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Effects of the removal of overstory hemlock from hemlock-dominated forests on eastern redback salamanders

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Abstract

Eastern hemlock (*Tsuga canadensis*) is a common conifer throughout northeastern North America. The species is threatened by the exotic hemlock woolly adelgid (HWA), *Adelges tsugae*; infestation by this forest pest can result in high levels of mortality of overstory trees with a resultant change in understory vegetation composition and structure. Pre-salvage harvesting of overstory hemlock results in a residual stand compositionally and structurally similar to that resulting from mortality due to adelgid infestation, except for the occurrence of standing or fallen dead trees in adelgid infested stands. The vertebrate fauna of hemlock-dominated forests is poorly studied and the effects of the mortality or removal of overstory hemlock on forest fauna in these stands is unknown. This study reports the findings of a 3-year study of the effects of pre- or green-tree salvage of overstory hemlock from hemlock-hardwood stands on terrestrial salamanders. The residual hemlock stocking was reduced an average of 60% following harvesting and the understory vegetation responded vigorously. The relative abundance of eastern redback salamanders was reduced in harvested stands but the effect was ephemeral and salamander numbers appear to be increasing within a few years of the logging. It appears that hemlock defoliation and mortality due to HWA infestation or pre-salvage harvesting of live hemlock will result in only a brief reduction in the principal terrestrial salamander of hemlock-dominated forests. Published by Elsevier Science B.V.

Keywords: Eastern hemlock; *Tsuga canadensis*; Eastern redback salamander; *Plethodon cinereus*; Redback salamander; Hemlock woolly adelgid; *Adelges tsugae*

1. Introduction

Eastern hemlock (*Tsuga canadensis*) is a common conifer in the northeastern and northcentral United States and adjacent Canadian Provinces (Godman and Lancaster, 1990). It is a common associate of three major forest type groups that account for 7% of timberland area in the northeastern states and 57% of timberland in the northcentral states (Powell et al., 1993). In the northern United States, hemlock is estimated to occur on 7.6 million hectares of timberland (Schmidt and McWilliams, 1996). It is a common associate in pine (*Pinus* sp.), spruce-fir (*Picea* sp.–*Abies* sp.) and northern hardwoods forest types. Hemlock also occurs in pure stands or in pure groups within stands dominated by other species. The species is a common conifer in all northeastern states and is the third most common tree species in southern New England (Brooks et al., 1993).

The wildlife resources of hemlock-dominated forests are poorly studied. Reviews of wildlife species

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assemblages of hemlock-dominated forests reference little original research specifically on wildlife in hemlock with the possible exception of white-tailed deer (*Odocoileus virginianus*) and breeding birds (DeGraaf et al., 1992; Benzinger, 1994a,b; Lapin, 1994; Howe and Mossman, 1996; Wydeven and Hay, 1996; Mitchel, 1999; Yamasaki et al., 2000).

There is a common perception that forest-floor fauna in mature hemlock forests are depauperate in composition and number because of a sparse ground cover. Wildlife species richness in hemlock-dominated stands is considerably less than in other common forest types of New England, excluding spruce-fir, at all stand ages (DeGraaf et al., 1992; Yamasaki et al., 2000). Two fully terrestrial salamanders occur in New England. They are known to utilize, though not prefer, hemlock forest, as do the six pond- or stream-breeding amphibian species of the region (DeGraaf et al., 1992).

The health and viability of eastern hemlock has been threatened throughout its range by the introduction and spread of an introduced forest pest, the hemlock woolly adelgid (HWA), *Adelges tsugae*. HWA was first observed in eastern hemlock in Virginia in the early 1950s (Souto et al., 1996). By 1997 it was reported to occur from Massachusetts south through southern New York, New Jersey, eastern Pennsylvania, and along the Appalachian chain through Maryland and Virginia and adjacent West Virginia (Forest Health Protection, 1998). HWA is perceived as a serious threat to hemlock, with high levels of defoliation and mortality expected from the infestation (Evans et al., 1996; Orwig and Foster, 1998; Jenkins et al., 1999).

The potential impacts of hemlock woolly adelgid infestation on the flora and fauna of hemlock-dominated forests are potentially great, but have been poorly studied to date (Evans et al., 1996). In overlapping studies in south-central Connecticut, Orwig and Foster (1998) and Jenkins et al. (1999) describe the response of hemlock-dominated forest stands to HWA infestations. Hemlock mortality is highly variable, with smaller suppressed trees suffering higher mortality rates. Downed woody debris accumulated in stands with severe HWA damage. Canopy disturbance resulted in increased understory light availability, possible increased soil temperature, and a prolific understory response, especially of black birch (*Betula lenta*) seedlings. Neither study assessed faunal response to HWA infestation.

The threat of HWA infestation and subsequent mortality has lead to increased harvesting of hemlock, particularly in southern New England (Foster, 2000). The effects of the removal of overstory hemlock from hemlock-dominated stands, either from HWA-caused mortality or harvesting, on wildlife is unknown. This study was implemented to assess the effects of the harvesting of overstory hemlock on forest-floor fauna, with an emphasis on fully terrestrial salamanders. In New England the eastern redback salamander (*Plethodon cinereus*, hereafter redback salamander) is the only widespread and common terrestrial salamander species. Salamanders were emphasized because less is known of the amphibian community compared to other forest floor vertebrates (e.g. small mammals) and because of the current concerns with amphibian declines and with the effects of forestry operations on amphibians (Petranka et al., 1993; deMaynadier and Hunter, 1995; Harpole and Hass, 1999).

I hypothesized that pre-salvage harvesting of overstory hemlock would result in a decline in the relative abundance of redback salamanders. However, the magnitude of change was uncertain as the regeneration and growth response of the understory was expected to be rapid and dramatic following the removal of the overstory canopy (Orwig and Foster, 1998). A closed understory canopy, even under an open to partially open over-story canopy, should create forest floor microclimatic conditions to allow for the retention of terrestrial amphibians (deMaynadier and Hunter, 1995, 1999).

2. Study area

The study occurred on the watershed of the Barkhamsted Reservoir located in northwestern Hartford and Litchfield counties Connecticut, and in adjacent in Hampden county Massachusetts (72°57′W, 41°53′N). The reservoir and portions of the contributing watershed are managed by the Metropolitan District Commission (MDC) to supply water to the greater Hartford metropolitan area. The forested area of the watershed managed by the MDC totals 5320 ha. Of this, 1490 ha are typed as hemlock-hardwood, the dominant forest type.

In response to a hemlock looper (*Lambdina fiscellaria*) infestation that caused localized defoliation, and the expected arrival of HWA, the MDC began green-tree or pre-salvage of hemlock in the early 1990s. The objective of the salvage cuts was to harvest the hemlock trees before they were killed by pests and deteriorated in commercial volume and value. The silvicultural prescription was to harvest all commercial-sized (overstory) hemlock, with some additional volume of other, mostly hardwood species, to improve the value of the timber sale. Hemlocks on wet sites or on steep slopes were not cut.

Three removal and three control stands, classified as hemlock-hardwood type and of similar tree size and height, were selected for study. The study stands were selected from all harvested or uncut hemlock-dominated stands based on comparable size and stocking of hemlock. All control stands and two of the three removal stands were within 6 km of each other, mid-way up the west side of the Reservoir. The third removal stand was located on the Valley Brook tributary in Granville, Massachusetts.

The hemlock-removal stands are labeled PS (pre-salvage), i.e. PS2–PS4. PS2 was harvested in 1994; 22 m^3/ha of hemlock and 15.2 m^3/ha of other species were cut on 36.6 ha. On the 39.7 ha of PS3, 19.3 m^3/ha of hemlock and 4.5 m^3/ha of other species were harvested in 1996. The cut area of PS4 is 50.6 ha; 11.2 m^3/ha of hemlock and 4.1 m^3/ha of other species were removed in 1992. An average of 64% of hemlock basal area and 28% of other species were harvested. The uncut, control stands are labeled UC1–UC3 and are 53.4 ha (UC1), 40.4 (UC2), and 91.1 (UC3) in area.

3. Methods

Stand maps for the control stands were provided by the MDC. Harvested stands were mapped using a Reinhardt Redy Mapper®. Transects were installed along the long dimension of each stand with additional transects installed perpendicularly until total transect length exceeded 1500 m. Thirty plot centers were systematically located along the transects at 50 m intervals, using a random start for the first plot location. Plot centers were located >25 m from the stand boundaries.

Habitat composition and structure were sampled on nested, fixed-area circular plots. Trees ($\geq$2.5 cm dbh (diameter at breast height)) and slash/coarse woody debris were tallied on 250 m^2 plots. Shrubs, saplings, established seedlings, and herbaceous vegetation were counted or cover was estimated on 5 m^2 plots. Stump diameters were measured to estimate the dbh of harvested trees (Wharton, 1984). The slope, aspect, and terrain position of each plot was recorded.

Terrestrial salamanders were surveyed using cover boards (DeGraaf and Yamasaki, 1992; Fellers and Drost, 1994; Brooks, 1999). Two green hemlock boards, 1 m$\times$25 cm, were placed in contact with the humus at each plot in the summer of 1996. Boards were placed 1.25 m from the plot center, perpendicular to the direction of the transect. The boards were surveyed for salamanders four times in 1997 and twice a year, May and October, in 1998 and 1999. At each survey, the boards were turned and all vertebrate specimens were recorded by species. Color phase (redback, lead phase, or red phase) and size class (young-of-year (<30 mm snout-vent length), immatures (30–40 mm), or matures (>40 mm); Sayler, 1966) were recorded for each redback salamander.

All percent measurements were arcsine transformed before calculating averages or other parametric analysis (Zar, 1974). The effect of the removal of hemlock overstory on the number of redback salamander observations were analyzed by repeated measures analysis of variance. The number of salamander observations per stand and survey were first standardized to number per 60 boards, to account for boards that could not be re-located. The square root of the standardized number of observation were used in the analysis to improve normalcy. For consistency, only results of May and October surveys were analyzed. The effects of the harvesting treatment size/age-class distributions was assessed using a chi-square analysis. Associations between relative redback salamander abundance and habitat features were assessed by Pearson correlation, significance was corrected for multiple comparisons.

4. Results

Although the pre-treatment conditions were similar between the control and hemlock-removal stands, the post-treatment conditions were quite dissimilar

Table 1
Compositional and structural characteristics of the stands and average (and S.D.) treatment conditions, Barkhamsted Reservoir watershed, Connecticut, 1996

Characteristic	Hemlock-removal stands			Treatment average	Uncut, control stands			Treatment average
	PS2	PS3	PS4		UC1	UC2	UC3	
Overstory basal area (m^2/ha)								
Post-harvest, live trees								
Hemlock	4.2	7.8	9.4	7.1 (2.7)	20.1	21.3	21.3	18.5 (3.9)
Other conifer	0.9	0.5	1.0	0.8 (0.3)	0.4	0.7	0.4	0.5 (0.2)
All deciduous	14.6	18.5	16.8	16.6 (2.0)	20.5	21.3	22.6	21.5 (1.1)
All species	19.7	26.9	27.4	24.7 (4.3)	40.9	43.3	37.0	40.4 (3.2)
Post-harvest, stumps								
Hemlock	11.1	12.1	13.1	12.1 (1.0)				
Other species	7.8	5.6	7.0	6.8 (1.1)				
Pre-harvest, all species[a]	38.6	44.6	47.5	43.6 (4.5)				
Understory stem density (1000s/ha)								
All conifers	1.1	2.9	5.0	3.0 (2.0)	1.2	1.0	2.3	1.5 (0.7)
Red maple	26.9	23.5	90.1	46.8 (37.5)	13.8	14.5	15.4	14.6 (0.8)
Black birch	13.6	11.7	26.0	17.1 (7.8)	0.1	0.7	0.8	0.5 (0.4)
White ash	29.1	1.8	47.5	26.1 (23.0)	0.8	0.6	5.1	2.2 (2.5)
All deciduous	98.5	59.4	200.8	119.6 (73.0)	18.9	19.2	25.2	21.1 (3.6)
Shrubs	3.0	16.7	7.5	9.1 (7.0)	1.4	2.5	26.3	10.1 (14.1)
Ground cover (%)								
Total vegetative	40.6	15.1	18.3	23.9 (2.5)	6.3	6.6	17.3	9.5 (1.0)
Coarse woody debris	19.5	6.6	15.1	13.2 (1.0)	2.3	7.3	3.0	3.9 (0.4)
Logging slash	26.5	22.1	26.4	25.0 (0.1)				

[a] Estimate including stumps.

(Table 1). Using data from stumps, there was no significant difference in pre-treatment basal area of hemlock ($F_{1,4} < 0.1, p > 0.5$) or of all species ($F_{1,4} = 0.43, p > 0.5$) between the hemlock-removal and control stands. Following the removal of an average 17.5 m^3/ha hemlock and 7.9 m^3/ha of other species, the hemlock-removal stands had lower basal areas and more open canopies (Table 1). Consequently, understory vegetation flourished following harvests, with greater total vegetative ground cover and greater density of understory woody stems in the harvested stands (Table 1).

Red maple (*Acer rubrum*) was the most abundant species in stands of both treatments. Other common species included black birch (*Betula lenta*) and white ash (*Fraxinus americana*). The average density of shrubs was greater in the uncut, control stands but this was a result of exceedingly high density in UC3 (Table 1). Common shrub species included striped maple (*A. pensylvanicum*), witch hazel (*Hamamelis virginiana*), mountain laurel (*Kalmia angustifolia*), American elderberry (*Sambucus canadensis*), and *Viburnum* spp. Total vegetative ground cover was also more abundant in the hemlock-removal stands, composed principally of woody-stems, forbs and ferns, as was the cover of single pieces of coarse woody debris and multiple-piece slash or logging residue (Table 1).

Over the course of the study, 10 species were observed under the cover boards (Table 2). Redback salamanders were the most common species, and the only one observed in sufficient numbers to assess the treatment effects. Red-spotted newts (*Notopthalmus viridescens*) were the second most common species and were observed more frequently in uncut, control stands. Spotted salamanders (*Ambystoma maculatum*) were observed only in control stands. Two-lined salamanders (*Eurycea bislineata*) were observed in stands in both treatments at plots adjacent to streams.

The number of redback salamander observations was greater in the uncut control stands than in the

Table 2
Total number of vertebrates observed under cover boards by species, treatment, and stand, Barkhamsted Reservoir watershed, Connecticut, 1997–99

	Hemlock-removal stands			Uncut, control stands		
	PS2	PS3	PS4	UC1	UC2	UC3
Red-spotted newt (*Notopthalmus viridescens*)	3	2	0	2	9	6
Spotted salamander (*Ambystoma maculatum*)	0	0	0	5	1	2
Redback salamander (*Plethodon cinereus*)	26	86	62	104	133	145
Two-lined salamander (*Eurycea bislineata*)	0	0	1	4	1	0
Common garter snake (*Thamnophis sauritus*)	1	0	0	1	0	0
Milk snake (*Lampropeltis triangulum*)	1	0	0	0	0	0
Northern ringneck snake (*Diadophis punctatus*)	2	0	0	0	0	0
Northern short-tailed shrew (*Blarina brevicauda*)	1	0	0	0	0	0
White-footed mouse (*Peromyscus leucopus*)	0	0	0	1	6	0
Southern redbacked vole (*Clethrionomys gapperi*)	0	1	0	0	0	0

hemlock-removal stands at each survey (Table 3). The number of redback salamander observations was significantly different between treatments ($F_{1,4} = 9.21$, $p = 0.039$). Using May survey results, the number of observations were high in the first year following timber harvests, declined to a low point in the fourth year, and then started to recover (Fig. 1). These numbers are very preliminary as there are only one or two data values per year. The number redback salamander observations of were greatly reduced in the late spring and summer months of 1997 (Table 3). The numbers differed significantly among survey months ($F_{4,16} = 10.567$, $p < 0.001$), but there was no significant interaction effect between treatment and survey month ($F_{4,16} = 0.305$, $p = 0.871$). Just shy of 50% of the observed redback salamanders were 'large' mature specimens, 40% were 'medium'-sized juveniles, and 12.5% were 'small' young-of-the-year. No significant difference was found in size-class distributions by treatment ($X^2 = 2.868$, $v = 2$, $0.25 > p > 0.1$).

Study-wide, the number of redback salamander observations was significantly correlated with overstory basal area ($r_p = 0.366$, $p < 0.001$), slash cover ($r_p = -0.399$, $p < 0.001$), and the cover of graminoids ($r_p = 0.264$, $p = 0.03$). No significant correlations between numbers of redback salamander

Table 3
Number of redback salamanders observed under cover boards by treatment, stand, year, and month, and average standardized[a] numbers by treatment, year, and month, Barkhamsted Reservoir watershed, Connecticut, 1997–99

Month	Hemlock-removal stands			Treatment average[a]	Uncut, control stands			Treatment average[a]
	PS2	PS3	PS4		UC1	UC2	UC3	
1997								
May	5	23	13	12.8 (1.6)	20	26	27	25.6 (0.1)
June	2	7	4	4.1 (0.4)	4	8	7	6.3 (0.2)
July	0	5	4	2.0 (1.5)	9	9	13	10.4 (0.1)
August	1	6	2	2.6 (0.6)	5	10	10	8.2 (0.3)
1998								
May	2	4	6	4.2 (0.4)	13	12	15	14.0 (<0.1)
October	5	21	13	13.0 (1.2)	28	27	29	28.5 (<0.1)
1999								
May	7	9	11	9.8 (0.3)	10	18	26	18.7 (1.1)
October	4	11	9	8.3 (0.5)	15	23	18	18.7 (0.2)

[a] Average of standardized number (per 60 cover boards) of salamanders, following square root transformation.

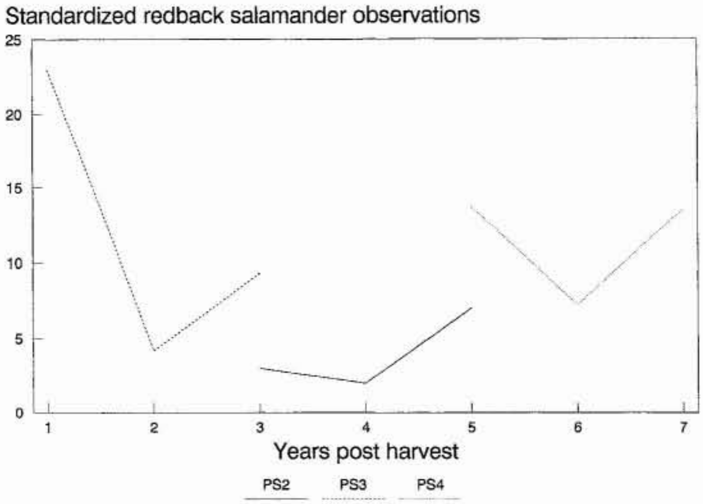

Fig. 1. Standardized number (per 60 cover boards) of redback salamander observations in May surveys by year following timber harvest and stand, Barkhamsted Reservoir watershed, Connecticut, 1997–99.

observations and habitat features were found within the hemlock-removal treatment after correcting for multiple comparisons.

5. Discussion

The vegetative response to HWA infestation of hemlock-dominated stands was generally similar to that observed in this study, but differed in scale and time. The effects of HWA occur over several years at the scale of individual trees ('gradual gaps'), whereas the effects of logging are immediate and occur at the larger scale of the stand ('sudden gaps') (Jenkins et al., 1999). However, because of site restrictions, hemlock remained in the hemlock-removal stands following logging which resembled the patchy distribution of live hemlock following HWA-caused mortality. The understory response of the study stands to logging was similar to that described by Orwig and Foster (1998) and Jenkins et al. (1999), with a flush of understory growth, particularly of black birch seedlings. Other species of woody regeneration were also abundant, especially red maple, as sprout growth from harvested stumps.

The abundance of amphibians, including redback salamanders is lower in coniferous forests than deciduous forests (DeGraaf and Rudis, 1990; Wyman and Jancola, 1992). The abundance of redback salamanders was reduced in hemlock-dominated stands following the removal of a large percentage of overstory hemlock trees (Table 2). The lower number of redback salamanders in hemlock removal stands was constant across all surveys (Table 3). But more importantly, redback salamander numbers remained substantial in all removal stands. No spotted salamanders and a much lower number of two-lined salamanders were observed in the removal stands. For both species the number of observations was very small and no quantitative comparisons could be made. It is uncertain whether the observed pattern of reduced numbers in the removal stands is an effect of the harvesting or a lack of aquatic breeding sites (i.e. vernal ponds for spotted salamanders and low-order streams for two-lined) in the removal stands.

The number of salamander observations suggest a dramatic decline in abundance a year or two after a timber harvest but with a recovery in numbers in later years (Fig. 1). Total numbers of salamanders in stand PS3, the most recently harvested stand remained high, suggesting that the impact of the timber harvest was not fully felt by redback salamanders (Table 3). Numbers were least in the stand with the intermediate-aged harvest (PS2) and then more than doubled in the stand with the oldest harvest (PS4). The same pattern of recovery is seen if one expresses salamander observations in the harvested stands as a percentage of the average observations in the uncut stands. Using only May and October surveys, average redback salamander observations in the most recently harvested stand (PS3) was 61% of average observations in the uncut stands. Salamander observations in PS2, with the intermediate-aged harvest was only 21.6% of those in uncut stands while those in the stand with the oldest harvest (PS4) had recovered to 49.2% of control (uncut) conditions.

The occurrence and resultant mortality of hemlock from hemlock woolly adelgid infestation is certain to spread further across the distribution of eastern hemlock. An effective control has yet to be developed for natural or non-ornamental hemlock forest stands. Studies of HWA infested stands suggest that the compositional and structural changes following the mortality of overstory hemlocks is similar to the effects observed in this study following harvesting of overstory hemlocks. The results of this study suggest that while the abundance of terrestrial redback salamanders may decline from pre-HWA numbers, redback salamanders should be retained through the immediate period following hemlock mortality and recover in numbers as the replacement stand develops.

6. Conclusions

The hemlock woolly adelgid has the potential to cause extensive defoliation and mortality across the range of eastern hemlock in northeastern North America. Mortality due to HWA is often less than complete, with some trees not infested or with sufficient vigor to survive. These patterns of mortality would likely result in changes in understory vegetation and allow for the continued survival and rapid recovery of redback salamanders, the principal terrestrial salamander of hemlock dominated forests.

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