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Effect of Harvesting Regime on Beech Root Sprouts and Seedlings in a North-Central Maine Forest Long Affected by Beech Bark Disease

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Abstract

In Maine, northern hardwood stands long affected by beech bark disease often contain large numbers of American beech trees severely damaged by the disease. Methods are needed to improve stand quality by reducing the proportion of susceptible trees, and increasing the number of resistant trees. A 6-year study was conducted in north-central Maine to determine the effects of commonly used harvesting systems on the incidence and growth of beech root sprouts and seedlings. Stands were clearcut or thinned in 1991 in winter or summer. Seedlings and root sprouts in 15-ft-radius plots (174) around trees or stumps of resistant or susceptible trees were counted annually from 1992 to 1994, and the annual growth of more than 3,100 sprouts or seedlings in these plots was monitored. Initially, the most sprouts developed in the summer clearcuts, but differences attributable to harvest treatment disappeared after 4 years. By 1994, there were significantly more sprouts around resistant trees than around severely diseased trees. Interactions occurred between the amount of root disturbance (leading to root sprouts) and the amount of light available for growth. Thus, more sprouts developed after clearcuts than after thinnings, and sprout growth was best around resistant trees left standing and poorest around susceptible trees that were cut. Summer clearcuts drastically reduced the number of existing beech seedlings and prevented new "recruits." Seedling growth was related primarily to the amount of light received as a consequence of the harvests or disease-caused crown thinning. Because of the high initial proportions of beech in these stands, it is likely that only the clearcuts will materially affect stand composition. The regeneration changes observed support other studies that reported that clearcuts (and group-selection cuts) encourage shade-intolerant and intermediate species. However, the presence of advance regeneration or significant sprout reproduction of tolerant species will ensure that those species regain their former importance.

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Introduction

Beech bark disease (BBD) results when the bark of American beech (*Fagus grandifolia* Ehrh.), infested and altered by the beech scale insect, (*Cryptococcus fagisuga* Lind.), is invaded and killed by one or more species of fungi in the genus *Nectria* (Ehrlich 1934; Spaulding et al. 1936; Cotter and Blanchard 1981; Houston 1994). The beech scale and probably the principal fungal pathogen, *N. coccinea* var. *faginata* (Lohm. and Watson), was accidentally introduced to Nova Scotia around 1890 and discovered in Maine in 1931 (Ehrlich 1934; Mahoney et al. 1999). Today, all of Maine is part of an "aftermath" zone forest (Shigo 1972) long affected by the scale/*Nectria* complex. Dense, young stands of beech stems of root sprout and seedling origin in aftermath forests often become highly defective as they accumulate cankers (Houston 1975). With time, many of these trees and older susceptible survivors of the original outbreak lose vigor (Houston 1975), slow in growth, and die (Houston 1994; Gove and Houston 1996).

Within the aftermath forests, some beech trees (usually less than 1 percent) remain scale free and show no signs of BBD. These trees, which often occur in groups (Houston 1983), are resistant to *C. fagisuga* (Houston 1982, 1983). Isozyme studies have shown that such trees are closely related genetically (half- or full-sib families) or are identical (derived vegetatively from root sprouts) (Houston and Houston 1987, 1994).

American beech not only produces root sprouts but also is highly shade tolerant, affording beech a potent mechanism with which to conserve genes in times of disturbance and to perpetuate them as forest development ensues. Root sprouting in beech is a response to disturbances that wound roots (Jones and Raynal 1986), e.g., frost heaving, browsing, and logging. Sprouts arise from adventitious buds that originate within callus tissues associated with wounds (Jones and Raynal 1986); their initiation also seems influenced by exposure to light and higher temperatures (Maini and Horton 1966; Kormanik and Brown 1967; Held 1983; Jones and Raynal 1988). Apical control of sprout initiation seems weaker in beech than in other species (Jones 1986).

BBD can influence root sprouting directly by adversely affecting parent-tree vigor and indirectly by causing changes in canopy density from crown thinning, tree death, and harvesting. In uncut stands, fewer sprouts were produced around isolated, low-vigor beech trees compared with high-vigor trees, though there were no differences in vigor of the sprouts themselves (Jones and Raynal 1987). Sprout initiation, growth, and survival may decrease when only several scattered parent beech trees decline in stands where beech density is low (Twery and Patterson 1984). However, sprout initiation or growth can be stimulated when many trees decline and die in beech-rich stands (Houston 1975; Ostrofsky and McCormack 1986). Root sprouting also was influenced by season of injury. Jones and Raynal (1988) found that fewer sprouts were initiated when roots of uncut trees were wounded in fall than in spring. They attributed this result to high mortality of fall-wounded roots and to less vigorous callus formation. It also is possible that harvests conducted in winter when roots and soil are frozen or snow covered might result in fewer root wounds and fewer sprouts compared to summer harvests.

The availability of harvesting practices that control both how and to what degree root systems are disturbed and the level to which roots are exposed to light and higher temperatures may hold the key to regulating root sprout initiation and development. Understanding the comparative consequences of such management practices for trees resistant or suceptible to BBD could improve the quality of beech in severely affected stands. Also, it is important to understand how different management practices influence the incidence, growth, and survival of beech seedlings present at the time of harvest as well as those recruited later.

This paper presents results of a study that investigated how forest management practices affect the initiation and development of beech root sprouts and seedlings. Four hypotheses were tested:

1. Root sprout initiation and development and seedling development in beech is favored more by summer than winter harvests.

2. More root sprouts will develop, and growth of sprouts and seedlings will be greater around resistant (high-vigor) trees than around diseased (low-vigor) trees.

3. More root sprouts will develop, and growth of root sprouts and seedlings will be greater around trees in partially cut stands than in stands with complete overstory removal.

4. More root sprouts will develop and growth of sprouts and seedlings will be greater around cut trees than those left standing.

Materials and Methods

Forest Stands

The study area was located on public lands near Lake Seboeis in north-central Maine. It consisted of 15 contiguous 10-acre (4-ha) blocks of forest that straddled a broad, north-south-oriented ridge ranging in elevation from 560 to 760 ft (168 to 228 m) above sea level (Fig. 1). The forest comprised 40 to 100-year-old second- or third-growth northern hardwoods dominated by beech. There were heavy admixtures of sugar maple (*Acer saccharum* Marsh.) in some blocks.

Block corners were determined by GPS and plotted on a U.S. Geological Survey quadrangle map (Fig. 1). Parallel transects were established at 132-foot (39.6-m) intervals within each block to facilitate locating, numbering, and mapping all resistant beech trees ≥ 8 inches (20 cm) in diameter at breast height (d.b.h.). Resistant trees were defined as those that were free of beech scale and evidence of BBD. More than 180 resistant trees were mapped, many of which were in groups.

Trees

From the pool of mapped trees we selected 180 resistant trees for study. Selected trees were at least 30 feet (9 m) apart to allow a discrete, 15-ft-radius (4.5-m) plot to be established around them. In 12 of the 15 blocks, at least eight suitable resistant trees were found and mapped. In three blocks there were only three or four resistant trees; these blocks were designated as no-cut controls.

Each selected resistant tree was paired with a nearby, highly susceptible tree of comparable diameter and crown class that exhibited severe BBD crown symptoms. In all, there were 216 study trees comprising eight resistant/susceptible pairs in each of the 12 blocks to be cut and four pairs in each of the three no-cut control blocks.

Treatments

Harvest treatments and times were chosen to reflect management practices commonly used in Maine. Treatments were not assigned randomly but were dictated by practical considerations of harvest equipment capability and winter accessibility. Blocks 1-6 were harvested in winter (January-March 1991) when snow was present or soil was frozen; the remaining six blocks (7, 8, 11-14) were cut in summer (June-August 1991) (Fig. 1). Felling and extraction were done by chain-saw crews and skidders.

Three of the six winter-cut blocks (3, 5, 6) and three summer-cut blocks (11, 12, 13) were clearcut (all merchantable stems); the remaining blocks (1, 2, 4 and 7, 8, 14) were partially cut to reduce basal area by approximately 30 percent. No trees were cut in the control blocks (9, 10, 15). Thus, there were five block-level treatments replicated 3 times: winter clearcuts (WC), winter partial cuts (WP), summer clearcuts (SC), summer partial cuts (SP) and no-cut controls (NC) (Fig. 1).

Four of the eight resistant/susceptible tree pairs in each harvest block were chosen randomly to be cut; the remaining four pairs, including those in the clearcut blocks, were left standing.

Measurements

Overstory stand data

Prior to harvesting in 1989 or 1990, data on overstory composition and structure were obtained in plots centered around each of the 216 study trees. Species, d.b.h., crown class, and the distance and azimuth from the center plot tree were recorded for all trees selected by a BAF 10 prism. In 1992 or 1993, stand data were obtained in these "prism" plots around the study trees (or stumps) in the thinned blocks to determine changes created by the thinnings. At the time of the preharvest measurements, the condition of all living beech trees, including the central plot tree, was noted. An index of tree condition for each block was calculated by dividing the sum of weighted condition scores (good = 1, fair = 4, poor = 16) by the number of beech trees.

Regeneration data

Data on tree-species regeneration were obtained in a series of twelve 1-m-radius (3.28-ft) plots (hereafter termed 1-m regen plots) placed systematically along a diagonal transect across each block. The following data were obtained in 1989 and again in 1994 to determine changes in regeneration resulting from harvest treatment: counts, by species, of all seedlings and sprouts that were < 1.0 inch (2.54 cm) in diameter at 4 inches (10 cm) above ground and < 1.0 m tall. Beech seedlings were recorded separately from beech sprouts.

Study plot data

In summer 1991, 15-ft-radius plots around each study tree or stump were carefully cleared of tree limbs and other debris to facilitate counting and measuring beech sprouts and seedlings. For various reasons, only 174 of the original 216 plots could be used; these are referred to as "selected tree plots."

Each sprout's point of origin was noted as being the top, side, or bottom of its parent root, and the parent root's horizontal diameter (mm) was measured at the point of sprout origin. Sprouts were classified as single or a member of a sprout cluster. In the clusters, the largest, most vigorous sprout was measured and tagged. If this sprout died, the next largest living sprout in the cluster

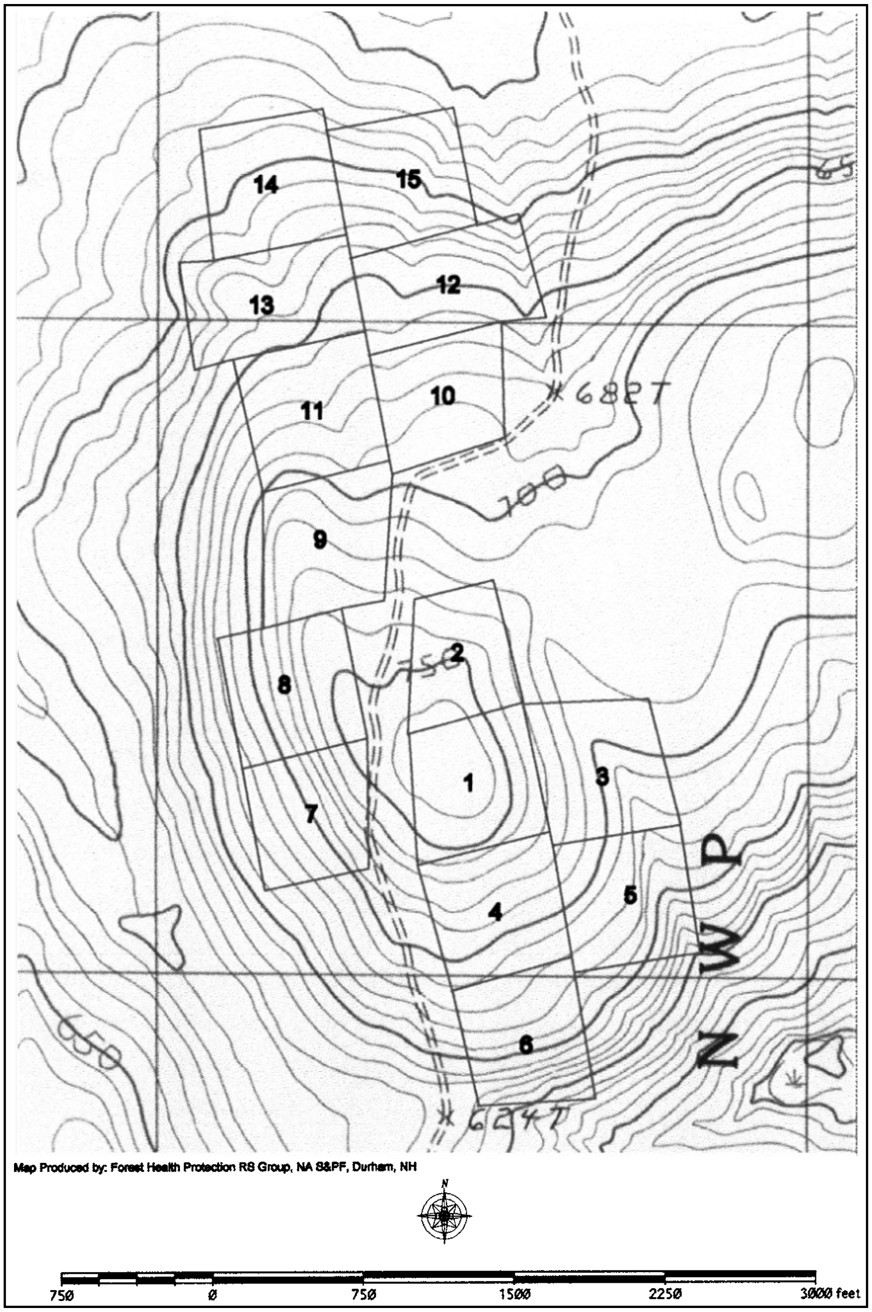

Figure 1.—Location of fifteen 10-acre harvest treatment blocks near Seboeis, Maine: WP = winter partial cuts (blocks 1, 2, 4); WC = winter clearcuts (3, 5, 6); SP = summer partial cuts (7, 8, 14); SC = summer clearcuts (11, 12, 13); NC = no cut controls (9, 10, 15).

was recruited and measured. The cause of death of sprouts and seedlings was determined when possible.

Available solar radiation was measured in July-August 1995 in four randomly chosen selected tree plots in two of the three blocks in each harvest treatment. Measurements were obtained with a LAI-2000 Plant Canopy Analyzer[1] for correlation with growth rates of the sprouts and seedlings in these plots. Thirty measurements were made at 4 feet (1.2 m) above ground in each plot.

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 1.—Preharvest mean basal area (ft^2/acre) for species in 12 harvested treatment blocks

	Block														
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Beech	90.0	66.2	89.4	88.1	80.6	72.5	74.4	58.8			58.1	65.0	48.1	52.5	
Sugar maple	5.0	3.8	6.9	12.5	10.0	10.0	8.1	15.6			2.5	13.1	6.9	10.6	
Yellow birch		3.8	3.8	1.9		1.3	1.9	12.5			8.8	9.4	9.4	10.0	
Ironwood		1.3	.6								1.9		.6		
Stripe maple				.6		.6		.6			1.3	.6	.6	1.3	
White ash					1.3	2.5					.6	.6	.6		
Basswood											.6				
Red maple								5.0							
Pin cherry			.6												
White birch							.6								
Red spruce	.6	9.4	3.8	4.4	6.9	2.5	.6	2.5			3.8	1.3	1.3	2.5	
Balsam fir								2.5			1.9	.6		1.9	
Hemlock		.6				1.3		.6						.6	
White-cedar														2.5	
White pine							1.9								
Total	95.6	85.1	104.4	107.5	100.6	90.6	87.5	98.1			79.4	90.0	68.8	81.9	

Statistical analysis

Data obtained in the 36 1-m regen plots for each harvest treatment were pooled to provide means for comparing numbers of beech sprouts and seedlings before and after harvests. Data were analzyed by ANOVA within years and Studentized t-tests were used to compare means between measurement years. Differences were considered significant if p=0.05 or less.

Data acquired in the selected tree plots (15-ft radius) were pooled across reps (blocks) to provide means for comparing numbers of beech sprouts and seedlings in each year that were around resistant or susceptible beech trees that were cut or left standing. A 3-way ANOVA was used to determine differences among main effects: harvest regime, cut/leave status of plot tree, and the resistance/susceptibility status of the plot tree, and their interactions. A Bonferroni test was used to detect differences among treatment means.

Data for the monitored sprouts and seedlings in the selected tree plots were pooled across reps (blocks) to provide means for comparing the diameter and height growth in each year and overall. A 2-way ANOVA examined the effects on growth of the harvest treatments (including the no-cut treatment), the resistance/susceptibility (R/S) status of the plot trees, and the interactions; a Bonferroni test compared differences among harvest treatment means. A 3-way ANOVA examined the effects on growth of sprouts and seedlings of the harvest treatments, the R/S status, and the cut/leave status of the plot trees and their interactions. A Bonferroni test was used to detect differences among harvest treatment means. Spearman correlations were used to examine the relationship of available light to overall mean height and diameter growth of sprouts and seedlings.

Results

Stand Composition and Structure

The fifteen 10-acre blocks of forest in this study differed considerably in preharvest composition and structure (Table 1). Mean block basal area ranged from 69 to 108 ft^2/acre (15 to 24 m^2/ha). Beech was by far the dominant species, ranging from 48 to 90 ft^2/acre (11-20 m^2/ha). There were relatively small amounts of sugar maple, yellow birch (*Betula alleghaniensis* Britton), and red spruce (*Picea rubens* Sargent) in most blocks. Other species were found occasionally at low levels. In general, stands highest in total basal area were those on the southern portion of the study area that sloped to the southeast or west (blocks 1, 3-8); blocks on the northern end of the study area, which sloped to the north and northwest, had lower basal areas, especially of beech (2, 11-14).

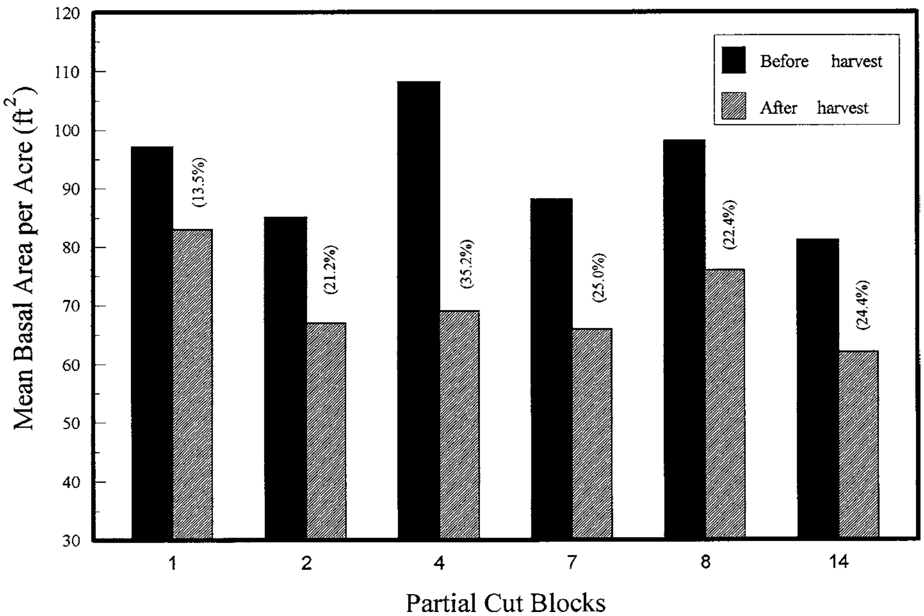

Figure 2.—Mean basal area in partial cut blocks before and after harvest (numbers in parentheses are percent reductions in basal area).

Partial cutting was designed to reduce the overstory by about 30 percent, but this objective was not achieved in most cases (Fig. 2). This treatment reduced overstory volume from 13.5 to 35 percent.

Beech Tree Condition

There was relatively little difference in the condition of beech trees among the blocks. Beech trees in block 13 (southwest aspect) had the poorest average crown condition while those in block 6 (northeast) had the best. Trees growing in the moister lower slopes of block 6 seemed better able to tolerate the effects of BBD than their counterparts growing on the drier, more exposed northwest slopes.

Regeneration

There were marked changes in species composition and numbers of seedlings present in the 1-m regen plots 5 years after treatments (Table 2). Most noticeable was the presence or increase in abundance of intolerant species, either light seeded, e.g., the birches, quaking aspen (*Populus tremuloides* Michx.), and white ash (*Fraxinus americana* L.) or present in the seed bank, e.g., pin cherry (*Prunus pensylvanica* L.f.). This was especially the case in the stands harvested in summer. Beech seedlings increased or decreased slightly in all blocks except WP where increases were significant, while sugar maple, except in the same WP blocks, generally decreased, significantly so in the clearcuts. Striped maple (*Acer pensylvanicum* L.) increased dramatically in the NC control blocks and SP blocks but decreased in all others. Conifers generally were more abundant after the harvests. Species such as bigtooth aspen (*Populus grandidentata* Michx.), black ash (*Fraxinus nigra* Marsh.), ironwood (*Ostrya virginiana*) (Mill.) K. Koch, northern white-cedar (*Thuja occidentalis* L.), and white spruce (*Picea glauca*) (Moench) Voss were found occasionally in low numbers.

Effect of Harvest Treatments on Numbers of Beech Sprouts and Seedlings

Mean counts of beech sprouts and seedlings in selected tree plots are shown in Figure 3A-E. Mean values for the 3 years, expressed both as counts and as numbers per square foot of beech basal area are given in Table 3. Data for 1994, the final year of measurement, are given in Tables 4-5.

The most sprouts and the fewest seedlings were around plot trees in the SC blocks the year after harvest (Fig. 3C, Table 3), but sprouts in the SP blocks (Fig. 3D) increased each year and equaled or slightly exceeded those in the clearcuts by 1994 (Table 4). Also by 1994, there were significant differences in the number of sprouts in the selected tree plots attributable to harvest treatments and to the resistance/susceptibility status of the plot trees (Table 4). These differences seemed to reflect the relative amount of root disturbance rather than the amount of beech basal area present. Harvest treatments that created the most disturbance triggered the most root sprouts (Table 3); the NC blocks had the fewest sprouts. The number of beech seedlings around plot trees, while significantly affected by harvest treatment, was not affected by the R/S or cut/leave status of the plot tree. By contrast, the number of beech seedlings seemed to reflect the amount of beech basal area in the treatment blocks (Table 3). The most

Table 2.—Seedling regeneration (< 1 m tall, < 2.5 cm in diameter) by species in thirty-six 1-m-radius regen plots in each harvest treatment before (1989) and 5 years after (1994) harvest; values inflated to number of seedlings per acre

	Winter clearcut		Winter partial cut		Summer clearcut		Summer partial cut		No cut	
Species	1989	1994	1989	1994	1989	1994	1989	1994	1989	1994
Beech	6,118	8,515	14,383	**25,008	6,547	6,082	6,225	5,939	9,731	7,191
Sugar maple	59,335	**34,490	29,409	32,021	18,962	**6,046	23,792	14,526	25,152	32,880
Yellow birch	1,717	4,258	1,216	**12,307	894	**7,549	393	**16,493	680	1,610
Striped maple	4,472	2,540	9,696	*6,082	5,868	*2,826	13,352	21,538	7,835	**32,307
Red maple	644	501	1,825	1,753	1,395	1,360	2,361	**10,697	3,435	2,433
White ash	250	**3,229	72	250	179	787	0	322	250	858
Quaking aspen	0	36	0	0	0	8,157	0	72	0	0
Pin cherry	36	394	0	143	0	1,217	0	215	0	0
White birch	0	501	0	0	0	322	0	1,753	0	644
Grey birch	0	36	0	0	0	859	0	0	0	0
Balsam fir	0	0	107	72	179	143	751	1,395	1,252	1,717
Red spruce	0	250	322	823	0	36	0	215	0	37
White pine	0	0	0	36	0	36	0	250	0	212

Note: Asterisks indicate significant changes between years within harvest type using Studentized t-test (* = 0.05; ** = 0.01).

seedlings by far were in the WP blocks (Fig. 3B, Table 5), a consequence of the large numbers present before harvest (which was a consequence of the high beech basal area). There also were relatively large numbers of seedlings in the WC blocks (Fig. 3A, Tables 3, 5), which, prior to harvest, had high basal areas of beech and large preharvest numbers of seedlings (see results for the 1-m regen plots that follow). There were little differences in seedling numbers between the controls and the SP blocks (Fig. 3D-E, Tables 3, 5), but the SC was devastating to the seedlings (Fig. 3C, Tables 3, 5).

By 1994 within all harvested blocks, there were more sprouts around resistant trees or stumps than around susceptible ones. While this difference was significant (p=.036) overall, within treatments it was significant (p<.05) only for the SP harvest (Table 4). Overall, sprout numbers were not significantly different around trees left standing vs. those that were cut, but there were significantly (p=.059) more sprouts around resistant tree stumps than around resistant trees left standing (Table 4).

By contrast, there were no significant differences in the number of seedlings around resistant and susceptible trees by 1994. However, there were significantly more seedlings around both resistant and susceptible trees in the winter-harvested blocks (p=<.05) and, within these, significantly more in the WP blocks (Table 5). The winter-cut blocks had the highest beech basal area and also the healthiest trees. Differences in the number of seedlings present, related to whether trees were cut or left standing, were not significant, though within the WC treatments, the number of seedlings was significantly greater (p=.07) around standing trees than around stumps (Table 5). Abundant seed was produced in 1992.

Table 3.—Mean number of beech sprouts and seedlings per acre in the selected tree plots by harvest treatment (mean of 3 years for harvested blocks, 2 years for control blocks). Numbers in parentheses are seedlings per ft^2 beech basal area

Treatment	Sprouts	Seedlings
Winter clearcuts (WC)	1,736	5,585 (69)
Winter partial cuts (WP)	1,325	14,891 (183)
Summer clearcuts (SC)	2,253	649 (11)
Summer partial cuts (SP)	1,565	3,013 (49)
Controls (NC)	675	2,967 (49)

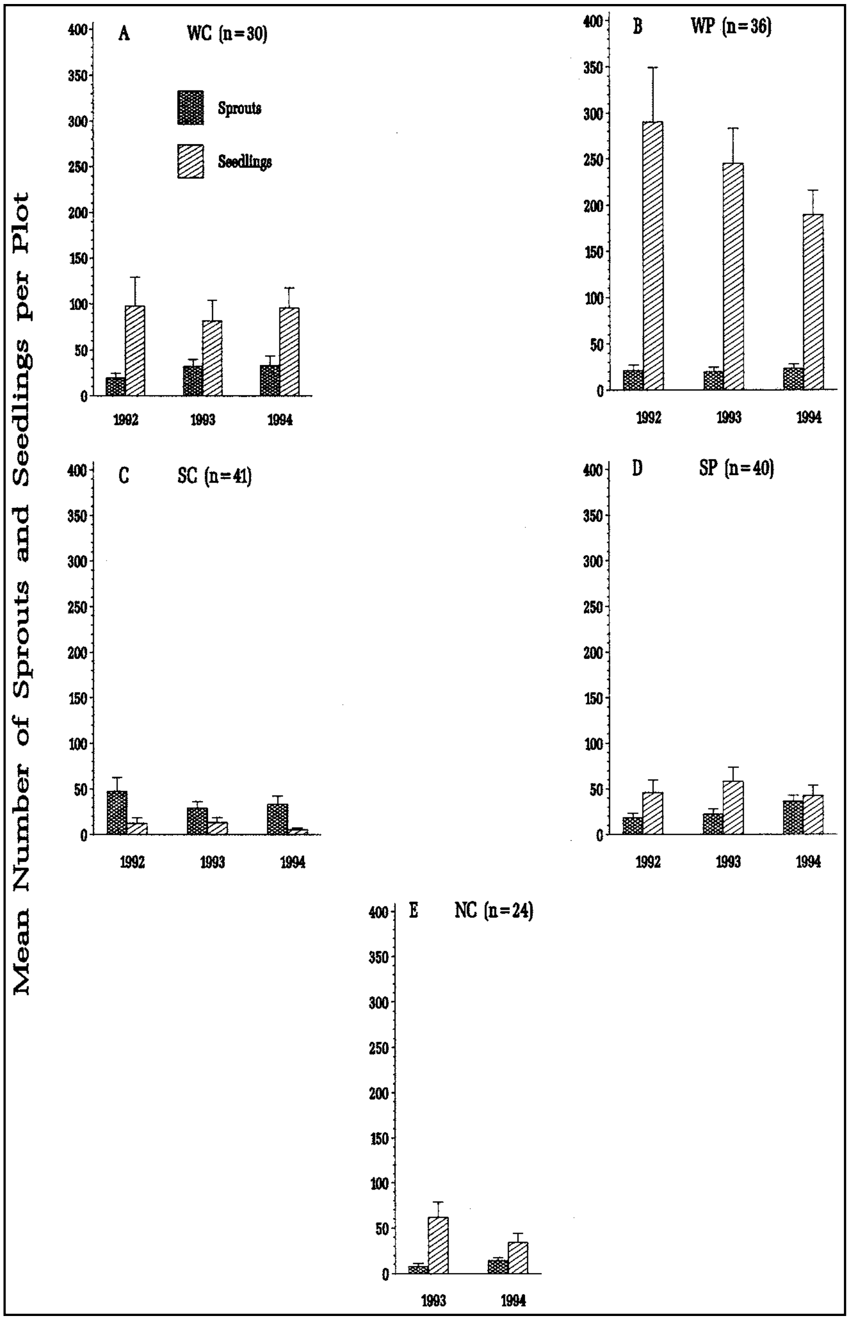

Figure 3.—Mean number of sprouts and seedlings within 15-foot radius plots for each measurement year and each harvest treatment (N = number of 15-foot radius study plots within treatment).

The estimated number of sprouts and seedlings per acre (minus the 1-year-old seedlings) in the 1995 random tree plots was similar (though slightly higher in most cases) to that in the selected tree plots in 1994 (Table 6). As with the selected tree plots, seedling numbers seemed related to the basal area of beech.

Mean counts of beech sprouts and seedlings in the 1-m regen plots in summer 1989 and in summer of 1994 are compared in Table 6 and Figure 4. In general, the trends for change in relative numbers for sprouts and seedlings in these plots were similar to those in the larger selected tree plots. However, the estimated number of seedlings and sprouts per acre for the two sets of plots differed markedly. The number of sprouts (1994) estimated from the 1-m regen plot data was consistently about twice that estimated from the selected tree plot data (Table 6). By contrast, seedling numbers estimated from the 1-m regen plot data were both lower (WC, SP, NC), and higher (WP, SC) than those estimated from the selected tree plot data (Table 6).

Table 4.—Mean number of beech sprouts present in 1994 in different treatment blocks in the selected tree plots around resistant or susceptible trees and for trees that were cut or left standing (no trees were cut in the NC treatment)

		Resistant plots			Susceptible plots		
Treatment	Overall	All[1]	Cut	Standing	All	Cut	Standing
WC	33.2	40.5[b] (61)[2]	35.6 (45)	43.1 (55)	25.8[ab] (39)	27.5 (53)	23.9 (47)
WP	23.5	24.7[ab] (53)	31.4 (61)	19.9 (39)	22.2[ab] (47)	22.6 (51)	21.8 (49)
SC	33.1	35.7[b] (54)	35.0 (49)	36.4 (51)	30.8[b] (46)	21.8 (41)	38.9 (59)
SP	36.1	43.5[b]A (60)	52.3 (60)	34.7 (40)	28.7[ab]B (40)	31.1 (54)	26.3 (46)
NC	14.5	13.8[a] (48)		13.8 (48)	15.1[a] (52)		15.1 (52)
All		33.1 (57)	39.6A (58)	28.5B (42)	25.4 (43)	25.8 (51)	25.1 (49)

[1]Means in columns for All trees (cut and standing) followed by a different lower case letter are significantly different (p = 0.05) using a Bonferroni test; within rows, means followed by a different upper case letter are significantly different.
[2]Numbers in parentheses are proportions of sprouts within each treatment.

Monitored Sprouts and Seedlings

About 1,100 sprouts and 2,050 seedlings were followed individually in the selected tree plots for 2 or 3 years. In only nine blocks were the desired 20 sprouts and/or seedlings present in all plots. Some blocks, especially 11-15, had plots with few candidates, which resulted in low block means. Nevertheless, a sufficient number of plants was measured to provide a clear picture of where and when sprouts and seedlings developed, how much they grew, and how well they survived during the study period. Central to the objectives of this study is the information gained regarding the occurrence and development of root sprouts.

Root Sprouts: Patterns of Development

Size of parent roots

Although the sprouts observed in this study were on roots whose diameters ranged from < 0.04 to 3.1 inches (0.1 to 7.9 cm) at the points where sprouts occurred, 75 percent occurred where roots measured 0.2 to 0.8 inch (0.5 to 2.0 cm) in diameter. The distribution of parent roots by size class was similar for all harvest treatments.

Origin on parent roots

Harvest treatment had little effect on where sprouts developed on roots; 69 percent originated from the tops of roots, (28 percent from the bottoms, and 3 percent from the sides). This sprouting pattern, which reflected the patterns of wounding, revealed a relatively large number of injuries to the undersides of roots when they were bruised against underlying rocks.

Clusters vs single sprout sprouts

Many root sprouts developed in clusters of 2 to 10 or more; 65 percent of the sprouts monitored in the study were in clusters. Clearcut blocks had the greatest proportion of sprout clusters (71 percent) but there were significantly more clusters than single sprouts only in the SC blocks; thinned blocks had less (60 percent), and the controls had equal proportions of single sprouts and sprout clusters. Within the five size classes of parent roots (0.2 to 1.2 inches; 0.5 to 3.0 cm) that bore 92 percent of the sprouts, the proportion of clusters to single sprouts increased consistently as parent-root diameter increased. There was significantly more ($p < 0.01$) sprouting as clusters than as single sprouts in the four largest classes (0.4 to 1.2 inches; 1.0 to 3.0 cm).

Growth of Sprouts and Seedlings

Effects of harvest treatment

When the effects on sprout and seedling growth of the five harvest treatments, the resistance/susceptibility status of the plot trees, and their interactions were analyzed, only harvest treatment was significant ($p=.0003$). The mean height and diameter growth of sprouts and seedlings from 1992-93, 1993-94, and overall from 1992 to 1994 are given in Table 7. After 3 years, height growth was greatest in the WC's and less, successively, in the SC's, WP's, SP's, and NC's. Many of the differences were significant. Sprouts outgrew seedlings by 50 to 60 percent in clearcuts, 30 to 35 percent in thinned stands, and 80 percent in uncut stands. Diameter growth of sprouts and seedlings in the WC's equaled that in the SC's, which, in turn, exceeded

Table 5.—Mean number of seedlings present in 1994 in different treatment blocks in the selected tree plots around resistant or susceptible trees and for trees that were cut or left standing (no trees were cut in the NC treatment)

Treatment	Mean beech basal area	Overall	Resistant plots[1]			Susceptible plots[1]		
			All	Cut	Standing	All	Cut	Standing
	ft²							
WC	80.8	95.7[b]	94.9[b] (1.2; 50)[2]	84.7 (45)	103.7A (55)	96.5[b] (1.2; 50)	69.8 (35)	127.0B (65)
WP	81.4	192.9[a]	182.7[a] (2.2; 47)	195.9 (53)	173.2 (47)	203.6[a] (2.5; 53)	216.9 (53)	193.0 (47)
SC	57.1	5.8[d]	5.5[c] (0.1; 49)	4.6 (46)	6.4 (58)	6.1[d] (0.1; 51)	5.4 (45)	6.6 (55)
SP	61.9	42.5[c]	44.5[c] (0.7; 52)	45.0 (50)	44.1 (49)	40.4[c] (0.6; 48)	35.8 (44)	44.9 (56)
NC	60.4	34.8[c]	28.3[c] (0.5; 41)		28.3	40.8[c] (0.7; 59)		40.7
All			73.0 (49)	75.9 (52)	71.0 (48)	76.0 (51)	75.1 (50)	76.6 (50)

[1]Column means followed by different letters are significantly ($p = 0.05$) different from each other using a Bonferroni test; within rows, means followed by A are significantly ($p = 0.07$) different from those followed by B.
[2]Numbers in parentheses are seedlings per ft^2 beech basal area, followed by proportion of seedlings within each treatment that were around resistant or susceptible trees.

Table 6.—Mean number of beech seedlings and sprouts per plot and per acre from pre- and post-harvest measurements in thirty-six 1-m regen plots in each treatment

Treatment	x basal area of beech/acre	Estimate basis	1989[1] Sprouts	1989[1] Seed	1994[1] Sprouts	1994[1] Seed
	(ft²)					
WC	80.8	x/plot	2.0[a]	2.75[b]	3.64[a]	2.97[b]
		x/acre	2,576	3,542	4,688	3,825
					(+2,642)[2]	(-2,027)
WP	81.4	x/plot	3.08[a]	8.0[a]	1.61[a]	17.77[a]
		x/acre	3,967	10,303	2,074	22,887
					(+644)	(+11,201)
SC	57.1	x/plot	0.53[b]	4.56[b]	4.50[a]	0.33[b]
		x/acre	683	5,873	5,796	425
					(+3,750)	(+66)
SP	61.9	x/plot	0.61[b]	4.22[b]	3.31[a]	1.30[b]
		x/acre	786	5,435	4,263	1,674
					(+2,039)	(-945)
NC	60.4	x/plot	0.69[b]	6.86[b]	4.22[a]	1.36[b]
		x/acre	889	8,836	5,435	1,752
					(+4,554)	(-368)

[1]Within columns, means followed by different letters are significantly (p=0.05) different from each other using a Bonferroni test.
[2]Parentheses include numbers above or below those estimated from the 15-ft selected tree plots.

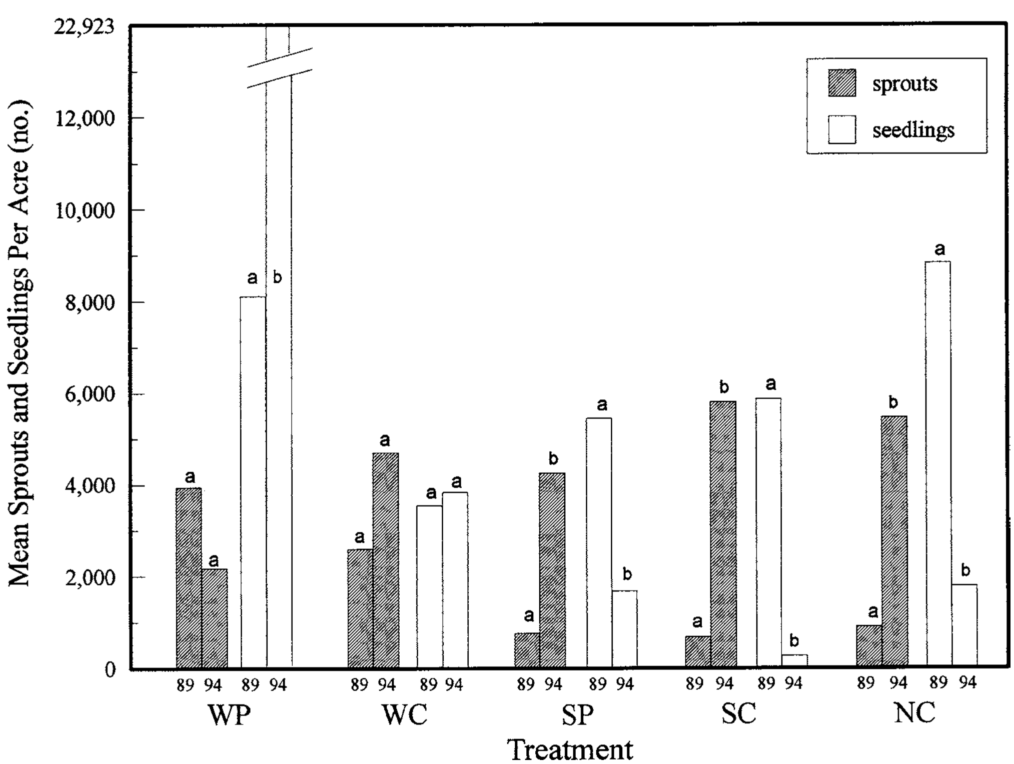

Figure 4.—Mean number of sprouts and seedlings per acre in 1-m-radius regeneration plots before (1989) and after (1994) harvest treatments. Significant differences ($p < 0.01$) between measurement years for each category are indicated by different letters as determined by Studentized t-test.

that in SP's and WP's. Diameter growth of sprouts was twice that of the seedlings.

Differences in height and diameter growth attributable to harvest treatments seemed related to differences in the amount of light reaching the understory. Thus, for both sprouts and seedlings, height and diameter growth was consistently greater in the summer and winter clearcuts than in their corresponding partial cuts (Fig. 5A,B). Also, for all but the sprout height growth for 1993-94 in the WP blocks (Fig. 5A) and for both height and diameter growth in the SC blocks (Fig. 5A,B), growth of both sprouts and seedlings seems strongly and positively related to the amount of light received at 4 feet above ground. The least growth occurred in the NC blocks.

After 3 years, the relationship of light (as a result of harvest treatment) on height growth was highly significant only for seedlings (p=0.0007, R^2 = 0.50). The overall influence of light level (treatment result) on diameter growth was significant for both seedlings (p = 0.0002, R^2+0.46) and sprouts (0.01, R^2= 0.27).

Resistance/susceptibility and cut/leave status of parent tree

There were significant differences in growth of sprouts and seedlings when the effects of harvest treatment (excluding the no-cut treatment), the resistance/ susceptibility and cut/leave status of the plot tree, and their interactions were compared (Table 8). While the main effect of harvest treatment was highly significant in nearly all cases, there were highly significant interactions, especially between harvest treatments and cut/leave status, and, for seedling height growth, between resistance/susceptibility and cut/leave status.

Harvest treatment significantly affected diameter but not height growth of sprouts around resistant trees, and both diameter and height growth around susceptible trees; seedlings growth was significantly affected around both resistant and susceptible trees (Table 9).

In general, growth of sprouts and seedlings was better (sometimes significantly) around trees left standing in clearcut blocks, and around the stumps of cut trees in partial cut blocks (Table 10). Within all harvested blocks, height growth of sprouts was best around resistant parent trees that were left standing, slightly less around cut resistant trees and standing susceptible trees, and poorest around the cut susceptible trees (Table 11). Average height growth of sprouts around resistant trees in the control blocks was about half that in the harvested blocks.

Seedling growth was best around resistant cut trees and poorest around resistant leave trees. Growth of seedlings around susceptible trees was the same whether or not the trees were cut. Seedling growth in the no-cut control blocks was poor compared to that in the harvested blocks, reflecting the growth response of seedlings to increased light (Table 11). Thus, in some cases, growth seemed affected more by whether the sprout or seedling was growing around a resistant or susceptible tree, or a cut or leave tree, than by when or how the stand was harvested.

Demographics of Sprouts and Seedlings

Age

Age distributions of all monitored sprouts and seedlings as of summer 1993 are shown in Figure 6A-C. Most sprouts were 2 to 3 years old in 1993, a consequence of injuries made to root systems during harvest in 1991. In blocks harvested in winter, 54 percent of the sprouts were 3 years old and 30 percent were 2 years old in 1993 (or 1 and 2 years old, respectively, when first measured in 1992) (Fig. 6B). By contrast, 70 percent of the sprouts in the summer harvest blocks were 2 years old in 1993 (Fig. 6C).

Age distributions of seedlings differed from those of sprouts in that they reflected the ages of seedlings already established at harvest time as well as those that became established thereafter. The presence of 1- and 2-year-old seedlings in harvested blocks in 1993 reflects those that were added in years after plots were established, and a large proportion of 1-year-old seedlings in the control blocks (included in Figure 6A) reflects the fact that plots in those blocks were not established until 1993. There were good seed crops in 1992.

The distribution pattern of seedling ages suggests the occurrence of alternating heavy seed years (Fig. 6A). This pattern was more evident in some blocks than in others. Seed years were heavy primarily in even years except in blocks, 3, 4, 5, and 6, where relatively high proportions of seedlings originated from seed produced in 1989. Although these blocks were harvested in winter and most were clearcut, the age distributions in them and in other blocks probably is less a consequence of harvest treatment than of block locations, the patchiness of seeding trees (BA) over the 150-acre (60-ha) study area, and possibly cacheing activities of seed-dispersing agents, particularly bluejays (*Cyanocitta cristata* L.).

Sprout and seedling mortality

By summer 1993, 140 sprouts and 71 seedlings had died, and by the next year, an additional 123 sprouts and 162 seedlings were dead (Table 11). Although nearly the same number of sprouts and seedlings had died (263 vs. 233) by 1994, proportionally about twice as many sprouts (including "successors") than seedlings died (24 vs. 11 percent). Sixteen of the 35 successor sprouts in clusters died between 1993 and 1994; in most cases, all other sprouts in those clusters also had died. There was a tendency, toward higher sprout

Table 7.—Mean height and diameter growth of monitored sprouts and seedlings by treatment, 1992-94

Treatment		1992 - 1993			1993 – 1994			1992 - 1994		
		Number	Height	Diameter	Number	Height	Diameter	Number	Height	Diameter
			cm	*mm*		*cm*	*mm*		*cm*	*mm*
WC	Sprouts	152	23a	4a	143	26a	2a	140	50a	6a
	Seedlings	428	15A	3A	427	15A	1A	423	30A	3A
WP	Sprouts	165	21ab	3b	156	19b	1ab	156	40b	4b
	Seedlings	185	6B	2B	523	8B	< 1B	511	15B	2C
SC	Sprouts	265	21ab	4a	312	21b	1a	219	46ab	6a
	Seedlings	175	10B	2B	174	7BC	1A	151	17B	3B
SP	Sprouts	163	16b	2b	201	19b	1ab	152	37b	4b
	Seedlings	339	4C	1C	389	5CD	< 1B	303	9C	1D
NC	Sprouts	59	19ab	-	65	13b	< 1b	56	31b	-
	Seedlings	176	3C	-	311	3D	< 1B	166	6C	-

Note: Within columns, values with different letters are significantly different ($p = 0.05$) using a Bonferroni test.

Table 8. —Significant F values[a] for diameter and height growth of sprouts and seedlings for the 3 years following harvest treatments in 1991 and overall

Item	1992-1993				1993-1994				1992-1994			
	Sprouts		Seedlings		Sprouts		Seedlings		Sprouts		Seedlings	
	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height
HT	.0003	.04	.0001	.001		.004	.0001	.0001	.0002	.005	.0001	.0001
R/S									.03			
C/L								.004				
HT x R/S												
HT x C/L				.05		.0003	.01		.03	.0001	.01	
R/S x C/L								.0001				.0001
HT x R/S x C/L												

[a]3-way ANOVA of four harvest treatments (HT), resistance/susceptibility (R/S) status, cut/leave (C/L) status, and their interactions.

Table 9. —Mean height and diameter growth of sprouts and seedlings around resistant or susceptible trees in the different treatment blocks, 1992-94

Treatment		Resistant trees		Susceptible trees	
		Height	Diameter	Height	Diameter
		cm	*mm*	*cm*	*mm*
W C	Sprouts	45.0A[1]	5.5A	47.8A	4.8A
	Seedlings	29.8a	3.5a	29.5a	3.2a
W P	Sprouts	37.7A	4.2BC	31.8B	2.9B
	Seedlings	16.2b	2.0b	13.4b	1.8b
S C	Sprouts	42.0A	4.8AB	38.5AB	4.5A
	Seedlings	18.9b	2.5b	16.1b	2.7a
S P	Sprouts	34.5A	3.6C	31.2B	3.6AB
	Seedlings	7.2c	1.2c	10.1cd	1.5b
N C	Sprouts	31.6A	-	33.1B	-
	Seedlings	7.1c	-	5.7d	-

Note: Within columns, unlike letters indicate significant differences (p = 0.05) among harvest treatments for sprouts and seedlings using a Bonferroni test.

Table 10.—Situations where the height or diameter growth of monitored sprouts and seedlings was significantly greater (p = 0.05 or as indicated) around trees cut (A) or left standing (B) in harvested blocks, 1992-94

Treatment		1992-1993		1993-1994		1992-1994	
		Height	Diameter	Height	Diameter	Height	Diameter
WC	Sprouts	(B)[1]	B (0.07)[2]	NS	NS	NS	NS
	Seedlings	NS	NS	NS	(B)	(B)	NS
WP	Seedlings	(A)	(A)	(A)	NS	(A)	(A)
SC	Sprouts	NS	(B)	(B)	NS	(B)	(B)
SP	Sprouts	(A)	A (0.06)	(A)	A (0.06)	(A)	NS

[1]Presence of letter indicates significant difference in column, using Studentized t-test; NS = not significant.

Table 11. —Mean diameter and height growth of sprouts and seedlings around resistant or susceptible parent trees that were cut or left standing in harvested blocks, and growth data for control blocks, 1992-94

Item	Resistant parents	Susceptible parents
	Harvested Blocks	
Cut trees	Sprouts (n = 212) Diameter: 4.5 mm Height: 43.3 cm	Sprouts (n = 86) Diameter: 4.1 mm Height: 39.6 cm
Cut trees	Seedlings (n = 260) Diameter: 2.6 mm Height: 24.1 cm	Seedlings (n = 371) Diameter: 2.3 mm Height: 18.8 cm
Leave trees	Sprouts (n = 221) Diameter: 5.3 mm Height: 46.0 cm	Sprouts (n = 139) Diameter: 4.0 mm Height: 43.3 cm
Leave trees	Seedlings (n = 337) Diameter: 2.18 mm Height: 16.3 cm	Seedlings (n = 411) Diameter: 2.4 mm Height: 19.2 cm
	Control Blocks	
	Sprouts (n = 31) Height: 28.9 mm	Sprouts (n = 26) Height: 34.3 mm
	Seedlings (n = 76) Height: 6.6 cm	Seedlings (n = 92) Height: 5.6 cm

mortality in the summer treatments (22 to 28 percent) than in the winter treatments (14 to 15 percent). Overall sprout mortality was lowest in the no-cut stand, which also had the fewest sprouts.

Causes of mortality varied in importance for sprouts and seedlings and between treatments (Table 12). Oystershell scale (*Lepidosaphes ulmi* L.) attack was severe on seedlings in most treatments (especially in the thinned blocks) and on sprouts in the WP blocks. *L. ulmi* was the most important mortality agent in several blocks. It was not possible to determine why many of the sprouts and seedlings died, though it is likely that many were affected adversely by the increased light, heat, and desiccation associated with sudden and massive removal of overstory canopy.

Sprout mortality vs. cut or leave status of parent trees

Significantly more of the monitored sprouts around cut trees died (26.5 percent) compared to those around leave trees (15.7 percent), a consequence primarily of the significant mortality in the clearcut treatments (Fig. 7). There was little difference in sprout mortality related to cut/leave status of their parent tree in the thinned blocks, though mortality was highest in the summer-cut blocks. Mortality was highest in SC's and lowest in the NC blocks.

Sprout mortality vs. resistant/susceptible parent tree

There was no consistent relationship between the mortality of the monitored sprouts and the resistance/susceptibility status of the study plot tree. Overall, 21 percent of the sprouts around resistant, high-vigor trees died compared to 19 percent for those around susceptible, low-vigor trees. However, since 62.5 percent of the sprouts that were monitored were around resistant trees, it is probable that in the long run, more of them will survive to become trees, especially if they are on roots of trees left standing. For both resistant and susceptible trees, mortality of sprouts was higher in the summer-cut blocks (resistant tree plots: 26 percent; susceptible tree plots: 24 percent) than in the winter-cut blocks (resistant tree plots: 17 percent; susceptible tree plots: 9 percent).

Discussion

Regeneration

The changes that occurred in species composition regeneration following harvesting were expected. The marked increase in light and the soil scarification created by tree felling and skidding, especially in the clearcut blocks, created conditions favorable for germination and establishment of wind-dispersed pioneer species and for species such as pin cherry that were present in the seedbank. These results confirm those of other studies that showed that, at least for the next generation, clearcutting encourages shade-intolerant and intermediate species (Leak and Smith 1997; Leak et al. 1987; Marquis 1967; Patton 1997).

Both the numbers and growth of sprouts initiated by treatment disturbances were affected by vigor (resistant vs. susceptible) of the parent tree (and its root system) and the amount of light received as a consequence of crown density of the parent tree or the effects of harvest. Seedling numbers reflected the numbers present at the time of treatment (related to beech BA), while seedling growth was affected primarily by light availability.

The major influence of light on growth of understory sprouts and seedlings resulted in interactions among harvest treatments (overall light availability related to thinned vs. clearcut vs. no-cut stands), crown removal (cut vs. leave trees), crown transparency (resistant vs. susceptible trees), and length of time of increased light availability (winter vs. summer harvests). These interactions prevented definitive "tests" of the four main effects proposed in the initial hypotheses.

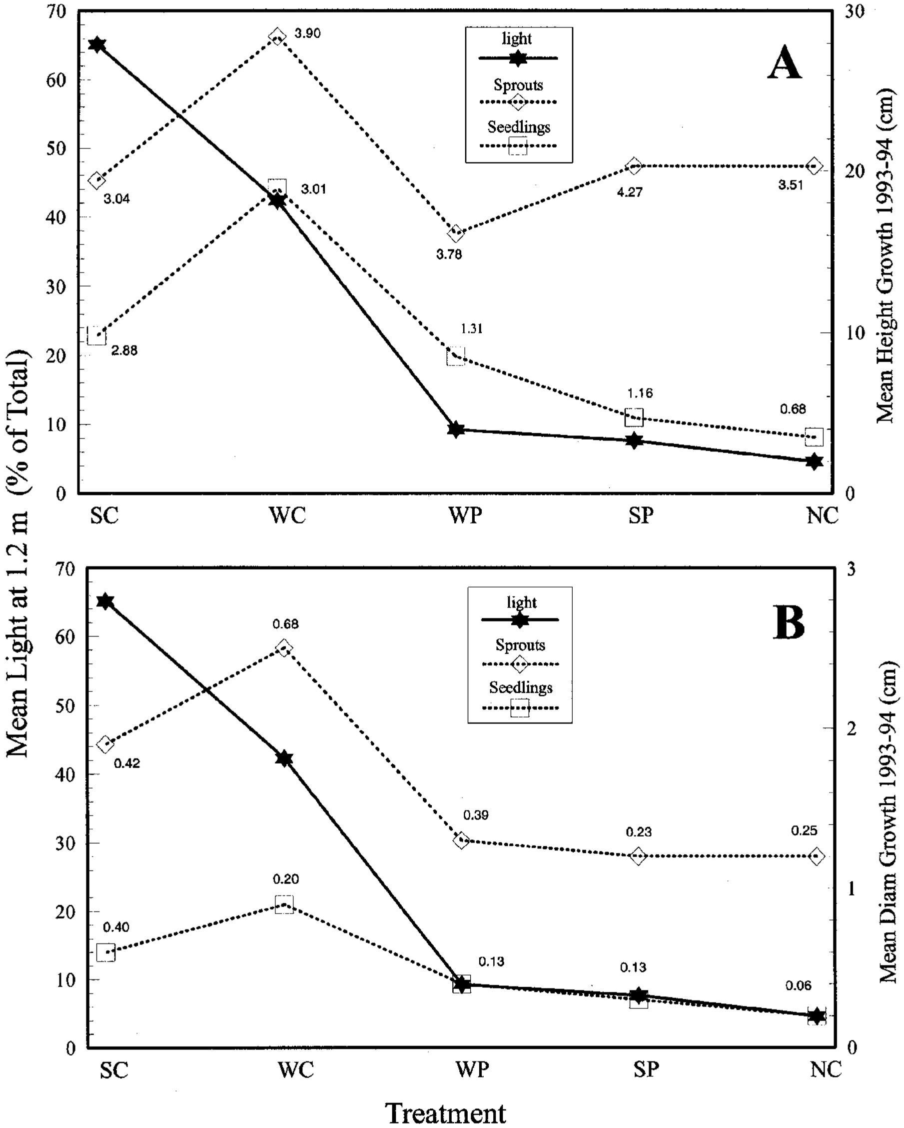

Figure 5.—Mean height (A) and diameter (B) growth of monitored sprouts and seedlings, 1993 to 1994, in eight study plots per harvest treatment, and mean percent of available light recorded at 4 feet above ground, July 31-August 3, 1995 (numbers at points are standard errors of the mean).

<u>Hypothesis 1</u>: <u>Root sprout initiation and development and seedling development</u> <u>in beech is favored more by summer than winter harvests</u>.

Although data acquired in the 1-m regen plots revealed that prior to harvest there were significantly more beech root sprouts in blocks to be harvested in winter than in blocks to be harvested in summer, these differences had disappeared by 1994. Similarly, data from the larger study plots showed that by the third and fourth years after treatment, there were no significant differences in the number of sprouts associated with harvest season even though there were more sprouts in the summer clearcuts in the first season after harvest (1992). Increases in the number of sprouts in the 1-m regen plots were significant only in blocks harvested in the summer and in the controls.

The slight but consistently larger number of sprouts (except for the NC blocks) and seedlings (except for the WC blocks) in the "once entered" randomly chosen tree plots compared to the often entered selected tree plots suggests that activities associated with the initial plot clearing and the subsequent visits may have adversely affected both sprout and seedling survival. High numbers of 1-year old seedlings in the control and thinned blocks in 1995 and their extremely low numbers in the clearcut blocks attests to heavy seed production in 1994 and the absence of a seed source in the cleared blocks.

The slightly greater growth of sprouts and seedlings in the winter-cut blocks compared to their summer counterparts is likely a consequence primarily of the extended period that these plants were exposed to

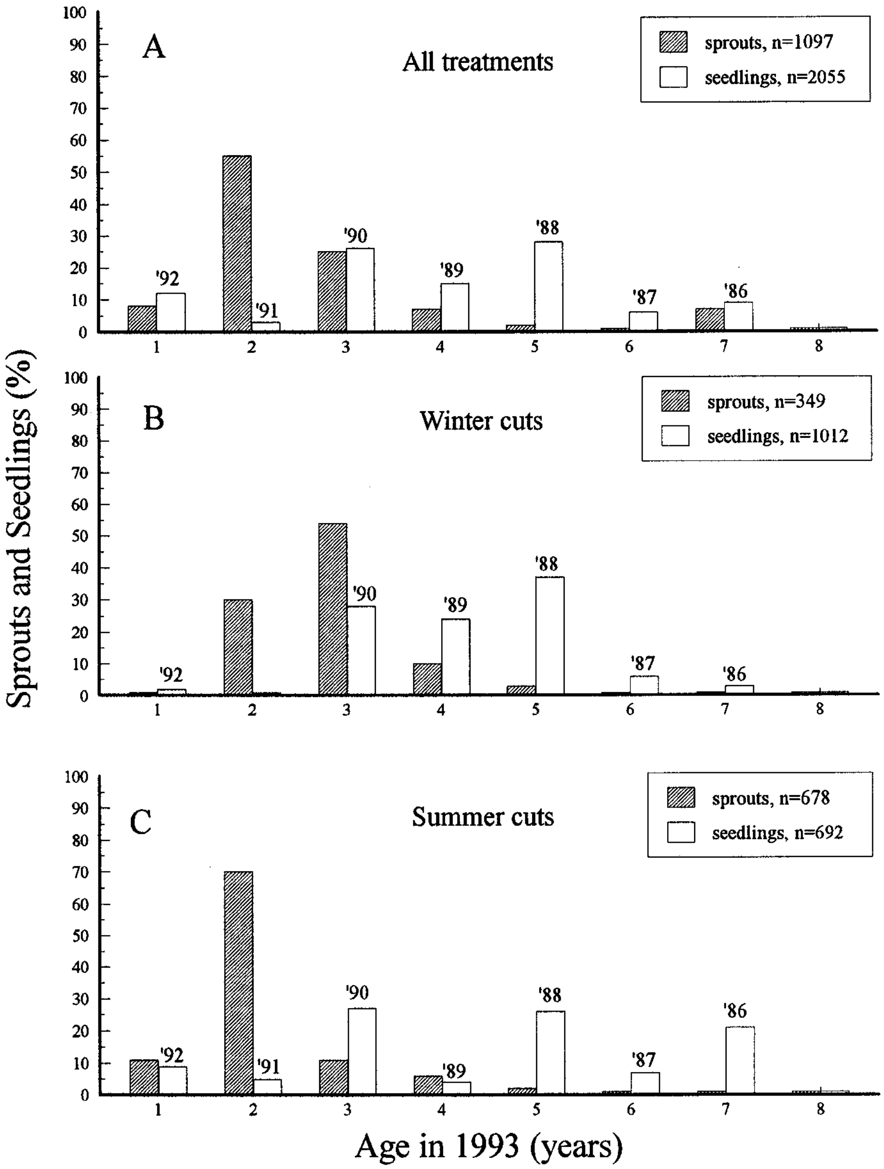

Figure 6.—Age distribution as of 1993 of monitored sprouts and seedlings overall (A) in winter-cut blocks (B), and in summer-cut blocks (C); (numbers over bars for seedlings are the seed/years).

increased light in 1991. It also is possible that the growth of beech was favored by the shading afforded by the herbaceous growth that quickly developed, particularly in the WC blocks.

Hypothesis 2: More sprouts will develop and growth of sprouts and seedlings will be greater around resistant than around diseased trees.

By 1994, more sprouts were present around resistant trees than susceptible ones—significantly so within stands thinned in the summer (SP) and overall. As a consequence, more sprouts (62.5 percent) were monitored around resistant trees than around susceptible trees. It is likely that the susceptible trees in this study (chosen because their crowns were debilitated) were so low in vigor that they responded less vigorously to root injuries and produced fewer sprouts.

The vigor of parent trees seemed to affect sprout growth, though this growth also was influenced by whether parent trees were cut or left standing (see Hypothesis 4). Height growth of sprouts was best around resistant trees left standing, less so around resistant cut trees and susceptible standing trees, and poorest beneath susceptible cut trees. This suggests that the vigor of the parent tree (and its root system) may influence the success of the sprouts that develop. By contrast, seedlings responded primarily to the availability of light because their growth around fully foliated resistant trees was enhanced if the tree was cut but not when thin-crowned susceptible trees were cut.

Table 12.—Mortality rates and causes for monitored sprouts and seedlings by treatment, 1994

Treatment	Mortality by 1994	
	Sprouts[a]	Seedlings[a]
WC	32 of 166 dead (19%) Oystershell scale (9%) Mechanical damage (53%) Unknown (28%)	10 of 437 dead (2%) Mortality due to various causes
WP	30 of 183 dead (16%) Oystershell scale (47%) Mechanical damage (33%) Unknown (17%)	55 of 576 dead (9%) Oystershell scale (84%) Mechanical damage (11%) Unknown (5%)
SC	129 of 429 dead (30%) Unknown (73%) Mechanical and browse (23%) Other (7%)	37 of 211 dead (17%) Oystershell scale (38%) Unknown (43%) Browse or mechanical (16%)
SP	67 of 249 dead (27%) Oystershell scale (9%) Unknown (49%) Browse (28%)	92 of 481 dead (19%) Oystershell scale (60%) Unknown (30%) Browse or mechanical (10%)
NC	5 of 70 dead (7%) Mortality due to various causes	39 of 350 dead (11%) Oystershell scale (18%) Unknown (72%) Browse or mechanical (10%)

[a]Sprout and seedling mortality by 1993 was 13% (140 of 1,097) and 3% (71 of 2,055), respectively.

Hypothesis 3: More sprouts will develop and their growth and the growth of seedlings will be greater around trees (or stumps) in partially cut than in clearcut stands.

By 1994, there were no significant differences in the mean number of sprouts attributable to cutting regimes. However, there were differences. Around resistant trees cut in the winter there were more sprouts in clearcuts than in thinned blocks. The reverse was true for stands harvested in the summer. These differences probably reflect the interactions between the amount of sprout-triggering root injury (more in the clearcuts) and the amount of protective shading (more in the WC blocks than in the SC blocks by herbaceous growth, and in the SP blocks by residual trees).

For both seedlings and sprouts, overall height and diameter growth was greatest in the clearcuts, less in the thinned, and least in the no-cut blocks, suggesting that light is the primary factor influencing growth. The relative amount of light available is strongly correlated with the growth of sprouts and seedlings. Interestingly, growth seems favored by some degree of shade as both sprouts and seedlings grew better in clearcut blocks beneath trees left standing and in thinned blocks beneath trees that were cut (see Hypothesis 4). This latter relationship also can be seen in WC blocks, where growth was best and early growth of understory vegetation reduced the light available to seedlings and sprouts by about 20 percent compared to the SC blocks.

Hypothesis 4: More sprouts will develop and growth of sprouts and seedlings will be greater around cut trees than around trees left standing.

The number of sprouts in the plots was not related to whether trees were cut or left standing. However, within the resistant-tree plots, more sprouts developed in thinned blocks around trees that were cut and around uncut trees in the clearcut blocks. Again, this may reflect the interaction between the amount of root injury and the increased light made available by cutting the plot trees in thinned plots (more light, more root disturbances) and not cutting them in the clearcuts (more protection from drying out, less disturbance). These differences were not as obvious for susceptible trees, perhaps because their thin crowns provided little shade before and after harvest. In some cases in clearcuts, light passing through the thin crowns of

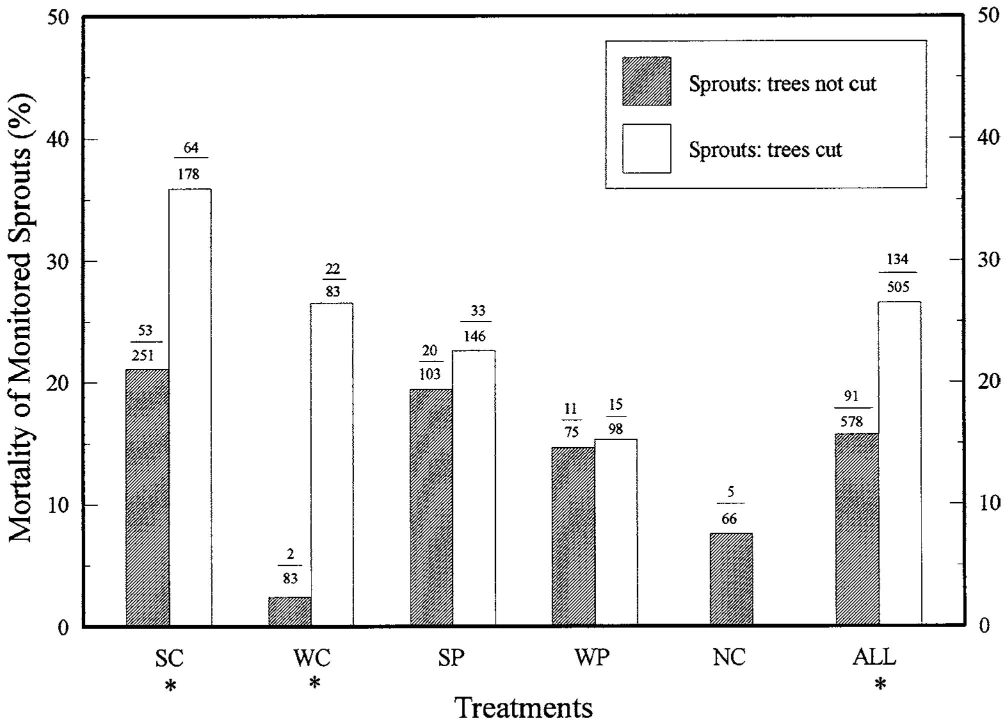

Figure 7—.Proportion of sprouts that died in each treatment around trees or stumps (ratios). Asterisks indicate treatments where differences were significant (p=0.05) between plots with trees cut or not cut.

susceptible trees had encouraged advance development of herbaceous plants that could have provided protective shade to developing sprouts. The relatively high proportion of sprouts in control blocks, where no large equipment was used, suggests that even a minor disturbance such as stepping on roots is sufficient to injure roots and trigger sprouting.

The growth of both sprouts and seedlings was significantly affected by harvest treatment and especially by the interaction of harvest regime and the cut/leave status of the tree. This relationship also reflects the availability of light that was created by the different harvest systems and modified by whether the overtopping plot trees were removed or left standing, and, for seedlings, whether the plot trees were healthy and fully foliated or diseased and thin crowned.

Recommendations for Increasing Sprouts of Resistant Trees

1. Winter vs. summer harvests: No significant differences in numbers of sprouts were attributable to season of harvest. More sprouts developed initially after summer clearcuts, but differences related to season of cut disappeared with time. Thus, under the conditions of this trial, the initial flush of root sprouts in summer harvests attributable to the greater number of root injuries (roots not protected by frozen ground or by snow cover) was offset both by the subsequent greater sprout mortality in the hot, dry, exposed blocks, and by a continuous production of sprouts in the more protected winter-harvested blocks. For growth, light was more important than season of harvest per se, though within the length of this study, sprouts developing in the winter-harvested blocks had the benefit of several additional months of exposure to increased light regimes in the first growing season.

Recommendation: Conduct winter harvests to enhance sprout development, growth, and persistence.

2. Resistant vs. susceptible trees: More sprouts developed around resistant (high-vigor) than around susceptible (low-vigor) trees, and their growth was best around resistant trees, particularly when trees were left standing. Sprout numbers were slightly higher around resistant trees that were cut in thinned blocks or left standing in clearcuts. The slightly higher numbers of sprouts around the harvested resistant trees would not seem to justify cutting them for this purpose since resistant trees left in the stand likely will produce more root sprouts in the long run. And, although not addressed in this study, leaving resistant trees and removing susceptible ones, especially in clearcuts, probably will enhance opportunities for sexual production of resistant seedlings.

Recommendation: Retain resistant trees even in clearcuts.

The susceptible trees used in this study were severely debilitated by BBD and had thin crowns and chlorotic foliage. Less susceptible trees, more vigorous than those used here, may have responded more comparably to the resistant trees. Since trees vary in susceptibility to BBD, it is important to retain for seed or sprout production trees that are least infested, infected, or damaged by the disease. Root injuries and consequent root sprouting by susceptible trees, both harvested or retained, can be reduced by using predetermined skid trails and/or equipment designed to minimize root damage.

3. Partial vs. clearcuts: Although there were no significant differences between thinned and clearcut blocks, the number of sprouts around resistant trees was highest in winter clearcuts and summer thinnings; growth was greatest in the clearcuts.

<u>Recommendation</u>: Harvest clearcuts in winter and conduct thinnings in summer. Identify and retain resistant trees in all cases.

4. Cut vs. standing trees: In the thinned blocks, more sprouts developed around the resistant trees that were cut than around those left standing. However, these differences probably are insufficient to warrant removing these resistant trees from the stand.

<u>Recommendation</u>: Identify and retain resistant trees.

It should be noted that improvements in beech quality or in species composition resulting from these recommendations will not occur rapidly and may not be permanent. The results reported here represent an initial glimpse of the immediate responses by a number of forest stands to harvesting practices conducted under "real world" conditions. Research is needed to confirm the trends observed here for the occurrence and development of beech root sprouts and seedlings and other species.

Harvest treatment had little influence on sprout numbers except that there were significantly more sprouts initially in the SC blocks than in the NC controls. The season of harvest, degree of overstory removal, and cutting or leaving trees had little effect on the numbers of sprouts.

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Forests in Maine often contain many trees severely damaged by the disease. Methods are needed to reduce numbers of susceptible and increase numbers of resistant trees. This paper describes how commonly-used harvesting systems affect the incidence and growth of beech root sprouts and seedlings. Harvest treatments were clearcutting and thinning in winter and summer, 1991. Interactions occurred between the amount of root disturbance (leading to root sprouts) and amount of light available for growth. More sprouts developed after clearcuts than thinnings, and around resistant than susceptible trees. Sprout growth was best around resistant trees left standing, poorest around diseased trees that were cut. Summer clearcuts reduced exisiting seedlings and prevented “recruits”; seedling growth was related to amount of light received—a consequence of the harvests or disease-caused crown thinning.

Keywords: beech, root sprouts, seedlings, beech bark disease

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