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Effects of Restoration Burns on Macroinvertebrates in Southern Appalachian Pine-Oak Forests

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Abstract: Cover board arrays were used to measure the relative abundance of macroinvertebrates and terrestrial salamanders on prescribed burn and control sites in xeric southern Appalachians of northern Georgia and southeastern Tennessee pine-oak forests. Three microsite variables were measured at each cover board: cover board moisture level, temperature under the cover board, and soil moisture. Soil moisture was significantly higher on the burn sites than the controls after the prescribed fire. Two groups of macroinvertebrates, Homoptera and Hymenoptera, were more abundant on the burn sites than the control sites. Coleoptera and Stylommatophora were significantly more abundant in riparian and low slope positions than upland positions; whereas, the other macroinvertebrate groups were not significantly related to slope position. Thirteen salamanders were found during the four sampling periods. Overall, there was little evidence of negative post-fire impacts on macroinvertebrates or salamanders.

Key Words: cover boards; fire; invertebrates; salamanders; restoration.

INTRODUCTION

Forest managers increasingly use prescribed fire as a tool to restore ecosystem health and maintain diversity in fire-dependent communities (Vose 2000). In the southern Appalachian Mountains, fire is important for the long-term maintenance of pine and pine-oak forests on ridgetops and xeric south/west aspects (Barden and Woods 1976; Harmon 1982; Elliott et al. 1999). However, in recent decades fire suppression has altered forest composition. Until the 1940s, fires ignited both by lightning and by humans occurred frequently enough to favor establishment of yellow pines (*Pinus* spp.) and oaks (*Quercus* spp.) in xeric communities, but retard growth and establishment of more fire intolerant species such as red maple (*Acer rubrum* L.), black gum (*Nyssa sylvatica* Marshall), and eastern white pine (*Pinus strobus* L.) (Barden and Woods 1976; Harmon 1982). In the Great Smoky Mountains National Park, fire suppression in pine forests since 1940 has altered the fire return interval from 10–40 yr (between 1856 and 1940) to over 2000 yr (Harmon 1982).

Although fire is being used on a limited, but increasing basis as a tool to restore declining pine-oak communities in the southern Appalachians, little research

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investigated the impact of prescribed burns on macroinvertebrates (Crossley et al. 1999) and terrestrial salamanders in the region (Ford et al. 1999). Macroinvertebrates play an important role in ecosystem processes, particularly in organic matter decomposition. Additionally, macroinvertebrates are the primary food source for salamanders and several other vertebrate species. Although a number of studies have examined fire effect on macroinvertebrate diversity and abundance (Richardson and Holliday 1982; Holliday 1984; Provencher et al. 2002), little is known about macroinvertebrate responses to burning in the southern Appalachian Mountains. Crossley et al. (1999) investigated the responses of microarthropods to a restoration fire in the southern Appalachians; although terrestrial salamanders feed on microarthropod species such as mites (Arachnida: Acari), most of their diet consists of macroinvertebrates (Hamilton 1932; Davidson 1956; Whitaker and Rubin 1971). Therefore, macroinvertebrate distribution and abundance are related to terrestrial salamander abundance.

Most scientific attention in the southern Appalachians has focused on the effects of timber harvesting on salamanders (Ash 1988; Petranka et al. 1993; Harpole and Haas 1999), but only one study has focused on the response of terrestrial salamanders to fire (Ford et al. 1999). Woodland salamanders are sensitive to changes in their environment (Wyman 1988; Petranka et al. 1993; Herbeck and Larsen 1999) and have been proposed as indicators for monitoring biodiversity and ecosystem integrity (Welsh and Droege 2001). Burton and Likens (1975a) found salamander biomass on the Hubbard Brook Experimental Forest in New Hampshire to be approximately twice that of birds and about equal to that of small mammals. Petranka and Murray (2001) found that salamander biomass along a southern Appalachian stream was 16.53 kg per hectare, 14 times greater than the estimates reported for the Hubbard Brook Experimental Forest. Terrestrial salamanders have high protein content, suggesting that salamanders are a good source of high-quality food for predators (Burton and Likens 1975b). Though salamanders do not directly act as significant agents for cycling nutrients, their role as consumers of detritivores probably influences litter decomposition rates and nutrient availability (Burton and Likens 1975b; Wyman 1998).

Relative abundances of macroinvertebrates and terrestrial salamanders were determined after a restoration burn in degraded mixed pine-oak forests in the southern Appalachian Mountains. The silvicultural objectives of the prescribed fire were to reduce non-desirable tree and shrub species, particularly eastern white pine and mountain laurel (*Kalmia latifolia* L.), and to prepare a seedbed for Virginia pine (*Pinus virginiana* Miller) and shortleaf pine (*Pinus echinata* Miller). Two null hypotheses tested: 1) no significant difference in the relative abundance of macroinvertebrates or salamanders in burned vs. control sites; 2) no significant difference in the relative abundance of macroinvertebrates or salamanders along a topographic moisture gradient from upper dry slopes to lower riparian areas.

SITE DESCRIPTION

The study area was located on the extreme southwestern edge of the Blue Ridge Physiographic province. Three sites were in Chattahoochee National Forest, Murray County, Georgia (34°49′N, 84°41′W), and three sites were in Cherokee National

Forest, Polk County, Tennessee (35°00′N, 84°39′W). Each site was named after the nearest stream and type of treatment: Georgia - Muskrat Control (MRC), Muskrat Burn (MRB), and Conasauga Springs Burn (CSB); Tennessee - Sawmill Control (SMC), Sawmill Burn (SMB), and Halfway Burn (HWB). All six sites were within the Conasauga River watershed and were within 21 km of each other. Elevation ranged from 260–415 m. All sites had southern aspects, ranging from 135–225°. Mean annual temperature was 14°C and mean annual precipitation was 135 cm (Cleveland, TN, National Climatic Database, www.ncdc.noaa.gov). Sites were mixed pine-oak forests with an overstory dominated by Virginia pine, shortleaf pine, scarlet oak (*Quercus coccinea* Muenchh.), white oak (*Q. alba* L.), red maple, sourwood (*Oxydendrum arboreum* (L.) DC.), and blackgum. A southern pine beetle (*Dendroctonus frontalis* Zimmermann) outbreak occurred throughout the region during the study. This infestation caused extensive mortality of pines in four of the study sites: MRC, MRB, SMC, and SMB. Elliott and Vose (2005a) provided a more detailed description of each site, including pre- and post-burn vegetation characteristics.

Four of the six sites were burned on 28 March 2001, with two sites left as controls. Burning began at the top of the ridge on each site, with strip head fires ignited at 10–20 m intervals from the ridge to the riparian zone. This method of burning resulted in a low to moderately intense fire. Hubbard et al. (2004) provided more detailed characteristics (i.e., intensity, severity) of each burn.

MATERIALS AND METHODS

Cover boards were used to sample macroinvertebrates and salamanders. All sample methods (natural cover searches, artificial cover searches, night searches, leaf litter searches, pitfall traps) show high temporal and spatial variation (Grant et al. 1992; Kirkland et al. 1996; Hyde and Simons 2001). The cover board method was chosen for this study because it has been shown as an efficient method for sampling some groups of macroinvertebrates (Maier 1983; 1986) and terrestrial salamanders (DeGraaf and Yamasaki 1992; Monti et al. 2000; Hyde and Simons 2001). Hyde and Simons (2001) found that cover board transects were an effective sampling technique for terrestrial salamanders in the Great Smoky Mountains National Park, which lies in the same physiographic region as our study area. To address problems associated with using cover boards for sampling large salamanders (Hyde and Simons 2001), we used large cover boards and placed a high number of boards per site. We used the cover board data as an index for comparing burn vs. control treatments, but not for quantifying absolute population abundance of macroinvertebrates or terrestrial salamanders.

Five 16 × 24 m permanent plots were established at each of the six study sites. The long sides of the rectangular plots were parallel to the contour of the slope. Five plots were placed at equal intervals (30–40 m) from the top of the slope to the bottom of the slope (i.e., riparian, lower slope, mid-slope, upper slope, and ridge). A smaller 10 × 20 m plot within the center of each plot was established to measure a number of biotic and abiotic variables (e.g., amount of coarse woody debris, amount of leaf litter, identification and measurements of trees, shrubs, and herbs, soil water chemistry, etc.) were being carried out for other research projects that were taking place simultaneously with this research (see Hubbard et al. 2004; Elliott and Vose 2005a; Elliott and Vose 2005b).

Cover boards were installed 16–17 May 2001 at the Georgia study sites. One week later (22–23 May 2001) cover boards were installed at the Tennessee sites. Cover boards were untreated eastern white pine, cut into 30.5 × 30.5 × 2.5 cm squares, a size recommended by the Patuxent Wildlife Research Center's Terrestrial Salamander Monitoring Program: Recommended Protocol for Running Cover Object Arrays (http://www.im.nbs.gov/sally/sally4.html; accessed February 2005). Fifty boards were placed at each of the six sites (300 boards total). Five boards were placed in a line transect parallel to the upper and lower boundary of each plot, for a total of ten cover boards per plot. Boards were placed approximately six meters apart to eliminate bias based on recapture distances for several species of salamanders (Mathis et al. 1995). All leaf and humus material was removed prior to installing cover boards. The mineral soil was leveled and boards were placed firmly so that they would not shift. Leaf litter and humus were scattered over the exposed boards to keep the boards moist so that they would be more attractive to salamanders. The location of each board was marked with a flag and then left undisturbed for three months to allow them to settle and permit macroinvertebrate and salamander use.

Boards were checked 5–7 months after the burn, once in August, once in September, and twice in October. The order of our visits was randomized to eliminate potential bias associated with different periods of salamander activity that might occur during the day. Since Jaeger (1979; 1980) found the presence of redback salamanders (*Plethodon cinereus* (Green)) under cover objects to be negatively related to rain within the previous 24 hrs, sampling did not occur within 24 hrs of the last rainfall event. Start time and end time at each plot was noted and the air temperature was measured in the shade near the center of each plot. Relative moisture of the litter and humus layer (dry/moist) was noted at each plot, as well as general weather conditions (e.g., sunny, partly cloudy, cloudy). A Reotemp model TM99A soil temperature probe was used to determine the temperature under the boards to the nearest 0.1° C prior to lifting the boards. The probe tip was inserted approximately 9 cm between the board and soil surface and near the midpoint of one side of the board; and the temperature was recorded. A Campbell Scientific Hydrosense™ soil moisture probe was used in August. The soil moisture probe was inserted approximately 5 cm uphill of each board. The probe measured soil moisture to a depth of 20 cm.

After recording the temperature and soil moisture, the board was tilted up on one corner and the area under the board was searched for macroinvertebrates and salamanders, and the underside of the board was checked for macroinvertebrates. Macroinvertebrates were identified to the lowest known taxonomic group and were listed as either present or absent. Moreover, land snails (Gastropoda: Stylommatophora) were counted to test whether treatment or slope position affected the distribution or density of snails found under cover boards. Snails being high in calcium, made them an important food source for salamanders (Burton and Likens 1975b); therefore, snails could be an indicator of salamander response to burning.

Terrestrial salamanders were captured and identified to species. A salamander-restraining device was used (Wise and Buchanan 1992) to hold the salamanders while the total length (tip of snout to tip of tail) and snout-to-vent length (SVL) of each individual was measured to the nearest millimeter. A spray bottle filled with nearby

stream water to keep the salamanders moist was used during the handling process. After the salamanders were measured, they were placed next to the board where they were found and gently "coerced" back under the board.

All macroinvertebrates and salamanders were identified after the cover board moisture level (CBML) was determined. Four categories described the moisture level under the boards: 1) ≥ 90% of the soil and litter under the board damp to the touch, underside of cover board damp, spider webs contain water droplets, litter "glistening" with moisture; 2) 60–89% of the soil and litter under the board damp to the touch, portion of board damp on the underside, spider webs may have water droplets, litter not "glistening"; 3) 31–60% of the soil and litter under the board damp to the touch, underside of cover board not damp, spider webs do not contain water droplets, litter not "glistening"; 4) ≤ 30% of the soil and litter under the board damp to the touch, underside of cover board not damp, spider webs do not contain water droplets, litter not "glistening." Two days were required to survey all of the cover boards. Only one investigator identified species and determined the cover board moisture level throughout the study to limit bias.

A two-factor analysis of variance (ANOVA) (PROC GLM, SAS Institute Inc. 1996) was used to determine whether CBML, temperature beneath the cover boards, and soil moisture were significantly different between treatments (burn vs. control) and among slope positions (riparian, lower slope, mid-slope, upper slope, and ridge). The data (PROC RANK, SAS Institute Inc. 1996) was ranked before using analysis of variance to determine significant differences because CBML is a categorical variable. Macroinvertebrate relative abundance between treatments and slope positions was analyzed by analysis of variance (PROC GLM, SAS Institute Inc.1996). Relative abundance was calculated as the proportion of all cover board searches (i.e., frequency of occurrence expressed as a percentage) within a plot that contained a taxon. Spearman Correlation Coefficients (PROC CORR, SAS Institute Inc.1996) tested the significance of CBML, temperature beneath the cover boards, and soil moisture on the percent occurrence of a taxonomic group of macroinvertebrates to determine if the presence of one macroinvertebrate group had a significant effect on the presence/absence of another macroinvertebrate group. The level of significance for all tests at $\alpha \leq 0.1$ was set because a liberal approach is often justified when examining factors causing population declines (Askins et al. 1990; Caughley and Gunn 1996).

RESULTS

Treatment and slope position had few effects on microsite variables (Table 1). Temperature and CBML were not significantly affected by treatment or slope position. Soil moisture was significantly higher on the burn sites than the control sites. Higher soil moisture was recorded on the riparian plots, decreasing with increasing upslope position. However, soil moisture was not significantly related to slope position (Table 1).

Seven classes and 13 orders of macroinvertebrates were identified under the cover boards: Arachnida (including Araneae (spiders) and Scorpiones (scorpions)); Chilopoda (centipedes); Diplopoda (millipedes); Insecta (including Dictyoptera (cockroaches), Coleoptera (beetles), Hemiptera (true bugs), Homoptera (aphids), Hymenoptera (ants), Isoptera (termites), Lepidoptera (moths), Orthoptera (crickets)

Table 1. Average cover board moisture level (CBML), temperature under the cover boards, and percent soil moisture content at five slope positions for the burn and control sites in dry, pine-oak forests, Conasauga River watershed, Chattahoochee National Forest, GA and Cherokee National Forest, TN, August–October, 2001. Two-factor analysis of variance with treatment (burn and control) and slope position (riparian, lower slope, mid-slope, upper slope, and ridge) as the two factors. Standard errors are in parentheses.

	Burn					Control				
	Riparian	Lower	Mid	Upper	Ridge	Riparian	Lower	Mid	Upper	Ridge
CBML	1.6 (0.1)	1.4 (0.1)	1.6 (0.1)	1.7 (0.1)	2.0 (0.3)	1.7 (0.2)	1.7 (0.1)	1.6 (0.3)	1.6 (0.1)	1.8 (0.3)
Temperature (°C)	19.0 (0.5)	19.6 (0.4)	20.3 (0.5)	20.3 (0.7)	20.2 (0.6)	19.2 (0.8)	19.7 (1.1)	19.7 (1.3)	19.5 (1.0)	19.7 (1.0)
Soil moisture (%)	27.8 (2.6)	26.7 (1.7)	25.3 (3.3)	23.2 (2.5)	21.7 (2.5)	21.3 (1.3)	15.4 (0.1)	17.6 (1.8)	18.8 (2.2)	19.1 (2.5)

p-values from Analysis of Variance

Source of Variation	df	CBML	Temperature	Soil Moisture
Treatment	1	0.805	0.379	0.001
Slope	4	0.811	0.974	0.586
Treatment × slope	4	0.645	0.959	0.587
Error	20			
Corrected total	29			

and Thysanura (bristletails)); Malacostraca (including Isopoda (sowbugs)); Gastropoda (including Stylommatophora (land snails)); and Oligochaeta (earthworms). Additionally, unknown arthropods, including many larvae were observed. Hemiptera (1 observation), Lepidoptera (4 observations), Thysanura (4 observations), Isopoda (6 observations), unknown arthropod larvae (20 observations), and unknown arthropods (6 observations) were not included in our statistical analysis because of low number of observations.

Slope position was significant for Coleoptera and Stylommatophora. More cover boards harbored Coleoptera and Stylommatophora on riparian plots than the other slope positions (Table 2). Slope position was only significant for two groups of macroinvertebrates; therefore, differences between treatments were evaluated with a one-factor analysis of variance (Table 3). Significant differences were noted between burn and control sites for two groups of macroinvertebrates. Homoptera and Hymenoptera were significantly more abundant on burn sites than control sites (Table 3). Although not significant, Chilopoda and Diploda appeared to be more abundant on the control sites than the burn sites (Table 3).

Significant relationships existed between microsite variables (i.e., CBML, temperature beneath the cover board, soil moisture) and some groups of macroinvertebrates (Table 4). CBML was negatively correlated with temperature beneath the cover boards. As expected, CBML increased with increasing soil moisture. Scorpiones, Coleoptera, Hymenoptera, Isoptera, and Orthoptera were negatively correlated to CBML, while Oligochaeta was positively correlated to CBML. Temperature under the cover board declined with an increase in soil moisture. Stylommatophora and Oligochaeta were negatively correlated with the temperature under the boards, whereas Scorpiones, Hymenoptera, and Isoptera were positively correlated with the temperature under the boards. There was a positive correlation between soil moisture and Homoptera. Significant correlations existed among groups of macroinvertebrates (Table 4) as Oligochaeta were positively correlated with Araneae and negatively correlated with Scorpiones.

Stylommatophora were found during 104 board searches from a total of 1200 searches over the course of this study (300 cover boards $\times$ 4 sampling periods; 8.7% of total board checks). Eighty searches of these 104 observations had one Stylommatophora, fifteen searches yielded two Stylommatophora, eight searches yielded three Stylommatophora, and one board search had four Stylommatophora present. No statistical analyses were performed on Stylommatophora because of their relatively low numbers per board

Only thirteen salamanders were found under the cover boards from a total of 1200 board checks. Ten northern slimy salamanders (*Plethodon glutinosus* (Green)), two Blue Ridge two-lined salamanders *(Eurycea wilderae* Dunn), and one blackchin red salamander (*Pseudotriton ruber schencki* (Brimley)) were observed. Since SVL measurements were different between salamanders of the same species found in the same plot, no recaptures were assumed. No further statistical analyses were run because of the low number of salamanders observed. We counted eight salamanders in the burn sites (n = 800 searches) and five in the control sites (n = 400 searches). We found ten salamanders in the riparian plots (n = 240 searches), 0 in the lower slope and mid-slope plots (n = 480 searches), three in the upper slope plots (n = 240 searches), and 0 in the ridge plots (n=240 searches).

Table 2. Two-factor Analysis of Variance with treatment (burned, control) and slope position (ridge, lower slope, mid-slope, upper slope, and ridge) as the two factors for frequency of occurrence of macroinvertebrates in the Conasauga River watershed, Cherokee National Forest, TN and Chattahoochee National Forest, GA.

		p-Values From Analysis of Variance											
Source of Variation	df	Araneae	Scorpio.	Chilop.	Diplop.	Dicty.	Coleop.	Homop.	Hymen.	Isoptera	Orthop.	Stylom.	Oligo.
Treatment	1	0.656	0.571	0.143	0.265	0.198	0.621	**0.031**	**0.088**	0.227	0.259	0.690	0.478
Slope	4	0.989	0.341	0.493	0.792	0.319	**0.062**	0.394	0.386	0.794	0.471	**0.007**	0.814
Treatment × slope	4	0.985	0.843	0.628	0.935	0.937	0.709	0.945	0.856	0.375	0.991	0.888	0.948
Error	20												
Corrected Total	29												

Table 3. Average frequency of occurrence of macroinvertebrates over a 4 sample period (August–October, 2001) between burned and control sites for the Conasauga River watershed, Cherokee National Forest, TN and Chattahoochee National Forest, GA. Standard errors are in parentheses.

Macroinvertebrate	Burn (n=20)	Control (n=10)	p-Value
Araneae	85.6 (2.4)	87.8 (3.0))	0.602
Scorpiones	7.4 (1.4)	5.8 (2.6)	0.559
Chilopoda	21.5 (2.6)	28.2 (3.0)	0.118
Diplopoda	15.2 (1.8)	19.2 (2.6)	0.207
Dictyoptera	17.4 (2.9)	10.8 (3.3)	0.174
Coleoptera	7.1 (1.4)	6.0 (1.9)	0.642
Homoptera	18.5 (2.6)	8.8 (0.2.4)	**0.024**
Hymenoptera	45.8 (3.2)	36.0 (3.6)	**0.070**
Isoptera	12.4 (2.4)	7.8 (2.0)	0.222
Orthoptera	6.4 (1.3)	4.0 (1.0)	0.229
Stylommatophora	10.8 (1.3)	10.0 (1.7)	0.739
Oligochaeta	1.6 (0.6)	2.5 (1.0)	0.423

Note: p-values are from Analysis of Variance (PROC GLM, SAS Institute, Inc. 1996).

Table 4. Spearman correlation coefficients (r) and p-values of microsite variables and macroinvertebrates, Conasauga River watershed, Cherokee National Forest, TN and Chattahoochee National Forest, GA. Significant ($p \leq 0.10$, $n=30$) relationships are highlighted in bold.

	Oligo.	Stylo.	Ortho.	Isoptera	Hymen.	Homop.	Coleop.	Dicty.	Diplo.	Chilo.	Scorp.	Araneae	SM	Temp
CBML	**−0.484**	0.013	**0.427**	**0.408**	**0.338**	−0.044	**0.369**	**0.327**	−0.222	0.249	**0.419**	**−0.510**	**−0.358**	**0.626**
	0.007	0.946	**0.019**	**0.025**	**0.068**	0.819	**0.045**	**0.078**	0.238	0.184	**0.021**	**0.004**	**0.052**	**<0.001**
Temp.	**−0.688**	**−0.354**	**0.346**	**0.455**	0.262	0.266	−0.084	0.197	−0.209	0.152	**0.704**	**−0.807**	**−0.417**	
	<0.001	**0.055**	**0.061**	**0.012**	0.163	0.155	0.659	0.297	0.267	0.424	**<0.001**	**<0.001**	**0.022**	
SM	0.022	0.291	−0.100	0.063	0.143	**0.346**	0.167	0.272	0.091	−0.247	−0.244	0.285		
	0.908	0.119	0.600	0.740	0.451	**0.061**	0.379	0.146	0.632	0.188	0.195	0.127		
Araneae	**0.606**	0.080	**−0.355**	**−0.487**	−0.152	−0.127	0.063	−0.021	−0.062	0.107	**−0.473**			
	<0.001	0.676	**0.055**	**0.006**	0.424	0.504	0.740	0.911	0.746	0.575	**0.008**			
Scorpiones	**−0.670**	−0.219	0.012	0.156	0.206	0.244	−0.138	0.065	−0.210	−0.045				
	<0.001	0.245	0.948	0.412	0.274	0.194	0.468	0.734	0.265	0.814				
Chilopoda	−0.025	−0.008	−0.031	−0.113	0.244	0.189	0.042	**0.416**	**−0.406**					
	0.897	0.965	0.869	0.553	0.194	0.318	0.825	**0.022**	**0.026**					
Diplopoda	0.060	−0.159	−0.131	−0.098	−0.266	**−0.403**	−0.143	**−0.359**						
	0.754	0.400	0.489	0.606	0.155	**0.027**	0.452	**0.051**						
Dictyoptera	−0.088	−0.003	0.292	**0.323**	**0.456**	0.305	**0.447**							
	0.645	0.988	0.118	**0.082**	**0.011**	0.101	**0.013**							
Coleoptera	0.055	**0.405**	**0.357**	0.265	**0.378**	−0.071								
	0.771	**0.026**	**0.053**	0.157	**0.040**	0.710								
Homoptera	−0.182	−0.119	−0.274	0.245	**0.655**									
	0.335	0.530	0.143	0.192	**<0.001**									
Hymenoptera	−0.191	−0.080	−0.007	**0.316**										
	0.311	0.673	0.970	**0.089**										
Isoptera	−0.280	0.043	**0.468**											
	0.134	0.820	**0.009**											
Orthoptera	−0.194	0.024												
	0.304	0.898												
Stylommatophora	0.080													
	0.676													

DISCUSSION

Only soil moisture, of the three physical microsite variables measured, was significantly different between burn and control sites. Hubbard et al. (2004) also found that soil moisture was higher in burn than control sites in the Conasauga River watershed. Overstory and understory mortality from fire may have reduced transpiration, and resulted in a subsequent increase in soil moisture. Higher soil moisture should have a positive effect on macroinvertebrates and terrestrial salamanders, because the increased post-fire soil moisture would enhance micro-environmental conditions of the underground retreats used by salamanders (Heatwole 1960). Terrestrial salamanders spend 70–80% of their lives in underground burrows (Taub 1961). They then emerge at night during favorable conditions to forage for invertebrates within the leaf litter (Ash 1995). Prescribed fires in the Conasauga River watershed reduced the leaf litter by nearly 70% (Hubbard et al. 2004). Increased soil moisture following fire may permit salamander populations to remain stable despite the short-term loss of leaf litter and may explain why terrestrial salamander abundance does not differ between burn and non-burn sites despite the leaf litter being consumed by fire (Ford et al. 1999; Floyd et al. 2002).

Furthermore, there was generally a positive relationship between soil moisture and macroinvertebrate abundance and diversity (Coleman and Crossley 1996). Some groups of macroinvertebrates were significantly related to each other. However, we did not know if these groups were related because they use similar microenvironments (e.g., temperature and moisture conditions) or if there was a competitive or mutualist interaction between groups. Homoptera and Hymenoptera, for example, were significantly positively related but not consistently related with temperature or soil moisture for both groups. Conversely, Oligochaeta and Scorpiones were negatively correlated with each other; Oligochaeta was negatively related to CBML and temperature and Scorpiones was positively related to CBML and temperature. Thus, Oligochaeta and Scorpiones may have been utilizing different environmental conditions rather than having a direct competitive or predator-prey interaction. However, more research may be necessary to explain these complex relationships.

Little evidence was found of negative fire effects on macroinvertebrates or salamanders for the 5–7 month post-burn period. None of the macroinvertebrates were significantly more abundant on the control sites than the burned sites. However, two groups of macroinvertebrates, Homoptera and Hymenoptera, were more abundant beneath cover boards on the burned sites than the control sites. Restoration burns in the Conasauga River watershed, in addition to increased soil moisture, resulted in sprouting of many of the hardwood species (Elliott and Vose 2005a). New sprouts are more palatable to herbivores (Owensby et al. 1970; Nagel 1973; Dunwiddie 1991) and may partially explain why these two macroinvertebrate groups increased after the burn. Richardson and Holliday (1982), Holliday (1984), and Provencher et al. (2002) have reported an increase in some groups of macroinvertebrates after fire.

Although only thirteen salamanders were observed, our sampling adequately reflected the low numbers of salamanders inhabiting this forest community relative to other forest types. Heatwole (1962), Mitchell et al. (1997), and Hanlin et al. (2000) documented that terrestrial salamanders prefer mesic hardwood forests to xeric pine

forests. Low numbers of salamanders cannot be attributed to time of year effects, since boards were surveyed both in summer (August) and mid- fall (October), when mean captures of plethodontid salamanders in the southern Appalachians are near their lowest and highest, respectively (Barker 1997). Overall, the cover boards held moisture well and the temperature under the boards was within the range preferred by plethodontid salamanders (Spotila 1972). Moreover, our sampling intensity was adequate, having placed a total of 300 cover boards throughout the six sites. However, because of the low number of salamanders found under the cover boards, future terrestrial salamander studies in xeric pine-oak communities in the southern Appalachians should use other sampling methods (e.g., pitfall traps) to verify the estimates of low salamander density determined with the cover board arrays.

Slope position played a role in determining the distribution of two macroinvertebrate groups, Coleoptera and Stylommatophora. Although soil moisture and temperature under the boards were not significantly different among slope positions, soil moisture decreased and temperature increased with elevation. This moisture and temperature gradient might be partially responsible for the distribution of macroinvertebrate groups, though other factors, such as the change of the vegetation community along an elevation gradient, also may play a role.

Decades of fire suppression, poor logging practices, and southern pine beetle infestations have degraded pine-oak communities in the southern Appalachians. Prescribed fire increasingly is used as a tool to restore these declining communities. This study indicated that the prescribed fires used to restore pine-oak communities in the Conasauga River watershed had few negative short-term effects on either macroinvertebrates or terrestrial salamanders. However, it may take repeated burnings (ca. 10 yr intervals) to achieve and maintain desired conditions in these communities (Harmon 1982), and it is not clear how successive burns might influence macroinvertebrates or salamanders.

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