ELSEVIER

Forest Ecology and Management 155 (2002) 131–141

Forest Ecology
and
Management

www.elsevier.com/locate/foreco

Stand age and habitat influences on salamanders in Appalachian cove hardwood forests

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Abstract

We surveyed cove hardwood stands aged 15, 25, 50, and ≥85 years following clearcutting in the southern Appalachian Mountains of northern Georgia to assess the effects of stand age and stand habitat characteristics on salamander communities using drift-fence array and pitfall methodologies from May 1994 to April 1995. Over a 60,060 pitfall trapnight effort, we collected 3937 salamanders represented by *Desmognathus aeneus*, *Desmognathus monticola*, *Desmognathus ocoee*, *Desmognathus quadramaculatus*, *Eurycea bislineata*, *Gyrinophilus porphyriticus*, *Pseudotriton ruber*, *Plethodon glutinosus*, *Plethodon serratus*, and *Notophthalmus viridescens*. Analysis of covariance with pitfall array to stream distance as the covariate showed that salamander species richness and diversity measures and numbers of *Desmognathus aeneus* and *Desmognathus ocoee* were highest in stands ≥85 years. *Eurycea bislineata* and *Plethodon glutinosus* were more abundant in stands ≤50 years old than in stands ≥85 years. Within cove hardwood stands, species richness and diversity measures and relative abundances of *Desmognathus* spp. and *Gyrinophilus porphyriticus* were negatively correlated with distance to stream. Species richness and diversity were positively correlated to amounts of emergent rock. Species richness, diversity and relative abundances of *Desmognathus* spp. were correlated with basal area within stands and extent of connected mesic, cove hardwood habitat and amount of cove habitat within 1 km radius among stands. *Eurycea bislineata* was negatively correlated with landform index, a measure of surrounding landform sheltering, and *Plethodon glutinosus* was positively correlated with elevation in cove hardwood stands. Our research indicates stand age is an important factor in explaining the abundance and community composition of salamanders in southern Appalachian cove hardwood communities. Because southern Appalachian woodland salamander communities are slow to recover and are substantially changed following disturbances such as clearcutting, populations in small, isolated cove hardwood stands might be more vulnerable to extirpation or may require longer recovery times than those in larger coves. Managers may need to assess habitat features such as cove extent and habitat connectivity to minimize impacts on these taxa by forest management activities in southern Appalachian cove hardwood communities. Published by Elsevier Science B.V.

Keywords: Clearcutting; Cove hardwoods; Habitat connectivity; Salamanders; Southern Appalachians

1. Introduction

Salamander communities constitute an important ecological component of Appalachian ecosystems, often exceeding the combined biomass of other terrestrial vertebrates (Burton and Likens, 1975;

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0378-1127/02/$ – see front matter. Published by Elsevier Science B.V.
PII: S0378-1127(01)00553-9

Hairston, 1987). In the southeastern United States, species diversity of woodland salamanders (family: Plethodontidae) reaches its zenith in the southern Appalachians (Martof et al., 1980, Wilson, 1995). Accordingly, recent attention has focused on the negative impact of clearcutting on woodland salamanders within the region (Ash, 1988, 1997; Petranka et al., 1993, 1994; Harpole and Haas, 1999). In the short-term, clearcutting in the southern Appalachians produces habitat conditions unfavorable for salamanders by increasing forest floor temperatures (Johnson et al., 1985) and reducing leaf litter depth and microsite moisture (Ash, 1995). Recovery times for salamander communities following clearcutting may vary depending upon salamander community composition prior to timber harvest (Ash, 1988) and upon site characteristics such as elevation, aspect, and plant community (Diller and Wallace, 1994; Ford et al., 1999; Harper and Guynn, 1999). Petranka et al. (1993, 1994) suggest that salamander communities require 50–80 years for full recovery to pre-harvest conditions following clearcutting in the southern Appalachians. Conversely, others believe that recovery times might be much less in the southern Appalachians (Ash, 1997; Harper and Guynn, 1999). Central to the issue of salamander recovery following timber harvest are both the short-term and long-term fate of on-site salamanders, and if salamanders on-site or in nearby surrounding forests provide the recolonizing source as clearcuts mature.

Questions regarding sampling methodologies and study site selection have plagued researchers studying salamander response to timber harvest in the southern Appalachians (Ash and Bruce, 1994; DeMaynadier and Hunter, 1995; Ash and Pollock, 1999; Petranka, 1999). For example, proximity to water is an important factor explaining salamander community assemblages in the southern Appalachians (Bruce, 1996) and may serve as a strong confounding factor in examining stand age to salamander community relationships, particularly for those in the genus *Desmognathus*. Also, timing of sampling effort throughout the year can have profound influences on study results, as above-ground terrestrial activity patterns vary from species to species (Petranka, 1998).

To better assess the relationship of clearcutting to salamanders in the southern Appalachians, we initiated a study of salamander abundance among a well-matched, chrono-sequence of cove hardwood stands that were similar in most characteristics except stand age. Additionally, we sought to examine micro- and stand-level habitat factors both dependent and independent of stand age that might be important to salamanders in the southern Appalachians.

2. Methods

In the winter of 1994, we selected 13 cove hardwood stands for study in the Brasstown Ranger District (BRD) of the Chattahoochee National Forest. Stands were located in the Cooper Creek watershed (seven stands), the Miller Cove watershed (two stands) and the Wolf Creek watershed (three stands) in Union County, Georgia and the Hiwassee River headwaters (one stand) in Towns County, Georgia using US Forest Service Continuous Inventory and Stand Condition (CISC) data followed by site visits and assessments. To control for variables other than stand age that might influence salamander communities, criteria used for site selection included: forest cover type recorded as yellow-poplar *(Liriodendron tulipifera* L.) or yellow poplar-northern red oak (*Quercus rubra* L.)–white oak (*Q. alba* L.), elevations between 700 and 1200 m, northerly site exposure, presence of a concave cove landform, and absence of a dense ericaceous shrub layer. We also chose to wholly contain our study within the BRD for logistic reasons and to minimize potential differences in woodland salamander assemblages that can occur within small geographic areas in the southern Appalachians. Actual study site elevations ranged from 730 to 1030 m.

In addition to yellow-poplar and northern red oak, other common overstory species were yellow buckeye (*Aesculus octandra* Marshall), basswood (*Tilia americana* L.), and white ash (*Fraxinus americana* L.). A rich herbaceous understory was present at each site (Ford et al., 2000). Soils at each site were deep, well drained stony loams with a deep humus layer in the Porter and Saunook Series (Wharton, 1989; Cabe, 1995).

We constructed five drift-fence arrays with pitfall traps in three each of these stands aged approximately 15, 25, and 50 years and in the four stands ≥85 years old. Stands ≤25 years were regenerated following clearcutting under US Forest Service stewardship.

Exact history of older stands is unknown, but the dominance of yellow-poplar, a shade-intolerant species, in an even-aged structure with little or no large downed woody debris, suggests the 50-year-old stands originated following clearcutting or heavy selection harvests. Stands $\geq$85 years originated after the widespread logging of the southern Appalachians that occurred at the turn of the century (Smith and Linnartz, 1980; Johnson et al., 1993). Portions of two of the older stands in our study, on the Cooper Creek Scenic Area and the Sosebee Cove Scenic area were never logged (Wentworth, personal communication; Duffy and Meier, 1992). Although cove hardwood communities are abundant in the southern Appalachians and the BRD, it is important to note that three factors limited our cove hardwood stand choices. Potential cove hardwood study areas identified in CISC data that were within designated wilderness areas were administratively excluded from this study. Site visits and assessments often revealed errors in CISC overstory type coding or the presence of dense ericaceous shrub growth usually indicating a lower slope position and a more riparian-influenced woodland. Lastly, 50-year-old cove hardwood stands that originated in the 1940s were relatively uncommon on the BRD, as were cove hardwood stands $\leq$15 years of age.

In each of 13 stands, we installed five drift-fence arrays. Drift-fence arrays with pitfalls are effective methodologies for sampling herpetofauna (Gibbons and Semlitsch, 1982; Mitchell et al., 1997) and shrews (Kirkland and Sheppard, 1994), another facet of this study reported elsewhere (Ford et al., 1997). Array 1 was placed in the center or ravine of the cove, with arrays 2, 3, 4, and 5 installed 50 m away in SE, SW, NW, and NE directions, respectively, from the center point of array 1 (Fig. 1). Because the distance between arrays was large relative to the limited movements and small home ranges of many woodland salamanders (Madison, 1969; Holomuzki, 1982; Mathis, 1991; Petranka et al., 1993, 1994; Petranka, 1998), we considered each array to be an independent sampling unit. Individual arrays consisted of four, 3 m long × 61 cm high aluminum flashing arms arranged in an X (Fig. 1). The bottom of the flashing was buried approximately 20 cm below the soil surface. One pitfall was placed on either side of the flashing near each arm end, and one in each of the four intersections at the center of the array (Fig. 1). Pitfall traps were plastic 946 cm^3 drink cups buried flush with the ground and against the sides of the flashing. Each pitfall cup was filled one-third its volume with 10% formalin to preserve specimens. Trapping was conducted for 7 days at the beginning of each monthly lunar cycle from May 1994 to April 1995, except February 1995 when harsh winter weather uncharacteristic of north Georgia precluded access to the study sites. All collection periods experienced at least one precipitation event over their duration. Following each collection period, salamanders were identified to species and reposited at the University of Georgia Museum of Natural History. Nomenclature follows Petranka (1998).

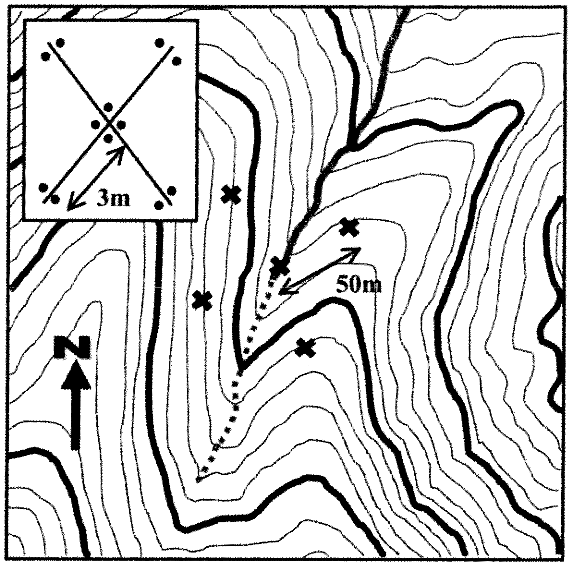

Fig. 1. Typical pitfall drift-fence array design for salamander collection in cove hardwood stands on the Chattahoochee National Forest, Georgia, 1994–1995. Inset depicts pitfall placement at individual drift-fence array (see text for complete description).

Because factors that influence salamander distribution and abundance vary among stands irrespective of overstory age, we measured nine micro-habitat variables at drift-fence arrays and calculated seven stand-level variables and topographic metrics for each study site. Within 10 m circular plots around each drift-fence array, we measured litter depth (LITTER), loose soil depth (SOIL), percent canopy cover (CANOPY), amount and types of coarse woody debris, and amount of emergent rock (ROCK). LITTER and SOIL were measured at one randomly chosen point in each quadrant of each circular plot. LITTER was recorded by brushing away leaves in a small area and measuring the height of the litter to a discernible O layer. SOIL was measured as the distance a piece of construction rebar could be driven in the soil until rock was encountered. CANOPY was calculated using a spherical densiometer. Over each plot, total coarse woody debris area (CWD) was calculated by tallying length and prostrate height at midpoint of all down woody debris ≥ 10 cm diameter. Coarse woody debris ≥ 60 cm prostrate height was considered large and a separate tally of that class was made as well (LGCWD). Each piece of coarse woody debris counted was assessed for decay class (DECAY) following criteria set by Hardt (1993) for the southern Appalachians. Area of emergent rock (ROCK) per plot was calculated by measuring emergent rock length and width above the soil surface. The distance from each array to the nearest seep, spring, creek, or other water source (DISTANCE) was measured to the nearest meter.

Parameters measured across each stand included elevation (ELEV), landform index (LFI), plot surface shape (PSS), aspect (ASPECT), cove area surrounding each study site (COVEHA), total cove area within 1 km of each study site (COVEKM), and stand basal area (BASAL). With the exception of BASAL, these variables were computed from digital terrain models using analytical procedures in ARC/INFO GRID® geographic information software. LFI indicates the degree to which a site is sheltered by surrounding landforms; lower values (≤ 0.15) reflect a less-sheltered position (McNab, 1993). The PSS characterizes the degree of convexity or concavity by comparing the elevation at the center of each study site to elevations of the immediate surrounding landscape (approximately 1 ha). Values typically range from -1.0 (highly concave) to 1.0 (highly convex). Aspect values were linearized using the formula $(1 - \text{cosine (aspect in degrees)}) + (1 - \text{sine (aspect in degrees)})$ so that northeasterly aspects had the lowest values and southwesterly aspects the highest. COVEHA was defined as the area with an $\text{LFI} > 0.24$ (highly sheltered sites), or $0.25 > \text{LFI} > 0.15$ and $\text{PSS} < -0.025$ (less sheltered, but concave sites) at each study stand. Threshold values for LFI and PSS were determined based on prior experience of one of the authors (Odom, 1996) and others (McNab, 1993, 1996) in using these indices to quantify topography in the southern Appalachians. To compute COVEKM, the total area defined as "cove" within 1 km of each study site was summed using proximity and overlay functions in ArcView® Spatial Analyst. BASAL was calculated using a 10-factor handheld prism ($\text{m}^2\,\text{ha}^{-1}$) at each drift-fence array and averaged across each stand (Grosenbaugh, 1952), as it is not a particularly meaningful fine-scaled, micro-habitat variable.

Salamander collections were summed by species across all months. Species richness and Shannon's diversity (H' [$\log_e$]) was calculated for each drift-fence array (Pielou, 1966). Although Shannon's diversity calculations often are biased conservatively with actual H' less than observed H' (Kempton, 1979), these measures are used widely in terrestrial ecology research (Magurran, 1988). To test for differences among stand age and to account for the influence of the proximity of water to drift-fence arrays, we analyzed salamander collection data by species richness and diversity, and by species abundance values using analysis of covariance (ANCOVA) (Steel and Torrie, 1980). The experiment-wide error rate was set at $P = 0.05$ and, using Bonferroni's correction method, $P = 0.003$ was used for individual tests (Sokal and Rohlf, 1995). Mean values of species richness and diversity and species abundance values were reported using treatment means adjusted for the covariate DISTANCE (SAS, 1991). To address questions of salamander recovery following timber harvest, we used orthogonal contrasts of treatment means to test for differences between young-aged stands (15- and 25-year-old stands) that originated following modern clearcutting versus the oldest stands (≥ 85 years), between young-aged stands and 50-year-old stands, and between 50- and ≥ 85-year-old stands (Montgomery, 1991; SAS, 1991). To assess the importance of micro-habitat variables on salamanders, Spearman's rank correlations were performed between richness and diversity values and species collection values with drift-fence micro-habitat variables. To assess the importance of stand-level landscape variables on salamander relative abundance, Spearman's rank correlations were performed between richness, diversity, and species collection values averaged across each stand with topographic metrics.

3. Results

During the 60,060 pitfall trapnight effort, we collected 3937 salamanders. This included 184 *Desmognathus aeneus* (Brown and Bishop), 59 *Desmognathus monticola* (Dunn), 392 *Desmognathus ocoee* (Nicholls), 21 *Desmognathus quadramaculatus* (Holbrook), 626 *Eurycea bislineata* (Green), 45 *Gyrinophilus porphyriticus* (Green), 17 *Pseudotriton ruber* (Latreille), 2,556 *Plethodon glutinosus* (Green), 30 *Plethodon serratus* Grobman, and 7 *Notophthalmus viridescens* (Raf.). Stand age effects were significant and distance from drift-fence arrays to water was a significant covariate for species richness and diversity measures (Table 1). Species richness and diversity measures were greater in ≥85-year-old stands than in young-aged stands or 50-year-old stands (Table 2). *Desmognathus quadramaculatus*, *Pseudotriton ruber*, *Plethodon serratus*, and *Notophthalmus viridescens* collections were excluded from individual ANCOVA tests due to low overall collection numbers. Stand age effects were significant for all other species except

Table 1

Analysis of covariance table for salamander species richness, Shannon's diversity, and species relative abundance among cove hardwood stands 15, 25, 50, and ≥85 years of age for 60,060 pitfall trapnights on the Chattahoochee National Forest, Georgia, 1994–1995[a]

Source	d.f.	SS	MS	*F*	*P*
Species richness					
AGE	3	15.42	5.14	5.34	0.0025
DISTANCE	1	25.28	25.28	26.25	0.0001
Error	60	57.78	0.96		
Shannon's diversity					
AGE	3	1.92	0.65	11.75	0.0001
DISTANCE	1	1.46	1.46	26.14	0.0001
Error	60	3.36	0.06		
Desmognathus aeneus					
AGE	3	16.10	5.37	8.16	0.0001
DISTANCE	1	2.98	2.98	4.55	0.0371
Error	60	39.46	0.66		
Desmognathus monticola					
AGE	3	0.37	0.122	0.17	0.9155
DISTANCE	1	4.99	4.99	6.99	0.0104
Error	60	42.85	0.714		
Desmognathus ocoee					
AGE	3	60.32	20.11	7.81	0.0002
DISTANCE	1	38.93	38.93	18.05	0.0001
Error	60	129.46	2.15		
Eurycea bislineata					
AGE	3	50.47	16.82	14.82	0.0001
DISTANCE	1	7.02	7.02	6.19	0.0157
Error	60	68.09	1.13		
Gyrinophilus porphyriticus					
AGE	3	2.27	0.76	1.90	0.1398
DISTANCE	1	4.15	4.15	10.36	0.0021
Error	60	24.03	0.40		
Plethodon glutinosus					
AGE	3	51.63	17.21	5.57	0.0019
DISTANCE	1	0.12	0.12	0.04	0.8448
Error	60	185.31	3.08		

[a] Stand age = AGE and distance from drift-fence array to water = DISTANCE.

Table 2
Mean salamander species richness, Shannon's diversity, and species relative abundance, and contrasts adjusted for distance from drift-fence array to water covariate among cove hardwood stands 15, 25, 50, and ≥85 years of age for 60,060 pitfall trapnights on the Chattahoochee National Forest, Georgia, 1994–1995[a]

	Stand age (years)			
	15	25	50	≥85
Species richness[b]				
Mean	3.77	4.06	4.14	5.01
S.E.	0.25	0.27	0.26	0.22
Shannon's diversity[c]				
Mean	0.55	0.54	0.45	0.88
S.E.	0.06	0.06	0.06	0.05
Desmognathus aeneus[d]				
Mean	1.20	1.28	0.76	2.09
S.E.	0.21	0.22	0.22	0.18
Desmognathus monticola[e]				
Mean	0.38	0.30	0.33	0.49
S.E.	0.22	0.23	0.23	0.18
Desmognathus ocoee[f]				
Mean	1.11	1.39	0.07	2.71
S.E.	0.38	0.40	0.39	0.33
Desmognathus quadramaculatus[g]				
Mean	0.02	0.12	0.10	0.49
S.E.	0.12	0.13	0.13	0.11
Eurycea bislineata[h]				
Mean	2.36	4.53	2.04	2.37
S.E.	0.28	0.29	0.29	0.24
Gyrinophilus porphyriticus[i]				
Mean	0.58	0.19	0.30	0.64
S.E.	0.16	0.17	0.17	0.14
Pseudotriton ruber[g]				
Mean	0.12	0.56	0.12	0.05
S.E.	0.12	0.12	0.12	0.10
Plethodon glutinosus[j]				
Mean	5.18	7.37	6.39	5.18
S.E.	0.45	0.48	0.47	0.39
Plethodon serratus[g]				
Mean	0	0	0.92	0
S.E.	0	0	0.14	0
Notophthalmus viridescens[g]				
Mean	0.15	0	0.13	0.15
S.E.	0.07	0	0.08	0.07

[a] Means are reported by total trapnights per individual array (924 pitfall trapnights) across individual stand ages ($n = 15$ arrays each in stands aged 15, 25, and 50 years and $n = 20$). For contrasts, YG represents stands aged 15 and 25 years.

[b] Contrasts: YG < 85 ($P = 0.0003$), YG = 50 ($P = 0.4892$), 50 < 85 ($P = 0.0149$).

[c] Contrasts: YG < 85 ($P = 0.0001$), YG = 50 ($P = 0.2387$), 50 < 85 ($P = 0.0001$).

[d] Contrasts: YG < 85 ($P = 0.007$), YG = 50 ($P = 0.0798$), 50 < 85 ($P = 0.0001$).

[e] Contrasts: YG = 85 ($P = 0.5513$), YG = 50 ($P = 0.9622$), 50 = 85 ($P = 0.5894$).

[f] Contrasts: YG < 85 ($P = 0.0011$), YG > 50 ($P = 0.0196$), 50 < 85 ($P = 0.0001$).

[g] Excluded from ANCOVA (see text).

[h] Contrasts: YG > 85 ($P = 0.001$), YG > 50 ($P = 0.0002$), 50 = 85 ($P = 0.3797$).

[i] Contrasts: YG = 85 ($P = 0.1769$), YG = 50 ($P = 0.6902$), 50 = 85 ($P = 0.1344$).

[j] Contrasts: YG > 85 ($P = 0.038$), YG < 50 ($P = 0.0001$), 50 = 85 ($P = 0.0551$).

Desmognathus monticola and *Gyrinophilus porphyriticus* (Table 1). Distance from drift-fence arrays to water was a significant covariate for all species tested except *Plethodon glutinosus* (Table 1). Relative abundances of *Desmognathus aeneus* and *Desmognathus ocoee* were greater in ≥85-year-old stands than in either young-aged or 50-year-old stands (Table 2). Relative abundances of *Eurycea bislineata* and *Plethodon glutinosus* were greater in young-aged stands than in ≥85-year-old stands (Table 2).

Species richness, species diversity, and the relative abundances of salamanders were not significantly correlated with most micro-habitat variables measured, notably LITTER, SOIL, CWD, LGCWD, and DECAY. Abundances of *Plethodon glutinosus* and *Plethodon serratus* were negatively correlated with CANOPY (Table 3). Species richness, species diversity and abundance of *Desmognathus ocoee* were positively correlated with ROCK (Table 3). Species richness and diversity measures and collections of *Desmognathus monticola* and *Gyrinophilus porphyriticus* were negatively correlated with DISTANCE (Table 3).

Among stand-level habitat variables, ASPECT and PSS were not correlated with species richness and diversity or with the relative abundances of any individual species. *Plethodon glutinosus* was positively correlated with ELEV (Table 4). *Desmognathus quadramaculatus* was positively correlated with LFI and *Eurycea bislineata* was negatively correlated with LFI (Table 4). Species richness, species diversity, and abundances of *Desmognathus ocoee, Desmognathus quadramaculatus*, and *Gyrinophilus porphyriticus* were positively correlated with COVEHA (Table 4). *Eurycea bislineata* was negatively correlated with COVEHA (Table 4). Species richness, species diversity and abundances of *Desmognathus monticola, Desmognathus ocoee, Desmognathus quadramaculatus,* and *Gyrinophilus porphyriticus* were positively correlated with COVEKM (Table 4). Species richness, species diversity, and collections of *Desmognathus ocoee* and *Desmognathus quadramaculatus* were positively correlated with BASAL (Table 4). *Eurycea bislineata* was negatively correlated with BASAL (Table 4).

Table 3
Spearman's correlation coefficients between micro-habitat variables and species richness, Shannon's diversity, and total abundances of salamanders per pitfall drift-fence array ($n = 65$), in cove hardwood stands 15, 25, 50, and ≥85 years of age on the Chattahoochee National Forest, Georgia, 1994–1995 (see text for variable descriptions)

	r_s	P
CANOPY		
Plethodon glutinosus	−0.3149	0.0106
Plethodon serratus	−0.3395	0.0057
DISTANCE		
Species richness	−0.5228	0.0001
Shannon's diversity	−0.5016	0.0001
Desmognathus monticola	−0.5267	0.0001
Gyrinophilus porphyriticus	−0.4931	0.0001
ROCK		
Species richness	0.4628	0.0001
Shannon's diversity	0.4643	0.0001
Desmognathus ocoee	0.4091	0.0001

Table 4
Spearman's correlation coefficients between stand-level variables and species richness, Shannon's diversity, and total abundances of salamanders in cove hardwood stands ($n = 13$), 15, 25, 50, and ≥85 years of age on the Chattahoochee National Forest, Georgia, 1994–1995 (see text for variable descriptions)

	r_s	P
BASAL		
Species richness	0.6384	0.0189
Shannon's diversity	0.5714	0.0413
Desmognathus ocoee	0.6443	0.0175
Desmognathus quadramaculatus	0.6241	0.0225
Eurycea bislineata	−0.5659	0.0438
COVEHA		
Species richness	0.5703	0.0419
Shannon's diversity	0.6056	0.0283
Desmognathus ocoee	0.6344	0.0199
Desmognathus quadramaculatus	0.5892	0.0341
Eurycea bislineata	−0.5556	0.0487
Gyrinophilus porphyriticus	0.5892	0.0341
COVEKM		
Species richness	0.6143	0.0255
Shannon's diversity	0.6217	0.0233
Desmognathus monticola	0.6008	0.0299
Desmognathus ocoee	0.5773	0.0388
Desmognathus quadramaculatus	0.7661	0.0023
Gyrinophilus porphyriticus	0.5849	0.0357
ELEV		
Plethodon glutinosus	0.7307	0.0045
LFI		
Desmognathus quadramaculatus	0.6545	0.0152
Eurycea bislineata	−0.5580	0.0475

4. Discussion

Our findings that salamander species richness and diversity measures and the relative abundance of salamander species, notably *Desmognathus* spp., were lower in young-aged cove hardwood stands relative to those ≥85 years-old is consistent with other research in the southern Appalachians (Ash, 1988; Petranka et al., 1993, 1994; Harpole and Haas, 1999). Similar trends have been reported in other environments (Blymer and McGinnes, 1977; Enge and Marion, 1986; Pough et al., 1987; Dupuis et al., 1995). Although stand age impacts to *Desmognathus* spp. could be a result of stream degradation and siltation rather than changed overstory conditions (Petranka et al., 1994), we assume that stream siltation in the 15 and 25-year-old stands we studied following timber harvest under US Forest Service stewardship was minimal. With some precautions, sediment load increases in aquatic systems from logging are generally short-lived in the Appalachians (Kochenderfer et al., 1997). Furthermore, species such as *Desmognathus aeneus* and *Desmognathus ocoee* often occur far from water. We believe that our year-round sampling effort and closely matched study areas provide strong evidence that clearcutting in southern Appalachians cove hardwood forests similar to those we surveyed on the BRD does negatively impact several salamander species. Assuming our older stands represent intact salamander communities in terms of richness and abundance, it appears from our analysis that recovery following clearcutting exceeds 50 years in these cove hardwood stands. We agree with the assertions of Petranka et al. (1994) that lower salamander numbers found in the initial years following timber harvest might not represent a threat in terms of overall species viability. However, the duration of these lowered numbers or altered community assemblages could represent a loss of biodiversity and or diminished ecosystem function. Accordingly, this would be in conflict with the charge of biodiversity maintenance and preservation of ecological processes that has been given to public land managers in the Southeast (Sharitz et al., 1992).

The relative abundances of some species were either unaffected by stand age or showed a negative relationship between increasing stand age and relative abundance. *Desmognathus monticola*, *Gyrinophilus porphyriticus*, and *Pseudotriton ruber*, collected in small numbers, were closely tied to seeps and streams found on our study sites, rather than in the surrounding forest, so stand age may have had little impact. All seven *Notophthalmus viridescens* collected were the terrestrial juvenile red eft stage. *Plethodon glutinosus* and *Eurycea bislineata* were more common in young-aged stands than in older cove hardwood stands in our study. Petranka et al. (1993) detected no difference in numbers of *Plethodon glutinosus* in high elevation forests in the southern Appalachians of western North Carolina between mature forest stands and stands ≥10 years of age. Although more xeric compared to the cove hardwood stands we studied, Ash (1988) noted that *Plethodon glutinosus* disappeared in recently clearcut oak-hickory (*Carya* sp.) stands in western North Carolina. Although *Eurycea bislineata* is aquatic in its breeding ecology, the species is distributed throughout mesic forests in the southern Appalachians (Wilson, 1995; Petranka, 1998). *Plethodon serratus* occurred in only two of the 50-year-old stands we surveyed. We selected study sites within a confined geographic area to reduce the possibility of sampling areas with dissimilar salamander communities, however, these two sites with *Plethodon serratus* occur at the species' easternmost distributional limit in north Georgia. All *Plethodon serratus* were collected in the fall and would not have been detected had we limited sampling to the spring or summer months.

Correlations of richness and diversity measures and relative salamander abundances with habitat variable correlates such as CANOPY or BASAL are not unusual. These variables are related to stand age that our data indicate is highly related to salamander abundance. The correlation between LFI and the relative abundance of *Desmognathus quadramaculatus* probably reflects the association with high LFI values and the presence of larger streams in the most concave cove sites. Species richness and diversity measures and abundance of *Desmognathus ocoee* correlates with ROCK may show the significance that emergent rock has for microsite moisture retention, refugia and feeding substrate important to woodland salamanders (DeMaynadier and Hunter, 1995). Indeed, emergent rock may have served as one of the primary long-term refugia and colonization sources for Plethodontids throughout the central and southern Appalachians following the widespread and destructive timber harvests in the early 1900's (T. Pauley, personal communication). Conversely, other variables such as LITTER, SOIL, CWD, LGCWD, and DECAY that varied across stands (see Ford et al., 1997, 2000), may have been well within upper or lower thresholds that would show significant correlations with salamander abundance. Although leaf litter does decline following clearcutting (Ash, 1995) and may take many years to return to pre-harvest depths (Likens et al., 1978), tree growth and stand development on cove hardwood sites in the southern Appalachians are rapid (Beck and Hooper, 1986) such that litter inputs and leaf litter cover may be relatively high within a few years following regeneration. Stands $\geq$85 years old contained the largest amounts of CWD and LGCWD, however, all of the young-aged stands we surveyed still contained considerable amounts of residual debris from the previous stand, much of which was at an advanced level of DECAY.

Our data clearly demonstrate that cove hardwood habitat area and the amount of nearby cove hardwood habitat as measured in the variables COVEHA and COVEKM are important factors influencing salamander abundance and species richness and diversity. Salamander abundance might decline due to changes in micro-habitat following clearcutting or from the effects of changed intra-specific or inter-specific competition or increased predation (Kramer et al., 1993; Petranka et al., 1993; Ash and Bruce, 1994). Regardless, the surrounding forest and connecting riparian areas might serve as the most important "source" for salamander recolonization (Dupuis et al., 1995). The salamander communities in our cove hardwood study sites that were imbedded in larger matrices of connected cove habitat or nearby cove habitat had the ability to recover more quickly from clearcutting than those that are more isolated from similar habitat (Fig. 2). In addition to stand-level management considerations for salamanders, such as leaving uncut patches within harvested stands, riparian area protection, and coarse woody debris retention throughout (Dupuis et al., 1995), landscape connectivity should be considered because it potentially aids recolonization of altered or fragmented habitats (DeMaynadier and Hunter, 1995) and helps maintain genetic integrity (Gibbs, 1998). Maintaining landscape connectivity and minimizing habitat fragmentation is a well-accepted tenet of conservation biology (Burkey, 1995) that has direct application in the conservation of the salamander communities we studied. Although current trends show a drastic decline in timber harvest on public lands in the southern Appalachians (Ford et al., 1997), forest managers may need to address salamander conservation at landscape scales, rather than solely at the stand-level. Additional experimental research linking landscape connectivity, forest management, and salamander conservation in the southern Appalachians in cove hardwood and other forest types seems warranted.

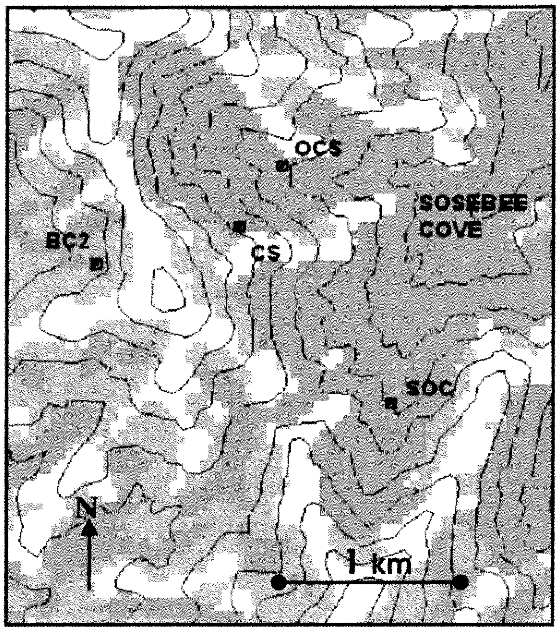

Fig. 2. Illustration of cove hardwood patch sizes surrounding pitfall drift-fence arrays in the Wolf Creek Watershed (CS, OCS, SOC) and the Miller Cove Watershed (BC2) on the Chattahoochee National Forest, Georgia, 1994–1995. Dark gray areas signify mesic, cove hardwood habitat, light gray areas signify drier sideslopes, and white areas signify xeric ridges as determined by GIS analysis. Salamander species richness and diversity is positively correlated to area of connected cove hardwood habitat (see text for complete discussion).

Acknowledgements

Funding for this study was provided by a challenge-cost share agreement between the USDA Forest

Service, Chattahoochee National Forest and the University of Georgia Museum of Natural History and NSF Grant BSR90116611. Special thanks goes to J. Boone, S. Castleberry, D. Krishon, P. Hale, L. Lepardo, T. McCay, and D. Weinand for field and lab assistance. K. Barker led collection crews and supervised specimen cataloging efforts. T. Pauley, L. Muller, J. Wentworth, and two anonymous reviewers reviewed earlier drafts of this manuscript. Without the leadership of the late J. Laerm, Director of the University of Georgia Museum of Natural History, this portion of the Chattahoochee Cove Biodiversity Project never would have been completed.

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