Early Regeneration Following the Presalvage Cutting of Hemlock from Hemlock-Dominated Stands

Robert T. Brooks, *USDA Forest Service, Northeastern Research Station, 201 Holdsworth Natural Resources Center, University of Massachusetts, Amherst, MA 01003-9285*

ABSTRACT: *Live overstory hemlock were cut from three hemlock hardwood stands on the watershed of the Barkhamsted Reservoir in northwestern Connecticut. The presalvage cuttings occurred during a hemlock looper outbreak and in anticipation of hemlock woolly adelgid (HWA) infestation. All merchantable and accessible hemlock trees were cut, as were a smaller quantity of other species. The stands were harvested in 1992, 1994, and 1995–96. Over- and understory vegetation were surveyed in the harvested stands and in three nearby uncut, control stands in 1996. Findings suggest that the cut stands will regenerate to hardwoods in the near term. Hemlock regeneration was minimal and insufficient to replace harvested trees. Presalvage cutting of hemlock from hemlock-dominated stands, which typically lack sufficient advance hemlock regeneration, will contribute to the loss of the cover type due to HWA-caused mortality. North. J. Appl. For. 21(1):12–18.*

Key Words: Eastern hemlock, green tree salvage, hemlock wooly adelgid, presalvage harvest, *Tsuga canadensis.*

Eastern hemlock (*Tsuga canadensis* L.) occurs in all the New England states, south along the Appalachian Mountains, west into Michigan, Wisconsin, and Minnesota, and in adjacent Canada (Godman and Lancaster 1990). In the northern United States, hemlock is estimated to occur on 18.7 million acres of timberland (Schmidt and McWilliams 1996), including an estimated 2.3 million acres of hemlock hardwood stands (McWilliams and Schmidt 2000). In southern New England, hemlock is the second most abundant conifer species after white pine (*Pinus strobus* L.), and third most common tree species after red maple (*Acer rubrum* L.) and white pine (Brooks et al. 1993). Eastern hemlock is generally most abundant in areas with cool, humid climates (Godman and Lancaster 1990, Quimbley 1996). The best sites for hemlock are on north- and east-facing slopes and in gorges. Fully stocked stands of hemlock tend to develop similar microclimatic conditions in the understory because of their full canopy and dense shading and deep litter.

Hemlock has had a variable economic history, but today's second-growth trees have reached sizes for which there is a market for both lumber and pulpwood (Quimbley 1996). However, production and marketing of hemlock lumber is unpromising due to the species slow growth, poor sawtimber value relative to pulpwood value, and flat or negative real stumpage prices (Howard et al. 2000).

Hemlock stands are not considered highly productive wildlife habitat, with wildlife species richness generally lower than in other conifer and hardwood forest types (Degraaf et al. 1992, DeGraaf and Yamasaki 2001). However, hemlock provides critical winter habitat for white-tailed deer (*Odocoileus virginianus*) and porcupines (*Erethizon dorsatum*) (Griesmer et al. 1998, Reay 2000). In the breeding season, black-throated green warbler (*Dendroica virens*), blackburnian warbler (*D. fusca*), winter wren (*Troglodytes troglodytes*), red-breasted nuthatch (*Sitta canadensis*), blue-headed vireo (*Vireo solitarius*), and the northern goshawk (*Accipiter gentilis*) are associated with hemlock forests (Benzinger 1994, Howe and Mossman 1996). During the nonbreeding season, hemlock provides important cover or forage (seed) resources for ruffed grouse (*Bonasa umbellus*), pine siskin (*Carduelis pinus*), American goldfinch (*C. tristis*), red (*Loxia curvirostra*) and white-winged (*L. leucoptera*) crossbills, evening grosbeak (*Coccothraustes vespertinus*), and red squirrels (*Tamiasciurus hudsonicus*) (Yamasaki et al. 2000). Streams draining hemlock

NOTE: Robert T. Brooks can be reached at (413) 545-1845; Fax: (413) 545-1860; rtbrooks@fs.fed.us. The author wishes to acknowledge Richard DeGraaf, Bill Leak, Matt Kelty, and two anonymous referees for their constructive reviews of the manuscript. L. "Bud" Sanders and his staff of the Metropolitan District Commission graciously provided logistic support for this study.

Table 1. Physiographic characteristics, stand area, and marked volume of harvested stands by stand, Barkhamsted Reservoir watershed, Connecticut, 1996.

Physiographic characteristic	Presalvage stands			Control stands		
	PS2	PS3	PS4[1]	UC1	UC2	UC3
Average slope (%)	20.7	7.6	15.8	26.5	10.8	12.4
CV slope (%)	39.0	71.1	27.0	38.5	62.8	60.2
Terrain position (No. of plots, $n = 30$)						
Top slope						1
Upper slope		10	5	3	5	2
Midslope	17	10	19	24	12	18
Bench	1	9	1	2	7	6
Lower slope	9	1	5	1	5	3
Bottomland	3				1	
Aspect						
North						1
Northeast	9	3		7	7	6
East	18	6		12	7	4
Southeast		3		5	1	5
South				2	2	4
Southwest		1	7	1	2	1
West			22		2	1
Northwest		2		1	2	2
No aspect[2]	3	15	1	2	7	6
Area (ac)	90.4	98.1	125.0	132.0	99.8	225.1
Marked volume (bd-ft/ac)[3]						
Total	6,371	4,076	2,626			
Eastern hemlock	3,768	3,307	1,923			

[1] Located in Granville, Massachusetts.
[2] Slope less than 5%.
[3] Timber sale announcement from L. Sanders, MDC.

forests have been shown to support substantially different benthic invertebrate communities, and the loss of hemlock from these drainages would have long-term impacts on these communities, other aquatic assemblages, and on downstream communities (Snyder et al. 2002).

Hemlock is sensitive to stress, including insect defoliation (Souto and Shields 2000). In the early 1990s, hemlock looper (*Lambdina fiscellaria*) occurred throughout New England, causing extensive damage. The hemlock woolly adelgid (HWA, *Adelges tsugae*), was first observed in eastern hemlock in the early 1950s (Souto et al. 1996). HWA is believed to have entered southern New England from Long Island, New York during Hurricane Gloria in 1985 (Orwig and Foster 1998). By 2000, HWA was reported to occur from Massachusetts south through southern New York, New Jersey, eastern Pennsylvania, and along the Appalachian chain through Maryland and western Virginia and adjacent West Virginia (Forest Health Protection 2002). HWA is perceived as a serious threat to hemlock, with infestation leading to high levels of defoliation and mortality (Evans et al. 1996, Orwig and Foster 1998).

Both the even-aged shelterwood system and uneven-aged selection systems have been recommended for regenerating hemlock (Lancaster 1985, Brissette and Kenefic 2000, Kenefic and Seymour 2000). To achieve successful hemlock regeneration, silvicultural systems need to conform to the site and stand conditions (Goerlich and Nyland 2000). The salvage of trees from a stand damaged by physical (e.g., wind, fire) or biological (e.g., insects, disease) agents can be used to recover some economic value of the stand (Nyland 1996, Smith et al. 1997). If potential damage is considered imminent, the presalvage cutting of vulnerable trees can be considered (Smith et al. 1997).

Such a situation existed on the watershed of the Barkhamsted Reservoir in the early 1990s, with the occurrence of a hemlock looper infestation and the nearby presence of HWA (L. Sanders, Metropolitan District Commision (MDC), 1996). In anticipation of extensive defoliation and mortality, the presalvage cutting of hemlock was implemented on several hemlock-dominated stands. In this article, I describe the early responses of understory vegetation and tree regeneration after the presalvage cutting of overstory hemlock and postulate on the implications of the composition of the regeneration for the success of hemlock in the future stands.

Methods

Study Site Description

The Barkhamsted Reservoir, created by the Saville Dam, is located in northwestern Connecticut on the East Branch of the Farmington River (72°57′30″ West, 41°54′ North). The area of the watershed, owned and managed by the MDC, is approximately 13,000 acres and is mostly forestland. Hemlock hardwood stands were the predominant forest type, comprising 28% of the ownership.

Three presalvage cut (PS2–PS4) and three uncut, control (UC1–UC3) stands were selected from a list of cut and uncut hemlock hardwood stands on the watershed. All candidate stands had been typed as hemlock hardwood, small sawlog, and 61–100 ft tall. All control stands and two of the three cut stands were located within 4 miles of each other, midway up the west side of the Reservoir. The third cut

Table 2. Average basal area by species and stand, live tree density, and quadratic stand diameter for hemlock and all species by stand Barkhamsted Reservoir watershed, Connecticut, 1996.

	Presalvage stands			Control stands		
	PS2	PS3	PS4[1]	UC1	UC2	UC3
Basal area (ft^2/ac), live trees						
Eastern hemlock	18.3	34.1	41.6	87.5	92.9	61.1
Other conifers	3.8	2.3	4.4	1.6	3.0	1.8
All conifers	22.1	36.3	45.9	89.1	95.9	62.9
Red maple	10.7	27.8	23.4	11.2	27.3	23.6
Sugar maple	16.8	1.2	11.4	10.1	9.8	3.0
Yellow birch	7.6	5.5	8.2	7.7	12.2	7.0
Black birch	3.8	7.4	10.1	23.0	12.6	23.5
American beech	11.4	20.8	7.7	9.0	9.3	23.0
White ash	1.9	1.2	4.8	5.2	6.2	5.9
Yellow-poplar	6.7	0.0	0.0	2.4	0.0	0.0
Northern red oak	3.1	13.3	5.7	12.6	13.8	9.1
Other deciduous	1.8	3.4	1.9	8.0	1.4	3.3
All deciduous	63.9	80.8	73.3	89.1	92.6	98.4
Total, all species	85.9	117.1	119.2	178.2	188.4	161.3
Basal area, stumps						
Eastern hemlock	48.5	52.8	57.0	0.0	0.0	0.0
Other species	33.8	24.5	30.7	0.0	0.0	0.0
Total preharvest basal area, all species, all live trees	168.2	194.4	206.9	178.2	188.4	161.3
Basal area, standing dead, all species	11.6	14.4	13.1	18.9	17.0	16.1
Density (#/ac), live trees						
Eastern hemlock	66	123	141	215	177	145
All species	181	380	296	407	365	397
Average diameter (in.), live trees						
Eastern hemlock	3.6	3.6	3.7	4.3	4.9	4.4
All species	4.7	3.8	4.3	4.5	4.9	4.3

[1] Located in Granville, Massachusetts.

stand was located in Granville, Massachusetts on Valley Brook, a tributary of the East Branch of the Farmington River. For the most part, the stands were located on mid-slope locations, but they extended across all terrain positions (Table 1). Stand slope was generally less than 15% except for PS2 and UC1; however, within-stand slope was quite variable in all stands. Aspects varied but were predominantly east-facing except for PS4, which was predominantly west-facing. Soils were mapped as Hollis, Chatfield, Charlton, or Woodbridge series, extremely or very stony or rocky, loam or sandy loam (Soil Conservation Service 1962, 1970, Natural Resources Conservation Service 1995).

The presalvage stands were cut in 1992 (PS4), 1994 (PS2), and 1995/96 (PS3). Stands PS2 and PS4 were cut in the fall and/or winter months; PS3 was cut in the summer months. All accessible overstory hemlocks were removed; hemlocks located on steep slopes or in wet areas were not cut. Marked hemlock volume ranged between 59% (PS2) and 81% (PS3) of total marked volume (Table 1). The residual stands were a patchwork of conditions, ranging from clearcut portions where pure hemlock had occurred and had been harvested to uncut, inaccessible patches. Harvested areas ranged between 90 and 125 acres, the sizes of the control stands were between 100 and 225 acres (Table 1).

Measurement and Analysis

Transects were installed in each stand, first across the long dimension of the stand, and then one or more shorter transects, parallel or perpendicular to the first, to cover the entire stand. Sample points were located at 50-m (165-ft) intervals along the transects, following a random start. Thirty systematically selected sample points were chosen for vegetation survey plots. Vegetation was measured on each plot in nested, circular, fixed-radius plots. Trees $\geq$2.5 cm (1 in) diameter at breast height (dbh) were tallied on 0.025-ha (0.06-ac) plots. The diameters of stumps of cut trees were measured to estimate their dbh (Wharton 1984). Shrubs, saplings, and seedlings were surveyed on 5-m^2 (54-ft^2) plots. The physiographic location (i.e., slope, aspect, terrain position) of each plot was recorded. Vegetation surveys were conducted in all stands in 1996, 1 year following most timber cutting in PS3, 2 years postcut in PS2, and 4 years postcut in PS4.

All observations recorded as percents were arcsine transformed before calculating stand and treatment averages (Zar 1974). Pre- and postcut conditions of the salvaged stands were compared to those of the control stands by analysis of variance; categorical data (e.g., terrain position) were analyzed using chi-square analysis.

Results

The study sites were physiographically similar; neither the distribution of plots by terrain position ($\chi^2 = 5.76$, $P \cong 0.89$) nor slope ($F_{df=1,4} = 0.089$, $P > 0.5$) differed between treatments. There was a difference in the distribution of plots between treatments by aspect ($\chi^2 = 33.1$, $P \cong 0.011$), with more south-facing plots in the control stands and more west-facing plots in the presalvage stands.

Prior to harvest, presalvage stands were compositionally and structurally similar to the control stands. Hemlock was the dominant overstory species in all stands of both treatments, averaging 44.0% (±0.02%) of total, live-tree basal area in presalvage stands before they were cut (i.e., including the estimated basal area of harvested trees) and 45.4% (±0.04%) of total, live-tree basal area in control stands (Table 2). Using precut data, no significant differences were found in hemlock ($F_{df=1,4} = 0.002$, $P > 0.5$), all conifer ($F_{df=1,4} = 0.066$, $P > 0.5$), all deciduous ($F_{df=1,4} = 1.484$, $P > 0.5$), and all species ($F_{df=1,4} = 0.434$, $P > 0.5$) basal area between treatments. The trees in control and presalvage stands, including both pre- and postcut conditions, had reverse-*J* diameter distributions with a decreasing number of trees per acre with increasing tree size, suggestive of multiaged composition (Figure 1).

As expected, timber harvesting reduced stocking, especially of hemlock, on the treated stands. Postcut hemlock basal area on presalvage stands was an average of 36% (±0.08%) of precut conditions and 39% of average hemlock basal area on the control stands (Table 2). Total live-tree basal area of the cut stands was reduced an average of 54% (±0.02%) of precut conditions and 61% of average basal area of the control stands. After the cuttings, hemlock remained the dominant species, even in the cut stands, with live hemlocks remaining on inoperable or protected locations or left elsewhere during harvesting.

Given the structural and compositional similarity between precut conditions on the presalvage stands and those on the control stands, it is reasonable to expect that the densities of advance regeneration were also similar between control and presalvage stands prior to cutting. Following the cuts, the average densities of seedling-sized (<1 in. dbh) trees in the cut stands (49,700/ac) were more than five times greater than the average density on the control stands (9,100/ac) (Table 3). However, because of the large variance in seedling densities on the presalvage stands (Fig. 2), the increase in seedling densities on the presalvage stands over those on the control stands was only marginally significant ($F_{df=1,4} = 5.378$, $P \cong 0.087$). The size and significance of the increase in densities of deciduous seedlings on postcut presalvage stands was similar ($F_{df=1,4} = 5.462$, $P \cong 0.085$), because deciduous species comprised an average of 97% of all regeneration on the presalvage stands and 93% on the control stands (Table 3). Hemlock seedlings were the dominant conifer regeneration, but there was no increase in hemlock seedling density on presalvage stands (1,100/ac) over those on control stands (500/ac) following cutting ($F_{df=1,4} = 0.852$, $P > 0.25$).

The pattern in densities of taller, established seedlings (>12 in. tall, <1 in. dbh, and with a greater chance of surviving) by treatment was similar to those for all seedlings, with a greater number of established seedlings on cut, presalvage stands than on control stands (Table 4). Again, due to the high variability in stem density among stands within treatments, especially for the presalvage stands (Fig. 2), there was no significant increase in the density of all established seedlings ($F_{df=1,4} = 1.106$, $P > 0.25$) or deciduous species ($F_{df=1,4} = 1.097$, $P > 0.25$) between treatments. The infrequent occurrence of established hemlock seedlings in stands of both treatments precluded an assessment of treatment effect on their density (Table 4).

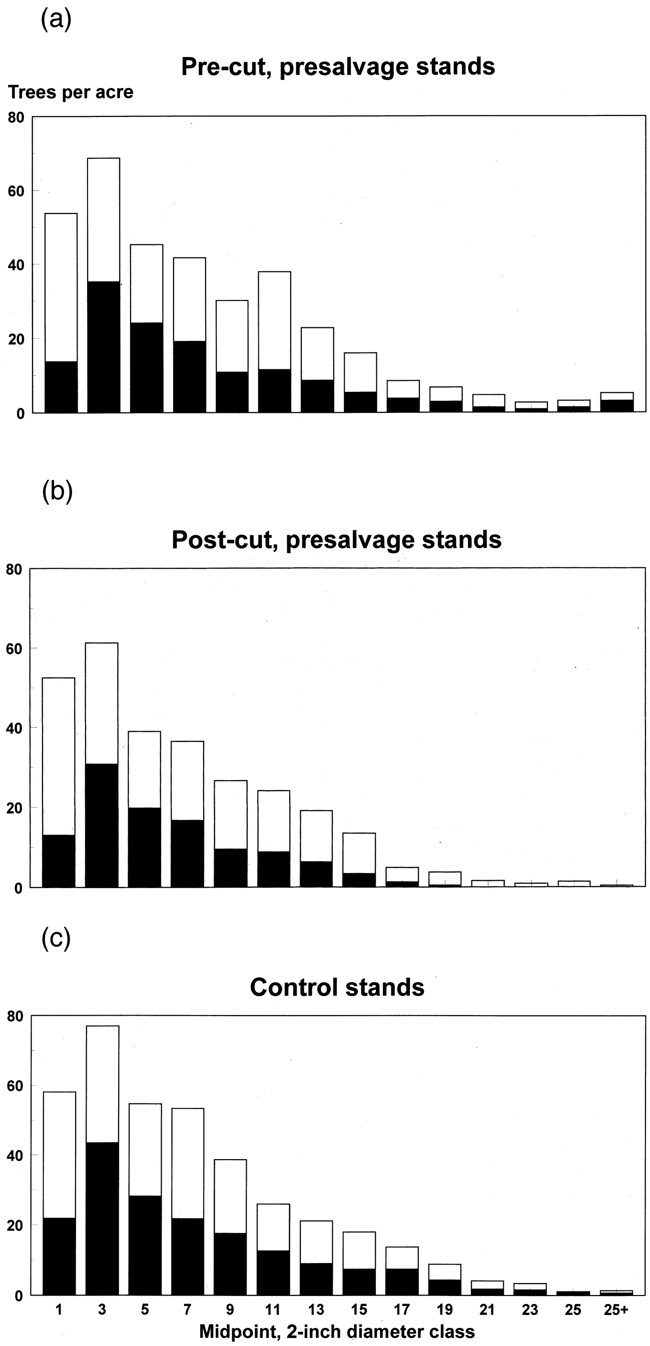

Figure 1. Average number of hemlock (solid bars) and other (open bars) trees per acre by treatment and 2-in. diameter class, Barkhamsted Reservoir watershed, Connecticut, 1996.

Seedling densities increased in the cut presalvage stands with time since harvest, with more than three times as many stems per acre in the earliest cut stand (PS4) than in the most recent cut stand (PS3) (Table 3). Red maple was the most common species of regeneration in both the cut and control

Table 3. Average number (in 100s) of understory woody stems (<1 in. dbh) per acre by species and stand, Barkhamsted Reservoir watershed, Connecticut, 1996.

	Presalvage stands			Treatment averages	
	PS2	PS3	PS4[1]	Presalvage	Control
Eastern hemlock	1	12	19	11	5
Other conifers	4	0	1	2	1
Total, conifer	5	12	20	13	6
Red maple	109	95	364	189	59
Sugar maple	47	0	9	19	1
Yellow birch	25	78	114	72	3
Black birch	55	47	105	69	2
American beech	23	8	24	18	8
White ash	118	7	192	106	9
Yellow-poplar	20	0	0	7	0
Northern red oak	1	3	3	2	2
Other deciduous	1	1	1	1	1
Total, deciduous	399	241	813	484	85
Total, all trees	404	253	833	497	91
Shrubs[2]	12	67	30	36	41
Total, all species	416	320	863	533	132

[1] Located in Granville, Massachusetts.
[2] Includes striped maple (*Acer pennsylvanicum*), witch hazel (*Hamamelis virginiana*), mountain laurel (*Kalmia angustifolia*), American elderberry (*Sambucus canadensis*), and *Viburnum* spp.

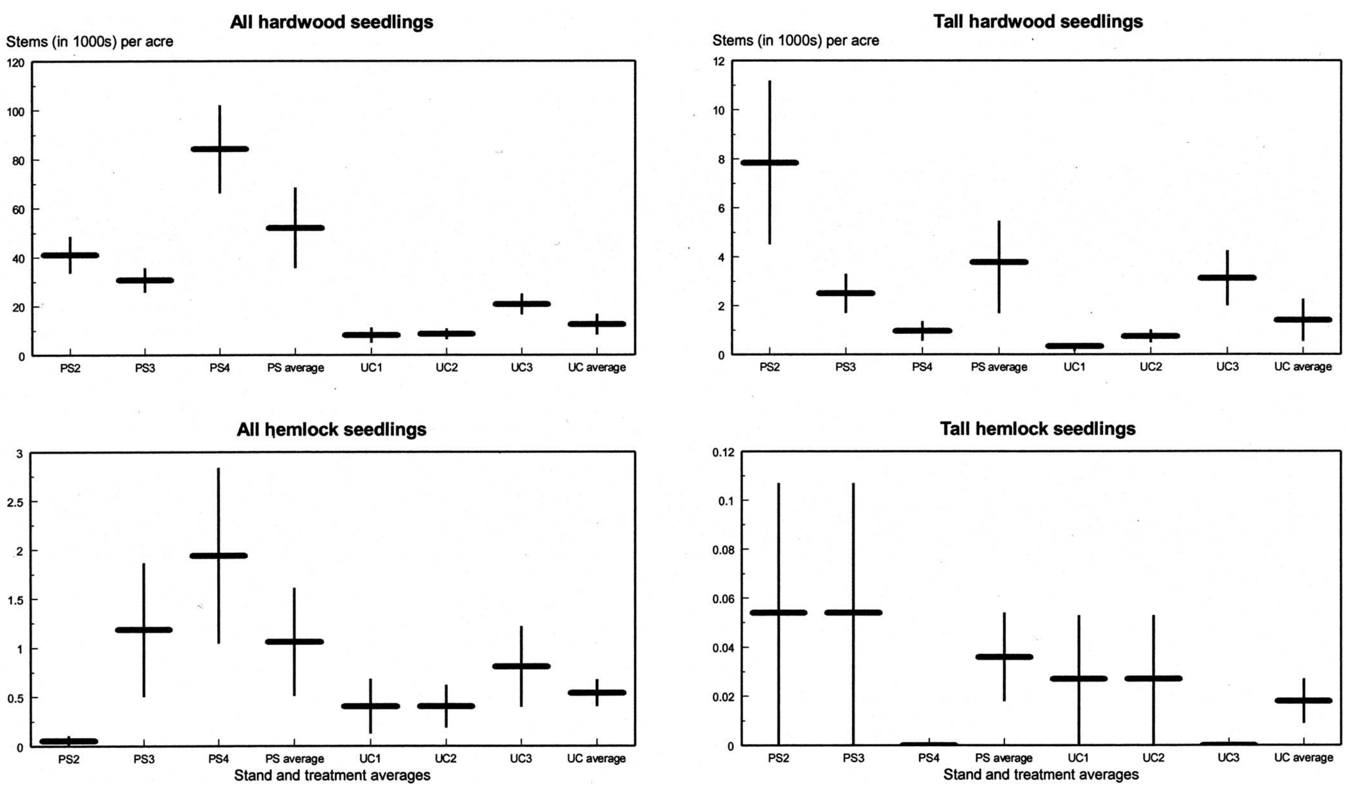

Figure 2. Mean (horizontal bar; standard error, vertical bar) number of hardwood and hemlock seedlings (<1 in. dbh) per acre by stand and treatment, Barkhamsted Reservoir watershed, Connecticut, 1996.

stands, but with densities in the cut stands (18,900/ac) much greater than in the control stands (5,900/ac). Birch (*Betula* spp.) and white ash (*Fraxinus americana*) regeneration were only slightly less common than red maple, and again more common in the cut than control stands.

Discussion

The presalvage cutting of hemlock in the three hemlock-dominated stands on the Barkhamsted Reservoir watershed in northwestern Connecticut reduced the dominance of

Table 4. Average number (in 100s) per acre of stems (<1 in. dbh) of regenerating eastern hemlock and all species by height class and stand or treatment, Barkhamsted Reservoir watershed, Connecticut, 1996.

Height class	Presalvage stands			Treatment averages	
Species	PS2	PS3	PS4[1]	Presalvage	Control
0–5.8 in.					
Eastern hemlock	0	11	19	10	5
All species	235	241	729	402	80
5.9–11.7 in.					
Eastern hemlock	0	<1	1	<1	<1
All species	94	4	94	64	4
11.8–39.3 in.					
Eastern hemlock	1	1	0	<1	<1
All species	72	6	9	29	5
39.4–59.0 in.					
Eastern hemlock	0	0	0	0	0
All species	2	1	0	1	1
>59.0 in.					
Eastern hemlock	0	0	0	0	<1
All species	1	1	1	1	1
Total, established (>11.8 in. height) stems					
Eastern hemlock	1	1	0	<1	<1
All species	75	8	10	31	7
Total, all stems					
Eastern hemlock	1	12	19	11	5
All species	404	253	833	497	91

[1] Located in Granville, Massachusetts.

hemlock and should result in the conversion of the stands to deciduous-dominated forest types with scattered hemlocks. This is based on the finding that there was likely no advance hemlock regeneration prior to cutting, consequently there was little to no hemlock regeneration found in the cut stands; seedling composition was dominated by deciduous species (Table 3). While hemlock regeneration density doubled following cutting (i.e., from 500 to 1,100 stems/ac), the density of deciduous species increased over fivefold. More importantly, the density of established hemlock regeneration (seedlings >12 in. in height) was unchanged between the cut and control stands while the density of established deciduous species increased by a factor of four.

This result is consistent with published studies of regeneration following natural and silvicultural disturbance of hemlock hardwood forests (reviewed by Goerlich and Nyland 1999, 2000). The successful regeneration of eastern hemlock is a complex process, spanning many years, requiring a reliable source of seed, a suitable seedbed, a partially shaded environment, and several years of favorable moisture (Lancaster 1985, Goerlich and Nyland 2000, Kelty 2000). The successful replacement of hemlock following harvesting would have required the release of advance regeneration at least 4–6 ft tall (Kelty 1989). Only a small number of hemlock seedlings were recorded in the control stands, and less than 100 per acre were of the recommended height (Table 4). If conditions in the control stands were representative of precut conditions in the presalvage stands, little advance regeneration of any species was present at the time of the harvests. The lack of well-developed, advance hemlock regeneration is typical; seedlings beneath closed hemlock hardwood canopies are commonly sparse (Kelty 2000). In the foreseeable future, the small number of seedling-sized hemlock in the presalvage stands precludes a return to hemlock dominance of these stands.

Factors contributing to hemlock regeneration failures include poor seed source and poor seedling establishment (Goerlich and Nyland 2000). Hemlock stocking in the cut stands had been sufficient for an adequate supply of seed prior to the presalvage cuts, generally exceeding the suggested 80–100 ft^2/ac (Kittredge and Ashton 1990). Hemlock seed does not accumulate in seed banks (Yorks et al. 2000), but hemlock typically produces some seed every year and large crops are frequent (2–3 years; Ruth 1974). Summer logging with associated scarification is recommended to create a mineral-soil seedbed (Lancaster 1985, Kelty 2000). While two of the three presalvage stands were cut in the fall or winter months, the minimal snowpack experienced in northwestern Connecticut (Climatological Data: New England, National Climatic Data Center, National Oceanic and Atmospheric Administration, Asheville, NC), should allow for adequate scarification during harvesting. Regardless, the presalvage cutting of the hemlock resulted in the vigorous growth of red maple and birch (Table 3). This response is compositionally similar to the regeneration that occurs following HWA-caused mortality (Orwig and Foster 1998).

In these presalvage cuts, there was no intention of regenerating hemlock when the cuts were planned (L. Sanders, MDC, 1996). Nevertheless, with the possibility of serious, regionwide loss of mature hemlock due to HWA, some effort should be given to managing hemlock-dominated stands to encourage and retain hemlock reproduction in regeneration cuts. In immature stands, thinning is appropriate to improve stocking and remove trees of lower vigor, and in mature stands, a two- or three-cut shelterwood system is recommended to regenerate hemlock (Lancaster 1985, Kelty 2000). Alternatively, both single-tree and group selection can be used to regenerate hemlock where deer browsing is not excessive (Webster and Lorimer 2002).

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