RELATIVE ABUNDANCE AND SPECIES RICHNESS OF TERRESTRIAL SALAMANDERS ON HARDWOOD ECOSYSTEM EXPERIMENT SITES BEFORE HARVESTING

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Abstract.—Terrestrial salamanders are ideal indicators of forest ecosystem integrity due to their abundance, their role in nutrient cycling, and their sensitivity to environmental change. To understand better how terrestrial salamanders are affected by forest management practices, we monitored species diversity and abundance before implementation of timber harvests within the forested landscape of the Hardwood Ecosystem Experiment in Indiana. We monitored 66 cover-object grids in fall 2007 and spring 2008 and conducted quadrat surveys at each grid in spring 2008. Cover-object sampling and quadrat surveys detected six salamander species. The most commonly encountered species were eastern red-backed (*Plethodon cinereus*) (n=3621 encounters) and northern zigzag salamanders (*P. dorsalis*) (n=1603 encounters). Mean salamander encounters per sampling occasion found by cover objects ranged among units from 6.6 to 11.1, whereas those found by quadrat surveys ranged from 1.5 to 7.3. Treatment types did not differ according to cover-object data, but quadrat surveys found greater mean encounter rates in control and even-aged units than in uneven-aged units. Encounter rates were greater during spring sampling compared to fall, and rates were greater on northeast-facing slopes in general.

INTRODUCTION

Terrestrial salamanders (family Plethodontidae) serve as excellent indicators of forest ecosystem health due to their important function in the ecosystem and their sensitivity to changes in the environment (Welsh and Droege 2001). These species are abundant vertebrates in eastern U.S. forests, occurring in densities as high as two per square meter (Jaeger 1980, Petranka 1998) and making up a large proportion of the biomass in forest habitats (Burton and Likens 1975). As top predators in the soil, terrestrial salamanders facilitate nutrient cycling by preying on small invertebrates and being consumed by larger predators (Davic and Welsh 2004). Lacking lungs, plethodontid salamanders require cool, moist microhabitats to facilitate cutaneous respiration (Petranka 1998). Furthermore, most members of Plethodontidae are terrestrial breeders with small territories, suggesting a limited ability to disperse in the wake of a disturbance (Kleeberger and Werner 1982, Welsh and Droege 2001). The high abundance of terrestrial salamanders, their role in nutrient cycling, their sensitivity to desiccation, and their limited dispersal ability make them a useful group to monitor before and after forest disturbance, because negative effects on salamanders could reflect negative effects on the wider ecosystem.

Previous studies on the effects of timber harvest techniques on salamanders have produced conflicting results and differ widely in duration, scale, region, and technique (deMaynadier and Hunter 1995). Many studies have found higher abundance of salamanders

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in mature forest stands compared to recent clearcuts (Grialou et al. 2000, Herbeck and Larsen 1999, Petranka et al. 1993), but Renken et al. (2004) found no differences in abundance among 13 herpetofaunal species up to 3 years post-harvest. Researchers disagree on the time it takes salamander populations to recover following clearcutting; estimates range from 15-20 years (Duguay and Wood 2002) to 50-60 years (Ford et al. 2002, Petranka et al. 1993, Pough et al. 1987).

The effects of other timber harvest techniques such as group selection cuts and shelterwoods are less clear than those of clearcuts. Some research indicates that negative effects may be mitigated by basal area left on site (Harpole and Haas 1999, Knapp et al. 2003, Ross et al. 2000). Other studies suggest effects may be short-lived but that repeated entries of multi-stage harvests could interfere with salamander population recovery (Morneault et al. 2004). Given the wide variation in study design and the sometimes conflicting conclusions of past research, further investigation is needed to understand how timber harvests affect terrestrial salamanders.

We examine the effects of even-aged and uneven-aged forest management on terrestrial salamanders within the context of the Hardwood Ecosystem Experiment (HEE). Objectives are to:

1. Compare salamander diversity and relative abundance across all treatment areas before harvesting,
2. Resample across treatment areas after timber harvests to examine effects of forest management on salamander diversity and relative abundance,
3. Evaluate salamander detection using multiple sampling techniques, and
4. Determine how salamander relative abundance and diversity are affected by proximity to a forest clearcut edge.

This paper describes the methods and results of pre-harvest data collection (objective 1), which took place in fall 2007 and spring 2008.

STUDY AREA

The study took place in Morgan-Monroe State Forest (MMSF) and Yellowwood State Forest (YSF) in Morgan, Monroe, and Brown Counties in south-central Indiana. The area is characterized by a mixture of oak-hickory (*Quercus-Carya*) and American beech-maple (*Fagus grandifolia-Acer*) forest across steep ridges and valleys. The study area and the HEE study design are described in detail by Kalb and Mycroft (this publication).

MATERIALS AND METHODS

Sampling

In May 2007, we established 66 cover-object grids throughout the 9 HEE study areas. Cover objects were 30cm x 30cm x 5cm untreated pine boards. Grids consisted of 30 objects arranged in a 6 x 5 array with 5-m spacing between each object (Fig. 1). Each object was placed in direct contact with the soil, with leaf litter and debris scraped away. Each of the three control units received two randomly placed grids. The three uneven-aged management units received eight grids each, one inside each of the eight areas designated for harvest openings (see Kalb and Mycroft, this publication: Fig. 5). The 3 even-aged management units received 12 grids each, 2 inside and 1 outside (at least 40 m from edge) of each of the 4 areas designated for harvest (see Kalb and Mycroft, this publication: Fig. 2).

Grids were placed approximately mid-slope and, to the extent possible, each management type received an equal number of grids on northeast- and southwest-facing slopes. North- and east-facing slopes tend to receive less solar energy and retain more precipitation than south- and west-facing slopes (Chen et al. 1999); thus, we tried to equalize sampling effort between these two extremes. Daytime searches of cover-object grids were conducted five times at 2-week intervals during September-November 2007 and four times at 2-week intervals during March-April 2008, before the implementation of harvests. Observers recorded the

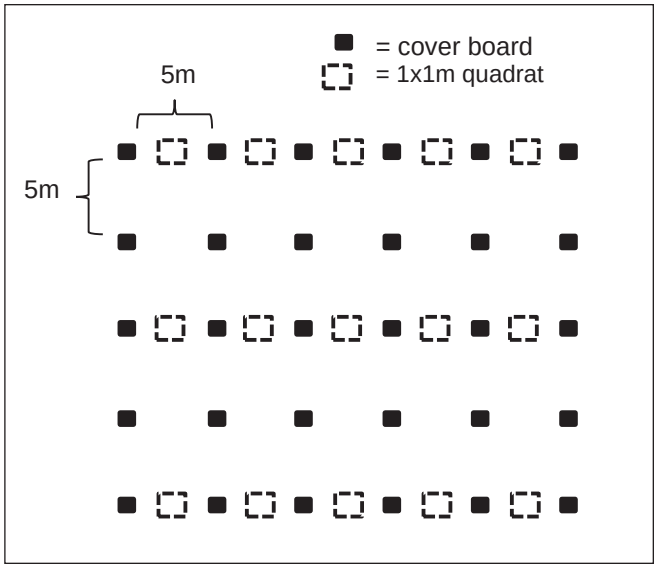

Figure 1.—Diagram of cover-object grid and quadrat placement. Cover objects were 30cm x 30cm x 5cm untreated pine boards spaced 5 m apart and placed in contact with the soil. Quadrats were 1m x 1m squares placed systematically between cover objects. During the first round of quadrat surveys in spring 2008, quadrats were placed on rows 1, 3, and 5 as shown here; during the second search they were placed on rows 2 and 4 and 5 m below row 5.

species and age class (adult snout-vent length [SVL] ≥34 mm; juvenile SVL ≤33 mm) (Petranka 1998) of salamanders found under objects.

Detection of terrestrial salamanders by any one sampling technique is imperfect because salamander surface activity varies with rainfall, soil moisture, and temperature (Hyde and Simons 2001, Jaeger 1980, Williams and Berkson 2004). The use of multiple sampling techniques may improve estimates of relative abundance (deMaynadier and Hunter 1995, Ryan et al. 2002). Thus, we employed the additional sampling technique of daytime quadrat searches. At each grid, observers carefully sifted through leaf litter and debris inside fifteen 1m x 1m quadrats placed between cover objects (Fig. 1), recording the species and age class of all salamanders encountered. Each grid received 2 such searches during March-April 2008, for a total of 1,980 quadrat searches. During the second round of quadrat sampling, the 15 plots were shifted downslope 5 m to avoid repeated disturbance of the same square-meter plots.

Habitat Characteristics

Detection of salamanders by artificial cover objects may vary depending on the amount of natural cover available (Hyde and Simons 2001). To determine if sites varied in natural cover prior to harvests, we measured volume of down woody debris (d.w.d.) using a line-intercept method (Kaiser 1983) at each cover-object grid in spring 2008. Observers walked two 20-m linear transects, 5 m upslope and 5 m downslope of the grid, and recorded the diameter of each piece of d.w.d. ≥10 cm at the point of intersection. Volume was calculated as described by Van Wagner (1968).

Precipitation and soil moisture may influence salamander surface activity; therefore, we obtained records of daily precipitation from National Oceanic and Atmospheric Administration cooperative stations (Martinsville 2SW, ID#125407 for Units 1-4; Nashville 2NNE, ID#126056 for Units 5-9) and determined the amount of precipitation that occurred during the 48 hours before each sampling occasion. We sampled soil moisture each time quadrat surveys were conducted in spring 2008 by taking five samples, one at each of the four corners and one at the center of each grid, with a soil probe to a depth of 10 cm. Soil samples were weighed wet, dried in an incubator at 40 °C for 5 days, and weighed dry to determine percentage moisture ([1 – (dry weight/wet weight)] x 100 percent). We averaged the values from the five samples taken at each grid to find mean percentage soil moisture.

Data Analysis

We standardized captures by sampling effort and present them as mean encounters per sampling occasion, where one sampling occasion is one check of a single grid. In determining the number of sampling occasions, we adjusted for missing or disturbed objects by subtracting the total proportion of disturbed grids from the total number of sampling occasions. Sample sizes (number of grids) differed by management type (e.g., unit 4 had 2 grids; unit 3 had 12 grids), so relatively high or low mean encounters presented herein may not reflect statistically significant trends.

In comparisons of slope aspects, grids were categorized as either northeast- or southwest-facing based on an azimuth taken in the middle of the top row of objects. Grids with an azimuth between 345° and 105° were categorized as "northeast" (N = 24); grids with an azimuth between 165° and 285° were categorized as "southwest" (N = 20). These categories include the compass range from north to east (0-90°) and from south to west (180°-270°), plus a buffer of 15° on either side. These wide ranges, though not strictly northeast and southwest, allowed us to include a similar number of grids within each category while excluding grids that more directly faced northwest and southeast. We excluded these "intermediate" (i.e., northwest and southeast) grids in slope comparisons because we expected they would mask slope effects between northeast and southwest slopes. This method resulted in 44 grids being included and 22 grids being omitted from slope comparisons.

RESULTS

The results presented in this paper are chiefly totals and averages. Detailed statistical comparisons of pre- and post-harvest data are presented elsewhere (MacNeil 2011).

During fall 2007-spring 2008, we encountered 5,092 salamanders of 5 species at the 66 cover-object grids (Table 1). Two species, eastern red-backed salamander (*Plethodon cinereus* Green), and northern zigzag salamander (*P. dorsalis* Cope), were encountered on every site in both seasons and collectively accounted for 89 and 97 percent of all encounters in fall 2007 and spring 2008, respectively. Mean encounters under cover objects for all species pooled ranged among units from 6.6 to 11.1 per sampling occasion (Table 1).

During spring 2008, we encountered 464 salamanders of 4 species in quadrat surveys (Table 2). Red-backed and zigzag salamanders were detected in all units and made up 98 percent of all encounters. Quadrat surveys did not detect southern two-lined (*Eurycea cirrigera* Green) or spotted salamanders (*Amybystoma maculatum* Shaw) but did detect eastern newts (*Notophthalmus viridescens* Rafinesque), which were not found under cover objects during the pre-harvest period. Mean encounters from quadrat surveys were much lower than those found by cover objects, ranging among units from 1.5 to 7.3 per sampling occasion (Table 2).

Table 1.—Total salamander encounters under wood cover objects at HEE units 1-9 during the pre-treatment period (fall 2007-spring 2008). Values in parentheses are mean encounters per sampling occasion.[a]

	Species[b]					
HEE unit	REBA	ZIZA	NOSL	SOTW	SPSA	Total
1	377 (5.2)	161 (2.2)	36 (0.5)	1 (0.0)	0	575 (8.0)
2	126 (7.0)	26 (1.4)	13 (0.7)	0	0	165 (9.2)
3	762 (7.1)	248 (2.3)	68 (0.6)	15 (0.1)	0	1,093 (10.1)
4	125 (6.9)	64 (3.6)	11 (0.6)	0	0	200 (11.1)
5	114 (6.3)	52 (2.9)	1 (0.1)	2 (0.1)	0	169 (9.4)
6	530 (4.9)	314 (2.9)	48 (0.4)	0	0	892 (8.3)
7	463 (6.4)	187 (2.6)	8 (0.1)	13 (0.2)	0	671 (9.3)
8	385 (5.3)	189 (2.6)	17 (0.2)	43 (0.6)	0	634 (8.8)
9	438 (4.2)	209 (2.0)	17 (0.2)	27 (0.3)	2 (0.0)	693 (6.6)
Total	3,320	1,450	219	101	2	5,092

[a] Sampling occasions are the product of the number of grids and the number of times grids were sampled within each unit. Numbers of sampling occasions corrected for missing and disturbed objects were as follows: 72 for units 1, 7, and 8; 18 for units 2, 4, and 5; 107.8 for unit 3; 108 for unit 6, and 104.7 for unit 9.

[b] REBA=eastern red-backed salamander; ZIZA=northern zigzag salamander; NOSL=northern slimy salamander; SOTW=southern two-lined salamander; SPSA=spotted salamander

Table 2.—Total salamander encounters in quadrat surveys at HEE units 1-9 during the pre-harvest period (spring 2008). Values in parentheses are mean encounters per sampling occasion.[a] Abbreviations and methods of computation follow Table 1.

	Species				
HEE unit	REBA	ZIZA	NOSL	NEWT[b]	Total
1	28 (1.8)	6 (0.4)	2 (0.1)	0	36 (2.3)
2	13 (3.3)	2 (0.5)	0	0	15 (3.8)
3	70 (2.9)	39 (1.6)	2 (0.1)	1 (0.0)	112 (4.7)
4	15 (3.8)	14 (3.5)	0	0	29 (7.3)
5	9 (2.3)	4 (1.0)	0	0	13 (3.3)
6	69 (2.9)	51 (2.1)	5 (0.2)	0	125 (5.2)
7	29 (1.8)	4 (0.3)	0	0	33 (2.1)
8	17 (1.1)	7 (0.4)	0	0	24 (1.5)
9	51 (2.1)	26 (1.1)	0	0	77 (3.2)
Total	301	153	9	1	464

[a] Numbers of sampling occasions were as follows: 16 for units 1, 7, and 8; 4 for units 2, 4, and 5; 24 for units 3, 6, and 9.
[b] NEWT=eastern newt (red eft)

We pooled encounters in the nine units by treatment to determine if salamander populations differed among treatment types before timber harvests. Data from cover objects showed few differences across treatment in mean encounters of all species (both individually and pooled; Fig. 2a). Quadrat surveys found higher encounter rates of all species pooled in control and even-aged units compared to uneven-aged units. This difference was driven largely by lower encounters of zigzag salamanders in uneven-aged units, although encounters of red-backed salamanders were also lower in uneven-aged units compared to the other treatment types (Fig. 2b).

Season affected salamander encounter rates under cover objects. For all species pooled within each unit, mean encounters under cover objects were greater in spring 2008 than in fall 2007 (Fig. 3). When considered individually, however, slimy (*P. glutinosus* Green) and southern two-lined salamanders did not follow this trend; mean encounters of these species were slightly lower in spring 2008 than in fall 2007.

Encounter rates also were affected by an interaction of season and slope aspect. In fall 2007, cover objects on northeast-facing slopes yielded higher mean encounter rates for all species pooled compared to those on southwest-facing slopes (Fig. 4). In spring

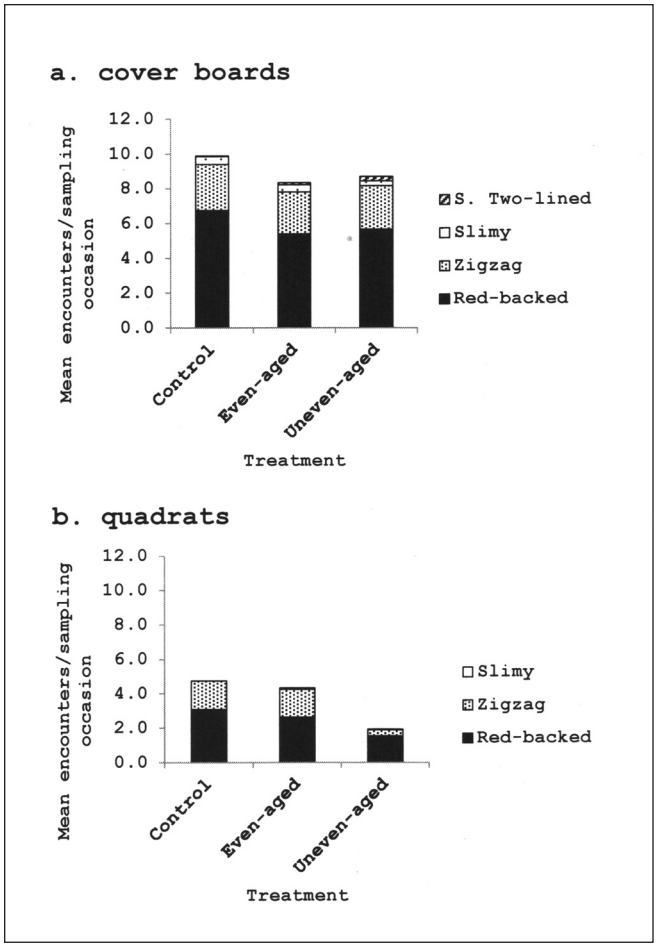

Figure 2.—Mean salamander encounters per sampling occasion found in a) cover-object grids and b) quadrat surveys in control (N=6), even-aged (N=36), and uneven-aged (N=24) HEE management units during the pre-harvest period (fall 2007-spring 2008).

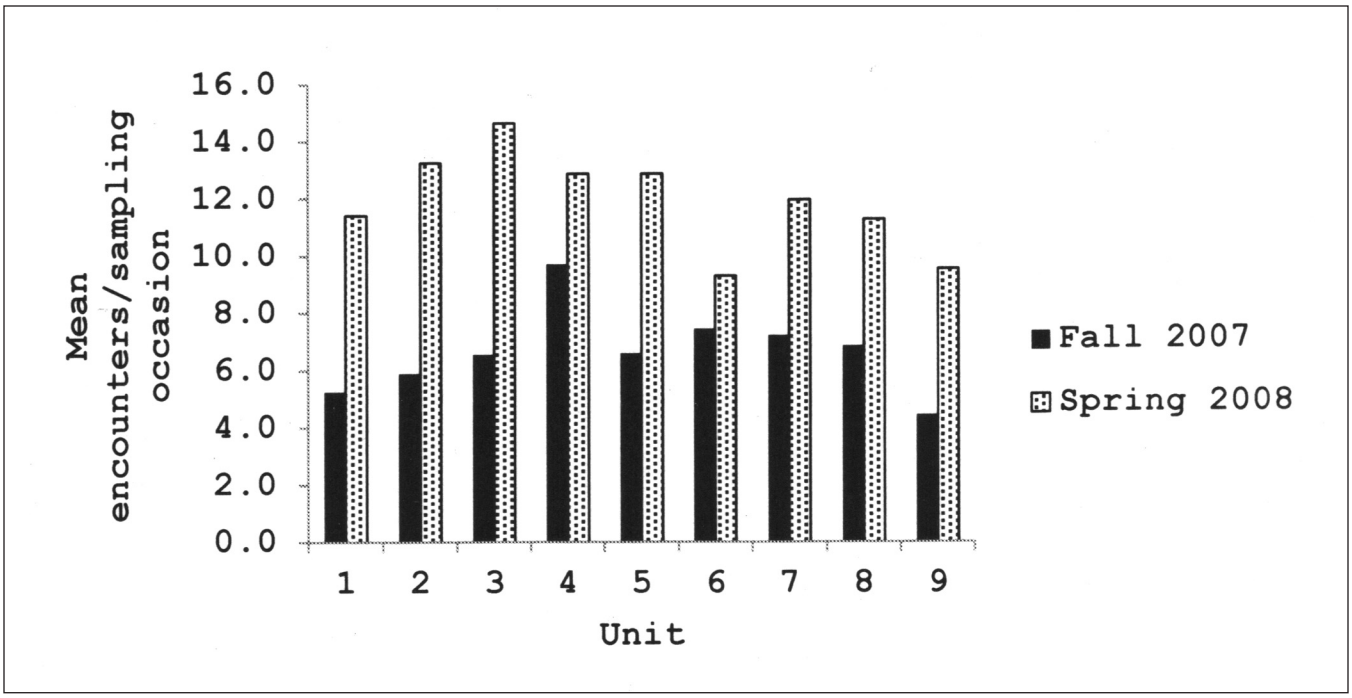

Figure 3.—Mean salamander encounters (all species pooled) per sampling occasion under cover objects in HEE sites 1-9 by season (pre-harvest). Units 2, 4, and 5 are controls; units 1, 7, and 8 are designated for uneven-aged management; units 3, 6, and 9 are designated for even-aged management.

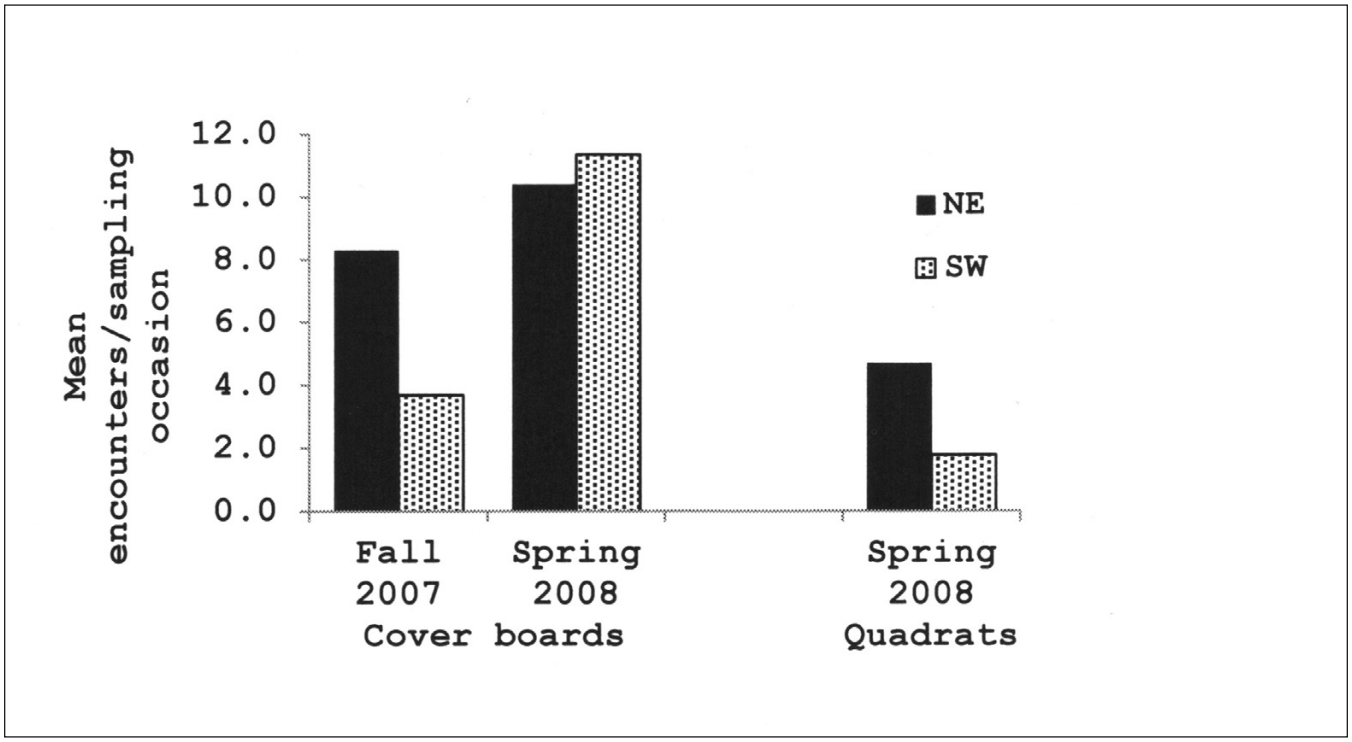

Figure 4.—Mean salamander encounters (all species pooled) per sampling occasion under cover objects and in quadrat surveys on northeast (NE, azimuth between 345° and 105°; N=24) and southwest (SW, azimuth between 165° and 285°; N=20) slopes in HEE sites in fall 2007 and spring 2008. Quadrat surveys were not conducted in fall 2007.

2008, this trend reversed such that the pooled mean encounters were slightly greater on southwest-facing slopes. Quadrat surveys on northeast-facing slopes yielded higher mean encounters of all species pooled compared to quadrat surveys on southwest-facing slopes (Fig. 4). Thus, the slope effect found by quadrats in spring 2008 resembled that found by cover objects in fall 2007, rather than that found by cover objects in spring 2008.

SUMMARY AND FUTURE WORK

Cover-object arrays detected five salamander species and quadrat surveys detected four, for a total of six unique salamander species detected in upland forest habitat on the HEE sites during the pre-harvest period. This total is 60 percent of the salamander species that use woody debris in upland, hardwood forests in south-central Indiana (Minton 2001, Williams et al. 2006). Encounter rates under cover objects did not vary greatly by unit or treatment. Quadrat surveys had lower encounter rates than cover objects, and units and treatments may differ according to the quadrat method, particularly with control and even-aged units having higher encounter rates compared to uneven-aged units.

Salamander encounters were greater in spring 2008 than fall 2007. In general, northeast slopes had greater encounter rates than southwest slopes for both cover-object sampling in fall 2007 and quadrat surveys in spring 2008. However, encounter rates were similar regardless of slope type for cover-object sampling in spring 2008, indicating a slope-by-season interaction for cover-object data.

Sampling continued in September-November 2008 on all cover-object grids not made inaccessible by logging activities, and continued on all grids each March-May and September-November from 2009 through 2011. Eighteen cover-object grids were added to control units in July 2009 to increase the total sample size in control units from 6 to 24. Quadrat surveys were conducted again in spring 2009 but were then discontinued due to low capture success. Down woody debris was measured as described above during each spring since harvests were implemented. Post-harvest sampling also involved the addition of 864 cover objects at 6 clearcuts to study the effects of silvicultural edges on terrestrial salamanders. This local-scale study included mass and SVL measurements of individual salamanders, as well as fine-scale habitat measurements such as canopy cover and leaf litter depth. Analysis methods for pre-harvest data are described fully by MacNeil (2011). To describe the analysis briefly, we used a mixed model analysis of variance in SAS 9.2 (SAS Institute Inc., Cary, NC) with fixed factors including unit, treatment, season, slope, and a random factor of grid nested in unit, with check as a repeated measure. “Check” represents a round of sampling (each 2-week period in which each grid was sampled once) and serves as a surrogate for time within a sampling season. Covariates include volume of d.w.d., amount of precipitation during the 48 hours before sampling, and, for quadrat data only, mean soil moisture. This model was used for each age class of each species captured in sufficient numbers.

This study offers several advantages over much of the previous research into the effects of timber harvests on salamanders. Advantages include sampling across the relatively large geographic area encompassed by the HEE, the collection of pre- as well as post-harvest data, the inclusion of both landscape and local scales, and the relatively long study duration (4 years). While this study investigates the immediate effects of harvests on salamanders, most of the sampling arrays will remain in place for continued monitoring in order to study long-term effects. The results of this study will be a valuable contribution to our understanding of how different forest management techniques impact terrestrial salamanders and the wider ecosystem.

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