Relative Abundance and Species Richness of Herpetofauna in Forest Stands in Pennsylvania

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ABSTRACT. The relative abundance and species richness of herpetofauna was investigated to assess the impact of recent logging operations in 47 forest stands in northeastern Pennsylvania during 1996 and 1997. Stands including nonindustrial private forestlands and public lands that have received some type of harvesting within the last 8 yr ranged from near complete overstory tree cover to complete removal of overstory cover. Stands included the two dominant forest types in the region: northern hardwood (*Betula, Fagus, Prunus, Acer,* and *Tsuga* spp.) and oak-hickory (*Quercus* and *Carya* spp.). A total of 8,181 individuals of 26 species (12 salamander, 7 snake, 6 frog, and 1 toad species) were observed in the study stands. The relative abundance and species richness of salamanders increased significantly with increasing retention of tree basal area. Forest stands containing > 15 m^2/ha live tree basal area appeared to be a threshold level for high salamander abundance. Snake species abundance and richness increased significantly with increasing removal of tree basal area. The abundance of anuran species showed no significant relationship with amount of tree basal area removal, but the relative abundance and species richness of anurans depended on the presence of water within or bordering the stands. Forest type did not change the overall response of herpetofauna community composition to forest harvesting, although salamanders were more abundant in northern hardwood stands, and snakes were more abundant in oak-hickory stands. Patterns and threshold levels of abundance and species richness of herpetofauna determined in this study may be used to maintain the abundance and richness of selected species when harvesting forest stands. For. Sci. 46(1):139–146.

Additional Key Words: Logging, nonindustrial private forests, conservation.

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REPTILES AND AMPHIBIANS (HERPETOFAUNA) represent important components of ecosystems in terms of biomass and food webs (Burton and Likens 1975, Pough et al. 1987, Hairston 1987). In addition, biomass of herpetofauna often exceeds that of mammals and birds (Burton and Likens 1975), indicating their relative importance in food chains. Worldwide, many types of amphibians appear to be in decline (Blaustein and Wake 1990, Wyman 1990, Dunson et al. 1992), and populations of several amphibian and reptile species in Pennsylvania are threatened, mostly due to habitat loss (Shaffer and McCoy 1991, Thorne et al. 1995).

Compared to other vertebrate wildlife, most herpetofauna have small home ranges (Hairston 1987, Corn and Bury 1989). Other herpetofauna such as the Ambysotmid salamanders may travel outside of their home ranges in search of vernal and autumnal pools or ponds for breeding (Shafer and McCoy 1991). These characteristics make amphibians susceptible to habitat alterations caused by forest harvesting. Reptile species may benefit from, or at least be unaffected by, forest harvesting (Enge and Marion 1986). Conversely, amphibian species may be negatively affected by the opening of the forest canopy and drying of the forest floor created by forest harvesting, as they require moist forest floor conditions associated with closed forest canopies (Shafer and McCoy 1991). In a review of 18 studies of amphibian responses to clearcutting, de Maynadier and Hunter (1995) found a 3.5-fold higher median abundance of amphibians in control stands compared to recently clearcut stands.

Abundance of amphibians may be affected by forest type as much as harvesting intensity (Bennett et al. 1980). Oak-hickory forests tend to be associated with dry, sandy soils compared to northern hardwood forests which are characterized by a rich, moist layer of topsoil. This layer of topsoil in northern hardwood forests provides a moister environment for amphibians than the forest floor conditions located within oak-hickory forests.

In addition to the removal of tree basal area, different forest harvesting practices may alter habitat conditions, such as the amount of woody debris, exposed rock, litter cover, and water. In Pennsylvania forests, 19 species of salamanders and 26 species of reptiles use logs, stumps, bark, and slash piles (Hassinger 1989). Rocks and leaf litter also serve as important cover for many herpetofauna species (Shaffer and McCoy 1991). Sources of water are also important breeding habitat for frogs, toads, and many species of salamanders.

We surveyed herpetofauna over a 2 yr period in forested stands in northeastern Pennsylvania to determine if the abundance and species richness of amphibian species (salamanders, frogs, and toads) would decrease, while snake species would increase, with decreases in tree basal area in 47 forest stands in northeastern Pennsylvania. In addition, we measured forest stand characteristics to determine if stands with higher amounts of woody debris, rock cover, litter cover, and temporary and permanent water contained a higher abundance and richness of herpetofauna.

Methods

Study Sites

In Pennsylvania, 75% of commercial forestlands are categorized as nonindustrial private forests (NIPF) with an average size of only 15.2 ha and average ownership period of approximately 10 yr (Widmann 1995). Our study stands were located in five counties in northeastern Pennsylvania (centered around Lat. 41°25', Long. 75°25'): Monroe, Pike, Susquehanna, Wayne, and Wyoming. This area lies within the glaciated low plateau and glaciated Pocono Plateau sections of the Allegheny Plateau Physiographic province. Elevations range from 110–895 m. Rainfall averages 110 cm/yr. Soils were derived from sandstone and siltstone.

We selected stands based on forest type, ownership, and harvest method and intensity to incorporate the variation in habitat characteristics that exist within the first 10 yr following logging in northeastern Pennsylvania. Stands represented the two major forest types in northeastern Pennsylvania, oak-hickory (n = 21) and northern hardwoods (n = 26). We selected 47 stands owned by NIPF landowners willing to cooperate with our project (n = 38), The Pennsylvania Bureau of Forestry (n = 5), The Pennsylvania Game Commission (n = 2), and The Nature Conservancy (n = 2). Stand sizes ranged from 10–12 ha. Thirty-four stands were logged 2–10 yr before initiation of the research, while 13 stands had not been harvested for over 70 yr. To incorporate the variation of stand conditions and harvesting practices used in northeastern Pennsylvania, we selected 5 clearcut stands, 2 diameter-limit cuts, and 27 stands that received some type of selection harvest. Habitat characteristics varied among stands as follows: live tree basal area ranged from 0.5–38.8 m^2/ha, conifer basal area ranged from 0.0–12.3 m^2/ha, shrub cover (1–3m tall) ranged from 0–45%, volume of woody debris (> 5 cm diameter) ranged from 7.4–110.1 m^3/ha, slash cover (≤ 5cm diameter) ranged from 0–45%, leaf litter cover ranged from 25–98%, and percent total ground cover (< 1 m tall) ranged from 21–95%.

Dominant tree species in oak-hickory stands were oak (*Quercus* spp.), hickories (*Carya* spp.), sassafras (*Sassafras albidum* [Nutt.] Nees), dogwood (*Cornus florida* L.), and pitch pine (*Pinus rigida* Mill.). Northern hardwood forest stands were composed of basswood (*Tilia americana* L.), sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), and yellow birch (*Betula alleghaniensis* Britton). Red maple (*Acer rubrum* L.), white pine (*Pinus strobus* L.), black birch (*Betula lenta* L.), and downy serviceberry (*Amelanchier arborea* [Michx. f.] Fern.) occurred in both forest types (Fredericksen 1998, Fredericksen 1999). Northern hardwood stands contained a greater amount of conifers than oak-hickory stands primarily due to the presence of eastern hemlock (Table 1). Similarly, snag basal area was higher in northern hardwood stands due to recent outbreaks of forest tent caterpillar (*Malacosoma disstria*). Shrub and ground vegetation of oak-hickory stands was dominated by blueberry (*Vaccinium* spp.) and mountain laurel (*Kalmia latifolia* L.) (Table 1). Fern species were the

Table 1. Pearson's correlations (*r*) and significance level (*P*) between tree basal area and forest type and habitat characteristics in 47 forested stands in northeastern Pennsylvania during 1996 and 1997.

Habitat characteristics	Tree basal area (*r*)	Tree basal area (*P*)	Forest type (*r*)	Forest type (*P*)
Conifer basal area	0.34	0.02	–0.46	0.001
Snag basal area	0.57	<0.001	–0.23	0.12
Shrub cover	–0.50	<0.001	0.30	0.04
Ground cover	–0.62	<0.001	–0.17	0.26
Fern cover	0.12	0.42	–0.47	0.001
Rubus species cover	–0.30	0.04	–0.54	<0.001
Blueberry cover	–0.25	0.09	0.70	<0.001
Woody debris	0.12	0.44	–0.31	0.04
Slash cover	–0.43	0.002	–0.23	0.13
Rock cover	0.03	0.83	0.18	0.22
Leaf litter cover	0.36	0.01	0.35	0.02
Permanent water	0.42	0.004	–0.42	0.004
Temporary water	0.34	0.02	–0.43	0.003

most abundant plants in the understory of northern hardwood stands with high amounts of tree basal area, while blackberry and raspberry (*Rubus* spp.) cover was associated with most northern hardwood stands with low amounts of tree basal area (Table 1). Temporary and permanent water was most prevalent in northern hardwood stands containing a high amount of residual, tree basal area.

Sampling stands from such a range of variation in forest type, ownership, and harvest method and intensity makes it easier to generalize these results across many stands, although precision may be low for any particular stand type. Thus, we conducted a 2 yr, retrospective analysis of the relative abundance and species richness of herpetofauna associated with different amounts of tree basal area, woody debris, ground cover, exposed rock, litter, and residual water sources resulting from differing harvesting intensities.

Sampling of Herpetofauna

We used time-constrained, area searches to survey 7 of the 21 oak–hickory sites during both 1996 and 1997, 5 stands only during 1996, and 9 stands only during 1997. We used time-constrained, area searches to sample 6 of the 26 northern hardwood stands during both 1996 and 1997, 15 stands only during 1996, and 5 stands only during 1997. The stands surveyed only in 1997 were unavailable for research at the time of the 1996 surveys and were added to the study to allow us to generalize our results over a larger portion of northeastern Pennsylvania and across a wider range of stand conditions following timber harvesting. Two separate time-constrained, area searches were conducted in each of 33 stands during 1996, the first occurring during July or August, and the second occurring during September. During 1997 we conducted two separate time-constrained, area searches in each of 27 stands, the first occurring during July or before 14 August, and the second occurring between 15 August and 12 September. Each time-constrained, area search consisted of four person-hours of systematic searching of possible cover items for herpetofauna and included the entire 10–12 ha forest stand. Investigation of cover items included examining the forest litter, under rocks, logs, and loose bark, in temporary pools, streams, and seeps, and the edges of permanent water sources.

To eliminate observer bias during the surveys, at least one of the two lead investigators for the project conducted each survey with the assistance of a combination of six wildlife technicians. Lead investigators trained the technicians in identification of herpetofauna, cover for herpetofauna, and the methodology of the project, and evaluated each technician on survey techniques before conducting any of the surveys. Researchers recorded the number of individuals by species for all herpetofauna encountered during the time-constrained, area surveys.

Sampling of Habitat Characteristics

We measured habitat characteristics during 1996 and 1997 for use in correlation analysis with the relative abundance and species richness of herpetofauna. Measurements of stand characteristics were based on methods developed by Harvey and Finley (1995). Habitat characteristics included coniferous, snag, and all live tree basal area (m^2/ha), percent shrub cover (1–3 m tall), volume of woody debris (> 5 cm diameter), percent slash cover (≤ 5 cm diameter), percent leaf litter cover, percent exposed rock, percent total ground cover (< 1 m tall), and the percentage of common dominant understory plant cover including fern, blueberry, and blackberry–raspberry. Basal area was sampled at 20 points located throughout the stand using a systematic sampling design so that all parts of the stand were represented equally. Basal area sampling was conducted using a 10 factor basal area (BAF) prism and included only trees greater than 7.5 cm dbh. We estimated cover ocularly in each stand using 15 randomly located 1 m^2 quadrats. Researchers sampled woody debris along 20 randomly located 40m-long transects by measuring and recording the diameters of all logs > 5cm in diameter that intersected the transect. We determined log volume from the measurements of woody debris using a formula described by Harvey and Finley (1995). An index was also developed to quantify the relative abundance of temporary and permanent water sources inside of and bordering each stand. Index scores ranged from 1–5 for each stand as follows: 1 = no known sources of water in or bordering the stand; 2 = one source of water bordering the stand, but none within the stand; 3 = more than one source of water bordering the stand, but none within the stand; 4 = one source of water within the stand; 5 = more than one source of water within the stand. Average precipitation for May–September of 1996 and 1997 was obtained from the Pennsylvania State Climatologist to determine if differences in precipitation between years affected herpetofauna in 13 stands that were surveyed in 1996 and 1997.

Data Analysis

The experimental unit for statistical analyses was the stand. Oak–hickory forest stands were assigned a value of 1, and northern hardwood forest stands were assigned a value of 2 for all statistical analyses. Pearson's correlation analysis was used to identify significant relationships between habitat characteristics for the 47 stands. How the habitat characteristics are related to residual tree basal area and forest type will help resource management professionals to better understand the results of the complex interactions between herpetofauna and the stand conditions following timber harvesting.

Numbers of each herpetofauna species from the time-constrained, area searches were recorded for each of 33 stands in 1996 and for each of 27 stands in 1997. Herpetofauna surveyed during the time-constrained, area searches were used to determine the relative abundance and species richness of herpetofauna for each forest stand. Paired *t*-tests were used to determine if the relative abundance and species richness of herpetofaunal orders were significantly different between time-constrained, area searches conducted in the 13 stands that were surveyed in both 1996 and 1997. The relative abundance and species richness of herpetofaunal orders that were not significantly different between years and the abundance of all individual herpetofaunal species were averaged for the 13 stands that received 2 yr of surveys. Forward stepwise regression was used to determine the influence of habitat characteristics in explaining the variation in relative abundance and richness of herpetofauna in the 47 forest stands. All habitat characteristics were included in the forward stepwise regression analyses. A probability value of 0.10 was the criteria used for entry in the regression model. Pearson's correlation analysis was used to identify significant relationships between relative abundance and richness of herpetofauna and tree basal area in each of the 47 stands. *T*-tests were used to determine if the abundance and species richness of salamander and snake species were significantly different above and below certain threshold amounts of tree basal area. We determined threshold levels of tree basal area by visually inspecting plots of the abundance and species richness of herpetofaunal orders and tree basal area.

Results

Time-constrained, area searches produced 5,097 individuals of 24 species (11 salamander, 6 snake, 6 frog, and 1 toad species) during 1996, and 3,084 individuals of 26 species (12 salamander, 7 snake, 6 frog, and 1 toad species) during 1997 (Table 2). The abundance and species richness of the salamanders and snakes were not significantly different ($P > 0.25$) between 1996 and 1997 for the 13 stands that were surveyed during both years. However, anuran richness was significantly higher ($P = 0.02$) in 1996, and although not statistically significant ($P = 0.14$), anuran abundance showed a trend toward being higher in the 13 stands in 1996. Higher abundance and richness of anurans in 1996 corresponded to the difference in precipitation between 1996 and 1997. The amount of precipitation for each month including May through September was higher in 1996 than during the same time periods in 1997. Total precipitation for May–September 1996 was 64.8 cm compared to only 36.2 cm during May–September 1997.

The abundance and richness of herpetofauna differed between stands as the amount of tree basal area in each stand varied. Tree basal area was the dominant habitat variable affecting the abundance and richness of salamanders and snakes. Tree basal area was the first habitat characteristic entered into stepwise regression models of the abundance and richness of salamanders and snakes (Tables 3 and 4). The abundance and richness of salamander species decreased with increasing removal of live tree basal area for both 1996

Table 2. Relative abundance of herpetofauna species surveyed using 2 time-constrained, area searches conducted between July-September, 1996 and 1997, in 47 forested stands in northeastern Pennsylvania.

Species	1996	1997
Four-toed salamander (*Hemidactylium scutatum*)	0	3
Jefferson salamander (*Ambystoma jeffersonianum*)	17	1
Marbled salamander (*Ambystoma opacum*)	2	9
Mountain dusky salamander (*Desmognathus ochrophaeus*)	430	428
Northern dusky salamander (*Desmognathus fuscus*)	144	140
Northern red salamander (*Pseudotriton ruber*)	2	3
Northern spring salamander (*Gyrinophilus porphyriticus*)	7	4
Northern two-lined salamander (*Eurycea bislineata*)	83	104
Redback salamander (*Plethodon cinereus*)	1,967	905
Red-spotted newt (*Notophthalmus viridescens*)	1,025	760
Slimy salamander (*Plethodon glutinosus*)	318	152
Spotted salamander(*Ambystoma maculatum*)	31	26
Salamander totals	4,026	2,535
Black rat snake (*Elaphe obsoleta*)	1	1
Eastern garter snake (*Thamnophis sirtalis*)	78	58
Eastern milk snake (*Lampropeltis triangulum*)	3	1
Eastern smooth green snake (*Opheodrys vernalis*)	0	4
Northern redbelly snake (*Storeria occipitomaculata*)	15	26
Northern ringneck snake (*Diadophis punctatus*)	81	76
Northern water snake (*Nerodia sipedon*)	2	1
Snake totals	180	167
Bullfrog (*Rana catesbeiana*)	1	3
Eastern American toad (*Bufo americanus*)	94	45
Eastern gray treefrog (*Hyla versicolor*)	17	3
Northern green frog (*Rana clamitans*)	448	198
Northern spring peeper (*Hyla crucifer*)	102	62
Pickerel frog (*Rana palustris*)	158	41
Wood frog(*Rana sylvatica*)	71	30
Anuran totals	891	382

Table 3. Results of forward stepwise regression analyses between salamanders and habitat characteristics in 47 forested stands in northeastern Pennsylvania during 1996 and 1997. Habitat characteristics are presented in the order that they were entered into the regression analyses. Cumulative R^2-statistics are displayed for the models as the habitat characteristics were entered into the regression analyses.

Salamander variables	Habitat characteristics	T-statistic	P-value	R^2-statistic (%)
Salamander abundance	Tree basal area	6.16	< 0.001	48.6
	Forest type	−2.24	0.030	53.9
Salamander richness	Tree basal area	3.59	0.001	37.2
	Conifer basal area	1.75	0.087	43.7
	Permanent water	1.63	0.110	47.0
Genus: *Ambystoma*	Tree basal area	2.46	0.018	18.8
	Conifer basal area	1.94	0.059	25.2
Genus: *Desmognathus*	Tree basal area	4.69	< 0.001	25.4
	Leaf litter cover	−2.39	0.021	34.0
Genus: *Plethodon*	Tree basal area	4.11	< 0.001	31.1
	Forest type	−2.22	0.031	38.1
Northern two-lined salamander (*Eurycea bislineata*)	Permanent water	2.81	0.007	24.6
	Ground cover	−3.28	0.002	35.5
	Woody debris	1.90	0.064	40.5
Red-spotted newt (*Notophthalmus viridescens*)	Tree basal area	2.70	0.010	14.0

and 1997 combined (Figure 1). Conversely, the abundance and richness of snake species increased with increasing removal of live tree basal area for both 1996 and 1997 combined (Figure 2). The abundance of anurans did not change significantly ($P > 0.10$) with varying amounts of live tree basal area. However, anuran richness was positively associated with tree basal area (Table 5).

The presence and amount of permanent water were the dominant habitat variables affecting the abundance and richness of anurans (Table 5). The abundance and species richness of anurans and species richness of salamanders were positively associated with permanent water sources, whereas the abundance and richness of snakes were positively associated with temporary water (Tables 3–5).

The abundance of common salamanders (e.g., salamanders found in more than five stands) increased with increasing tree basal area (Table 3). With increasing tree basal area, salamander abundance increased significantly

Table 4. Results of forward stepwise regression analyses between snakes and habitat characteristics in 47 forested stands in northeastern Pennsylvania during 1996 and 1997. Habitat characteristics are presented in the order that they were entered into the regression analyses. Cumulative R^2-statistics are displayed for the models as the habitat characteristics were entered into the regression analyses.

Snake variables	Habitat characteristics	T-statistic	P-value	R^2-statistic (%)
Snake abundance	Tree basal area	−1.76	0.086	30.5
	Temporary water	3.35	0.002	36.2
	Forest type	2.67	0.011	44.7
	Ground cover	3.48	0.001	52.2
	Fern cover	−2.80	0.008	59.9
Snake richness	Tree basal area	−3.95	< 0.001	41.8
	Forest type	5.72	< 0.001	53.9
	Temporary water	3.47	0.001	65.6
	Leaf litter cover	−2.27	0.028	70.3
	Snag basal area	−2.03	0.049	73.0
Eastern garter snake (*Thamnophis sirtalis*)	Leaf litter cover	−4.78	< 0.001	43.4
	Tree basal area	−4.08	< 0.001	49.0
	Woody debris	−3.00	0.005	51.2
	Snag basal area	2.56	0.014	57.1
	Temporary water	2.14	0.039	61.4
Northern redbelly snake (*Storeria occipitomaculata*)	Blueberry cover	4.51	< 0.001	30.4
	Tree basal area	−2.85	0.007	36.4
	Temporary water	2.57	0.014	44.9
Northern ringneck snake (*Diadophis punctatus*)	Blueberry cover	4.13	< 0.001	27.6
	Ground cover	2.05	0.046	33.9

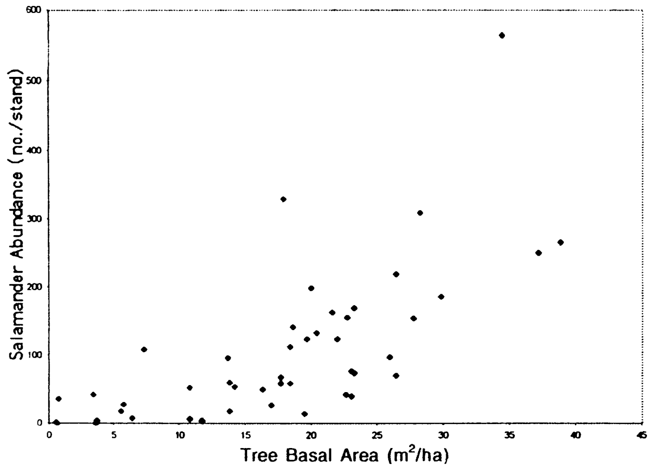

Figure 1. Relationship between salamander abundance and tree basal area for 47 forest stands in northeastern Pennsylvania for 1996 and 1997 combined. Pearson's coefficient of correlation (*r*) and the probability of a type I error (*P*) for statistical significance of a correlation are presented.

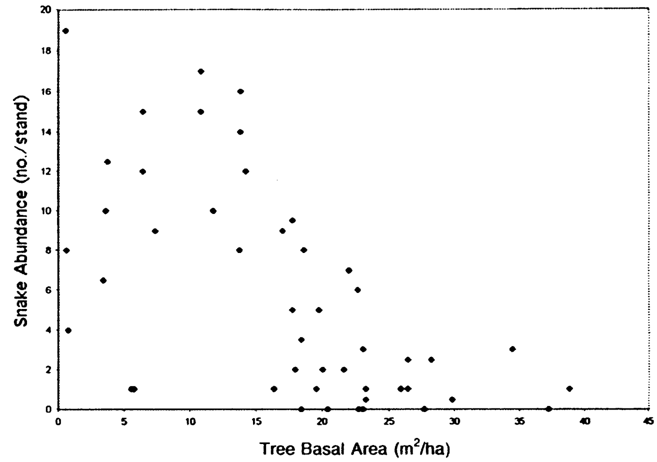

Figure 2. Relationship between snake abundance and tree basal area for 47 forest stands in northeastern Pennsylvania for 1996 and 1997 combined. Pearson's coefficient of correlation (*r*) and the probability of a type I error (*P*) for statistical significance of a correlation are presented.

($P < 0.001$) above 15m^2/ha live tree basal area (Figure 1). Redback salamander and red-spotted newt in the terrestrial stage were the most abundant salamander species in the study stands (Table 2) and appeared to be most responsible for determining the association between tree basal area and salamander abundance. Together, these two species accounted for 71% (44% for redback salamander and 27% for red-spotted newt) of all individual salamanders captured in study stands. However, the total abundance of all salamanders excluding redback salamander and red-spotted newt remained significantly and positively correlated with live tree basal area (r = 0.67, $P < 0.001$). Although the abundance of mountain and northern dusky salamander (Genus *Desmognathus*) was positively associated with increasing live tree basal area, like northern two-lined salamanders, these species only appeared in stands containing springs, seeps, and streams.

Three small terrestrial snake species were commonly found in the study stands. Northern redbelly and eastern garter snakes were positively associated with decreasing live tree basal area (Table 4). The abundance of northern ringneck snake was not significantly related to tree basal area, but like northern red belly snake, was associated with increasing blueberry ground cover.

The abundance of common frog or toad species was not significantly associated with tree basal area (Table 5). However, the relative abundance of frogs was affected by timber harvesting. Frogs from the genus *Rana* were positively associated with the presence of woody debris within the stands.

Discussion

Other recent studies (Perison et al. 1997) have indicated that the response of herpetofauna to forest harvesting is likely to be species-specific, thus limiting generalities about how reptile and amphibian groups are affected by forest management. However, the results of this study

Table 5. Results of forward stepwise regression analyses between anurans and habitat characteristics in 47 forested stands in northeastern Pennsylvania during 1996 and 1997. Habitat characteristics are presented in the order that they were entered into the regression analyses. Cumulative R^2-statistics are displayed for the models as the habitat characteristics were entered into the regression analyses.

Anuran variables	Habitat characteristics	*T*-statistic	*P*-value	R^2-statistic (%)
Anuran abundance	Permanent water	2.81	0.007	27.0
	Woody debris	2.07	0.044	29.9
	Slash cover	–1.69	0.098	34.3
Anuran richness	Permanent water	2.01	0.052	30.2
	Tree basal area	2.87	0.007	36.7
	Ground cover	1.76	0.085	40.6
	Blueberry cover	1.98	0.054	44.6
	Temporary water	1.67	0.103	48.2
Genus: *Hyla*	Leaf litter cover	2.26	0.029	10.8
	Permanent water	1.80	0.079	16.9
Genus: *Rana*	Permanent water	2.62	0.012	25.3
	Woody debris	2.20	0.034	28.8
	Slash cover	–1.73	0.090	33.5
Eastern American Toad	Fern cover	3.61	0.001	17.2
(*Bufo americanus*)	*Rubus* species cover	–2.13	0.039	24.9

clearly show an opposing association of snake and salamander species with respect to tree basal area. The abundance of salamander species in this study increased significantly with increasing tree basal area and/or species were restricted to sites with > $15m^2$/ha live tree basal area, whereas snakes were negatively associated with live tree basal area or were only found in heavily harvested stands.

Pough et al. (1987), Ash (1988), DeGraaf and Yamasaki (1992), and Petranka et al. (1993, 1994) have shown that salamander abundance and richness is significantly affected by overstory tree removal associated with forest harvesting in the northeastern United States. In a study in central New York, Pough et al. (1987) found that the abundance of salamanders in stands recently disturbed by forest management (firewood cuts, clearcuts, and conifer plantations) was lower than that of mature forest stands. DeGraaf and Yamasaki (1992) captured nearly four times as many salamanders in unharvested plots compared to clearcuts in New Hampshire. In the southern Appalachians, Ash (1988) and Petranka et al. (1993, 1994) found that clearcutting decreased the abundance and species richness of salamanders compared to uncut mature forest. Our study suggests that salamander species may respond negatively to removal of tree basal area beyond a certain threshold. The abundance of salamanders was significantly lower in stands with < $15m^2$/ha live tree basal area.

In contrast to our study, Pough et al. (1987) found that some species, such as the red-spotted newt in the terrestrial stage, appeared to increase in selectively cut stands compared to old growth stands. In our study, only northern two-lined salamander was not significantly associated with increases in tree basal area.

Eastern garter snake is a generalist species, often associated with moist microsites, while northern redbelly snake is associated more with closed forests than open areas (Shaffer and McCoy 1991). In our study, these species were associated with stands containing small amounts of residual tree basal area. Stands with minimal tree basal area within a predominantly forested landscape, such as the Pocono Mountain region of northeastern Pennsylvania, may offer greater opportunities for thermoregulation than closed canopy stands.

Unlike the relative abundance of salamanders and snakes, the relative abundance of anurans was not associated with live tree basal area. Despite their general requirement of moist conditions, frogs and toads have a greater tolerance of high temperatures than salamanders (Stebbins and Cohen 1995), which may allow them to exist in areas without extensive overstory cover or tree basal area, as long as there is water available. As expected, the relative abundance and species richness of frogs and toads increased in stands with temporary and permanent water. Also, a higher relative abundance and richness of anurans in 1996 compared to 1997 was most likely due to greater amount of precipitation during the 1996 field season. It is uncertain why frogs may have responded to differences in the amount of precipitation between 1996 and 1997, whereas salamander abundance and richness showed no significant difference between years.

In addition to tree basal area, other habitat variables also influenced the relative abundance and richness of herpetofauna in northeastern Pennsylvania. Forest type may be an important determinant of herpetofauna abundance and species composition (Bennett et al. 1980, DeGraaf and Rudis 1990, Frisbie et al. 1992), but forest type did not appear to be as important as live tree basal area in this study. Salamander abundance and richness were higher in northern hardwood stands. Snake abundance and richness were higher in oak-hickory stands, and cover of blueberry species, an indirect indicator of the oak-hickory forest type, was positively associated with northern redbelly and northern ringneck snakes. However, most species of salamanders and snakes occurred in both forest types. Of the species detected in at least five stands, all occurred within both forest types.

The lack of association between nearly all salamanders and snakes with changes in woody debris at the stand level may be explained by the large amount of woody debris in the form of felled culls and unmerchantable portions of harvested trees in all harvested stands of this study. However, a higher relative abundance of northern two-lined salamanders and anurans (particularly members from the genus *Rana*) was associated with increased abundance of woody debris in this study. Thus, stands may have exceeded a saturation level of woody debris cover for most salamanders and snakes, but not for frogs.

Management Implications

Forest harvesting influences the relative abundance, species richness, and species composition of herpetofauna in northern hardwood and oak-hickory forests, mainly by altering forest stand characteristics, especially tree basal area. Retaining at least $15m^2$/ha live tree basal area appears to be important for maintaining the relative abundance and species richness of salamanders. Like salamanders, higher anuran richness was associated with increases in tree basal area. Although not significantly related to live tree basal area, the relative abundance of anurans increased with the creation and retention of woody debris within harvested stands. Distinct threshold levels for snake abundance and species richness with live tree basal area were not evident, but the abundance and species richness of snakes increased with increased removal of tree basal area within predominantly forested landscapes.

It is important to note that this study only addresses temporary effects, up to 10 yr after logging. Additional factors not measured in this study such as soil compaction and litter depth following timber harvesting may influence herpetofaunal communities. Future studies should include measurements of additional factors that may influence herpetofaunal communities following timber harvesting such as litter depth and soil compaction. Further research is necessary to address how herpetofaunal communities respond to timber management in other geographical regions and after the initial 10 yr time period following harvesting examined in this study.

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