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# EFFECTS OF CANOPY THINNING BY HEMLOCK WOOLLY ADELGIDS ON THE LOCAL ABUNDANCE OF TERRESTRIAL SALAMANDERS

M. PATRICK BRANNON* and SHELLEY R. ROGERS

*Highlands Biological Station, P.O. Box 580, Highlands NC 28741*

*Abstract:* Terrestrial plethodontid salamanders, because of their ecophysiological requirements, are vulnerable to changes in the forest-floor microclimate as a result of canopy thinning by the hemlock woolly adelgid, *Adelges tsugae*. Repeated searches of natural cover objects for salamanders were conducted in areas with different levels of infestation and associated canopy loss. Several features of the microhabitat were also measured during each survey. Higher capture rates of salamanders occurred in areas with a deep and moist leaf litter layer regardless of the amount of canopy, suggesting that as long as leaf litter remains intact, canopy thinning by the hemlock woolly adelgid should have a minimal effect on local abundances of terrestrial salamanders.

*Key Words:* Canopy; hemlock woolly adelgid; Plethodontidae; salamanders; Southern Appalachians.

## INTRODUCTION

The hemlock woolly adelgid (HWA), *Adelges tsugae* Annand, an introduced aphid-like species that withdraws sap from the base of hemlock needles, is rapidly spreading throughout the hemlock forest ecosystems of the eastern United States (McClure, 1990). The HWA not only damages populations of eastern hemlock [*Tsuga canadensis* (L.) Carr], but it also alters the microclimates they create and their associated communities, leading to an overall reduction in landscape-scale biodiversity (Mahan, 1999). Canopy thinning by the HWA can affect soil temperature and moisture content, and may change hydrological cycles of streams in riparian zones dominated by hemlocks (Evans, 2002).

Salamanders are the most abundant forest-floor vertebrates in the Southern Appalachian Mountains (Petranka et al., 1994). Terrestrial salamanders are vulnerable to potential microclimate changes in HWA-infested forests because of their ecophysiological requirements (Brooks, 2001; Kizlinski et al., 2002). Members of the Family Plethodontidae are at a greater risk of desiccation because they exchange gases dermally (Spotila, 1972; Feder, 1983). Consequently, their microhabitat is restricted to moist soils and areas with generally cooler temperatures (Heatwole and Lim, 1961; Feder, 1983).

Forest-floor leaf litter is a critical microhabitat for salamanders because it retains water (Ash, 1995) and harbors a wide variety of invertebrate prey (Gist and Crossely, 1975). Canopy openings allow more sunlight to penetrate to the forest floor (Phillips and Shure, 1990), resulting in increased temperatures and subsequent drying of the leaf litter (Ash, 1995). Numerous studies have demonstrated the detrimental effect of canopy loss on salamander populations because of timber harvesting, and the resulting reduction of litter depth and moisture (Ash, 1988, 1997; Petranka et al., 1994; Grialou et al., 2000; Hicks

* pbrannon@email.wcu.edu

and Pearson, 2003; Knapp et al., 2003). We examined how changes in the forest-floor microhabitat from canopy thinning by the HWA affected the local abundance of terrestrial salamanders.

## MATERIALS AND METHODS

Three study sites were established in mixed hemlock–hardwood forests of the Nantahala National Forest in the vicinity of Highlands, Macon County, North Carolina. Each 2-ha site was selected based upon established classification parameters for percentage hemlock needle loss in the canopy (Whitley, 2002). Site A (35.076°N, 83.261°W) was classified as "healthy" (<5% loss), and was located near Turtle Pond Road off US 64 S, elevation approximately 1,000 m. This site had a southeasterly orientation and an average slope of 30°. Stand age was approximately 75 yr and consisted primarily of eastern hemlock, red oak (*Quercus rubra* L.), white pine (*Pinus strobus* L.), and tulip poplar (*Liriodendron tulipifera* L.), with a dense understory of rosebay rhododendron (*Rhododendron maximum* L.).

Site B (35.016°N, 83.142°W ) was classified as "in decline" (>50% needle loss), and was located along the Ellicott Wilderness Trail off Bull Pen Road, elevation 850 m. It had a southeasterly orientation and an average slope of 28°. Stand age at this site was 80 yr and consisted of white pine, eastern hemlock, tulip poplar, and red maple (*Acer rubrum* L.), with an understory of rosebay rhododendron.

Site C (35.026°N, 83.160°W) was classified as "intermediate" (≈25% needle loss) and was located along Walkingstick Road near Horse Cove, also at an elevation of 850 m. It had a northwesterly orientation and an average slope of 21°. Stand age was 90 yr and consisted mainly of tulip poplar, eastern hemlock, black birch (*Betula lenta* L.), and red maple.

Nine surveys of salamanders were conducted at each site in October of 2004. Daytime area-constrained searches of natural cover objects have been shown to generate valid indices of salamander diversity (Smith and Petranka, 2000). Coarse woody debris (CWD), especially in the latter stages of decay, serves as daytime refuges for salamanders (Jaeger, 1980b; Petranka et al., 1994). Three 100-m transects, spaced 100 m apart, were established across contours at each site. All CWD ≥7 cm in diameter and in decay classes 3, 4, and 5 (Petranka et al., 1994) was turned along each transect, and the number of each salamander species found was recorded. Logs were returned to their original positions after searching and a minimum of two days' recovery time elapsed between surveys to minimize disturbance.

Diameter and length of each log was measured in cm to obtain volume of salamander habitat searched. Total captures for each transect were converted to capture rate per volume of CWD because search effort was dependent upon the number and size of logs present. Capture rates between sites were analyzed using Student's *t* tests.

Other habitat variables were also measured. A 25-cm$^2$ sample of leaf litter was taken from a randomly selected point along each transect during each salamander survey. Each sample was weighed to obtain wet mass, dried at 80°C for 24 hr, and then re-weighed to obtain dry mass (Ash, 1995). Litter moisture content was calculated as wet mass minus dry mass and expressed as a percentage of wet mass. Measurements of litter depths for each survey were obtained by pressing a metric ruler through the litter to the point of resistance of the soil at points located at 10-m intervals along each transect.

Importance values for hemlocks at each site were obtained using the point-quarter method (Cox, 1996). Average overall percentage canopy cover was determined using a densitometer also at 10-m intervals. Maximum temperature readings (°C) between

Table 1. Values of *t* between pairs of study sites with different levels of hemlock needle loss; site A = "healthy," site B = "in decline," site C = "intermediate."

| Variable | Site A:Site B | Site B:Site C | Site A:Site C |
|---|---|---|---|
| % Canopy Cover | 2.45* | −1.41 | 5.66** |
| Maximum temperatures | −3.97** | −15.21** | 7.55*** |
| Litter depths | −1.06 | −4.33* | 3.49*** |
| % Litter moisture | −0.06 | −2.90** | 2.34** |
| Salamander capture rates | −0.49 | −2.37** | 2.57** |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

surveys were obtained by positioning a maxmin thermometer oriented with slope in the center of each study site. Differences in habitat variables per survey among sites were analyzed using Student's *t* tests. Spearman's rank analysis was used to examine correlations of the means for each habitat variable with salamander capture rates per survey, except for volume of CWD which was correlated with total number of captures per transect.

## RESULTS

Hemlock importance value was 69.97 at healthy site A, 57.63 at site decline site B, and 50.51 at the intermediate site C. Percentage canopy cover differed significantly between sites A and B ($t = 2.45$, $p = 0.05$) and between sites A and C ($t = 5.66$, $p < 0.01$), but not between sites B and C ($t = -1.41$, $p = 0.13$; Table 1). Mean canopy cover (±1 SE) was 78.8 ± 6.1% at site A, 69.7 ± 6.1% at site B, and 66.7 ± 3.1% at site C.

Maximum temperatures were significantly different between sites A and B ($t = -3.97$, $p < 0.01$), sites A and C ($t = 7.55$, $p < 0.001$), and sites B and C ($t = -15.21$, $p < 0.001$; Table 1). Mean maximum temperatures were highest at the decline site B (36.0 ± 0.9°C), lowest at Site C (23.0 ± 1.0°C), and intermediate at the healthy site A (32.8 ± 0.5°C).

Leaf litter depths differed significantly between sites A and C ($t = 3.49$, $p < 0.001$) and between sites B and C ($t = -4.33$, $p = 0.04$), but not between sites A and B ($t = -1.06$, $p = 0.15$; Table 1). Mean litter depth was highest at the decline site B (3.7 ± 0.2 cm), lowest at site C (2.8 ± 0.2 cm), and intermediate at the healthy site A (3.5 ± 0.2 cm). Percentage litter moisture also differed significantly between sites A and C ($t = 2.34$, $p = 0.01$) and between sites B and C ($t = -2.90$, $p < 0.01$), but not between sites A and B ($t = -0.06$, $p = 0.48$; Table 1). Mean litter moisture was 0.50 ± 0.02% at both the healthy site A and the decline site B and 0.44 ± 0.03% at the intermediate site C.

Total volume of CWD per transect was significantly different between sites B and C ($t = 3.55$, $p = 0.04$), but not between sites A and B ($t = 1.84$, $p = 0.10$) or sites A and C ($t = -0.33$, $p = 0.34$; Table 1). Mean overall volume of CWD per transect was 3.3 ± 1.0 $m^3$ at site A, 1.6 ± 0.1 $m^3$ at site B, and 3.7 ± 0.5 $m^3$ at Site C.

Site A yielded the greatest number of salamanders ($n = 44$), whereas Sites B ($n = 24$) and C ($n = 28$) were similar in salamander abundance (Table 2). The gray-cheeked salamander (*Plethodon metcalfi* Brimley) was the most abundant species across all sites. Salamander capture rates were similar between the healthy site A and the decline site B ($t = -0.49$, $p = 0.32$), but did differ significantly between sites A and C ($t = 2.57$, $p = 0.01$) or between sites B and C ($t = -2.37$, $p = 0.01$; Table 1). Mean capture rate was highest at the decline site B (0.66 ± 0.15 salamanders/$m^3$), lowest at the intermediate site C (0.27 ± 0.06), and moderate at the healthy site A (0.59 ± 0.12). Capture rates were significantly

Table 2. Total captures of terrestrial salamanders (n) at each site.

| Species | Common Name | Site A | Site B | Site C |
|---|---|---|---|---|
| *Desmognathus ocoee* Nicholls | Ocoee Salamander | 5 | 3 | 0 |
| *Eurycea wilderae* Dunn | Blue-Ridge Two-lined Salamander | 7 | 4 | 10 |
| *Notophthalmus viridescens* Baird | Eastern Newt (eft) | 0 | 2 | 0 |
| *Plethodon metcalfi* Brimley | S. Gray-cheeked Salamander | 22 | 12 | 13 |
| *P. oconaluftee* (Hairston) | S. Appalachian Salamander | 2 | 1 | 0 |
| *P. serratus* Grobman | S. Red-backed Salamander | 8 | 6 | 1 |
| Totals | | 44 | 24 | 28 |

correlated with litter depth ($r_s = 0.444$, p = .05) and percentage litter moisture ($r_s = 0.435$, p = .05; Table 3).

## DISCUSSION

A tall, stratified canopy moderates extreme weather conditions that might otherwise drastically alter microclimatic conditions on the forest floor. Large canopy gaps permit increased wind effects, greater penetration of solar radiation, and temperature extremes that can cause a reduction in leaf litter depth, dry mass, and moisture content (Ash, 1995; Chen et al., 1999). A deep layer of leaf litter retains moisture required by terrestrial plethodontid salamanders for cutaneous respiration (Spotila, 1972; Feder, 1983) and for deposition and development of eggs (Heatwole, 1961).

Deep leaf litter also harbors an abundance of invertebrate prey (Gist and Crossley, 1975). However, accessibility of prey is variable because foraging time in salamanders is restricted by humidity levels (Jaeger, 1980a). Rotten logs are important moisture refuges during dry periods (Whiles and Grubaugh, 1996), but under extended drought conditions food in these retreats can be depleted (Jaeger, 1980b). If the litter becomes too thin, patchy, or dry, then large populations of salamanders cannot exist (Ash, 1995, 1997).

However, in smaller canopy gaps litter dynamics and associated microclimates may resemble that of surrounding forested areas (Clinton, 2003; Phillips and Shure, 1990) because of the accumulation of allochthonous leaf fall (Shure and Phillips, 1987). For example, canopy thinning was greatest at the decline site B, yet litter depth was similar to that of the intact forest site A. Consequently, litter moisture at site B remained high despite having increased sunlight penetration and warmer temperatures.

Salamander abundance and diversity is related primarily to ground cover (Petranka et al., 1994; Welsh and Droege, 2001). Capture rates in this study were highest where leaf litter remained deep and moist. Presence of a partial canopy and other forest habitat features may adequately retain the microclimatic conditions required by terrestrial

Table 3. Spearman correlation coefficients ($r_s$) of habitat variables with terrestrial salamander capture rates. For volume of CWD, correlation is with total salamander captures.

| Habitat Variable | $r_s$ |
|---|---|
| % Canopy cover | 0.042 |
| Maximum temperatures | 0.400 |
| Litter depths | 0.444* |
| % Litter moisture | 0.435* |
| CWD volume | 0.001 |

* $p \leq 0.05$.

plethodontids in these areas (Greenberg, 2001). Although continued canopy loss could result in an initial reduction of terrestrial salamanders in forests affected by the hemlock woolly adelgid (Brooks, 2001), this study suggests that as long as the leaf litter layer remains intact, the long-term impact will likely be minimal.

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