condition of salamanders on preharvest and postharvest sample years by comparing means of mass-to-SVL ratios for red-backed salamanders (*Plethodon cinereus*) only. We combined data for salamanders captured from all transects in each Blacksburg plot and tested for preharvest and postharvest among-treatment differences in mass/SVL using a Kruskal-Wallis one-way layout (Minitab 1995).

RESULTS

SPECIES RICHNESS

Prior to timber harvest, we sampled the Blacksburg study site 8 times from April through October of 1994. We found 3 species on night transects at the Blacksburg site and 5 additional species off-transects (Table 3.1). We captured red-backed and white-spotted (*P. cylindraceus*) salamanders on all 7 treatment plots. Northern dusky salamanders (*Desmognathus fuscus*) were regularly seen in drainages on all treatment plots but were only caught during night transect sampling on those treatments that had transects passing near or through streams (4 of 7 treatment plots).

Table 3.1 Salamander species captured on Blacksburg 1 study site during preharvest (1994) and postharvest (1995) sampling (X). Asterisk (*) indicates species was observed on site but not captured during sampling.

		Preharvest (1994)	**Postharvest (1995)**
red-backed	*Plethodon cinereus*	X	X
white-spotted slimy	*P. cylindraceus*	X	X
northern dusky	*Desmognathus fuscus*	X	X
southern two-lined	*Eurycea cirrigera*	*	X
spring	*Gyrinophilus porphyriticus*	*	X
red-spotted newt	*Notophthalmus viridescens*	*	*
seal	*D. monticola*	*	
northern red	*Pseudotriton ruber*	*	

After timber harvest, we sampled the Blacksburg site 10 times during April through July 1995. We found 5 species on night transects and an additional 1 species off-transect (Table 3.1). We captured red-backed salamanders on transects on all 7 treatment plots and white-spotted slimy salamanders on all plots except the leave tree harvest. We captured 1 northern spring salamander (*Gyrinophilus porphyriticus*) and 2 southern two-lined salamanders (*Eurycea cirrigera*) on transects in the control plot. Northern dusky salamanders were observed in streams (4 of 7 treatment plots) but only 1 individual was caught during night sampling.

RELATIVE ABUNDANCE

Nighttime area-constrained searches. There was no significant difference in relative abundance of salamanders among treatments (all species combined) on the Blacksburg site (Table 3.2, n = 8, p = 0.949) prior to timber harvest. We captured 497 salamanders during 8 sample nights (mean density of 0.30 salamanders/m^2, Table 1 in Appendix (Table A1)). Mean number of salamanders observed on treatment plots ranged from 7.6 to 11.6 per transect (Figure 3.2). Red-backed salamanders accounted for 92 % of all captures.

There was a significant difference in among-treatment relative abundance of salamanders after timber harvest (Table 3.2, n = 10, p = 0.02). We captured 457 salamanders during 10 sample nights in 1995 (mean density of 0.22 salamanders/m^2, Table A2). We captured the most salamanders on the control, herbicide, and group selection treatments. The leavetree and shelterwood cuts

Table 3.2. Salamanders ($\bar{x}$ ±SE) captured per transect on each treatment per sampling period for preharvest (1994), postharvest (1995), and difference between each year.

	control	**herbicide**	**group selection**	**12-14 m^2 shelter.**	**4-7 m^2 shelter.**	**leavetree**	**clearcut**
1994	8.3 (2.2)	8.6 (1.8)	11.6 (3.2)	7.8 (1.7)	7.6 (1.7)	9.6 (2.8)	8.6 (2.0)
1995	9.5 (1.6)	8.9 (2.0)	8.6 (1.9)	5.0 (2.0)	3.7 (0.5)	3.7 (1.0)	6.3 (1.1)
change	+1.3	+0.3	-3.0	-2.8	-3.9	-5.9	-2.3

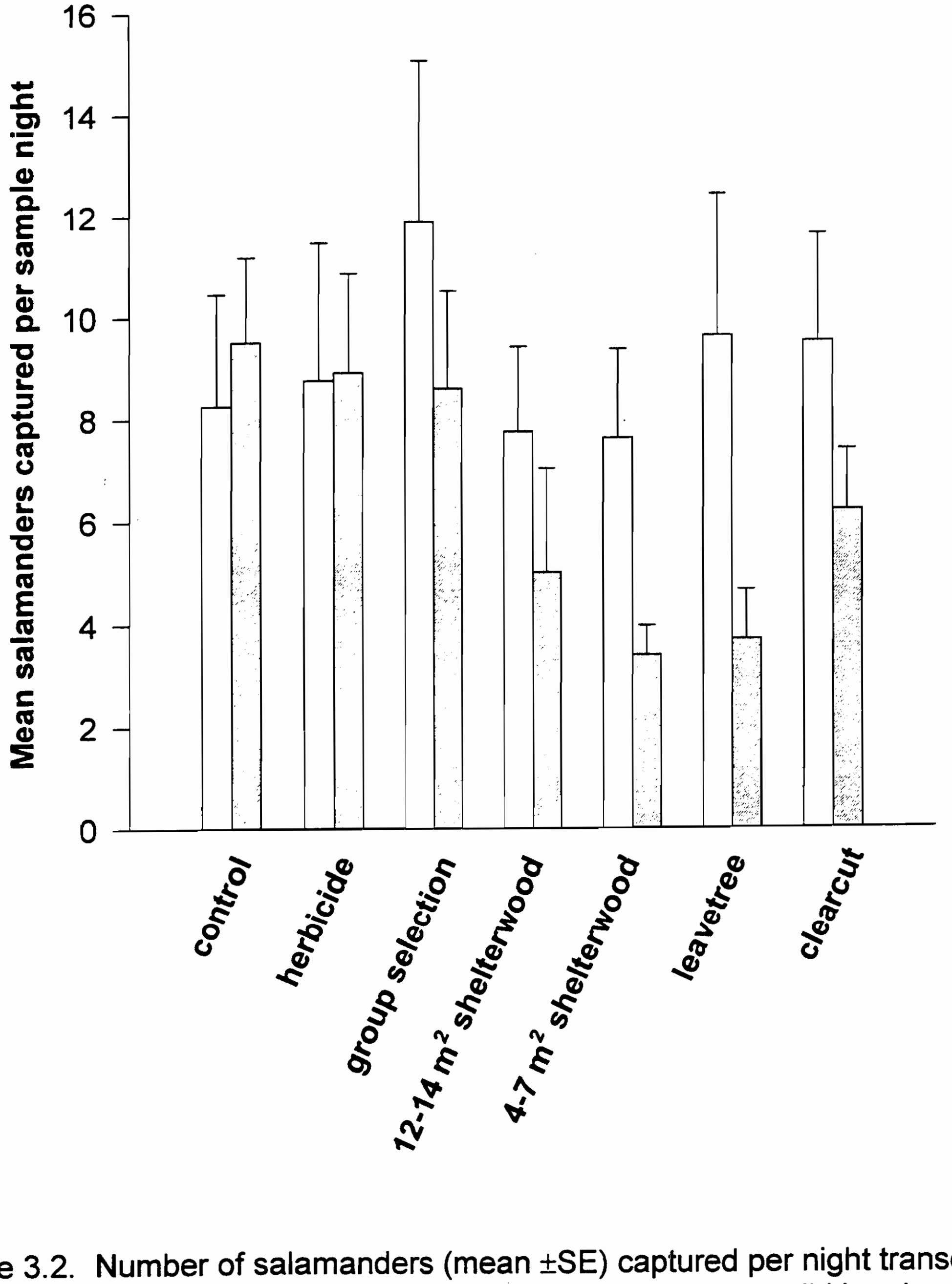

Figure 3.2. Number of salamanders (mean ±SE) captured per night transect during 1994 (preharvest, open bars) and 1995 (postharvest, solid bars). Treatment plots (x-axis) are arranged on all figures in increasing order of canopy removal (from left to right).

had the least number of captures. Mean number of salamanders observed on treatment plots ranged from 3.7 to 9.5 per transect (Figure 3.2). Red-backed salamanders accounted for 95.6% of all captures.

Relative abundance was lower after harvest on all treatments except for the control and herbicide plots (Figure 3.2). The control and herbicide plots had a slight increase in number of salamanders captured per transect after treatment.

Artificial cover objects. We sampled coverboards 10 times on the Blacksburg site during April through August 1995. Salamander use of coverboards was low on all treatment plots. The highest use on any sample date occurred on the herbicide understory treatment and consisted of 14 boards, each occupied by a single red-backed salamander, out of 50 coverboards (28%). There were no salamanders under coverboards on any treatment plot on 3 sample occasions (Table A3). When we eliminate the last 2 sample dates (no salamanders were found on any treatments), there was a significant difference in among-treatment salamander use of coverboards ($p = 0.029$, $H = 15.01$, $n = 8$). We found the highest coverboard use on the herbicide and control plots (Figure 3.3).

MICROHABITAT VARIABLES

Soil temperature at 2.5 and 10 cm was highest on treatments with the most canopy removed (clearcut, leavetree, 4-7 m^2 shelterwood, and group selection) (Figure 3.4). Percent soil moisture was highest on the clearcut and group selection (Figure 3.5).

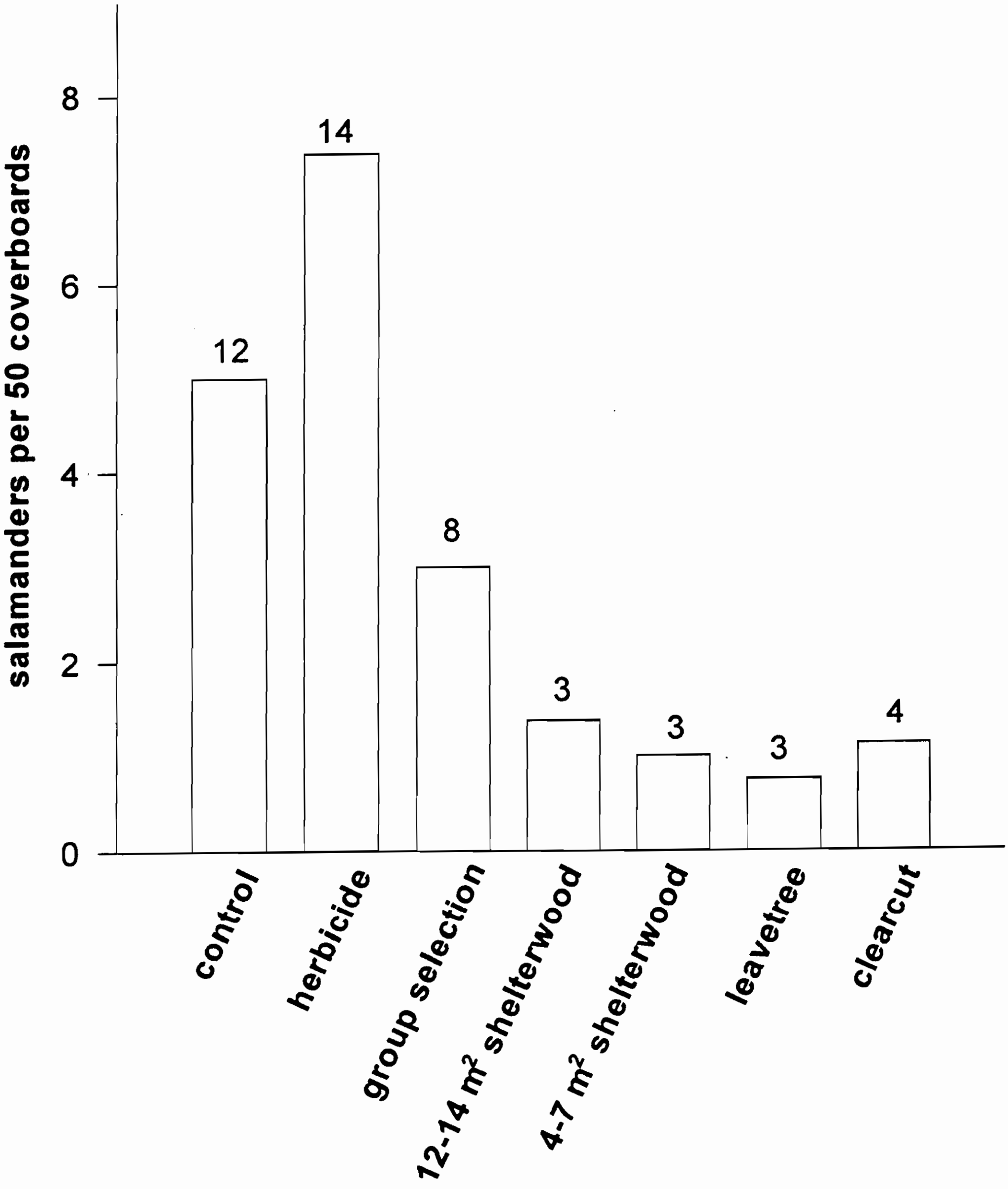

Figure 3.3 Mean (y-axis) and maximum (above bar) number of salamanders found per 50 coverboards during 1995 (postharvest).

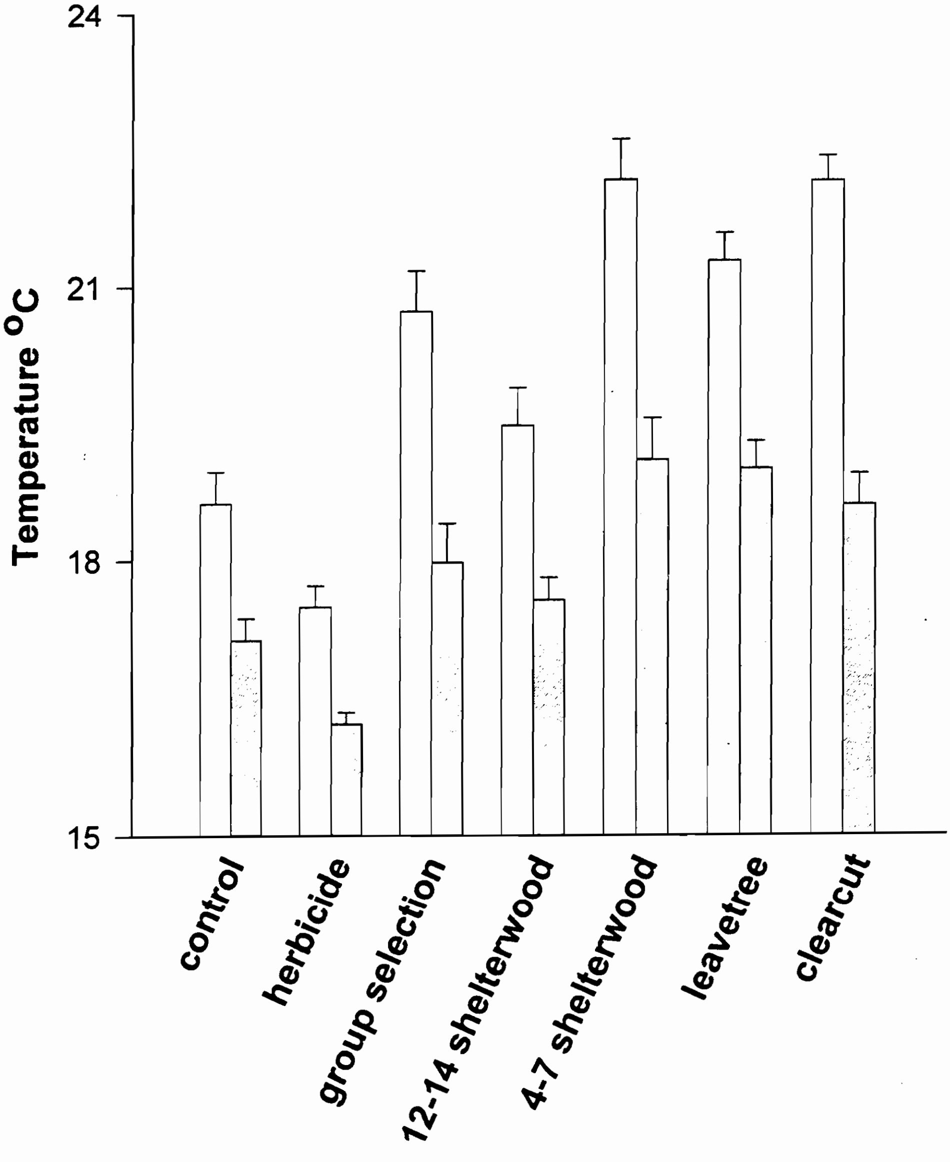

Figure 3.4. Soil temperature ($\bar{X} \pm SE$) at 2.5 cm (open bars) and 10 cm (hatched bars) in 1995 (postharvest) on Blacksburg study site.

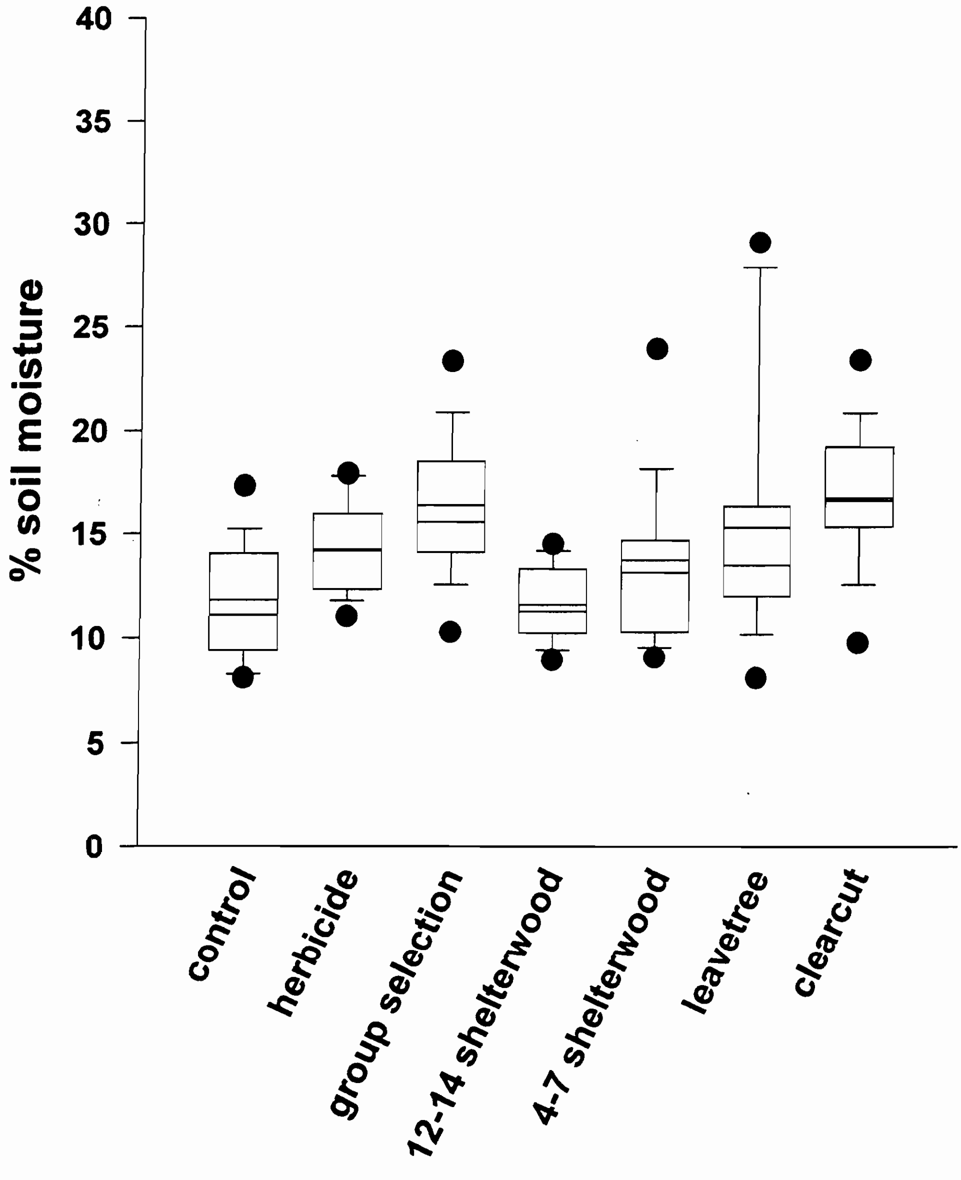

Figure 3.5. Percent soil moisture in 1995 (postharvest) on Blacksburg study site. Mean (heavy bar in box), median (light bar in box), 25th and 75th percentile (box), 10th and 90th percentile (bars outside box), and outliers (dots) for 8 transects sampled on each treatment plot.

Means of leaf litter biomass did not differ greatly among treatments, but variability was high on sites with the most trees removed (clearcut, leavetree, and 4-7 m^2 shelterwood) (Figure 3.6). Percent leaf litter moisture was highest on each of 3 consecutive days after rain on the control and herbicide plots (Figure 3.7). The clearcut, leavetree, and 4-7 m^2 shelterwood had the lowest percent litter moisture (Figure 3.7).

Litter coverage was highest on the control and herbicide treatments, and lowest on the clearcut (Table 3.3). Canopy coverage was greatest in the control and herbicide plots and corresponded directly with intensity of treatment (Table 3.3).

NUTRITIONAL CONDITION

There was no significant difference in ratios of mass/SVL among salamanders captured on each of the 7 treatment plots before harvest on the Blacksburg study site ($p = 0.876$, $H = 2.43$, $n = 7$) (Table 3.4). There was no significant difference in ratios of mass/SVL among treatments after harvest on the Blacksburg study site ($p = 0.7620$, $H = 3.36$, $n = 7$) (Table 3.4). No statistical analyses were performed to compare preharvest and postharvest nutritional condition.

DISCUSSION

Red-backed salamanders accounted for >95% of the total salamanders captured before and after harvest and were found on all treatment plots before and after harvest. White-spotted slimy salamanders were found on all plots

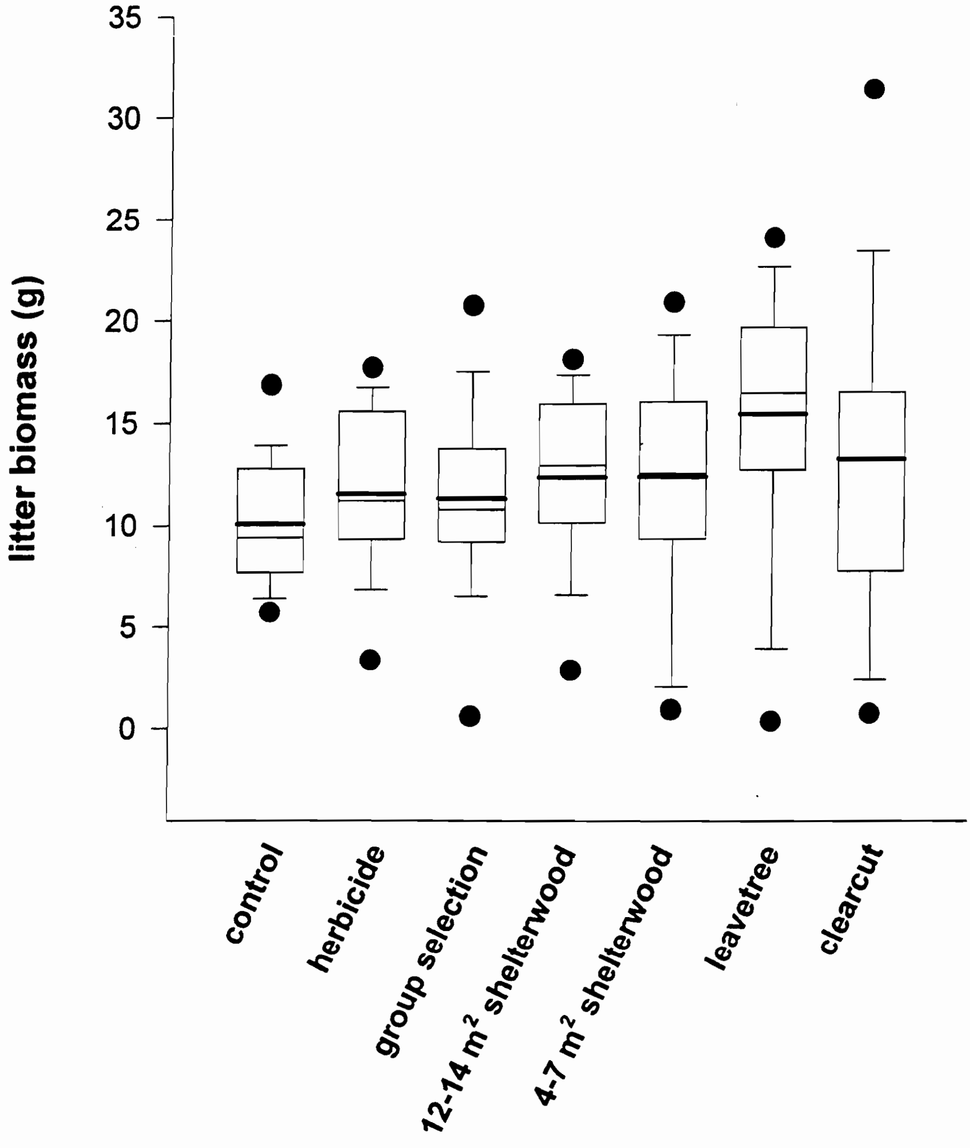

Figure 3.6. Range of leaf litter biomass in 1995 (postharvest) on Blacksburg study site. Mean (heavy bar in box), median (light bar in box), 25th and 75th percentile (box), 10th and 90th percentile (bars outside box), and outliers (dots) for 40 litter samples per treatment plot.

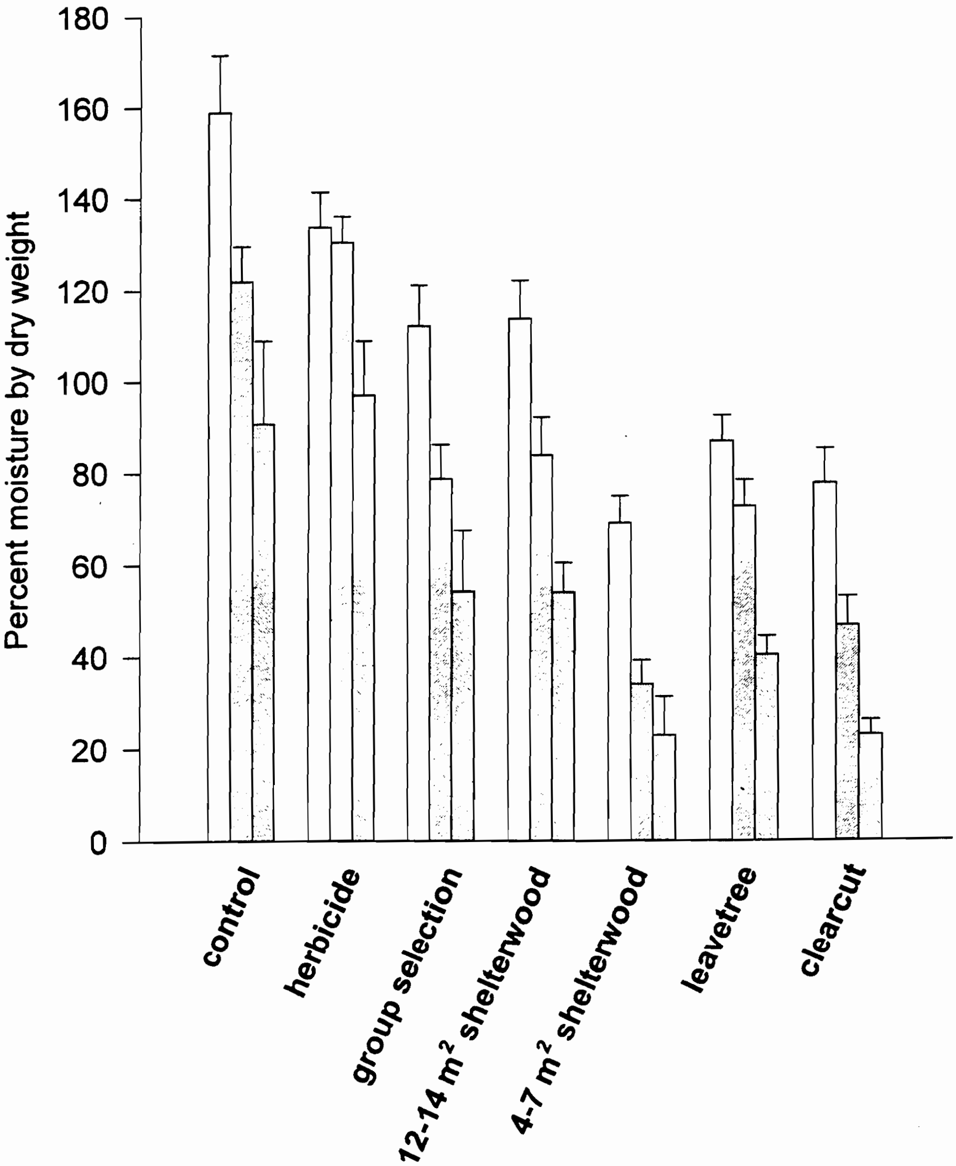

Figure 3.7. Percent moisture of leaf litter collected on 3 consecutive days after rain. Open bar collected 1 day after rain, cross-hatched bar collected 2 days after rain, stippled bar collected 3 days after rain (n=10 per treatment per day).

Table 3.3. Canopy coverage and leaf litter coverage in 1995 (postharvest). Data represent relative scores based on 0-5 ranking (mean (raw score)) for each variable.

Variable	control	herbicide	group selection	12-14 m^2 shelter.	4-7 m^2 shelter.	leavetree	clearcut
canopy coverage	4.5(534)	4.4(526)	2.1(254)	2.7(328)	1.6(196)	1.1(135)	0.46(55)
litter coverage	4.7(1126)	4.8(1148)	3.8(909)	4.1(977)	3.2(766)	3.2(762)	2.9(689)

Table 3.4. Among-treatment comparison of mass/SVL for adult red-backed salamanders captured during preharvest (1994) and postharvest (1995) sampling.

treatment	preharvest (1994)		postharvest (1995)	
	number captured	median mass/SVL	number captured	median mass/SVL
control	61	0.021	77	0.021
herbicide	56	0.021	75	0.020
group selection	74	0.020	77	0.020
12-14 m^2 shelter	49	0.021	45	0.020
4-7 m^2 shelter	55	0.019	31	0.018
leavetree	60	0.019	29	0.021
clearcut	65	0.021	59	0.019

before harvest but were absent from 2 treatments after harvest. Postharvest absence from 2 treatments may be due to changes in microclimate after canopy removal or simply because of high sampling variability and low sample size. We found too few (< 10) individuals of the other species during preharvest and postharvest sampling to identify any trends in presence or absence as a result of treatment effect. These less abundant species are regularly encountered in the area and breed in streams or ponds.

Red-backed salamanders are completely terrestrial and do not require streams for reproduction. Thus, distribution on the Blacksburg site was unrelated to water and there was no difference in relative abundance among treatment plots prior to timber harvest. Relative abundance decreased on the 5 Blacksburg treatment plots in which trees were harvested and increased slightly on the control and herbicide treatment. Understory vegetation decreased after herbicide treatment, but the canopy remained intact and the microhabitat conditions appear similar to the control plot.

Results from artificial coverboards follow the same trend as results from night transect sampling. More salamanders were found under coverboards on control and herbicide plots than plots with harvested trees. Artificial coverboards had limited effectiveness on the Blacksburg study sites. Boards dried out within a week after rainfall and were not occupied until sufficient rainfall to rewet them. Although coverboards have been used successfully in previous studies (DeGraaf and Yamasaki 1992, Fellers and Drost 1994), we averaged 16-24% occupancy

(8-12 out of 50) of our boards on unharvested sites during optimal sampling dates and no salamanders under boards during warm or dry periods. During no sampling period did we exceed 30% occupancy of our coverboards on unharvested plots. Coverboard use on harvested plots never exceeded 16%, averaged only 3% usage on the group selection plot, and averaged less than 3% usage on all other treatments. Following our sampling schedule (checking boards 2-3 days after rainfall every 2-3 weeks), we only found salamanders under boards on all treatment plots on 3 of 10 sample dates. On sites with greater rainfall, northern aspect, higher elevation, or lower temperatures the boards probably would have been more effective.

Removing the forest canopy through timber harvest increases evaporation of litter moisture and increases soil temperatures. Red-backed salamanders, like other ectotherms, show a direct correlation between basal metabolic rate and temperature. In addition, they are lungless and respire primarily through their moist skin. Surface activity is therefore restricted to cool, moist periods. Because their caloric requirements increase with increasing temperatures and they experience fewer foraging opportunities when their habitat becomes dry, terrestrial salamanders may have difficulty maintaining a positive energy balance on sites that have been harvested.

Preliminary results from Chapter 1 indicated that mass to SVL ratios could indicate variability in nutritional condition. However, we found no significant difference in mass/SVL among treatment plots before or after timber harvest.

This may be attributed to our low sample size. After treatments were applied, we were unable to find many adult salamanders on harvested plots. It is also possible that because we sampled salamanders during the first season after timber harvest, no effects of increased temperature and reduced foraging opportunities were apparent in our condition index. Salamanders may not have experienced any decrease in condition because they had not been subjected to stress long enough for changes to be apparent. Analysis of data from 1996 sampling may reveal different results. It is also possible that mass to SVL is not a good predictor of condition because of high individual variability.

Many studies have shown that terrestrial salamander populations do not decline until 2-5 years after harvesting (see review by deMaynadier and Hunter 1995). However, the dramatic declines in salamander numbers between 1994 and 1995 in those plots that experienced canopy disturbance compared to almost no change or slight increases in those plots with intact canopy strongly indicate that these changes occurred in response to the silvicultural treatments.

The effects of the 7 silvicultural treatments may not be fully manifested on salamander populations for several years. Most plethodontid salamanders are long-lived (up to 10 years) and reproduce every 2 years (Duellman and Trueb 1986, Hairston 1987). An accurate assessment of the effects of silvicultural treatments requires sampling populations over several reproductive seasons.

Pough et al. (1987) found no significant difference in the number of red-backed salamanders in a 60-year-old second growth forest and an adjacent old-growth forest and determined that the depth of leaf litter was the best predictor of above-ground salamander abundance. Likens et al. (1978) found that about 65 years are required to rebuild organic matter in the forest floor to preclearcut harvest levels. If forest floor recovery time is shorter in harvests that remove less of the canopy, salamander populations may be able to persist or recover faster under these regeneration methods relative to clearcuts. However, if even slight canopy disturbance has strong negative effects on salamander populations, then forests managed by clearcutting may maintain larger populations of salamanders, because a smaller area is disturbed in any given year to obtain the same volume of wood.

Removing only a portion of the forest canopy (e.g. shelterwood and group selection harvests) creates microclimate conditions that are cooler and retain more surface moisture than clearcuts. Soil temperatures at 2.5 cm were lower on treatment plots with more canopy cover retained. Soil temperatures at 10 cm followed a similar trend as 2.5 cm measurements but were less variable.

There was no consistent pattern in percent soil moisture content among treatments. Evapotranspiration is higher on unharvested sites resulting in lower soil moisture. At the same time, the water table typically rises on clearcut sites, resulting in higher soil moisture content. Figure 3.5 compares soil moisture on the 7 treatment plots in order of increasing canopy removal. The relatively high percent soil moisture on the herbicide and group selection treatments may be due to streams that transect the plots. The relatively low soil moisture on the 12-

14 m^2 shelterwood plot may be because it was the only plot without any streams present. In addition, whereas the initial treatment specified a basal area retention of 12-14 m^2 per hectare, the actual treatment retained approximately 15 m^2 per hectare. The retention of additional basal area resulted in final greater canopy coverage than intended. This may explain why the 12-14 m^2 shelterwood microclimate variables are not consistent with the expected trend of sites with less canopy coverage (more timber removed) to have more soil moisture, higher soil temperatures, and more litter moisture.

Although the difference in the mean leaf litter biomass was not large among treatments, the variability increased with increasing canopy removal. This is probably because of greater disturbance on harvested sites from the mechanical removal of timber. Leaf litter coverage follows a similar trend. Sites with most disturbance (greater canopy removal) had the lowest values. Higher variability in leaf litter biomass and lower values in leaf litter coverage would indicate more bare ground within the treatment plot.

Leaf litter moisture was lowest on each of the 3 consecutive days after rain on the treatment plots with the most canopy removed (4-7 m^2 shelterwood, leavetree, and clearcut). Leaf litter on these plots dried out much faster (as a percentage of total moisture) without the protective canopy cover. On sites with more canopy cover, salamanders will have more foraging opportunities because the leaf litter retains more moisture for several days after rain.

A qualitative comparison of the relative change in salamander abundance and the microhabitat variables corresponds with the prediction that salamander populations would remain stable on plots that maintained cool, moist habitat (Table 3.5). The control and herbicide plots were the only treatments to maintain the same relative abundance 1 year after harvest. Relative to other treatments, the control and herbicide plots had cooler soil temperatures, lower variability in leaf litter biomass, higher retention of moisture by leaf litter, higher leaf litter ground coverage, and greater canopy coverage.

Treatments that remove less canopy might be habitable by salamanders sooner after harvest than clearcuts because of the cumulative effect of regenerating young trees and the initial retention of part of the canopy. However, if partial harvests occur on a rotation schedule that is shorter than the time it takes salamanders to repopulate the harvested site (e.g. 5-15 years), harvesting the remaining trees may again reduce populations and increase the time required for salamander populations to return to preharvest levels.

Timber harvests that reduce salamander densities can potentially alter the genetic composition of local populations (Stiven and Bruce 1988). This may be problematic for species with limited distributions such as the Peaks of Otter (*Plethodon hubrichti*) or Red Hills salamander (*Phaeognathus hubrichti*), both of which are sensitive to timber harvesting (Kramer et. al 1993, Dodd 1991). Most of the southern Appalachians were clearcut around the turn of the century, yet salamander biomass, density and diversity in the region are among the highest

Table 3.5. Qualitative comparison between postharvest change in salamander abundance and microhabitat variables. Comparisons are ranked low, medium (med), and high relative to each other for each treatment.

	control	herbicide	group selection	12-14 m^2 shelter.	4-7 m^2 shelter.	leavetree	clearcut
soil temp:							
2.5cm	low	low	high	med	high	high	high
10 cm	low	low	med	low	high	high	high
soil moisture	low	med	high	low	med	high	high
leaf litter variability	low	low	med	low	med	high	high
leaf litter moisture	high	high	med	med	low	low	low
leaf litter coverage	high	high	med	med	low	low	low
canopy coverage	high	high	med	med	low	low	low
postharvest Δ in salamander abundance	low	low	high	high	high	high	high

in the world. Some evidence suggests that salamander density and diversity are greater in old-growth areas of the southern Appalachians (Petranka et al. 1994). We know little about salamander communities prior to European expansion into North America. Current densities and richness may be higher or lower than predisturbance levels because of changes in the forest structure and processes. An understanding of the effects of silvicultural practices on terrestrial salamander richness and abundance will require long-term monitoring of salamander communities.

We are currently continuing to sample the 5 sites discussed in this study and they are scheduled for harvesting during 1996-97. In addition, several other sites have been identified and scheduled for sampling and harvesting during 1996-98. Replication of this study design and long-term data collection at the study sites will enable us to assess the effects of the different silvicultural practices on terrestrial salamander species richness and abundance.

CONCLUSIONS

The primary goal of this experiment was to compare the effects over time of 7 silvicultural alternatives on terrestrial salamanders. Long-term data on salamander populations are relatively rare and are essential for effective management (Heyer et al. 1994). In addition, few studies have compared the effects of different forest management practices on salamander populations and few studies have both pre- and postharvest data from the same location. This study is unique because we have baseline data on all sites, we randomly assigned treatments to plots, we have been able to compare multiple salamander sampling techniques, we will monitor salamander populations over several generations, and we will have replicates with control plots in several physiographic provinces in the southern Appalachians.

Our preliminary results indicate that terrestrial salamander populations decrease after even partial removal of the forest canopy. This differs from several other studies that show salamander populations persisting for 2-5 years after harvest. We attribute the relatively rapid decline in salamander abundance on our study site to the location. All of our study sites are low elevation south-facing slopes (with medium to low timber site quality indices) which are relatively warm and dry compared to high elevation and/or northern exposures. Most hardwood forests in the mountains of Virginia are medium to low quality sites ($SI_{50} < 70$) (D. Wm. Smith, pers. commun.). Because low quality timber sales make up a significant portion of timber sales in Virginia and will continue to be harvested in the near future, more information on their effects on terrestrial salamanders is important to effectively manage populations.

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Table A1. Total salamanders captured per transect during preharvest sampling (1994) on Blacksburg study site.

sample date	control	herbicide	group selection	12-14 m^2 shelter.	4-7 m^2 shelter.	leavetree	clearcut	total
940410	20	14	26	12	10	22	14	118
940504	10	10	16	10	11	9	13	79
940507	8	7	14	7	9	14	8	67
940616	0	0	4	3	0	0	4	11
940627	2	1	0	6	3	2	3	17
940721	8	4	1	0	3	3	8	27
941014	6	24	17	14	13	9	2	85
941015	12	9	15	10	12	18	17	93
total	66	69	93	62	61	77	69	497

Table A2. Total salamanders captured per transect during postharvest sampling (1995) on Blacksburg study site.

Sample date	control	herbicide	group selection	12-14 m^2 shelter.	4-7 m^2 shelter.	leavetree	clearcut	total
950423	5	0	1	0	6	1	1	14
950430	7	8	11	5	6	7	9	53
950504	20	22	15	6	5	6	7	81
950510	13	14	18	22	3	9	13	92
950513	13	9	15	6	6	4	3	56
950527	9	11	6	2	2	3	4	37
950528	10	8	4	4	4	1	7	38
950602	4	5	9	5	2	1	9	35
950610	2	10	6	0	2	0	7	27
950702	12	2	1	0	1	5	3	24
total	95	89	86	50	37	37	63	457

Table A3. Total salamanders found under 50 coverboards per plot on Blacksburg study site during 1995.

Sampling date	control	herbicide	group selection	12-14 m^2 shelter.	4-7 m^2 shelter.	leavetree	clearcut
950425	12	12	8	3	3	3	4
950509	2	1	0	0	0	0	0
950512	8	11	5	2	2	1	2
950518	2	14	1	2	3	1	2
950531	10	12	8	3	0	0	1
950610	2	6	0	0	0	0	0
950518	0	0	0	0	0	0	0
950705	4	3	2	1	0	1	0
950721	0	0	0	0	0	0	0
950818	0	0	0	0	0	0	0
Total	40	59	24	11	8	6	9

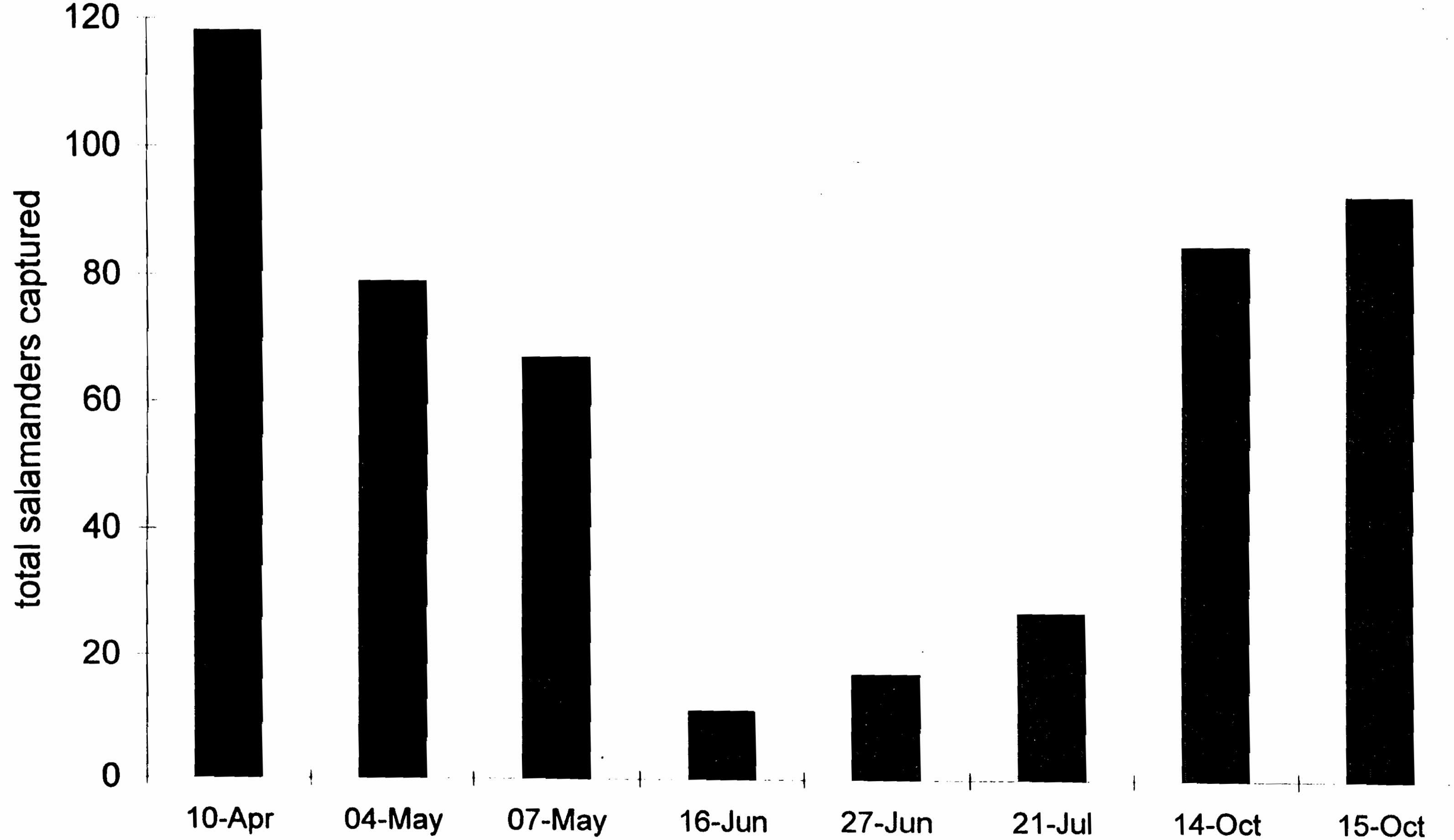

Figure A1. Total salamanders captured on Blacksburg treatment plots for each night sampled in 1994.

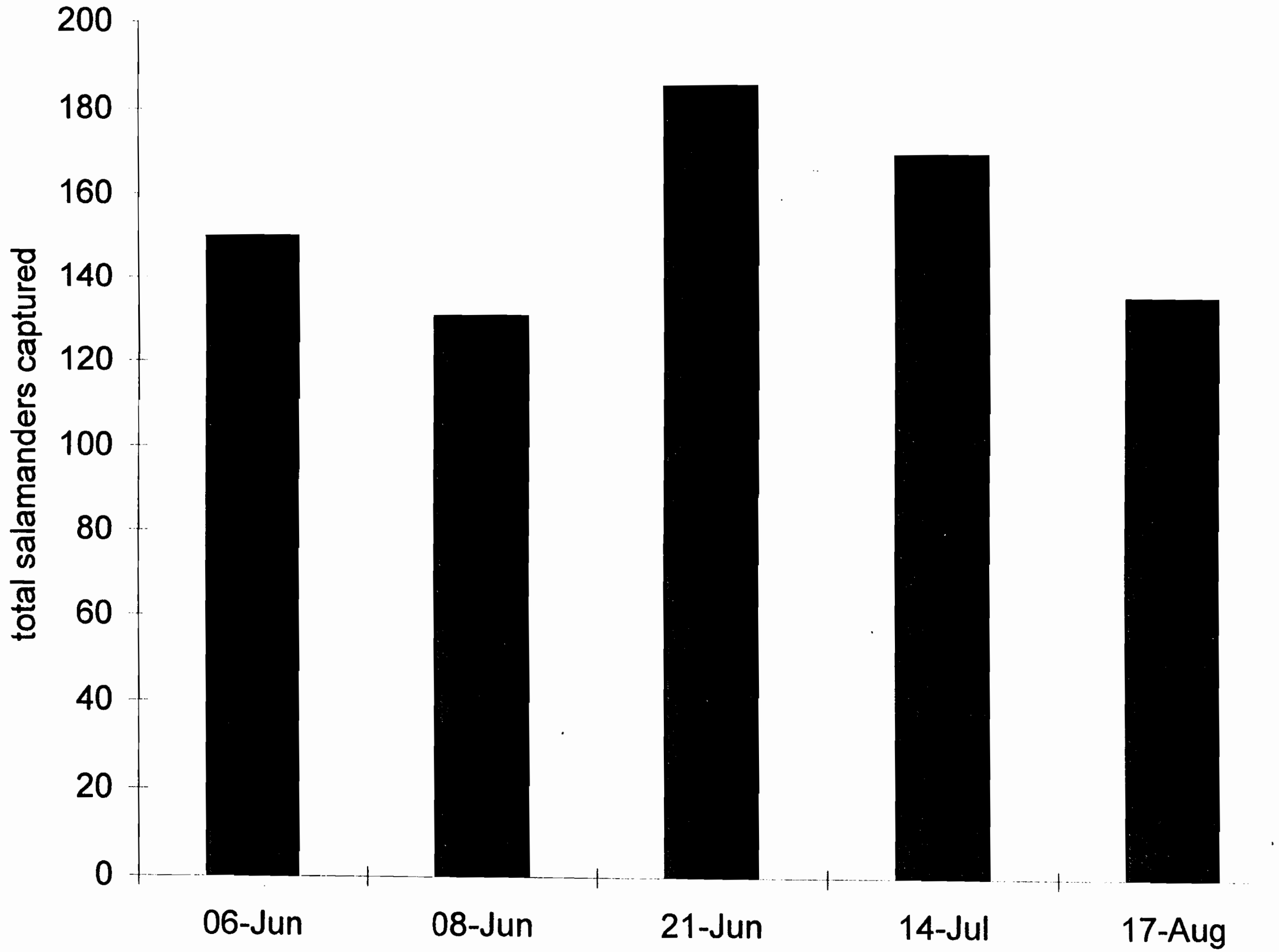

Figure A2. Total salamanders captured on Clinch 1 treatment plots for each night sampled in 1994.

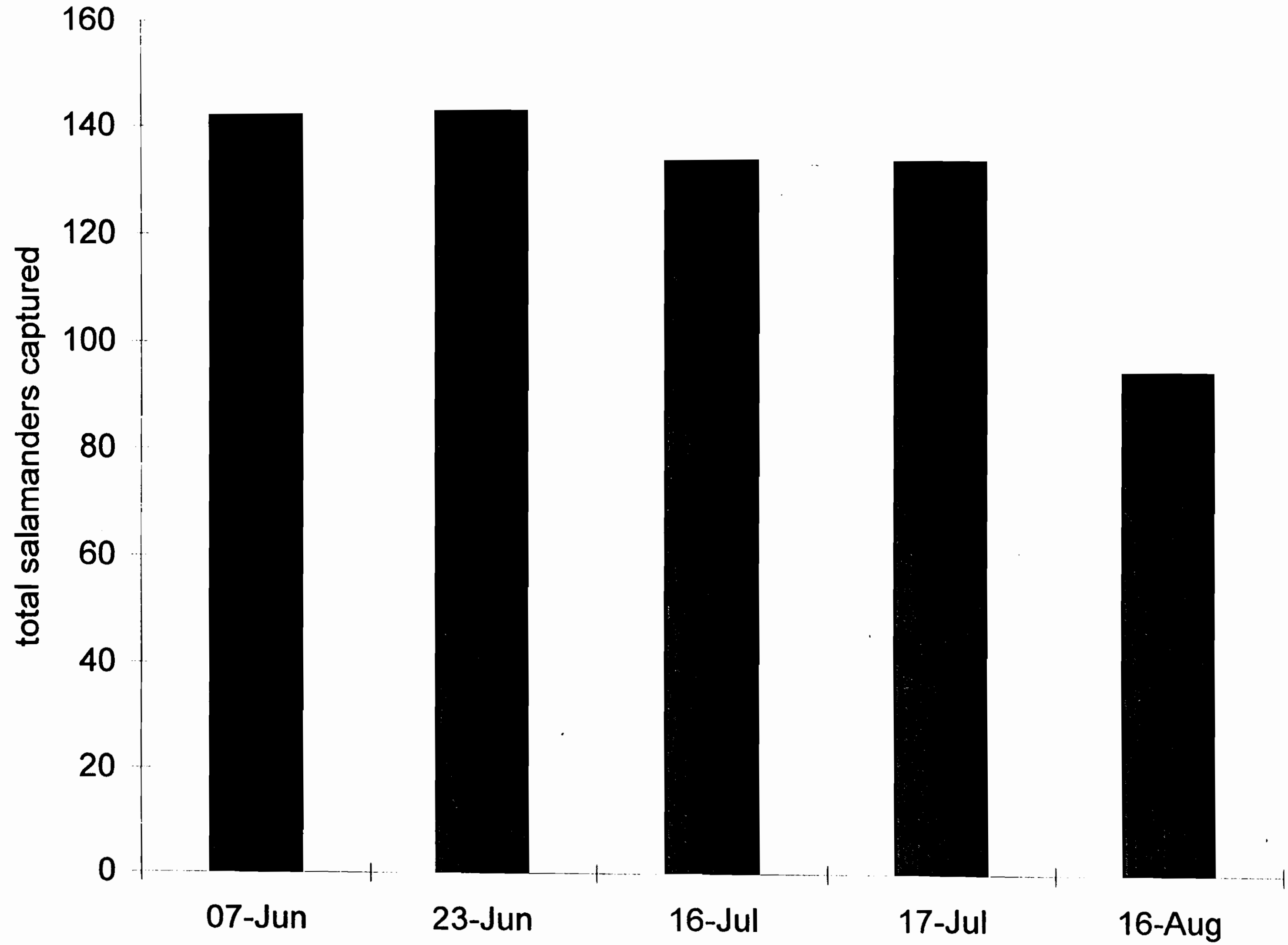

Figure A3. Total salamanders captured on Clinch 2 treatment plots for each night sampled in 1994.

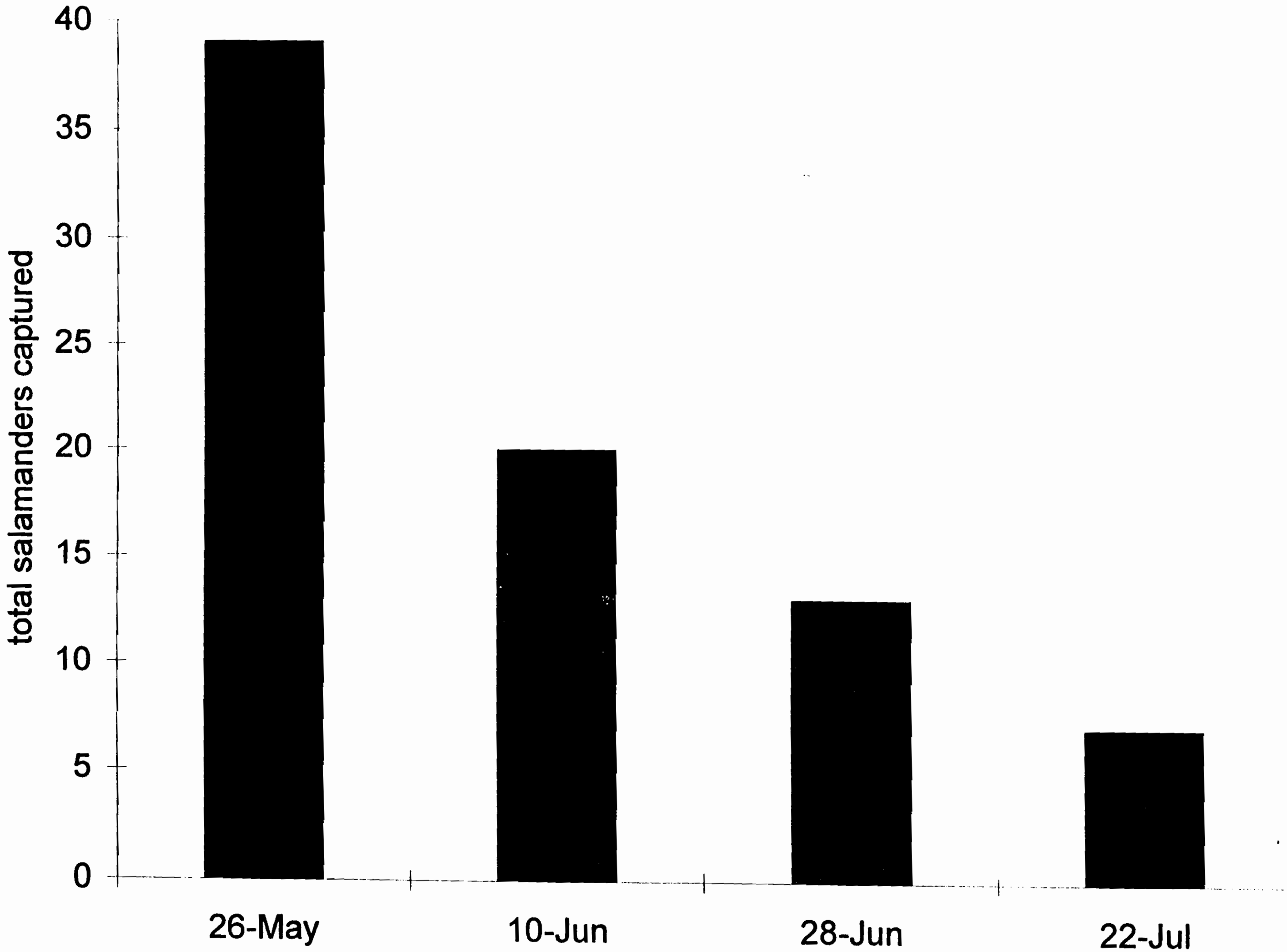

Figure A4. Total salamanders captured on Wythe treatment plots for each night sampled in 1994.

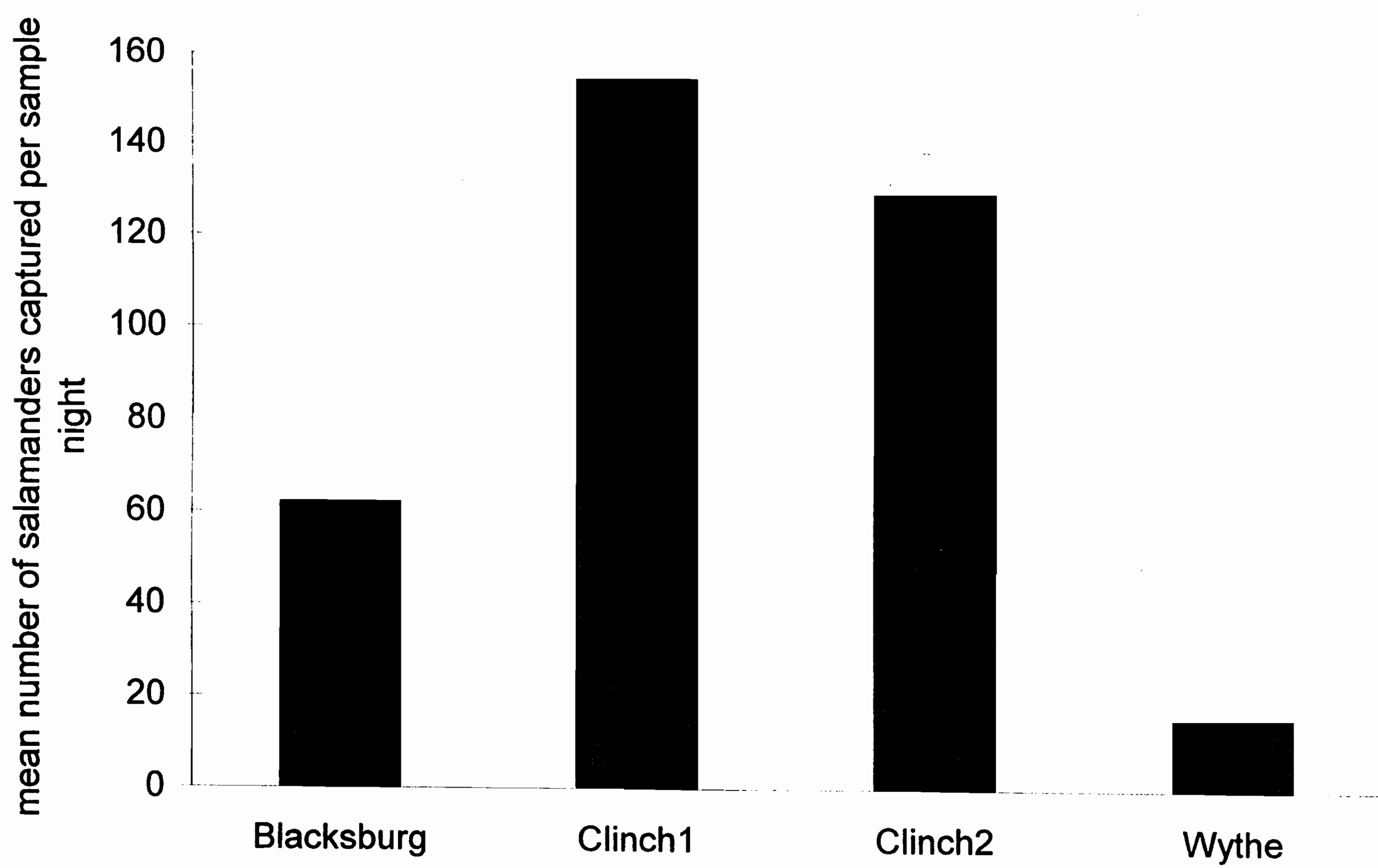

Figure A5. Mean number of salamanders captured (all treatment plots combined) per sample night on Blacksburg (8 sample nights), Clinch 1 (5 nights), Clinch 2 (5 nights), and Wythe (4 nights) study sites, 1994.

VITA

Douglas N. Harpole was born in Shreveport, Louisiana and grew up in Houston, Texas. In 1980, Doug received an Associate's Degree in Plant Operations from Texas State Technical College in Waco, Texas. After working for 12 years in hospital engineering for several hospitals in the Houston area, he returned to college and received a BS in Wildlife Ecology from Texas A&M University in 1993. In 1996, Doug completed his MS in Wildlife Science in the Department of Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University. Doug is married to Susan Harpole and has 2 daughters, Ashley and Natalie.