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Ten-Year Impact of Spruce Budworm on Spruce-Fir Forests of Maine

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Abstract

Annual measurements from 1975 to 1985 on 278 Maine spruce-fir plots infested by the spruce budworm were analyzed to determine the impact of species composition, growth, and mortality. Analyses were done by forest type, density, host-species composition, diameter, and percent fir or spruce composition classes. Balsam fir accounted for about one-quarter of the initial 1975 basal area per acre in both forest types. Mortality of fir was half of this initial basal area by 1985 in mixedwood stands, and three-quarters in softwood stands. Similarly, roughly 3 times as much of the initial spruce basal area was lost in softwood as in mixedwood stands. Balsam fir mortality increased with increasing basal-area density in both forest types, with higher losses in the softwood type. No such relation was found between either spruce or fir mortality and species-composition or size class. Heaviest losses occurred 2 years earlier in the highest density stands (more than 120 ft^2/acre). Heaviest losses in mixedwood stands usually occurred about 4 years after those in softwood stands. Harvests of spruce and fir were increasing over the 10-year period in softwood stands and decreasing in mixedwood stands. Spruce budworm accounted for 94 percent of the balsam fir mortality in mixedwood stands and 84 percent in softwood stands.

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Introduction

The spruce budworm (*Choristoneura fumiferana* (Clem.)) has been the most destructive forest insect in the spruce-fir region of New England and eastern Canada (Mog et al. 1982). Budworm damage is not limited to the epidemic period but may extend beyond the termination of the outbreak to cause reductions in the supply of available forest products. In spruce-fir forests, the budworm eliminates most of the fir and some spruce, resulting in an extended waiting period before the regeneration of the forest stand (Batzer 1969).

The most recent epidemic in Maine increased in the early 1970's and continued into the 1980's. During this period, forest managers and researchers in the state realized there was a need for a large-scale study to quantify the impact of spruce budworm. In 1975, a cooperative study was initiated by Federal, state, university, industrial and private organizations (Ashley et al. 1976). The beginning phases of this 10-year study, coordinated by the USDA Forest Service, the School of Forest Resources at the University of Maine at Orono, and the J.W. Sewall Company (Lawrence and Housewart 1981), were designed to determine the impact of budworm infestation on the growth and mortality of spruce-fir forests. Remeasured plots provided an estimate of budworm-caused mortality and information on expected growth reductions in surviving spruce-fir stands.

This report, the culmination of the 10-year study, reports on changes in forest structure and growth from 1975 through 1985. The study's objectives, design, and evolution during this period are found in Ashley et al. (1976) and in interim reports on budworm impact by Brann et al. (1981, 1983, 1985), Lawrence et al. (1979), Lawrence and Houseweart (1981), and Schlitz et al. (1983).

The analyses in this report are divided into three major sections. The first, *Changes in Forest Composition,* highlights changes that have taken place (by percent change in square feet of basal area per acre) over the first 5 years (1975-80) and the entire 10-year (1975-1985) period. Basal-area figures used in the calculation of percent change include all stand growth components except harvesting (harvest plots were excluded from the analysis). Therefore, the influence of the budworm on any one component of growth (e.g., mortality) cannot be determined directly from the analysis of forest composition. The section on *Components of Stand Growth* separates stand growth over the 10-year period into traditional stand-growth components. For example, mortality is treated in great detail. The third section, *Biennial Live Basal Area as Related to Stand Characteristics,* provides a more detailed picture of <u>when</u> growth reductions began, that is, when stands began to respond to the budworm epidemic.

Where possible, corollaries are drawn between the sections, though the reader is cautioned to note those differences between the data summarizations in each section when such comparisons are made.

Methods and Analysis

Permanent plots were established in 1975 at 406 locations throughout the spruce-fir region of Maine (Ashley et al. 1976). The study was designed with two-thirds of the plots located in softwood stands and the remainder in mixedwood stands. The number and location of the plots were not designed to represent the spruce-fir region within Maine. However, analysis of these plots can be used to follow growth and mortality relationships in similar stands within the spruce-fir forest type. Each plot consisted of a center milacre plot with a 1/50- and a 1/20-acre concentric plot (Brann et al. 1985).

Data collected on the 1/20-acre plot consisted of the following measurements for all trees larger than 4.5 inches in diameter at breast height (d.b.h.):

- Species.
- D.b.h. to the nearest 0.1 inch.
- Total height (in feet) to the nearest foot.
- Live crown length (in feet) to the nearest foot.
- Crown class (dominant, codominant, intermediate, overtopped).
- Tree condition (merchantable, cull, dead).
- Percent defoliation of new foliage (i.e., current-year's foliage).
- Cumulative percent defoliation of older foliage.
- Cause of death (budworm, blowdown, logging damage, harvest, other, unknown).

Additional data collected on the 1/50-acre plots included:

- Number of stems by species and 1-inch diameter classes from 0.6 to 4.5 inches.
- Degree of spruce budworm feeding on each tree (none, light, medium, heavy).

On each milacre plot, seedling counts by species group and the degree of budworm feeding on each host-species tree were recorded as none, light, medium, or heavy. Host species in this study were: balsam fir (*Abies balsamea* (L.) Mill.), red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.).

All analyses were performed on species groupings that consisted of fir, spruce (red, white, and black), hemlock, other softwoods, and hardwoods. Plots that were not continuously remeasured and plots that were harvested during the study were eliminated. Thus, this report is based on 278 of the original 406 plots. All of the plots were reclassified by forest type as softwood or mixedwood based on the total live basal area of each individual plot in 1975. Plots with more than a 60-percent combination of balsam fir, spruce, hemlock, and other softwoods were classified as softwood; plots with less than 60 percent of these species were classified as mixedwood. These classifications resulted in 204 (73 percent) softwood and 74 (27 percent) mixedwood plots.

All plots were categorized into fir and host-species composition classes (host species in this context implies the aggregation of balsam fir, the spruces, and eastern hemlock into one class grouping). The categories were based on the 1975 species composition as percentage of square feet of basal area and are presented as:

Forest type	Percent host		Percent fir	
	Class	No. plots	Class	No. plots
Softwood	< 60	53	< 20	93
	60-80	62	20-40	52
	80-100	89	40+	59
Mixedwood	< 35	35	< 20	34
	35-60	39	20+	40

The quadratic mean stand diameter in 1975 was used to assign each plot to one of the following diameter classes:

Diameter class (inches)		Number of plots	
		Softwood	Mixedwood
6	(4.6-6.5)[a]	19	7
7	(6.6-7.5)	62	19
8	(7.6-8.5)	72	21
9	(8.6-9.5)	32	15
10	(> 9.6)	19	12

[a]Range.

Due to a lack of small- and large-diameter stands, the 5- and 6-inch mean stand diameter-class plots were combined and the 10-inch and greater plots were combined to become the 6- and 10-inch mean stand diameter classes, respectively. Plots also were categorized by square feet of basal area in 1975 into the following categories:

Basal-area class (ft^2)		Number of plots	
		Softwood	Mixedwood
20	(< 40)[a]	6	4
60	(40-80)	43	14
100	(80-120)	49	23
140	(120-160)	53	20
180	(> 160)	53	13

[a]Range.

Changes in Forest Composition

The spruce budworm can drastically alter the species composition of the softwood and mixed-species forest through the mortality that results from continuous defoliation. To compare changes in forest composition, 5- and 10-year survivor basal area was compared with live basal area of each species group in 1975 (Table 1).

Within the softwood forest type from 1975 through 1985, the amount of balsam fir in 1975 decreased by 21 percent in 1980 and by 58 percent in 1985; spruce remained nearly constant over the 10-year period. The large reduction in fir was offset slightly by ingrowth and survivor growth of the other species. For example, hemlock basal area increased over the two periods. Increases by other species, however, were insufficient to maintain stocking at 1975 levels.

The balsam fir component decreased by 4 percent in the mixedwood stands by 1980 and by 30 percent by 1985. This reduction was smaller primarily because the total amount of fir in the stand was less than in the softwood type (Table 1). All other species in the mixedwood type (including spruce) increased in basal area. The decrease in fir basal area for the mixedwood type was offset by the increase in basal-area growth of the other species. This did not occur in softwood stands.

Additional classifications were used in an attempt to estimate the increase or decrease of fir or spruce composition as related to stand characteristics. Stand characteristics used were square feet of basal area (density), percentage of host species in the stand at the beginning of the study (host species), and mean stand diameter (size).

Density

As the basal-area class in softwood stands increased in density from 20 to 180 ft^2, the percent decline in fir composition by 1985 also increased, ranging from 41 to 71 except for the 20-ft^2 class (Table 2). The basal-area growth of spruce increased in all but the 20-ft^2 class during the first 5-year period; the 10-year figures show spruce increasing in stands with fewer than 100 ft^2 but then decreasing slightly in the higher density classes (Fig. 1). These numbers indicate a decrease in spruce composition of 3 to 4 percent at the highest densities. The other species increased in inverse proportion to increasing basal-area class.

The amount of balsam fir in the mixedwood type also declined in species composition from 19 to 34 percent by 1985 across the same range of basal-area classes (Table 2). Except for the top two density classes in which spruce declined by 1980 and 1985, and the 20-ft^2 class (spruce declined by 1985), the composition of spruce increased when compared to the 1975 basal area. The amount of fir was less than the amount of spruce in the softwood type in 1975; conversely, the amount of spruce was less than the amount of fir in the mixedwood type at all basal-area classes above 20 ft^2 (Fig. 2). By 1985, the percentage of fir was approximately the same in both softwood and mixedwood stands across all density classes (Fig. 3).

Table 1.—Species composition in square feet of basal area per acre, percent basal area in 1975, and change in basal area from 1975 through 1980 and from 1980 through 1985, by forest type

Year		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				SOFTWOOD			
1975	BA75[a]	34.7	45.3	7.5	22.8	13.7	124.0
	%BA75[b]	28.0	36.6	6.0	18.4	11.1	
	BA80	27.3	46.9	8.3	23.2	14.5	120.2
1980	%BA80[b]	22.0	37.8	6.7	18.8	11.7	
	%CH80[c]	-21.2	3.4	11.0	2.2	5.4	-3.0
	BA85	14.7	45.7	9.2	23.8	15.2	108.5
1985	%BA85[b]	11.9	36.8	7.4	19.2	12.3	
	%CH85	-57.6	0.7	23.3	4.4	10.6	-12.4
				MIXEDWOOD			
1975	BA75	24.3	16.6	2.1	5.2	66.9	115.2
	%BA75	21.1	14.4	1.9	4.5	58.1	
	BA80	23.3	17.0	2.6	5.6	69.9	118.3
1980	%BA80	20.2	14.8	2.2	4.8	60.7	
	%CH80	-4.3	2.7	19.2	6.8	4.4	2.7
	BA85	17.0	17.6	3.3	5.8	72.2	115.9
1985	%BA85	14.7	15.3	2.9	5.0	62.7	
	%CH85	-30.1	6.2	54.7	10.4	7.9	0.6

[a]Species composition in square feet of basal area/acre.
[b]Species composition as percent of total basal area in 1975, e.g., %BA80 = (BA80/124.0)*100.
[c]Change in percent basal area by species from 1975 to 1980 = (BA80 - BA75)/(BA75) * 100 = %CH80.

In summary, balsam fir mortality tends to be higher in softwood stands than in mixedwood stands across all basal-area classes, and tends to increase with increasing total basal area per acre regardless of stand type. In the mixedwood type, hemlock and other softwood species increased in all but the 140-ft^2 basal-area class. Hardwood species in the mixedwood type increased for the most part, especially in the lower density classes. However, the increase was less pronounced in the higher density classes. Ingrowth and survivor growth apparently were greater than mortality for these species.

Host Species

In a separate analysis, the plots were categorized by percentage of host species (Table 3). By 1985, the softwood type shows a 45- to 63-percent reduction in fir over the range of host species classes. Spruce showed a decrease by 1985 in the lowest composition class, but remained the same or increased by 1980 or 1985 in all other classes. Other species all showed increases by 1985. The mixedwood type shows a 29- to 33-percent reduction in fir and an increase in basal area of other species in all host classes by 1985. For both forest types, these results show no clear increase in fir mortality as the amount of host species increases; in fact, the mixedwood type shows a small decrease in mortality. However, fir mortality was higher in the softwood type while spruce mortality remained fairly constant across both forest types.

Size Class

Species composition was also categorized by quadratic mean stand-diameter classes ranging from 6 to 10 inches (Table 4). Within the softwood type, the decline in fir composition ranged from 40 to 65 percent by 1985 for the different diameter classes. The largest decreases were in the larger diameter classes. Spruce increased slightly in the smaller diameter stands and remained the same or decreased slightly in the larger diameter stands. Composi-

Table 2.—Species composition in percent of total basal area in 1975, 1980, and 1985, by forest type and basal-area class

Year	Basal-area class		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
	ft²							
					SOFTWOOD			
1975		%BA75[a]	17.3	54.8	5.9	16.5	5.5	
1980	20	%BA80[a]	7.5	52.8	8.7	18.9	5.9	
		%CH80[b]	-56.6	-3.7	48.8	15.1	6.8	-6.1
1985		%BA85[a]	6.3	58.1	15.2	20.3	7.9	
		%CH85	-63.8	6.0	158.7	23.6	42.3	7.8
1975		%BA75	32.5	35.3	2.3	17.5	12.4	
1980	60	%BA80	30.5	36.8	2.8	18.4	14.7	
		%CH80	-6.3	4.3	22.5	5.3	18.9	3.3
1985		%BA85	19.1	39.1	3.8	20.3	16.5	
		%CH85	-41.2	10.7	64.0	16.2	33.0	-1.2
1975		%BA75	29.9	33.3	9.6	14.6	12.6	
1980	100	%BA80	25.7	36.4	11.1	15.5	12.8	
		%CH80	-14.1	9.1	15.1	5.7	1.5	1.3
1985		%BA85	15.3	36.9	12.3	15.9	14.4	
		%CH85	-48.7	10.7	27.7	8.4	14.4	-5.3
1975		%BA75	29.7	35.2	3.8	19.1	12.1	
1980	140	%BA80	23.8	35.6	4.2	19.0	13.0	
		%CH80	-20.0	1.1	9.6	-0.6	7.2	-4.4
1985		%BA85	13.4	33.9	4.6	20.0	13.2	
		%CH85	-54.8	-3.7	19.9	4.6	9.0	-14.8
1975		%BA75	24.7	39.2	6.9	19.9	9.3	
1980	180	%BA80	16.9	40.2	7.4	20.3	9.5	
		%CH80	-31.5	2.6	7.3	1.9	1.5	-5.7
1985		%BA85	7.1	38.0	8.0	19.8	9.4	
		%CH85	-71.2	-3.1	16.2	-0.3	1.2	-17.6

Table 2.—Continued

Year	Basal-area class		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
	ft²							
				MIXEDWOOD				
1975		%BA75	0.0	19.1	0.0	14.6	66.2	
1980	20	%BA80	5.0	21.5	0.0	16.0	96.6	
		%CH80	0.0	12.3	0.0	9.2	45.9	39.1
1985		%BA85	13.8	13.8	0.0	17.4	116.5	
		%CH85	0.0	-27.9	0.0	18.8	75.9	61.5
1975		%BA75	27.9	8.7	4.6	7.6	51.2	
1980	60	%BA80	29.4	9.8	5.6	8.4	55.1	
		%CH80	5.6	12.5	21.9	11.0	7.5	8.3
1985		%BA85	22.7	11.8	7.2	9.7	60.1	
		%CH85	-18.7	35.6	58.3	27.8	17.3	11.5
1975		%BA75	22.2	11.4	1.1	3.2	62.1	
1980	100	%BA80	20.9	12.6	1.3	3.8	67.2	
		%CH80	-5.8	10.5	19.3	19.2	8.2	5.8
1985		%BA85	14.9	13.9	1.6	4.5	71.7	
		%CH85	-32.9	21.5	45.2	40.6	15.4	6.5
1975		%BA75	18.4	18.3	2.3	5.0	56.0	
1980	140	%BA80	17.2	19.6	2.7	5.0	57.7	
		%CH80	-6.6	7.4	18.0	-0.1	3.0	2.2
1985		%BA85	12.8	20.7	3.5	4.6	56.8	
		%CH85	-30.4	13.5	57.1	-8.2	1.4	-1.5
1975		%BA75	21.2	14.7	1.2	4.0	58.9	
1980	180	%BA80	20.0	13.0	1.5	4.2	58.9	
		%CH80	-5.6	-12.1	18.2	4.1	0.2	-2.5
1985		%BA85	14.0	11.7	1.9	4.1	60.4	
		%CH85	-33.9	-20.5	52.5	1.6	2.6	-7.9

[a]Species composition as percent of total basal area in 1975.
[b]Change in percent basal area by species from 1975 to 1980 = (BA80 - BA75)/(BA75) * 100 = %CH80.

Table 3.—Species composition in percent of total basal area in 1975, 1980, and 1985, by forest-type and host-species class

Year	Host-species class		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
	Percent							
					SOFTWOOD			
1975		%BA75[a]	18.4	16.5	2.5	49.2	13.4	
1980	< 60	%BA80[a]	14.9	16.4	2.8	50.5	14.1	
		%CH80[b]	-18.9	-0.2	13.2	2.5	5.3	-1.2
1985		%BA85[a]	10.1	15.9	3.1	51.4	15.2	
		%CH85	-45.2	-3.5	26.3	4.4	13.6	-4.3
1975		%BA75	29.5	33.2	6.5	14.0	16.9	
1980	60-80	%BA80	22.9	34.5	7.3	14.6	17.2	
		%CH80	-22.5	4.0	13.4	3.9	2.2	-3.5
1985		%BA85	10.8	34.8	8.3	14.7	17.8	
		%CH85	-63.4	5.0	27.5	4.9	5.5	-13.7
1975		%BA75	32.6	51.0	7.9	3.0	5.6	
1980	80-100	%BA80	25.7	53.0	8.6	2.8	6.3	
		%CH80	-21.1	3.9	9.2	-7.2	12.6	-3.7
1985		%BA85	13.7	50.8	9.5	3.1	6.6	
		%CH85	-58.1	-0.4	20.3	2.8	17.5	-16.4
					MIXEDWOOD			
1975		%BA75[a]	13.2	7.9	2.4	8.3	68.2	
1980	< 35	%BA80[a]	12.8	7.7	2.8	8.7	69.4	
		%CH80[b]	-2.9	-2.1	16.6	4.7	1.7	1.4
1985		%BA85[a]	8.8	8.4	3.4	8.7	72.3	
		%CH85	-33.4	6.7	43.0	4.4	6.0	1.6
1975		%BA75	27.4	19.6	1.4	1.5	50.1	
1980	35-60	%BA80	26.1	10.4	1.8	1.8	53.8	
		%CH80	-4.8	4.2	22.6	15.6	7.4	3.8
1985		%BA85	19.5	20.8	2.5	2.1	55.0	
		%CH85	-28.8	6.1	69.9	36.5	9.9	-0.2

[a]Species composition as percent of total basal area per acre in 1975.
[b]Change in percent basal area by species from 1975 to 1980 = (BA80 - BA75)/(BA75) * 100 = %CH80.
Note: Differences in totals due to rounding.

tion of other species varied, with hardwoods showing notable increases in smaller diameter stands.

The decline in fir composition in the mixedwood type ranged from 7 to 41 percent across all diameter classes by 1985. This smaller amount of mortality for mixedwoods versus softwoods is consistent with results for the basal-area and host-species classes. The large-diameter classes (9 and 10 inches) had less fir mortality, possibly because there was less fir in these stands in 1975. The other species, including spruce, did not show a discernible pattern by 1985. Hemlock had notable increases in basal-area composition over all diameter classes; however, one must not infer too much from these figures as hemlock is a minor component in these stands.

Balsam Fir and Spruce Stands

To follow the change in species composition from 1975 to 1985, a series of high percentage fir plots within the softwood type were compared. Plots exceeding 40-percent balsam fir composition in 1975 were reanalyzed in 1985 to assess any changes. Fifty-nine plots fell into this category; their distribution is shown in Figure 4. Thirty-five plots (59 percent) declined to less than 40-percent fir composition by 1985. Only 24 (41 percent) of the 59 plots retained at least 40-percent balsam fir.

By contrast, 83 plots in 1975 exceeding 40-percent spruce were classified by percent composition (Fig. 5). Six of these plots (7 percent) decreased to 40 percent or less by 1985. This indicates that the predominately spruce stands do not have high spruce mortality when compared to the high fir mortality in predominately fir stands.

Composition Summary

The amount of live fir in softwood stands decreased by 58 percent from 1975 to 1985 and decreased by 30 percent in mixedwood stands during the same interval. Growth on other species was insufficient to offset basal-area loss of fir in the softwood stands; however, their growth did compensate for fir loss in mixedwood stands over the same period. Hemlock, a minor component in stands of both types, showed high percentage increases in basal area over the study period. However, hemlock's contribution to overall species composition in 1975 was small.

Similar patterns were apparent when the plots were categorized by mean stand-diameter, basal-area, or host-species classes. An increase in the amount of total fir basal area within a stand resulted in increased fir mortality in both stand types. There was no such relationship when stands were categorized by percent of host-species or mean stand-diameter classes. In these instances, fir mortality is still high but clearly is not related to increases in host species or size class. Finally, plot-change analysis demonstrated that stands with a high percentage of fir experienced a high loss of the fir. However, stands with a high percentage of spruce in 1975 did not experience large losses of the spruce component during the epidemic.

Components of Stand Growth

The change in growing stock expressed in square feet of basal area per acre between 1975 and 1980 or 1985 can be partitioned into the following growth components: accretion, ingrowth, mortality, harvest, gross growth, and net growth. The definitions of these components of stand growth follow Husch et al. (1982) and were used in developing the interim reports (e.g., Brann et al. 1985):

- Accretion: An estimate of basal-area growth on trees that survived until the end of the measurement period plus the growth on mortality and harvested trees prior to their death.
- Ingrowth: The basal area of trees that have grown into the 5-inch class during the measurement period.
- Mortality: The basal area of trees that were alive in 1975 but died during the measurement period.
- Harvest: The basal area of trees that were alive in 1975 but have been harvested during the measurement period.
- Gross Growth: Accretion plus ingrowth.
- Net Growth: Gross growth less mortality and harvest.

General Trends

In this section harvested plots are included in the analyses to indicate how harvesting and salvage strategies have affected net growth for the represented region. Tables of growth-component estimates run for the 204 softwood and 74 mixedwood plots used elsewhere in this report are presented and can be compared with results for harvest plots. No attempt is made to explain discrepancies resulting from different harvest policies of different landowners. The distribution of plots including harvested plots, by year, is:

	Number of plots	
Year	Softwood	Mixedwood
1975	262	95
1980	261	95
1985	254	93

Table 5 presents the estimates of weighted average annual accretion, ingrowth, gross growth, net growth, mortality, and harvest of basal area for softwood and mixedwood stands with harvested plots included. The gross growth of the softwood and mixedwood stands for 1976, expressed in annual square feet of basal area per acre per year, was similar to the expected gross growth of nonimpacted stands (Solomon and Frank 1983). Accretion and ingrowth also were close to expected annual basal-area values for unstressed stands. However, the 10-year average for all species in 1985 indicated a considerable increase in mortality and decrease in accretion and ingrowth, resulting in a reduction in net growth. Except for balsam fir and spruce, accretion and ingrowth were nearly constant over the 10-year period in both stand types. Mortality probably was greater in softwood stands because of their higher composition of fir. Hardwood mortality was nearly 3 times greater in mixedwood than in softwood stands. This is attributed to the higher proportion of hardwoods in mixedwood stands. On a percentage basis, softwood stands showed approximately twice the amount of change as mixedwood stands from 1975 to 1985 in every category but mortality:

	Percent Change	
Growth component	Softwood	Mixedwood
Accretion	-31	-16
Ingrowth	-33	- 0
Gross growth	-31	-17
Mortality	+58	+39

Net growth was negative over all periods for most species in both softwood and mixedwood types (Figs. 6-7). For balsam fir, this was due primarily to the effects of increasing mortality and decreasing gross growth in both stand types. Fir harvests remained about the same during the

Table 4.—Species composition in percent of total basal area in 1975, 1980, and 1985, by forest-type and mean stand-diameter class

Year	Mean stand-diameter class		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
	Inches							
					SOFTWOOD			
1975		%BA75[a]	21.4	57.6	1.4	11.8	7.8	
1980	6	%BA80[a]	21.1	62.5	1.5	12.9	9.6	
		%CH80[b]	-1.3	8.4	6.6	9.0	24.1	7.6
1985		%BA85[a]	12.9	60.7	1.6	13.6	10.3	
		%CH85	-39.5	5.4	12.2	15.4	32.2	-0.9
1975		%BA75	34.1	39.6	2.9	13.9	9.4	
1980	7	%BA80	27.5	41.5	3.5	15.2	10.3	
		%CH80	-19.5	4.8	22.4	9.0	9.2	-2.0
1985		%BA85	14.4	39.6	4.4	16.8	10.9	
		%CH85	-57.8	-0.1	52.8	20.5	15.7	-13.9
1975		%BA75	31.1	33.7	3.4	20.0	11.7	
1980	8	%BA80	24.4	34.8	3.9	19.8	11.9	
		%CH80	-21.5	3.0	12.8	-0.9	1.1	-5.3
1985		%BA85	13.2	34.0	4.4	20.0	12.0	
		%CH85	-57.5	0.9	26.8	0.4	1.8	-16.4
1975		%BA75	23.8	30.8	8.5	20.4	16.5	
1980	9	%BA80	17.6	29.9	9.7	20.5	16.9	
		%CH80	-26.0	-2.7	13.2	0.5	2.7	-5.4
1985		%BA85	8.4	30.4	10.7	20.4	18.0	
		%CH85	-64.6	-1.3	25.2	0.0	9.5	-12.1
1975		%BA75	15.0	34.5	19.5	24.1	6.9	
1980	10	%BA80	10.1	36.0	20.6	24.3	7.8	
		%CH80	-32.5	4.4	5.2	1.0	12.7	-1.2
1985		%BA85	6.6	34.7	21.7	23.1	9.0	
		%CH85	-55.7	0.6	11.3	-4.1	28.9	-4.9

(Continued)

Table 4.—Continued

Year	Mean stand-diameter class		Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
	Inches							
				MIXEDWOOD				
1975		%BA75	20.1	8.0	5.4	6.4	60.2	
1980	6	%BA80	20.0	9.6	6.8	7.0	63.3	
		%CH80	-0.1	20.2	26.0	9.9	5.2	6.8
1985		%BA85	13.0	11.0	9.5	8.4	67.8	
		%CH85	-35.3	37.2	77.0	31.6	12.7	9.7
1975		%BA75	25.2	16.9	1.8	3.8	52.3	
1980	7	%BA80	26.2	18.1	2.3	4.5	59.2	
		%CH80	4.0	7.4	28.1	16.6	13.1	10.2
1985		%BA85	18.5	19.4	3.0	5.2	61.0	
		%CH85	-26.4	15.0	65.3	36.9	16.6	7.2
1975		%BA75	27.9	13.4	0.6	1.8	56.4	
1980	8	%BA80	24.6	13.4	0.6	1.9	60.4	
		%CH80	-11.6	0.6	12.0	5.9	7.1	1.0
1985		%BA85	16.6	14.2	1.0	1.6	63.6	
		%CH85	-40.6	5.9	77.9	-9.3	12.8	-3.0
1975		%BA75	14.2	16.4	0.5	8.1	60.8	
1980	9	%BA80	12.7	17.0	0.6	8.4	61.8	
		%CH80	-10.8	3.1	23.5	2.7	1.6	0.3
1985		%BA85	11.3	15.9	0.7	8.0	60.3	
		%CH85	-20.1	-3.4	44.0	-1.2	-0.8	-3.7
1975		%BA75	12.0	12.8	4.8	5.8	64.6	
1980	10	%BA80	13.5	12.1	5.5	6.1	61.0	
		%CH80	12.3	-4.9	13.9	4.9	-5.6	-1.8
1985		%BA85	11.2	12.9	6.7	6.5	64.3	
		%CH85	-6.6	1.1	38.6	11.8	-0.4	1.6

[a]Species composition as percent of total basal area per acre in 1975.
[b]Change in percent basal area by species from 1975 to 1980 =
(BA80 - BA75)/(BA75) * 100 = %CH80.
Note: Differences in totals due to rounding.

10-year period in the mixedwood type and increased in the softwood type. Spruce showed higher harvest than mortality in mixedwood stands, while there was no clear pattern in softwood stands. However, harvest of spruce was steadily increasing in softwood stands while it was decreasing in mixedwood stands. Hemlock showed positive net growth for both forest types while harvest and mortality were negligible.

Table 6 shows the components of stand growth with harvest plots excluded. The most notable difference between Tables 5 and 6 is that net growth is positive for spruce in both types in Table 6. Thus, spruce growth is equal to or greater than mortality in nonharvested stands.

Categorizing accretion and ingrowth by quadratic mean stand-diameter and basal-area classes did not reveal noteworthy differences among classes. In the softwood type, accretion increased and ingrowth decreased as mean stand diameter and basal-area density increased. However, for balsam fir and spruce, annual accretion and ingrowth basal area decreased from 1976 to 1985. The response was similar in the mixedwood type across diameter and basal-area classes. Average annual basal-area accretion and ingrowth decreased for both balsam fir and spruce.

Table 5.—Weighted average annual accretion, ingrowth, gross growth, mortality, harvest, and net growth, in square feet of basal area per acre, from 1975 through 1976, 1980, and 1985

Species	Year	Accretion +	Ingrowth =	Gross growth -	Mortality -	Harvest =	Net growth
		Growth component[a]					
SOFTWOOD							
Fir	1976	0.8	0.3	1.1	1.4	0.0	-0.3
	1980	0.5	0.1	0.6	2.0	0.2	-1.6
	1985	0.4	0.1	0.5	2.4	0.6	-2.5
Spruce	1976	1.0	0.1	1.1	0.6	0.1	0.4
	1980	0.7	0.1	0.8	0.5	0.5	-0.2
	1985	0.6	0.1	0.7	0.7	0.8	-0.8
Hemlock	1976	0.2	0.0	0.2	0.0	0.0	0.2
	1980	0.1	0.0	0.1	0.0	0.0	0.1
	1985	0.1	0.0	0.2	0.0	0.0	0.1
Other softwood	1976	0.4	0.0	0.4	0.3	0.1	0.0
	1980	0.3	0.0	0.3	0.2	0.1	0.0
	1985	0.3	0.1	0.4	0.3	0.2	-0.1
Hardwood	1976	0.3	0.1	0.4	0.1	0.0	0.3
	1980	0.3	0.1	0.4	0.2	0.0	0.2
	1985	0.3	0.1	0.4	0.3	0.1	0.0
Total	1976	2.6	0.6	3.2	2.4	0.3	0.5
	1980	1.9	0.4	2.3	3.0	0.9	-1.6
	1985	1.8	0.4	2.2	3.8	1.8	-3.4
MIXEDWOOD							
Fir	1976	0.6	0.3	0.9	0.7	0.3	-0.1
	1980	0.4	0.1	0.5	0.7	0.4	-0.6
	1985	0.4	0.1	0.5	1.2	0.3	-1.1
Spruce	1976	0.3	0.0	0.3	0.3	0.7	-0.7
	1980	0.3	0.0	0.3	0.2	0.3	-0.2
	1985	0.3	0.0	0.3	0.2	0.2	-0.1
Hemlock	1976	0.1	0.0	0.1	0.0	0.0	0.1
	1980	0.1	0.0	0.1	0.0	0.0	0.1
	1985	0.1	0.0	0.1	0.0	0.0	0.1
Other softwood	1976	0.1	0.0	0.1	0.0	0.0	0.1
	1980	0.1	0.0	0.1	0.1	0.1	-0.1
	1985	0.1	0.0	0.1	0.1	0.1	-0.1
Hardwood	1976	1.4	0.3	1.7	0.8	0.0	0.9
	1980	1.3	0.2	1.5	0.9	0.6	0.0
	1985	1.2	0.2	1.4	0.9	0.7	-0.2
Total	1976	2.5	0.5	3.0	1.8	1.0	0.2
	1980	2.1	0.5	2.6	2.0	1.4	-0.8
	1985	2.1	0.5	2.5	2.5	1.4	-1.3

[a]Cut plots included.

Table 6.—Weighted average annual accretion, ingrowth, gross growth, mortality, and net growth in square feet of basal area per acre, from 1975 through 1976, 1980, and 1985

		Growth component[a]							
Species	Year	Accretion	+	Ingrowth	=	Gross growth	-	Mortality	=	Net growth
				SOFTWOOD						
Fir	1976	0.7		0.2		1.0		1.4		-0.4
	1980	0.4		0.1		0.5		2.0		-1.5
	1985	0.4		0.1		0.5		2.5		-2.0
Spruce	1976	1.0		0.2		1.2		0.5		0.7
	1980	0.7		0.1		0.8		0.5		0.3
	1985	0.7		0.1		0.8		0.7		0.0
Hemlock	1976	0.2		0.0		0.2		0.0		0.2
	1980	0.2		0.0		0.2		0.0		0.2
	1985	0.2		0.0		0.2		0.0		0.2
Other softwood	1976	0.4		0.0		0.4		0.3		0.1
	1980	0.3		0.1		0.4		0.3		0.1
	1985	0.3		0.1		0.4		0.3		0.1
Hardwood	1976	0.3		0.1		0.4		0.1		0.3
	1980	0.3		0.1		0.4		0.2		0.2
	1985	0.3		0.1		0.4		0.2		0.2
Total	1976	2.6		0.6		3.2		2.3		0.9
	1980	1.9		0.4		2.3		3.0		-0.7
	1985	1.8		0.4		2.2		3.7		-1.5
				MIXEDWOOD						
Fir	1976	0.6		0.2		0.8		0.7		0.1
	1980	0.4		0.1		0.5		0.7		-0.2
	1985	0.4		0.1		0.5		1.2		-0.7
Spruce	1976	0.3		0.0		0.3		0.4		-0.1
	1980	0.3		0.0		0.3		0.2		0.1
	1985	0.3		0.0		0.3		0.2		0.1
Hemlock	1976	0.1		0.0		0.1		0.0		0.1
	1980	0.1		0.0		0.1		0.0		0.1
	1985	0.1		0.0		0.1		0.0		0.1
Other softwood	1976	0.1		0.0		0.1		0.0		0.1
	1980	0.1		0.0		0.1		0.0		0.1
	1985	0.1		0.0		0.1		0.0		0.1
Hardwood	1976	1.5		0.3		1.8		0.8		0.9
	1980	1.3		0.3		1.6		1.0		0.6
	1985	1.3		0.2		1.5		1.0		0.5
Total	1976	2.6		0.5		3.1		2.0		1.1
	1980	2.1		0.5		2.6		2.0		0.6
	1985	2.1		0.5		2.6		2.5		0.1

[a]Cut plots not included.

Table 7.—Annual live basal area and cumulative mortality, in square feet of basal area per acre, by species and forest type

	Live basal area						Cumulative mortality					
Year	Fir	Spruce	Hemlock	Softwood	Hardwood	Total	Fir	Spruce	Hemlock	Softwood	Hardwood	Total
						SOFTWOOD						
1975	34.7	45.2	7.5	22.8	13.7	124.0	—	—	—	—	—	—
1976	34.2	46.0	7.7	22.9	14.0	124.8	1.4	0.5	0.0	0.3	0.1	2.3
1977	33.2	46.1	7.8	23.2	14.1	124.4	2.9	0.8	0.0	0.3	0.4	4.4
1978	31.8	46.5	7.9	23.2	14.0	123.6	4.7	1.2	0.0	0.6	0.8	7.3
1979	30.4	46.7	8.1	23.1	14.4	122.6	6.7	1.9	0.0	1.1	0.8	10.5
1980	27.3	46.9	8.3	23.2	14.5	120.2	10.2	2.4	0.0	1.4	1.1	15.0
1981	24.2	46.9	8.5	22.6	14.7	116.8	13.8	3.1	0.0	2.4	1.3	20.7
1982	20.3	46.4	8.6	22.8	14.8	112.9	17.9	4.2	0.2	2.6	1.5	26.4
1983	18.7	46.5	8.8	23.1	14.7	111.8	19.9	5.0	0.2	2.8	1.9	29.7
1984	16.0	45.6	9.0	23.5	14.9	108.9	23.0	6.5	0.2	2.9	2.2	34.8
1985	14.7	45.7	9.2	23.8	15.2	108.5	24.7	7.2	0.2	3.0	2.3	37.4
						MIXEDWOOD						
1975	24.3	16.6	2.1	5.2	66.9	115.2	—	—	—	—	—	—
1976	24.4	16.5	2.2	5.3	67.8	116.3	0.7	0.4	0.0	0.0	0.9	2.0
1977	24.5	16.6	2.3	5.4	67.1	115.9	1.1	0.5	0.0	0.0	3.1	4.7
1978	24.4	16.6	2.4	5.3	67.8	116.5	1.7	0.8	0.0	0.1	4.1	6.8
1979	24.0	16.8	2.5	5.4	68.8	117.6	2.5	0.9	0.0	0.1	4.8	8.3
1980	23.3	17.0	2.6	5.6	69.9	118.3	3.7	1.0	0.0	0.1	5.2	10.0
1981	21.8	17.5	2.7	5.5	70.2	117.6	5.6	1.1	0.0	0.3	6.3	13.3
1982	20.4	17.3	2.8	5.4	70.8	116.8	7.4	1.5	0.0	0.5	6.9	16.3
1983	19.9	17.3	3.0	5.5	70.6	116.3	8.4	1.8	0.0	0.6	8.4	19.2
1984	17.3	17.2	3.2	5.6	71.4	114.8	11.5	2.4	0.0	0.6	9.2	23.7
1985	17.0	17.6	3.3	5.8	72.2	115.9	12.4	2.4	0.0	0.6	10.1	25.5

Mortality from 1975 through 1985

Yearly live basal area and cumulative mortality within the softwood and mixedwood forest types is shown in Table 7. The softwood type had 34.7 ft^2 of live basal area in balsam fir in 1975 or 28 percent of total species composition. The annual mortality rate for fir over 10 years averaged 2.5 ft^2/acre/year and accumulated to 24.7 ft^2 (71 percent of the fir or 20 percent of total species composition in 1975, Fig. 8). Thus, balsam fir accounted for 66 percent of the cumulative mortality for all species over the 10-year period. Spruce averaged 45 ft^2 of live basal area in 1975, or 37 percent of the 1975 species composition, and accounted for 19 percent of the cumulative mortality in the softwood type. The other species groupings had mortality patterns as expected in a forest not impacted by spruce budworms (Solomon and Frank 1983).

In the mixedwood type, balsam fir averaged 24.3 ft^2 of basal area in 1975, making up 21 percent of the stand. Annual mortality averaged 1.2 ft^2 over the 10 years and culminated at 12.4 ft^2/acre (Fig. 9). Total cumulative mortality consisted of 49 percent balsam fir, or 11 percent of total species composition in 1975. Cumulative mortality of spruce reached 2.4 ft^2, or about 9 percent of total cumulative mortality for all species. This is comparable to expected average annual mortality of stands not under spruce budworm attack (Solomon and Frank 1983).

In summary, Table 7 shows that balsam fir makes up about one-fourth of the basal area of both softwood and mixedwood stands (28 and 21 percent, respectively). When 10-year mortality is computed as a percentage of initial basal area, about three-quarters of the balsam fir is lost to mortality by 1985 in softwood stands, whereas only half is lost in mixedwood stands. In 1975 there was twice as much spruce in softwood as mixedwood stands (36 and 14 percent, respectively), and mortality as a percentage of initial basal area was about the same (16 and 14 percent). Therefore, roughly 3 times as much of the spruce basal area was lost to mortality in softwood as in mixedwood stands. Balsam fir mortality is much greater than spruce, especially red spruce, which is a major component of the softwood stands. White spruce, which is vulnerable to

Table 8.—Cumulative mortality of all species combined, in square feet of basal area per acre, by cause of death and forest type, 1976 through 1985

Year	Budworm	Blowdown	Logging damage	Other	Unknown	Total
			SOFTWOOD			
1976	0.3	0.8	0.0	0.6	0.5	2.3
1977	0.5	2.1	0.0	1.2	0.6	4.4
1978	1.4	2.9	0.1	1.7	1.3	7.3
1979	2.7	3.9	0.2	1.9	1.9	10.5
1980	4.8	5.6	0.2	2.0	2.3	15.0
1981	7.5	7.4	0.3	2.5	3.0	20.7
1982	11.9	8.0	0.3	2.6	3.6	26.4
1983	14.2	8.3	0.3	2.8	4.2	29.7
1984	17.3	9.5	0.3	2.9	4.6	34.8
1985	18.3	10.6	0.3	3.1	5.0	37.4
			MIXEDWOOD			
1976	0.0	0.4	0.0	0.6	1.0	2.0
1977	0.1	2.4	0.0	1.2	1.1	4.7
1978	0.1	2.5	0.1	2.7	1.3	6.8
1979	0.2	2.8	0.3	3.1	1.8	8.3
1980	0.9	3.1	0.3	3.6	2.2	10.0
1981	1.7	4.1	0.3	4.3	2.8	13.3
1982	3.3	4.8	0.3	4.3	3.6	16.3
1983	4.3	5.2	0.3	4.6	4.8	19.2
1984	6.4	6.6	0.3	4.8	5.5	23.7
1985	7.0	7.0	0.3	5.0	6.2	25.5

Note: Differences in totals due to rounding.

spruce budworm (Craighead 1925; Greenbank 1963a), was only a minor component of the spruce included in the study.

Cumulative balsam fir mortality relative to 1975 live basal area also was compared by mean stand-diameter classes, residual basal-area classes, host-species composition classes, and percentage of fir composition classes. Fir mortality appears independent of quadratic mean stand-diameter class for both stand types (Figs. 10-11). The 6- and 10-inch classes have the least cumulative mortality, possibly due in part to the fact that there is less live fir in the 1975 stand in these two classes. Figures 12 and 13 show that as density increased, cumulative mortality increased for softwood stands; the relationship is not as clear for mixedwood stands.

In general, cumulative fir mortality increased as the amount of host species in the stand increased. The exception was in host-species classes greater than 60 percent in softwood stands, where cumulative mortality was nearly equal (Figs. 14-15). These findings are consistent with those from the section on *Changes in Forest Composition.* Expanding this to a comparison of the amount of balsam fir mortality by percent fir composition in 1975 shows that as the amount of fir in the stand composition increased, cumulative mortality increased proportionally for both stand types (Figs. 16-17).

Cause of Mortality

The categories for cause of death were coded as: budworm, blowdown, logging damage, other, and unknown. These codes were assigned subjectively by field personnel based on their best judgment of what actually caused the death of individual trees. Table 8 presents cumulative mortality by forest type and cause of death. Budworm accounted for 49 percent of the total mortality by 1985 in the softwood type (Fig. 18). Blowdown was the second largest contributor to mortality in this type, accounting for 28 percent of total mortality. Logging damage, other, and unknown accounted for 1, 8, and 13 percent, respectively, in the softwood forest type.

In the mixedwood forest type, budworm, blowdown, and unknown causes accounted for 27, 27, and 24 percent of the total mortality, respectively (Fig. 19). The lower percentage of budworm-caused mortality no doubt is related to the lower percentage of balsam fir in the mixedwood forest type.

Using the same data, the 1975-80 growth impact study by Schiltz et al. (1983) reported that blowdown-caused mortality exceeded budworm-caused mortality for all species combined. This statement was true in 1980 but the reverse was true by 1981 in the softwood forest type, by 1982 overall, and by 1985 in the mixedwood forest type (Figs. 18-19).

Cumulative mortality for balsam fir by cause of death is shown in Table 9. The overall mortality pattern for balsam fir was similar to that for the softwood forest type (Table 8). The major difference in the mixedwood type was a higher percentage of budworm-caused mortality in fir compared to all species combined. Figures 20 and 21 show cumulative fir mortality and can be compared to the cumulative mortality of all species combined (Figs. 18-19). Ninety-four percent of the budworm-caused mortality in the mixedwood forest type is balsam fir; this drops to 85 percent in the softwood type. More important, there is a large difference in budworm-caused spruce mortality by forest type. In the softwood type, 15 percent of the budworm-caused mortality is spruce; in the mixedwood type, only 6 percent of the budworm-caused mortality is spruce. Therefore, spruce appears relatively unaffected by budworm attack in mixedwood stands. This conclusion is supported in Table 6, which shows positive net growth for spruce in mixedwood stands over the 10-year period.

Cause of death also was analyzed by mean stand-diameter class and basal-area class. Blowdown, budworm, and total mortality by mean stand-diameter class for the softwood forest type are shown in Figures 22-26. There are no apparent differences between diameter classes as related to cumulative mortality by cause of death. Note, however, that total mortality in the 6- and 10-inch diameter classes is considerably lower than in the other classes; this concurs with the results of total balsam fir mortality in the previous section (Fig. 10). By 1982, cumulative budworm-caused mortality surpassed blowdown in all but the 9-inch diameter class. Blowdown, budworm, and total mortality by basal-area class for the softwood forest type are shown in Figures 27-31 and in Table 10. As expected (Fig. 12), total cumulative mortality increases as basal-area density increases. Budworm-caused mortality exceeds blowdown-caused mortality after 1982 in all but the 20-ft^2 class.

Biennial Live Basal Area as Related to Stand Characteristics

This section looks at trends in biennial live basal area of survivor trees by forest type, mean stand-diameter class, basal-area class, host-species composition class, and fir composition class. Figure 32 shows biennial live basal area by species and forest type from 1975 through 1985. In the softwood forest type, fir showed large decreases in the last six years, the largest of which (6.2 ft^2) occurred between 1979 and 1981 (Table 7). The decrease in live fir basal area in the mixedwood type was less severe over the same period, the largest decrease occurring between 1983 and 1985. This may indicate a delay of several years in the intensity of feeding in mixedwood stands.

Host Species

The decrease in live fir basal area by host composition class followed the same trend as that for forest type (Table 11 and Fig. 33). In the softwood type, the major decrease in the < 60 percent host-species class began in 1979-81 (-2.9 ft^2/acre) and remained fairly constant through 1985. Within the 60-80 percent class, the largest decrease in fir occurred in 1979-81 (-8.3 ft^2/acre); live fir basal area subsequently decreased by 5.8 and 7.8 ft^2/acre over the next two periods, respectively. In the 80-100 percent class, a large decrease in live fir basal area began in the 1979-81 period (-6.8 ft^2/acre). The largest decrease occurred in the 1981-83 period (-6.9 ft^2/acre) and continued to decrease in 1983-85 (-4.4 ft^2/acre).

In the mixedwood type, the greatest decreases in live fir basal area occurred in 1983-85 for both host composition classes. The magnitude of the decreases was far less severe than in the softwood type. Live fir basal area decreased by 2.3 and 3.5 ft^2/acre for the < 35 and 35-60 percent host composition classes, respectively.

Fir composition. Reduction in biennial live fir basal area by fir composition class is presented in Table 12 and Figure 34. In the softwood forest type, the largest decrease in the two largest composition classes occurred from 1979 to 1981. The > 40 percent class lost 12.6 ft^2 and the 20-40 percent class lost 7.9 ft^2/acre. In the smallest class, the greatest reduction in live fir basal area did not occur until 1981-83 (1.5 ft^2). One possible explanation as to why mortality and the associated reduction in live fir basal area occurred later is that these stands are less favored while the spruce budworm population is small due to a lesser amount of the host species.

In the mixedwood forest type, the largest decrease in live fir basal area in the < 20 percent composition class was 0.9 ft^2/acre during 1979-81. In the 20-40 percent class, live fir basal area decreased by 4.7 ft^2/acre in 1983-85.

Size Class

When separated into mean stand-diameter classes, live fir basal area does not follow the reduction trend shown by forest type for all diameter classes (Table 13 and Fig. 35). In the softwood type, the 9- and 10-inch classes experienced their largest decline in live fir basal area in 1979-81,

Table 9.—Cumulative fir mortality, in square feet of basal area per acre, by cause of death and forest type, 1976 through 1985

Year	Budworm	Blowdown	Logging damage	Other	Unknown	Total
			SOFTWOOD			
1976	0.3	0.4	0.0	0.4	0.2	1.4
1977	0.4	1.5	0.0	0.6	0.3	2.9
1978	1.3	2.0	0.1	0.9	0.4	4.7
1979	2.6	2.4	0.1	1.0	0.6	6.7
1980	4.6	3.8	0.1	1.1	0.6	10.2
1981	7.0	4.8	0.1	1.2	0.7	13.8
1982	10.6	5.1	0.1	1.2	0.8	17.9
1983	12.5	5.1	0.1	1.2	0.9	19.9
1984	14.8	6.0	0.1	1.3	0.9	23.0
1985	15.5	6.8	0.1	1.3	1.0	24.7
			MIXEDWOOD			
1976	0.0	0.1	0.0	0.2	0.4	0.7
1977	0.1	0.3	0.0	0.3	0.5	1.1
1978	0.1	0.3	0.0	0.7	0.6	1.7
1979	0.2	0.6	0.0	1.0	0.7	2.5
1980	0.9	0.7	0.0	1.2	0.8	3.7
1981	1.7	1.7	0.0	1.3	0.9	5.6
1982	3.2	2.0	0.0	1.3	0.9	7.4
1983	4.0	2.0	0.0	1.4	0.9	8.4
1984	6.0	3.0	0.0	1.4	1.1	11.5
1985	6.6	3.3	0.0	1.4	1.1	12.4

Table 10.—Ten-year cumulative balsam fir mortality, in square feet of basal area per acre, by cause of death and basal-area class for softwood stands

Basal-area class (ft^2)	Budworm	Blowdown	Logging damage	Other	Unknown	Total
20	2.1	1.5	0.0	0.0	0.6	4.2
60	9.9	3.3	0.1	0.2	0.2	13.6
100	14.3	3.8	0.0	1.1	0.4	19.6
140	16.2	8.1	0.3	2.4	1.4	28.3
180	22.0	11.6	0.2	1.4	1.9	37.1

Table 11.—Biennial live species composition, in square feet of basal area per acre, by host species class and forest type, 1975 through 1985

Host-species class (percent)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				SOFTWOOD			
	1975	22.7	20.3	3.0	60.7	16.5	123.3
	1977	21.4	20.4	3.2	61.9	17.0	123.8
	1979	20.3	19.9	3.4	61.7	17.4	122.6
< 60	1981	17.4	20.6	3.5	60.4	17.8	119.7
	1983	15.0	20.3	3.7	61.9	18.1	118.9
	1985	12.5	19.6	3.8	63.4	18.8	118.0
	1975	37.2	41.8	8.2	17.7	21.2	126.0
	1977	35.1	42.7	8.6	18.0	21.5	125.9
	1979	32.6	43.5	9.1	18.2	21.4	124.8
60-80	1981	24.3	43.1	9.5	17.8	22.0	116.8
	1983	18.5	43.9	9.9	17.9	22.0	112.2
	1985	13.6	43.9	10.4	18.5	22.4	108.8
	1975	40.0	62.7	9.7	3.7	6.9	122.9
	1977	38.9	63.8	10.0	3.7	7.2	123.6
	1979	34.9	64.8	10.4	3.4	7.7	121.1
80-100	1981	28.1	65.2	10.8	3.4	7.7	115.1
	1983	21.2	63.8	11.0	3.6	7.6	107.2
	1985	16.8	62.4	11.6	3.8	8.1	102.7
				MIXEDWOOD			
	1975	14.2	8.5	2.6	9.0	73.5	107.8
	1977	14.7	8.1	2.7	9.2	72.1	106.9
	1979	14.7	8.2	2.9	9.2	73.8	108.8
< 35	1981	12.7	8.6	3.1	9.2	75.8	109.4
	1983	11.8	8.8	3.4	8.9	76.5	109.4
	1985	9.5	9.0	3.7	9.4	78.0	109.5
	1975	33.3	23.9	1.8	1.9	61.0	121.8
	1977	33.3	24.2	1.9	1.9	62.6	123.9
	1979	32.5	24.6	2.1	2.0	64.3	125.4
≥ 35	1981	29.9	25.4	2.3	2.2	65.1	125.0
	1983	27.2	25.0	2.6	2.4	65.4	122.6
	1985	23.7	25.3	3.0	2.5	67.1	121.6

losing 9.0 and 5.5 ft^2/acre respectively. The 8-inch class also showed a strong decrease during this period (-6.7 ft^2/acre), yet its greatest decrease was in 1981-83 (-7.1 ft^2/acre).

In the 6-inch diameter class in the softwood type, live fir basal area actually increased through 1977 and total stand live basal area in that class increased through 1981. These gains appear to be a response to the low 1975 stand density (93.8 ft^2/acre). The 6-inch class did not experience large reductions in live fir basal area until 1983-85 (-3.9 ft^2/acre), the greatest reduction in this class.

A possible hypothesis for the delay in mortality and associated reduction in live fir basal area is that the low total stand basal area associated with the 6-inch mean stand diameter has resulted in increased tree vigor compared to other diameter classes. Craighead (1925), McLintock (1948), and Blum and MacLean (1984) reported that increased tree vigor makes a tree less vulnerable to budworm-caused mortality. Blum and MacLean (1984) also reported that vulnerability increases as density increases (and vice versa) because of lower crown ratios and increased larval dispersal in high-density stands. The 6-inch mean stand-diameter class (with mean basal area of

Table 12.—Biennial live species composition, in square feet of basal area per acre, by fir-composition class and forest type, 1975 through 1985

Fir composition (percent)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				SOFTWOOD			
	1975	9.8	57.6	13.4	31.8	13.4	126.0
	1977	8.9	59.2	14.0	32.5	13.8	128.4
	1979	7.8	59.7	14.6	32.6	13.9	128.6
< 20	1981	6.5	60.5	15.3	31.8	14.2	128.3
	1983	5.0	59.9	16.0	32.5	14.4	127.7
	1985	4.0	58.8	16.7	33.3	14.7	127.6
	1975	38.2	47.7	2.6	21.7	15.7	125.9
	1977	36.4	47.9	2.7	22.3	15.6	125.0
	1979	34.1	48.8	2.8	21.9	15.9	123.4
20-40	1981	26.2	48.3	2.9	21.7	16.0	115.1
	1983	21.7	47.9	3.0	22.4	16.2	111.2
	1985	17.3	46.8	3.2	23.0	16.8	107.2
	1975	70.6	23.8	2.5	9.4	12.6	119.0
	1977	68.6	23.9	2.6	9.2	13.2	117.5
	1979	62.8	24.2	2.7	9.1	13.7	112.5
40-100	1981	50.2	24.2	2.8	8.9	14.2	100.3
	1983	37.8	24.0	2.5	8.9	14.0	87.3
	1985	29.2	24.0	2.7	9.3	14.6	79.7
				MIXEDWOOD			
	1975	7.7	20.5	4.0	8.1	66.8	107.1
	1977	8.3	20.4	4.2	8.3	65.6	106.9
	1979	8.5	20.8	4.7	8.2	66.4	108.6
< 20	1981	7.6	21.7	5.0	8.4	67.6	110.2
	1983	6.9	21.6	5.5	8.4	66.3	108.8
	1985	6.2	21.4	6.1	8.9	67.2	109.8
	1975	38.4	13.3	0.6	2.8	67.0	122.0
	1977	38.3	13.3	0.6	2.9	68.4	123.5
	1979	37.2	13.4	0.6	3.0	70.9	125.2
≥ 20	1981	33.9	13.9	0.7	3.0	72.4	123.9
	1983	30.9	13.6	0.8	3.0	74.3	122.7
	1985	26.2	14.4	0.9	3.1	76.5	121.1

93.8 ft^2/acre) is below full stocking on the spruce-fir stocking guide (Frank and Bjorkbom 1973; Solomon et al. 1987). Thus, the results of this study seem to support those previous findings.

In the mixedwood forest type, the 7-, 8-, and 10-inch diameter classes had the largest reductions in live fir basal in the 1983-85 period. However, the largest reduction in live fir basal area in the 6- and 9- inch classes, occurred in 1981-83 and 1979-81, respectively (Table 13 and Fig. 36). The 6-inch diameter class in the mixedwood type consists of only seven plots, so care should be taken in drawing conclusions. It is not known why the 9-inch class experiences a reduction in live fir basal area before the 8- and 10-inch classes.

Density

The analysis of live fir basal area by basal-area class in the softwood forest type shows that the greatest decreases occurred in three periods among the five basal-area classes (Table 14 and Fig. 37). In the 20, 140, and 180 ft^2 classes, the largest decrease in live fir basal area occurred from 1979 to 1981 (-1.4, -6.9, and -11.5 ft^2/acre,

Table 13.—Biennial survivor trees, in square feet of basal area per acre, by diameter class and forest type, 1975 through 1985

Diameter class (inches)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				SOFTWOOD			
	1975	20.1	54.1	1.3	11.1	7.3	93.8
	1977	21.3	56.1	1.3	11.7	8.3	98.8
	1979	21.0	57.9	1.4	12.1	8.8	101.1
6	1981	19.0	59.8	1.4	12.4	9.3	102.0
	1983	15.1	57.7	1.4	12.4	8.9	95.5
	1985	12.1	57.0	1.5	12.8	9.6	93.0
	1975	37.5	43.5	3.2	15.3	10.4	109.8
	1977	36.5	44.5	3.5	15.8	10.8	111.1
	1979	32.5	45.4	3.8	16.3	11.1	109.1
7	1981	26.9	45.2	4.1	17.1	11.1	104.4
	1983	21.1	44.4	4.5	17.8	11.5	99.3
	1985	15.8	43.5	4.9	18.5	12.0	94.6
	1975	39.3	42.6	4.3	25.2	14.8	126.3
	1977	37.3	43.4	4.6	25.5	15.2	125.9
	1979	34.1	43.6	4.8	24.9	14.9	122.4
8	1981	27.4	43.6	5.0	23.9	15.4	115.3
	1983	20.3	43.7	5.3	24.6	15.3	109.2
	1985	16.7	43.0	5.5	25.3	15.1	105.6
	1975	33.4	43.1	12.0	28.6	23.1	140.2
	1977	30.7	42.4	12.6	28.8	22.9	137.4
	1979	29.1	42.2	13.2	28.8	23.9	137.2
9	1981	20.1	42.5	13.9	27.3	24.1	127.9
	1983	16.4	43.2	14.0	28.0	23.9	125.5
	1985	11.8	42.6	15.0	28.6	25.3	123.2
	1975	24.6	56.6	32.1	39.6	11.4	164.1
	1977	22.5	58.0	32.5	40.5	11.8	165.3
	1979	20.7	58.5	33.3	39.5	12.4	164.4
10	1981	15.2	59.2	34.2	37.6	13.1	159.4
	1983	12.5	57.8	34.7	37.0	13.6	155.6
	1985	10.9	56.9	35.7	37.9	14.7	156.1

(Continued)

Table 13.—Continued

Diameter class (inches)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				MIXEDWOOD			
	1975	13.0	5.2	3.5	4.1	38.9	64.7
	1977	14.2	5.6	3.8	4.3	37.4	65.4
	1979	14.0	6.0	4.2	4.5	40.0	68.6
6	1981	11.5	6.4	4.5	5.0	40.9	68.4
	1983	8.4	6.7	4.9	5.2	41.8	67.1
	1985	8.4	7.1	6.2	5.5	43.9	71.0
	1975	25.2	16.9	1.8	3.8	52.5	100.3
	1977	26.3	17.0	1.9	4.0	55.3	104.6
	1979	26.8	17.8	2.3	4.2	57.8	108.8
7	1981	23.9	18.8	2.4	4.6	58.3	108.0
	1983	22.3	18.9	2.7	4.9	59.3	108.0
	1985	18.6	19.5	3.0	5.2	61.2	107.5
	1975	37.5	18.0	0.8	2.4	75.9	134.4
	1977	35.7	18.0	0.8	2.4	77.0	133.9
	1979	33.5	18.0	0.8	2.5	80.2	135.1
8	1981	32.3	18.5	1.0	2.1	82.7	136.6
	1983	27.9	18.3	1.2	1.9	84.7	134.1
	1985	22.3	19.0	1.4	2.1	85.5	130.4
	1975	17.0	19.7	0.6	9.8	72.9	119.9
	1977	17.8	20.3	0.6	10.0	75.6	124.4
	1979	17.3	20.1	0.7	9.7	72.9	120.7
9	1981	13.7	20.8	0.7	9.7	73.5	118.5
	1983	13.5	19.5	0.8	9.4	70.5	113.7
	1985	13.6	19.1	0.8	9.6	72.3	115.5
	1975	15.5	16.4	6.2	7.4	83.1	128.6
	1977	16.6	15.2	6.5	7.6	75.2	121.1
	1979	17.2	15.4	6.9	7.7	78.1	125.4
10	1981	16.3	15.9	7.3	7.9	79.9	127.3
	1983	16.9	16.4	8.1	8.1	81.0	130.5
	1985	14.5	16.6	8.6	8.3	82.7	130.7

respectively). In the 100-ft^2 class, the greatest decrease occurred from 1981 to 1983 (6.5 ft^2/acre); in the 60-ft^2 class, the greatest decrease occurred from 1983 to 1985 (3.0 ft^2/acre).

In the mixedwood forest type, none of the four plots in the 20-ft^2 basal-area class contained fir. The greatest reductions in live fir basal area occurred from 1983 to 1985 in all but the 60-ft^2 basal-area class (Table 14 and Fig. 38). In the 60-ft^2 class, the largest decrease occurred from 1979 to 1981 (-2.6 ft^2/acre). This trend is not evident in softwood stands.

Discussion and Conclusions

The analyses in this report have focused on determining the tabulation of mortality trends from 10-year growth impact data in Maine. The plots included in this study offer, in addition to the categorizations already discussed, a mixture of both protected and unprotected plots. Unfortunately, the beginning spray history records were not kept in such a manner as to allow categorization based on protection history. In addition, defoliation estimates were not constructed with adequate precision throughout the study to allow analysis by treatment, as in a designed

Table 14.—Biennial survivor trees, in square feet of basal area per acre, by basal-area class and forest type, 1975 through 1985

Basal-area class (ft^2)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
				SOFTWOOD			
	1975	4.6	14.6	1.6	4.4	1.5	26.5
	1977	4.1	15.1	1.7	4.7	1.5	27.2
	1979	3.0	13.8	2.3	4.9	1.6	25.6
20	1981	1.6	14.1	2.6	5.1	1.6	25.0
	1983	1.1	14.8	3.5	5.2	1.6	26.3
	1985	1.7	15.4	4.0	5.4	2.1	28.6
	1975	20.6	22.4	1.5	11.1	7.9	63.4
	1977	20.6	22.8	1.6	11.4	8.3	64.6
	1979	20.4	23.4	1.7	11.8	9.0	66.4
60	1981	17.5	23.9	1.9	11.6	9.7	64.5
	1983	15.1	24.8	2.2	12.2	9.5	63.8
	1985	12.1	24.8	2.4	12.9	10.4	62.7
	1975	30.2	33.7	9.7	14.8	12.7	101.0
	1977	29.8	34.5	10.4	15.4	13.1	103.1
	1979	27.7	36.3	10.9	15.3	12.8	103.0
100	1981	24.4	37.3	11.5	15.1	13.1	101.3
	1983	17.9	37.2	11.7	15.5	13.7	96.0
	1985	15.5	37.3	12.4	16.0	14.5	95.6
	1975	41.6	49.3	5.4	26.8	17.0	140.0
	1977	39.7	49.3	5.6	26.7	17.7	139.0
	1979	36.2	49.5	5.8	26.6	17.9	136.0
140	1981	29.3	49.2	6.0	26.0	18.3	128.9
	1983	24.3	48.9	6.2	27.0	18.4	124.9
	1985	18.8	47.5	6.4	28.0	18.5	119.3
	1975	46.7	74.3	13.1	37.6	17.6	189.3
	1977	43.3	76.1	13.4	38.5	17.6	188.8
	1979	38.2	75.9	13.8	37.9	18.1	183.9
180	1981	26.7	75.8	14.3	37.0	18.1	172.0
	1983	18.9	73.8	14.7	37.0	17.6	162.0
	1985	13.4	72.0	15.2	37.5	17.9	156.0

(Continued)

Table 14.—Continued

Basal-area class (ft²)	Year	Fir	Spruce	Hemlock	Softwoods	Hardwoods	Total
			MIXEDWOOD				
	1975	0.0	2.8	0.0	2.2	9.8	14.8
	1977	0.0	3.0	0.0	2.3	10.2	15.5
	1979	0.7	3.1	0.0	2.3	13.7	19.7
20	1981	0.9	3.2	0.0	2.4	14.7	21.2
	1983	1.0	3.3	0.0	2.5	16.0	22.8
	1985	2.0	2.0	0.0	2.6	17.2	23.9
	1975	17.4	5.4	2.9	4.7	32.0	62.4
	1977	18.2	5.8	3.1	5.0	32.8	64.7
	1979	19.0	5.9	3.3	5.2	33.0	66.4
60	1981	16.4	6.4	3.6	5.5	35.3	67.2
	1983	14.5	6.8	3.8	5.6	35.8	66.5
	1985	14.2	7.3	4.5	6.1	37.5	69.6
	1975	22.5	11.6	1.1	3.2	63.1	101.6
	1977	23.2	11.9	1.1	3.3	64.6	104.2
	1979	22.0	12.5	1.2	3.5	67.6	106.8
100	1981	19.3	13.2	1.4	4.0	68.6	106.4
	1983	18.0	13.5	1.5	4.3	70.8	108.1
	1985	15.1	14.1	1.6	4.5	72.9	108.2
	1975	25.9	25.6	3.2	7.0	78.7	140.4
	1977	25.2	26.1	3.3	7.2	80.9	142.7
	1979	24.8	26.9	3.7	6.9	80.3	142.5
140	1981	24.0	28.4	4.0	6.7	79.7	142.8
	1983	21.5	28.5	4.5	6.2	79.0	139.7
	1985	18.0	29.1	5.0	6.4	79.8	138.3
	1975	39.9	27.8	2.3	7.5	110.8	188.3
	1977	40.2	26.1	2.5	7.7	105.0	181.3
	1979	39.2	24.9	2.6	7.7	108.9	183.4
180	1981	35.3	24.4	2.8	7.2	112.9	182.6
	1983	32.5	22.3	3.3	7.4	111.8	177.3
	1985	26.3	22.1	3.6	7.6	113.7	173.3

experiment. Therefore, this study differs from many others reported in the literature in which results are given only for unprotected stands (uncontrolled outbreaks) (Baskerville and MacLean 1979; MacLean 1980; Blais 1985a; Osawa et al. 1986; MacLean and Ostaff 1989; Ostaff and MacLean 1989). As a result, differences in the results of this study and those of previous researchers, especially in Maine, may be due at least partially to the effects of the partial protection used during a portion of the study and are confounded with other possible effects.

MacLean (1980) noted that different mortality among stands may be due to three possible factors:

1. "Randomly different defoliation pressure."

2. "Targeted different defoliation pressures" as recognized by the spruce budworm.

3. "Stand characteristics, independent of budworm that result in various vulnerability."

It is the latter two factors that this report and many others have tried to address through data analysis and modeling.

However, as noted by Raske and Alvo (1986), under severe outbreaks with associated severe defoliation, "the resulting damage to all stands is likely to be similar." Equally as distressing, Baskerville and MacLean (1979) found extremes of greatest and least mortality in plots within 50 m of each other in what was considered to be a uniform stand. They concluded that "in uncontrolled outbreaks . . . budworm-caused tree mortality overrides normal variations in stand dynamics resulting from density and species mix." This supports conclusions of Raske and Alvo (1986). These observations are bothersome and somewhat frustrating to managers looking for methods for predicting stand vulnerability in the case of an outbreak in order to adjust long-term forest management goals. Indeed, in such situations, MacLean's first factor may be more important than the latter two, which may be more reasonable hypotheses under normal budworm pressures. In such cases under uncontrolled outbreaks, "randomly different defoliation pressures" might more aptly be shortened to chaos, and any hope of deriving any broadly applicable models of vulnerability may be futile, or, at best, subject to great uncertainty. However, trends often seem to arise even in the face of such uncertainty. The remainder of this section summarizes the important trends found in this study, and, where possible, compares our results with those of other studies.

Perhaps the least surprising finding of this study is that balsam fir was more vulnerable to spruce budworm than spruce species. Analyses of forest composition change and mortality both supported this finding (e.g., Tables 1, 5, 6). This result generally has come to be regarded as common knowledge by those dealing with budworm epidemics both from scientific and management perspectives, and is found throughout much of the literature (Craighead 1924; Westveld 1946; McLintock 1948; Greenbank 1963b; Blais 1985a,b). This trend also is apparent in both the softwood and mixedwood types—though both fir and spruce suffered higher losses in the softwood type. These losses translate to substantial negative net growth in both forest types for fir, while for spruce these losses are offset by gross growth, resulting in essentially no net change in softwood and a slight net increase in mixedwood stands (Tables 1 and 6).

Results of categorizing plots by density, mean stand diameter, and host-species composition class showed clear relationships only for density. Fir showed increasing mortality as stand density increased in both forest types; again, losses were higher in softwood stands (Figs. 12-13, Table 2). The amount of spruce increased over the 10-year period in stands < 100 ft^2 but decreased slightly in higher density stands. A study by MacLean and Ostaff (1989) in balsam fir stands during an uncontrolled budworm outbreak on Cape Breton, Nova Scotia, showed significant positive correlation between basal area (m^2) and dead merchantable volume (m^3) per hectare. In further support of our findings, Blum and MacLean (1985) cited several studies that have shown that "as stand density increases, so does vulnerability."

In a summary of seven published studies, MacLean (1980) found that in uncontrolled outbreaks, mature stands generally suffer higher fir mortality than immature stands (70-100 percent versus 30-70 percent). When increasing mean stand diameter is equated with increasing maturity in this study (which is possible among even-aged stands), our results confirm this increasing mortality. For balsam fir in softwood stands, the 6-inch mean stand-diameter class (recall that this class includes all trees 4.6 to 6.5 inches) represents a net change of -40 percent over the 10-year period (Table 4). Stands ≥ 7-inches in mean stand diameter all show net change averaging about -60 percent. Therefore, if one considers the 6-inch stands as <u>immature</u> and ≥ 7-inch stands as <u>mature</u> for balsam fir, there is a substantial increase in fir mortality between age classes.

For spruce in softwood stands, net change is positive for 6-inch stands and negative or zero for stands 7 inches or larger in mean stand diameter. Note that the distinction of a difference is not as sharp between immature and mature for spruce, so similar conclusions cannot be made. In mixedwood stands this pattern does not appear for fir, though it might be concluded for spruce. This may be due in part to structural differences between the two forest types because "if host trees are overtopped by nonhost trees, vulnerability is further decreased" (Blum and MacLean 1985). Overtopping or even crown competition by nonhost trees may account in part for the apparent lack of a trend of increased fir mortality in mature mixedwood stands.

With respect to host-species composition, Blum and MacLean (1985) noted that "vulnerability decreases as the percentage of nonhost species increases." Our data confirm this trend in the softwood type when stands of < 60 percent balsam fir are considered (Fig. 14). This is evident for the mixedwood type as the amount of host species increases. When considering fir mortality by fir composition, cumulative mortality consistently increased as the percent age of fir increased in both forest types (Figs. 16-17).

It is interesting to note that harvests were increasing over the 10-year period for spruce and fir in the softwood type but remaining constant or decreasing in the mixedwood type. In comparing the net growth in Tables 5 and 6 (i.e., with and without harvest plots included), net growth of all species in both types is negative (with the exception of hemlock and hardwoods) when harvested stands are included; net growth shows no or positive change for all species except fir in both forest types when harvested plots are not included. Further, harvesting of spruce and fir by 1985 is at least twice as heavy in softwood as in mixedwood stands. Increasing average annual spruce and fir harvests in the softwood type and associated decline harvests of spruce and fir in the mixedwood type seems to suggest that forest managers typically consider the more vulnerable stands for salvage, presalvage, or conversion operations. Such policies seem to be in line with the recommendations of other authors (Westveld 1946; McLintock 1948; Flexner et al. 1983; Blum and MacLean 1984; Blum and MacLean 1985). It also might be mentioned that by harvesting the high spruce and fir stands, it is possible that the spruce budworm attack became more concentrated in the remaining mixedwood stands.

In a discussion on spruce budworm ecology, Blais (1985b, p. 56) observed:

> It is dangerous to generalize on studies limited in time and place, and in recent years this has led to controversies on budworm epidemiology. To understand the behavior of budworm outbreaks and their effect on the forest, studies must be conducted in many regions as well as during the course of successive outbreaks within a region.

Recommendations

Two general recommendations can be advanced for Maine landowners faced with epidemic budworm populations in the future based on the analyses of average stand composition in this study. First, the trend that loss to spruce budworm seems to be higher with higher basal-area densities in softwood stands is important. It suggests that reducing the density of softwood stands to ≤ 120 ft^2 (the 100-ft^2 class) by cutting older fir may have a positive effect on trees lost to budworm damage. Biennial growth analysis showed that the stands with ≤ 120-ft^2 per acre sustained their highest losses up to 2 years after the highest density stands (with the exception of the understocked stands in the 20-ft^2 class). This suggests that reducing basal-area density without creating an extremely understocked condition in highly vulnerable stands in the face of an epidemic may help prolong peak losses by as much as 2 years. Note that this is not advanced as a general management guideline for balsam fir in non-impacted stands as a method of delaying the epidemic—the budworm will attack whether or not density is decreased in softwood stands. Instead, it is seen as a way of possibly extending the time until harvest for these stands and as a means of maintaining tree vigor when the stand is thinned at an early age.

In fact, this same general guideline was recognized more than 40 years ago by both Westveld (1946) and McLintock (1948). Both authors recognized purely on observational experiences that "particularly overmature, spire-topped, and slow-growing specimens [of balsam fir] appear to be most susceptible to budworm attack" (Westveld 1946). They recommended converting what we have classified as softwood stands to predominantly spruce and "maintaining stands in vigorous condition" (McLintock 1948). According to these authors, this would allow some young, vigorous balsam fir to be maintained in the stand. Thus, for forest managers to prevent the windthrow and blowdown that usually results from thinning in older spruce-fir stands, shorter cutting cycles and partial cutting to reduce fir components in softwood stands are advocated to meet these goals.

The second recommendation is complementary to the first. It seems from biennial-growth analysis that heaviest budworm pressure may occur up to 4 years later in mixedwood than in softwood stands. Also, it was noted earlier that even though balsam fir made up about the same proportionate amount in initial basal area per acre in both forest types (roughly one-quarter), 28 percent more of this initial basal area was lost to budworm in softwood than in mixedwood stands. Therefore, concentrating harvesting and protection efforts on softwood stands earlier in the epidemic seems reasonable as losses are proportionately higher and occur earlier here than in mixedwood stands. Again, an alternative might be to harvest the balsam fir before maturity through partial harvesting in both softwood and mixedwood stands. The resulting stand would be composed of more longer lived spruce and more vigorous, less susceptible fir. This would not only decrease the severity of attack but may reduce the fir mortality until normal harvesting practices can salvage the more vulnerable stands.

Acknowledgment

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Appendix A.

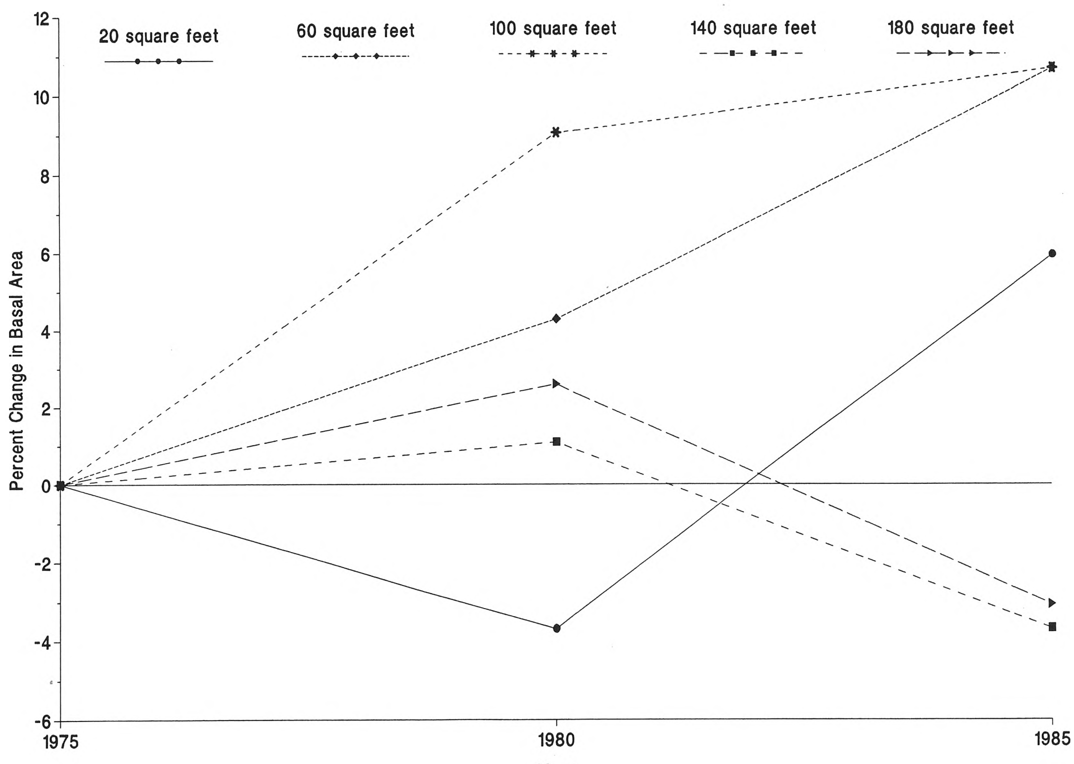

Figure 1.—Percent change in spruce basal-area composition in softwood type, 1975 through 1985.

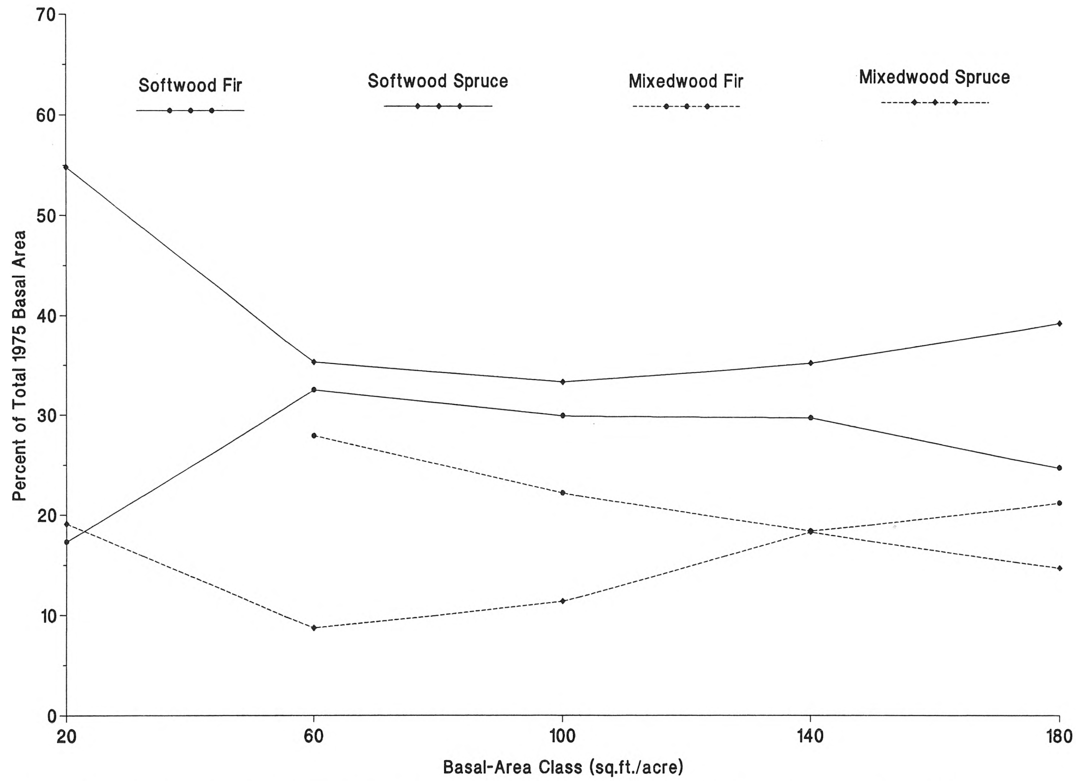

Figure 2.—Comparison of spruce and fir composition in softwood and mixedwood forest types in 1975.

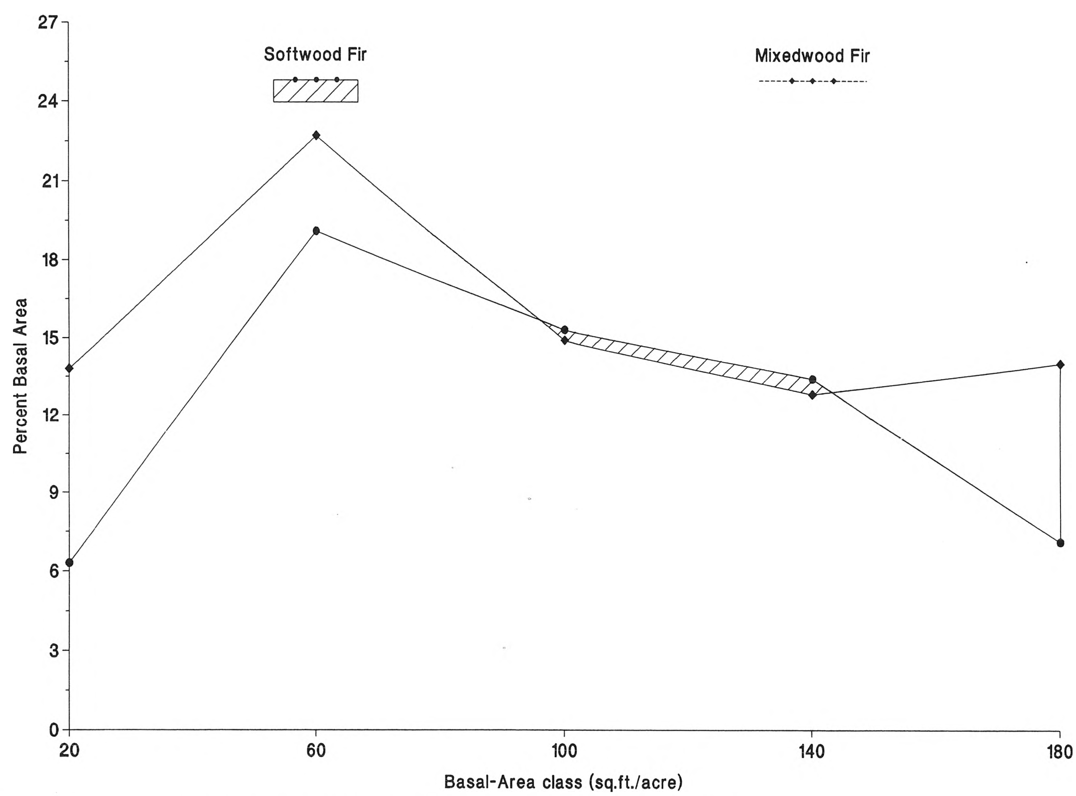

Figure 3.—Comparison of fir component in softwood and mixedwood stands in 1975.

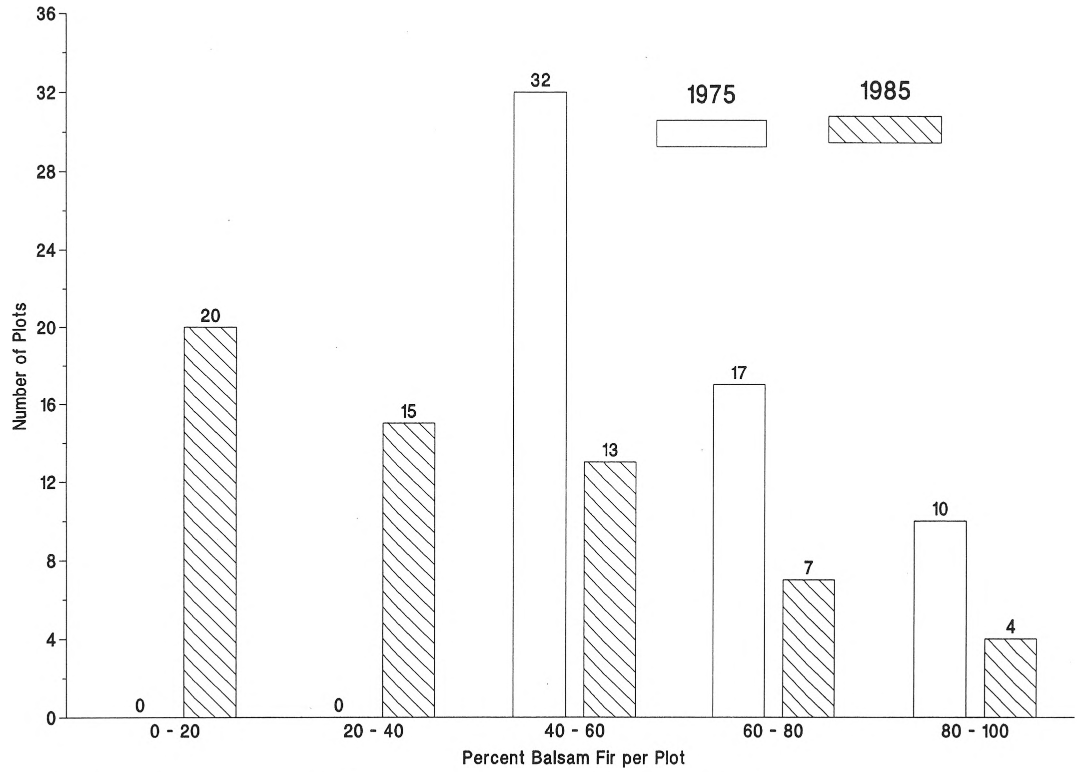

Figure 4.—Number of plots with more than 40 percent balsam fir basal area in 1975 that were reclassified in 1985, by percent balsam fir composition class.

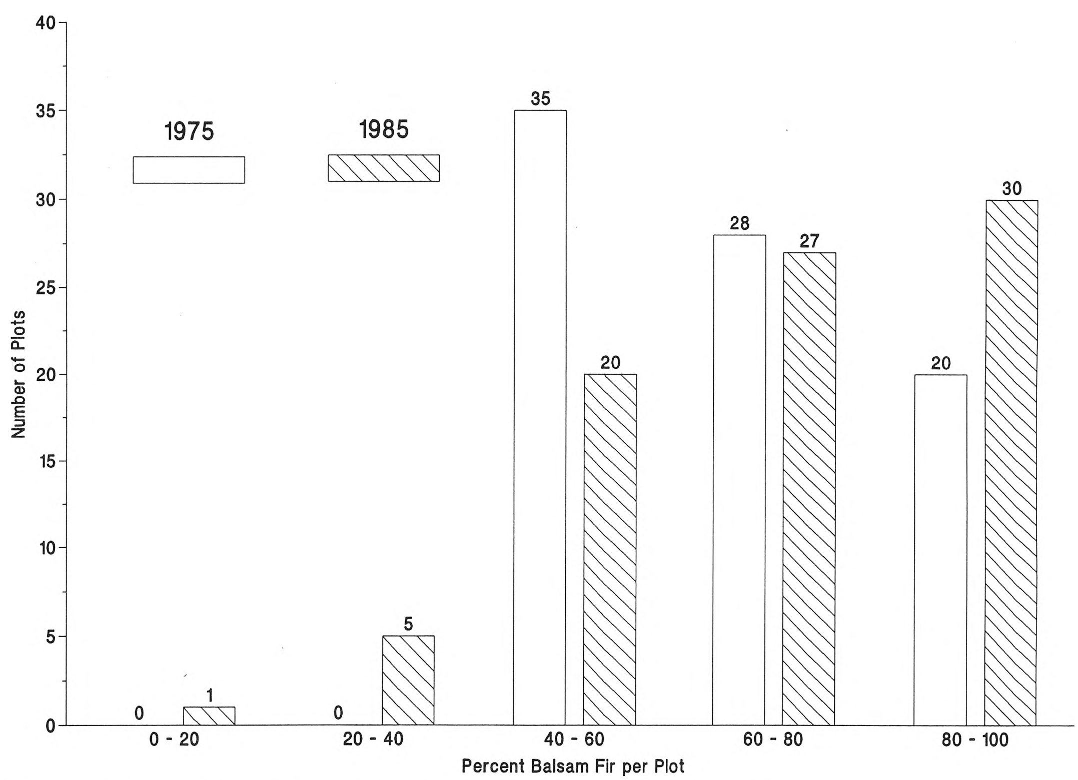

Figure 5.—Number of plots with more than 40 percent spruce basal area in 1975 that were reclassified in 1985, by percent spruce composition class.

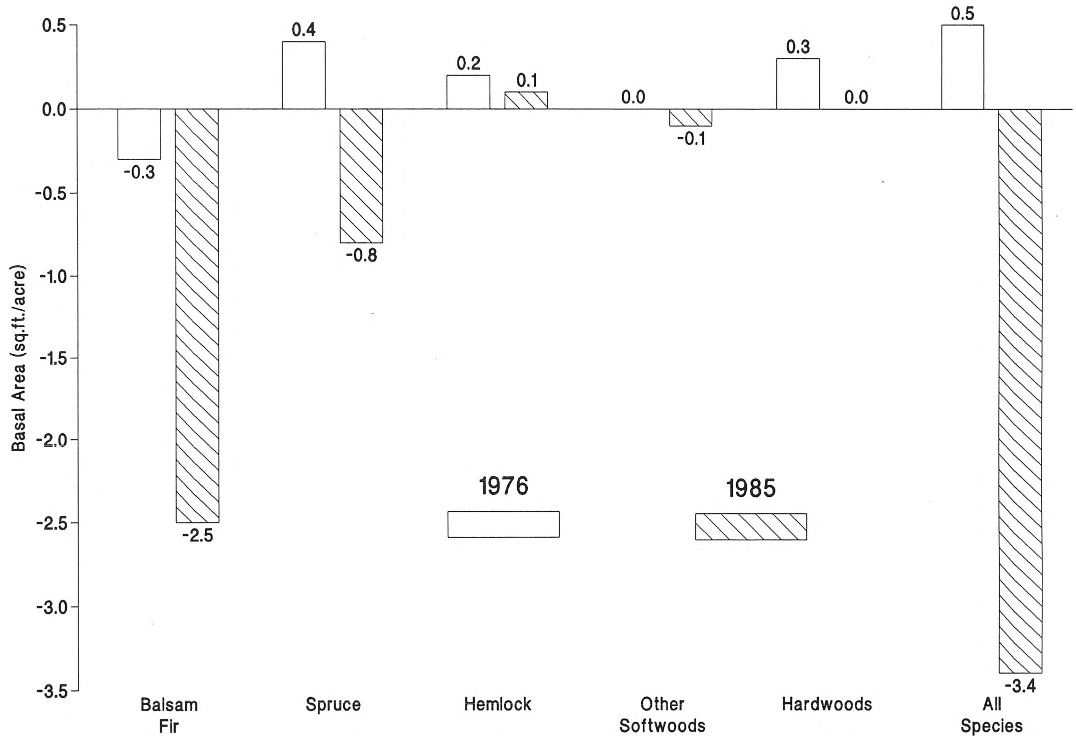

Figure 6.—Average annual net growth from 1975 to 1976 and 1985 by species—softwood.

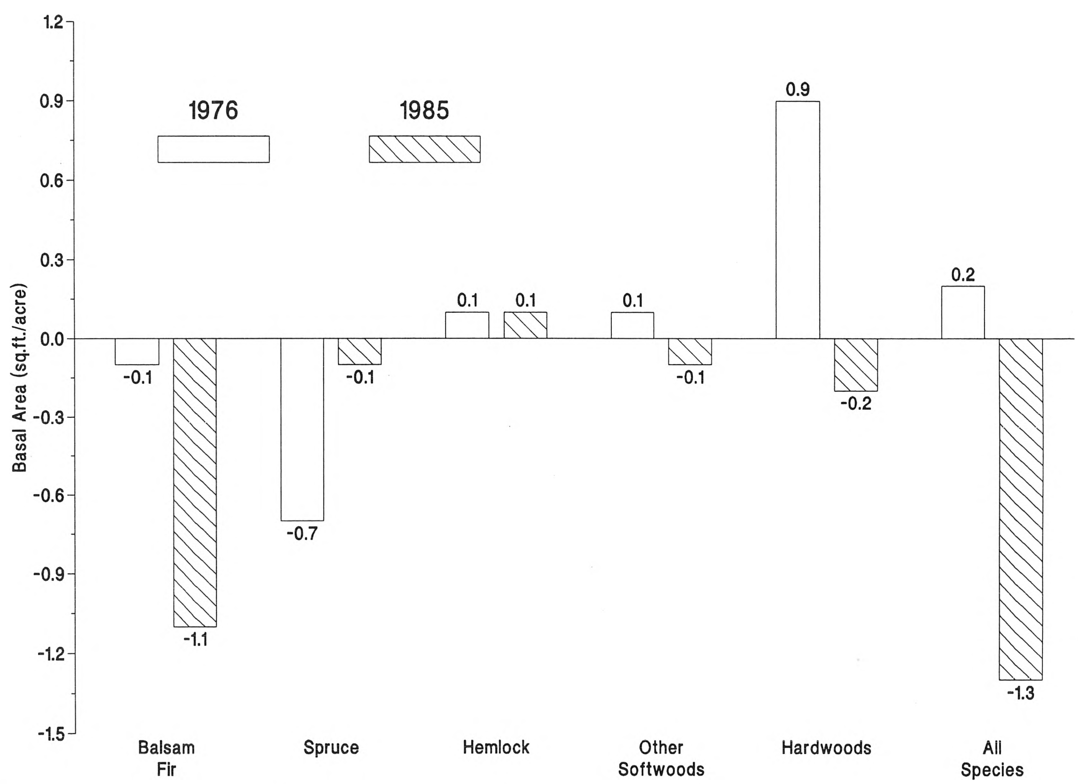

Figure 7.—Average annual net growth from 1975 to 1976 and 1985 by species—mixedwood.

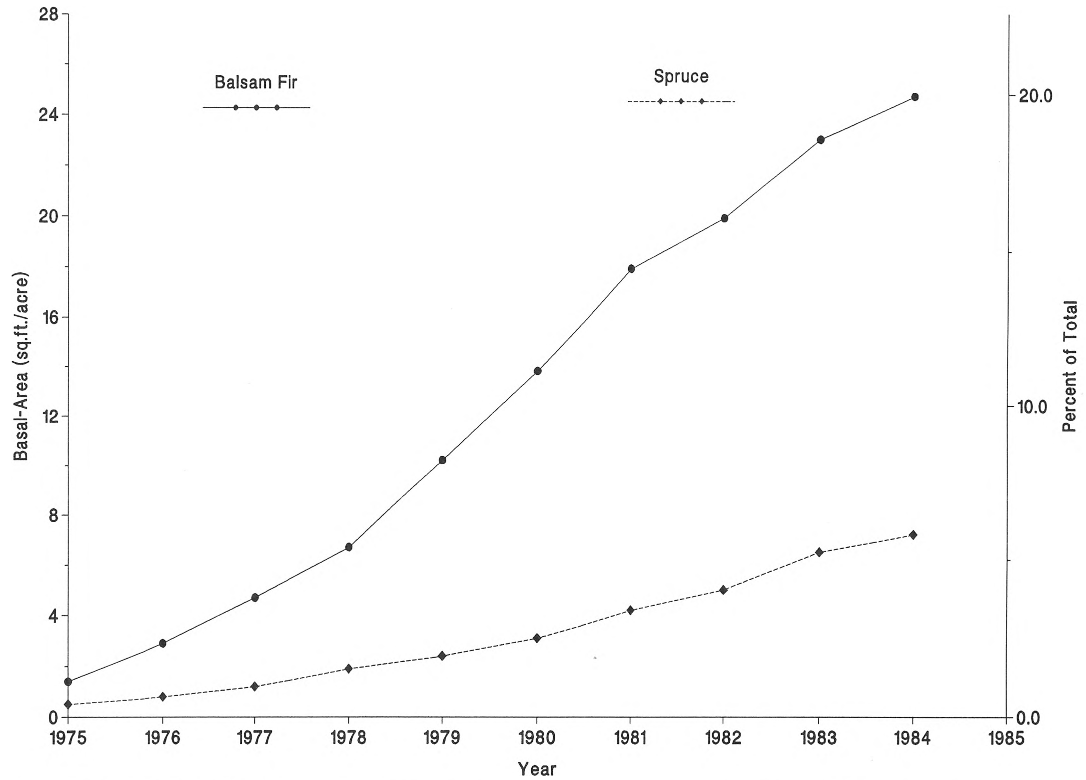

Figure 8.—Cumulative mortality of balsam fir and spruce and percent of live basal area in 1975—softwood.

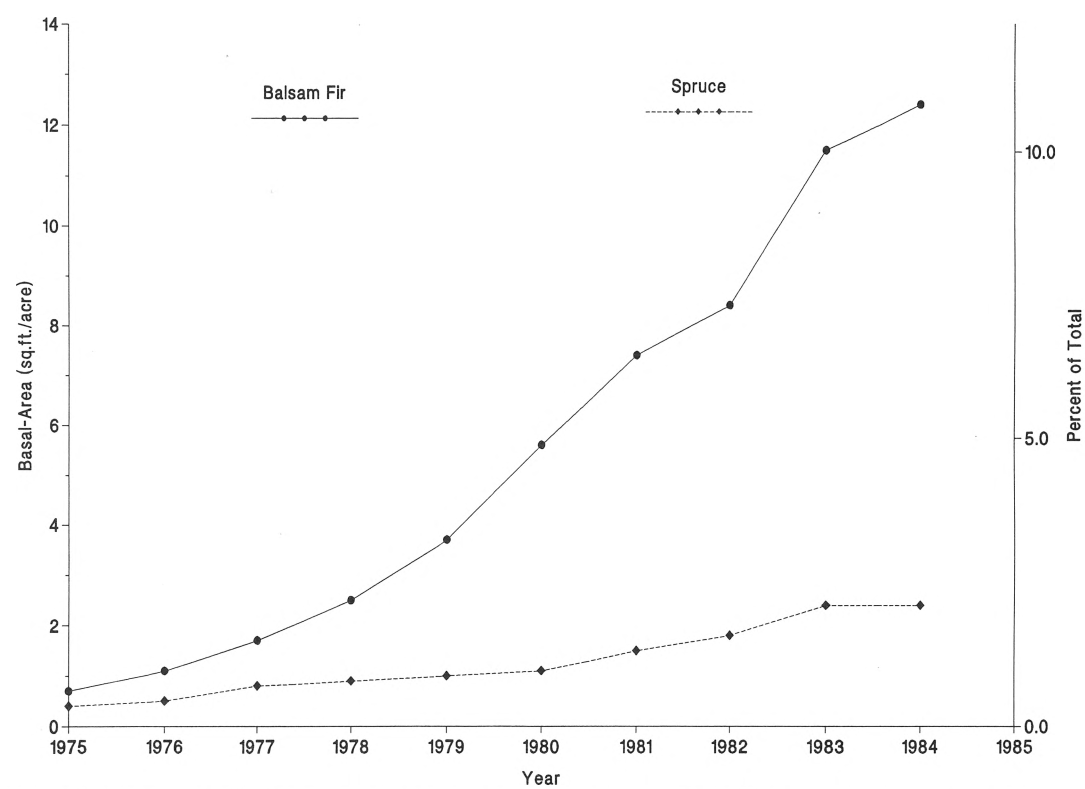

Figure 9.—Cumulative mortality of balsam fir and spruce and percent of live basal area in 1975—mixedwood.

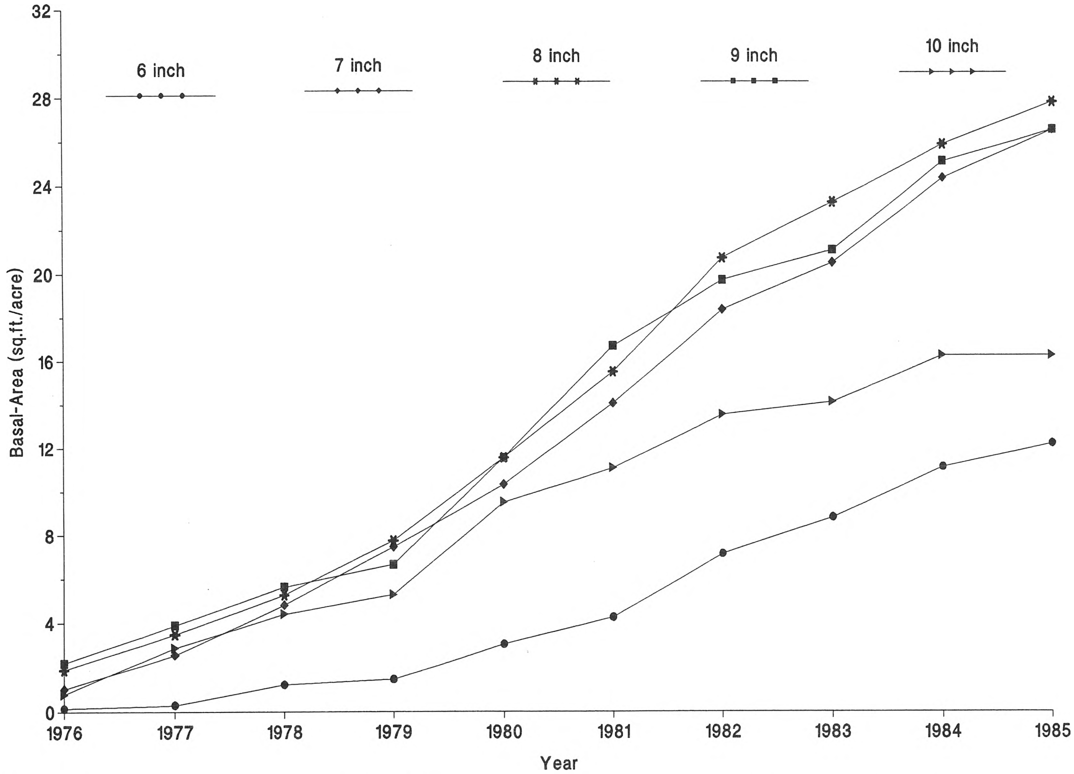

Figure 10.—Cumulative mortality of balsam fir in 1976 through 1985 by mean stand-diameter class—softwood.

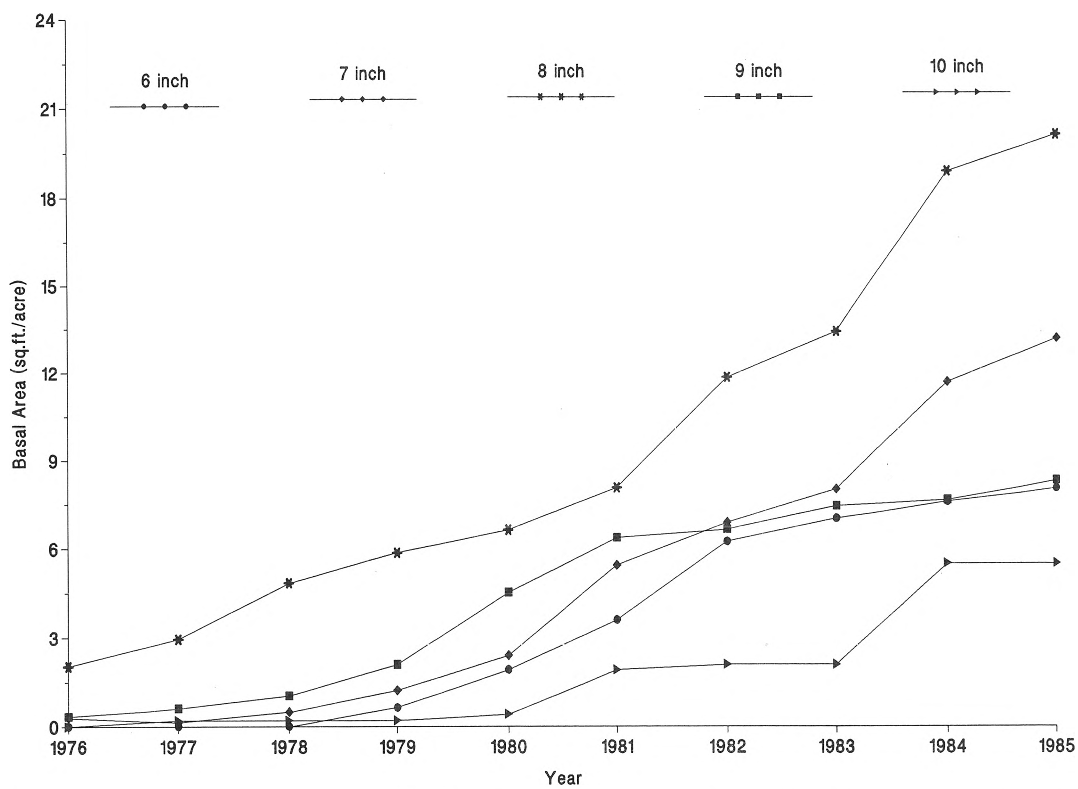

Figure 11.—Cumulative mortality of balsam fir in 1976 through 1985 by mean stand-diameter class—mixedwood.

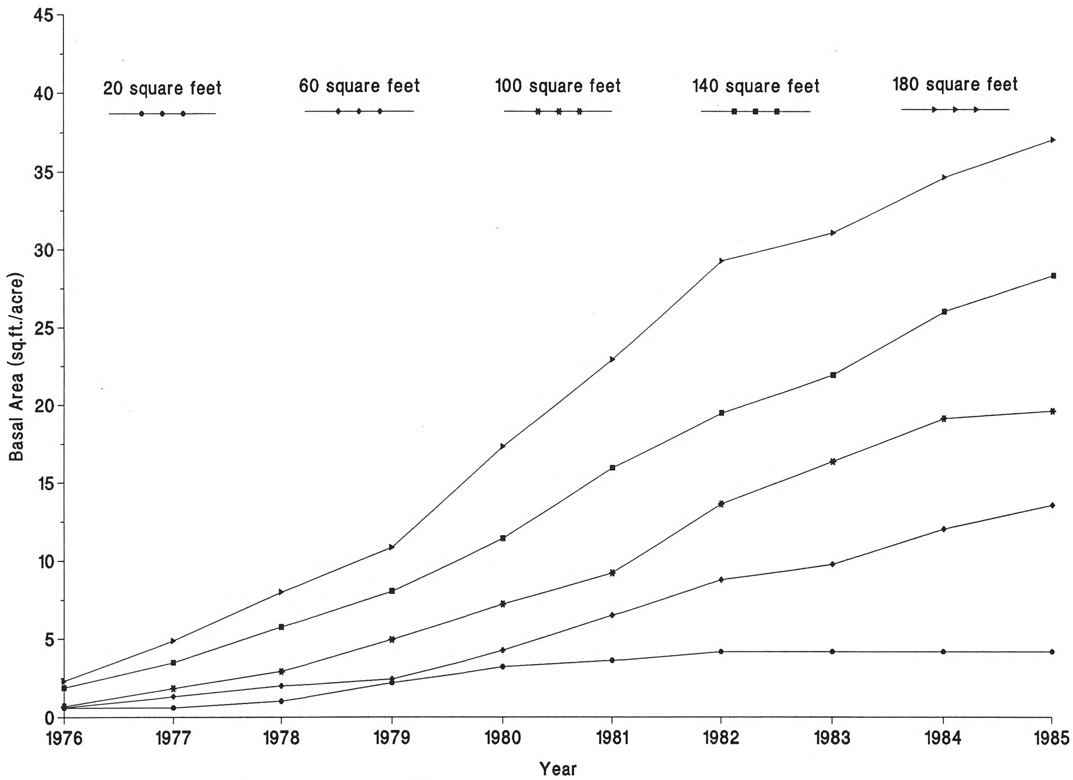

Figure 12.—Cumulative mortality of balsam fir in 1976 through 1985 by basal-area class—softwood.

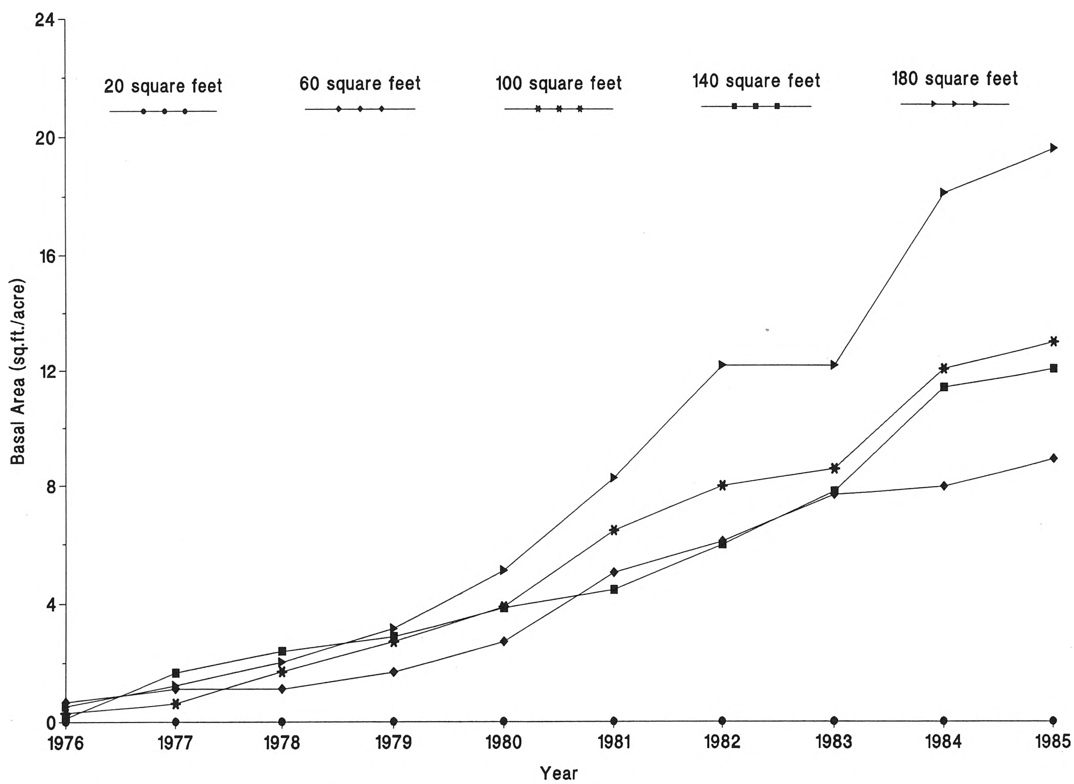

Figure 13.—Cumulative mortality of balsam fir in 1976 through 1985 by basal-area class—mixedwood.

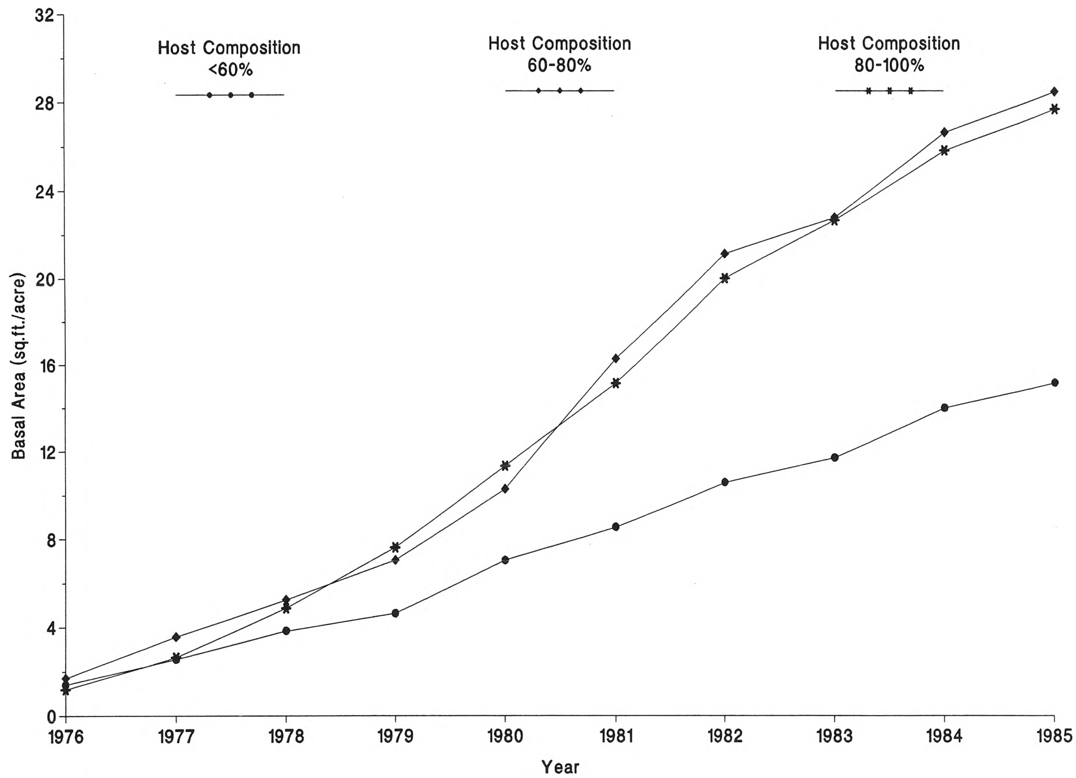

Figure 14.—Cumulative mortality of balsam fir in 1976 through 1985 by host-composition class—softwood.

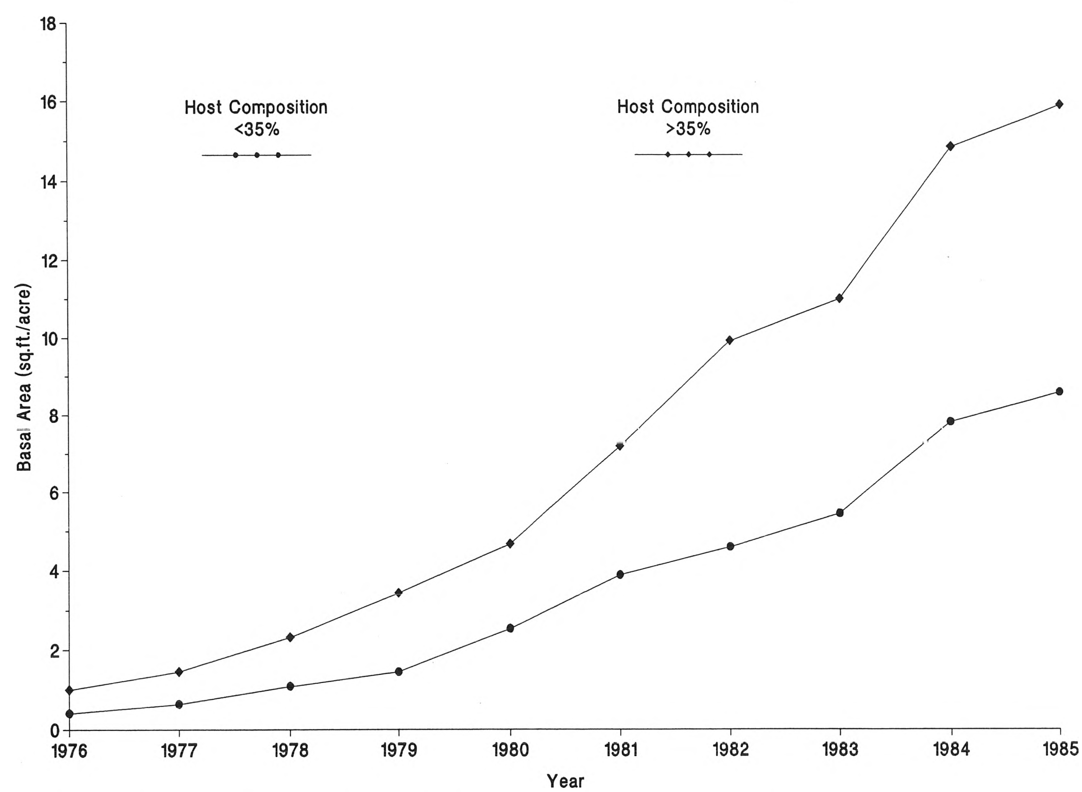

Figure 15.—Cumulative mortality of balsam fir in 1976 through 1985 by host-composition class—mixedwood.

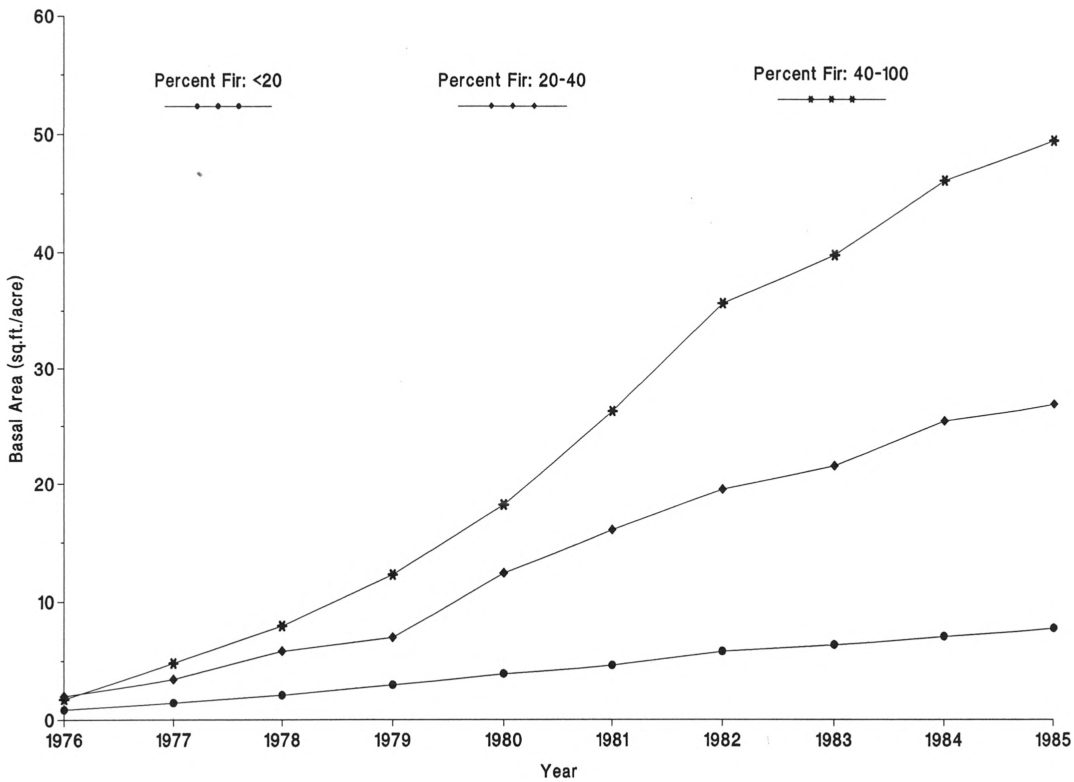

Figure 16.—Cumulative mortality of balsam fir in 1976 through 1985 by fir composition class—softwood.

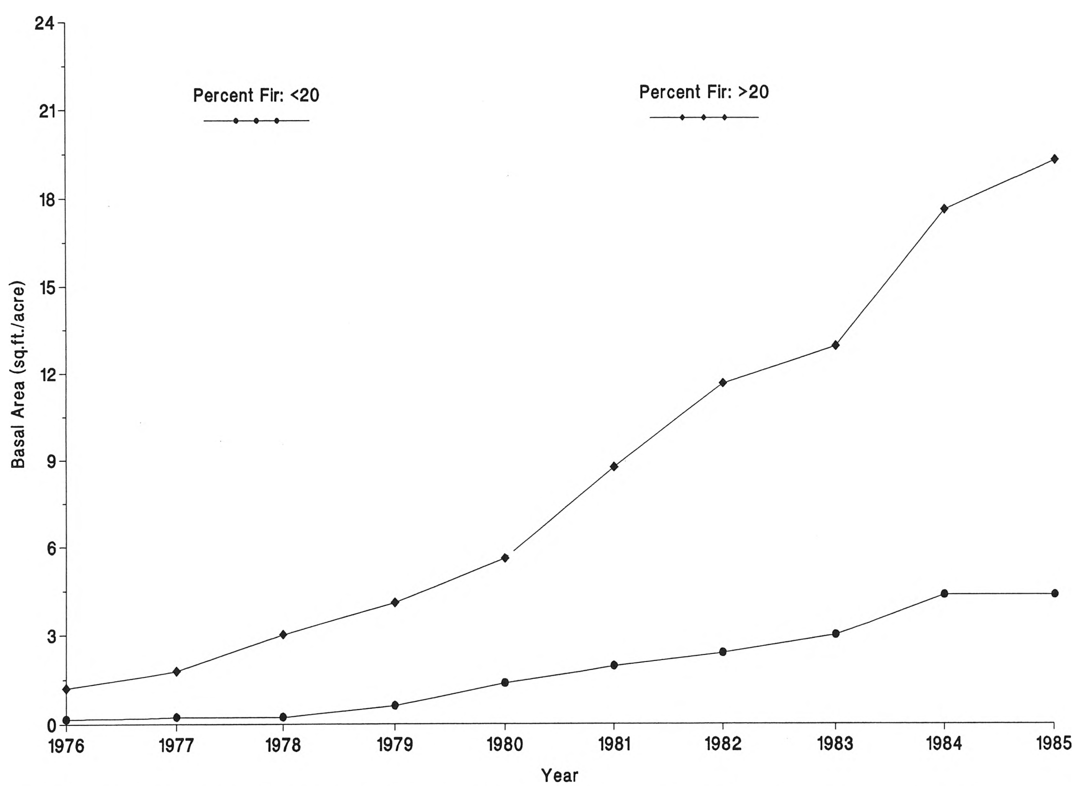

Figure 17.—Cumulative mortality of balsam fir in 1976 through 1985 by fir composition class—mixedwood.

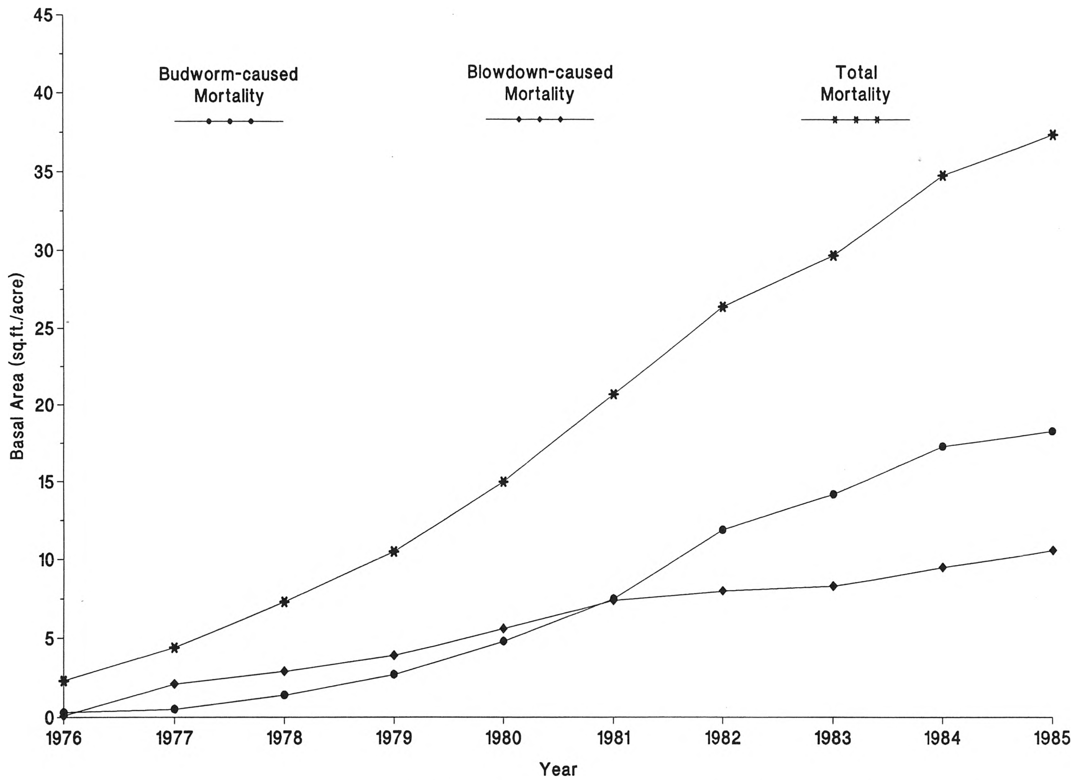

Figure 18.—Budworm-caused, blowdown-caused, and total cumulative mortality in 1976 through 1985—softwood.

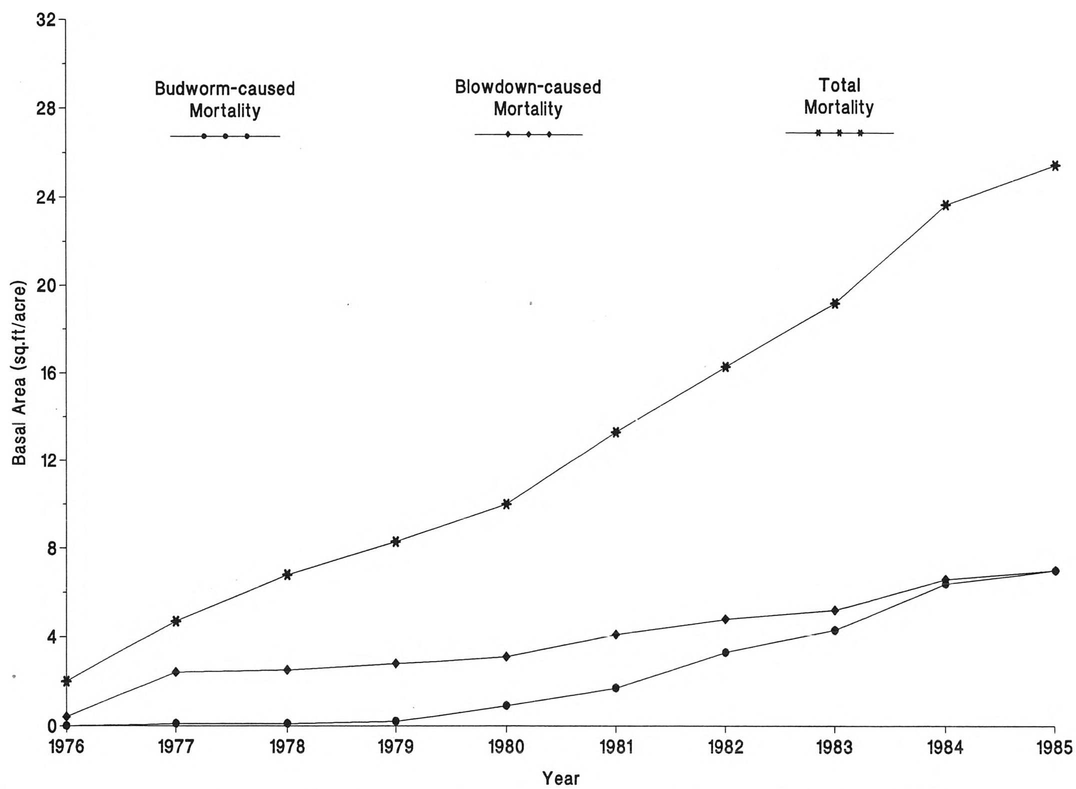

Figure 19.—Budworm-caused, blowdown-caused, and total cumulative mortality in 1976 through 1985—mixedwood.

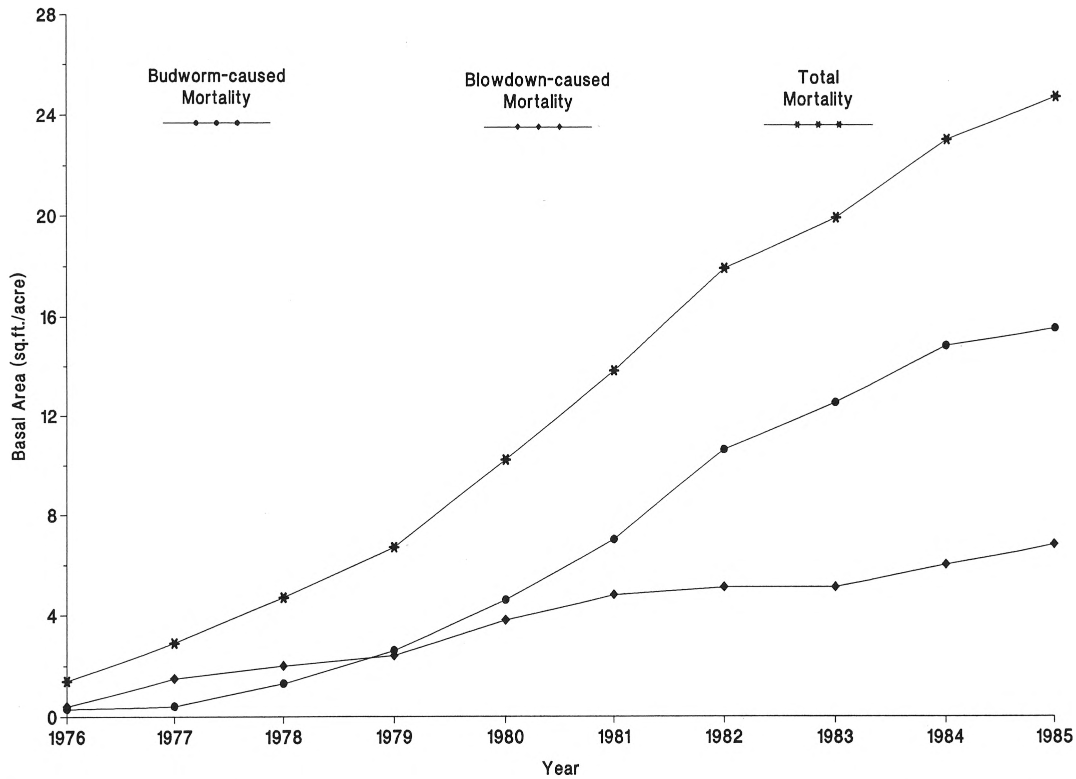

Figure 20.—Budworm-caused, blowdown-caused, and total cumulative fir mortality in 1976 through 1985—softwood.

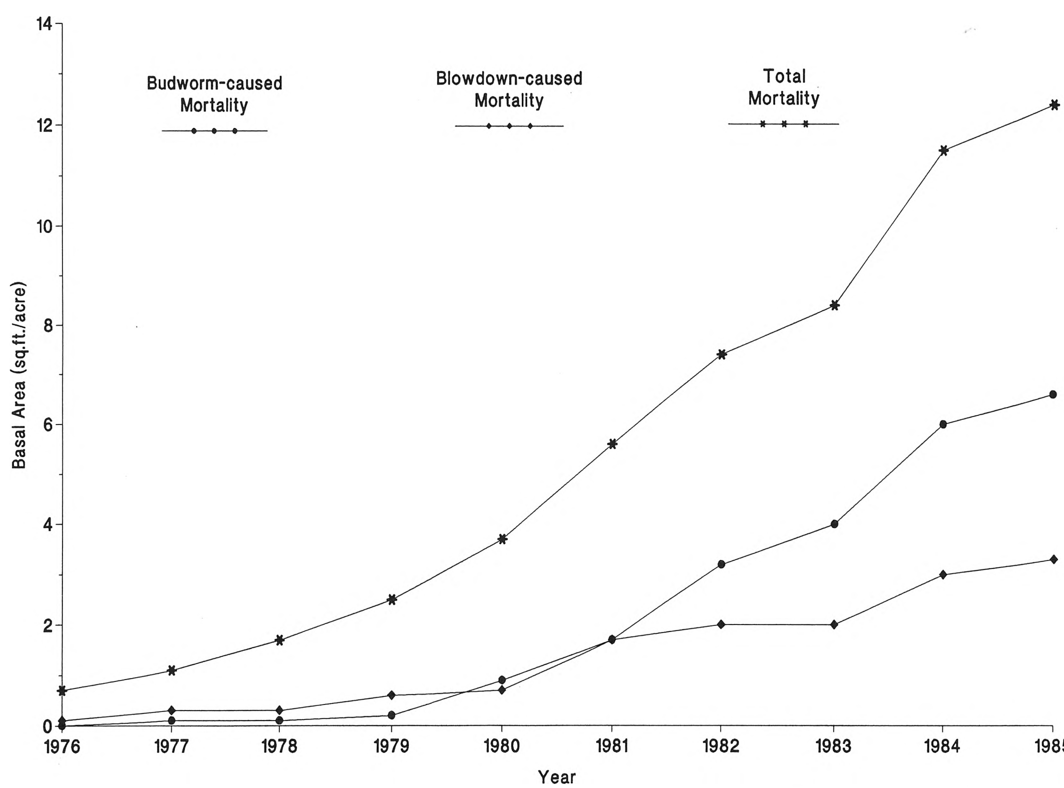

Figure 21.—Budworm-caused, blowdown-caused, and total cumulative fir mortality in 1976 through 1985—mixedwood.

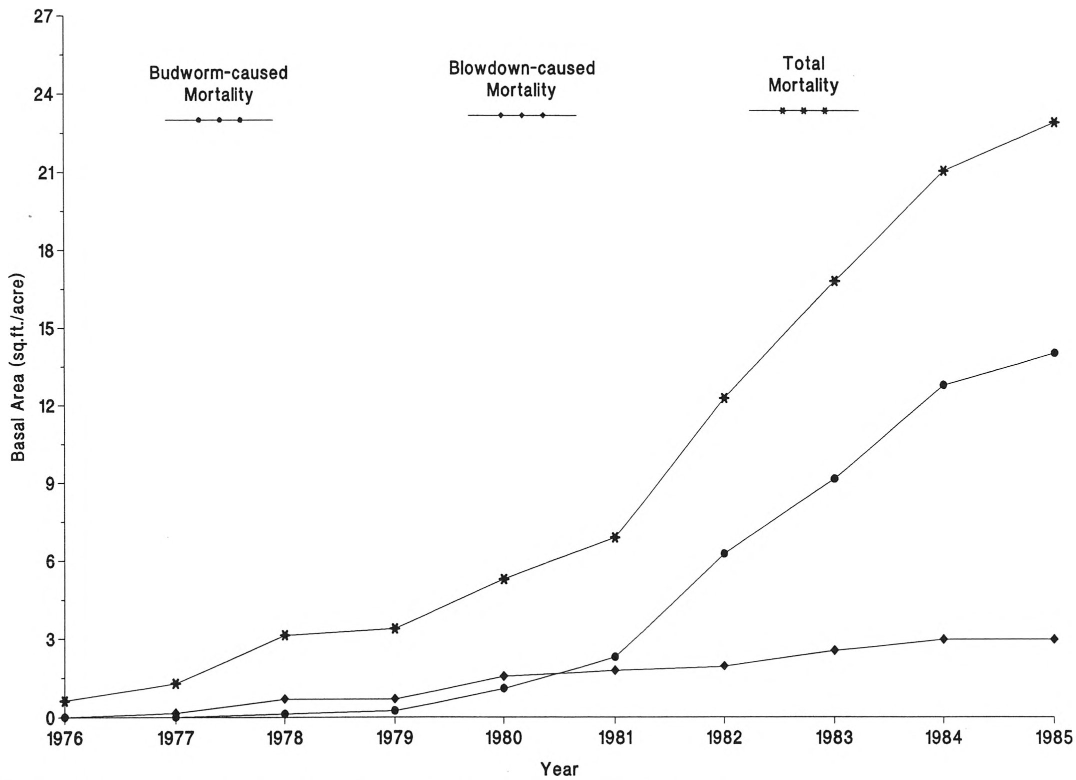

Figure 22.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 6-inch mean stand-diameter class.

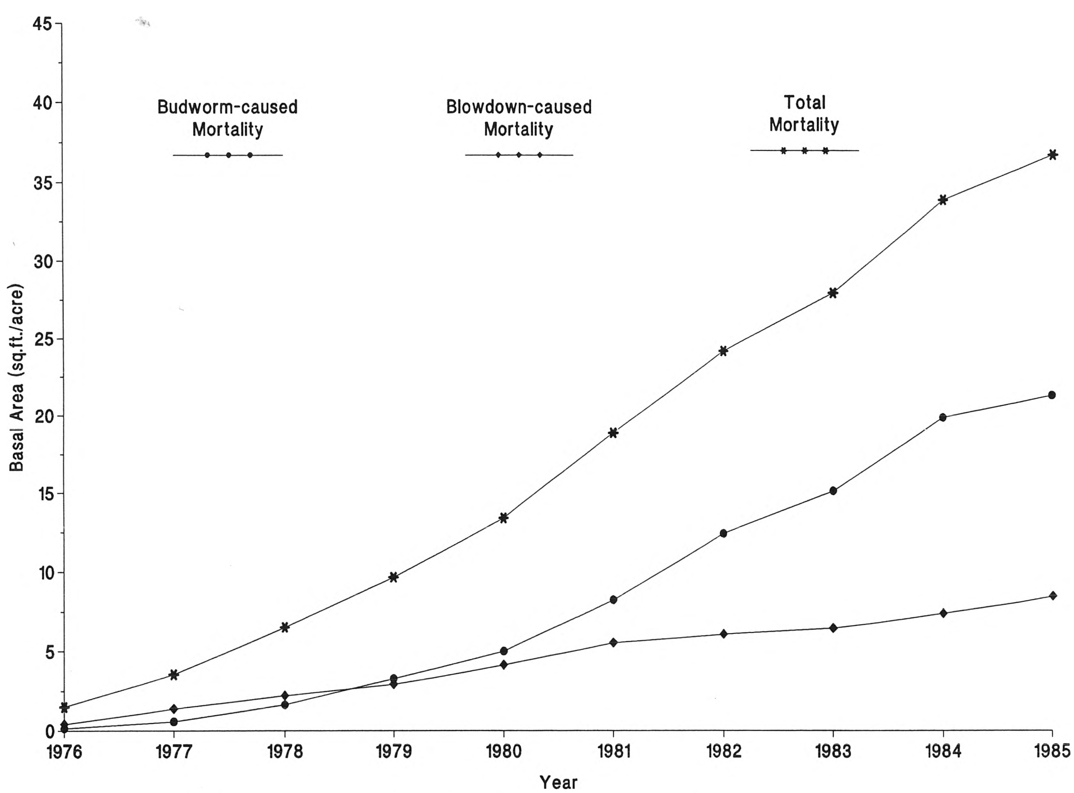

Figure 23.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 7-inch mean stand-diameter class.

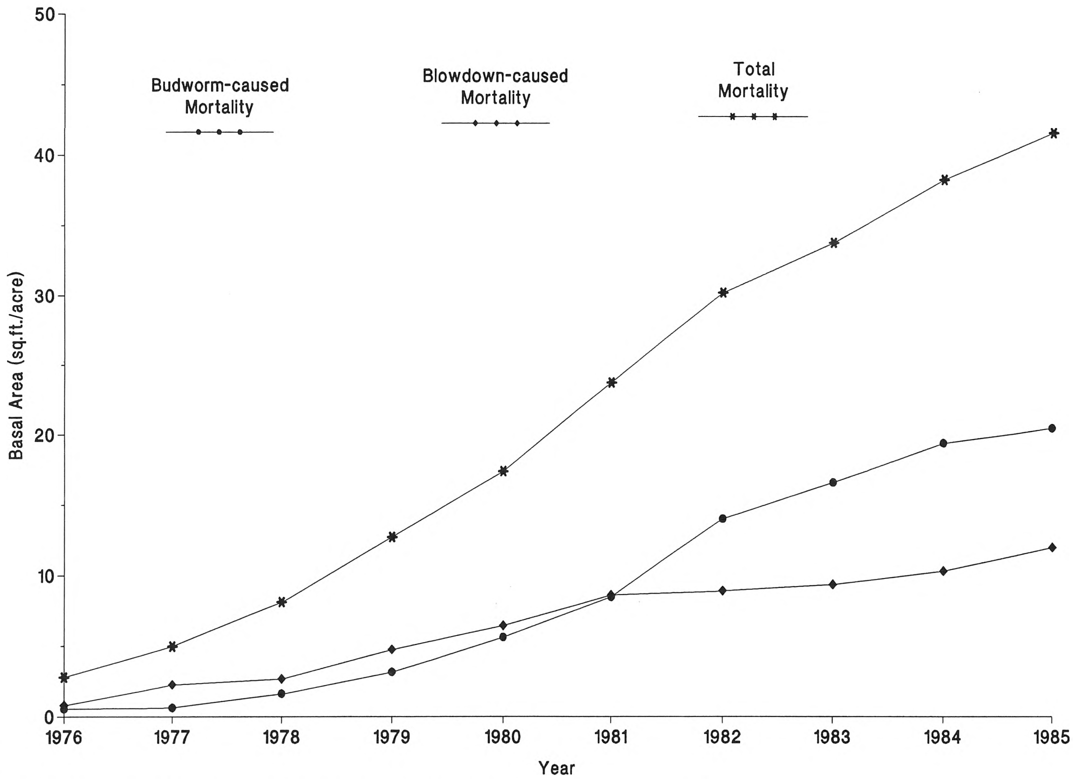

Figure 24.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 8-inch mean stand-diameter class.

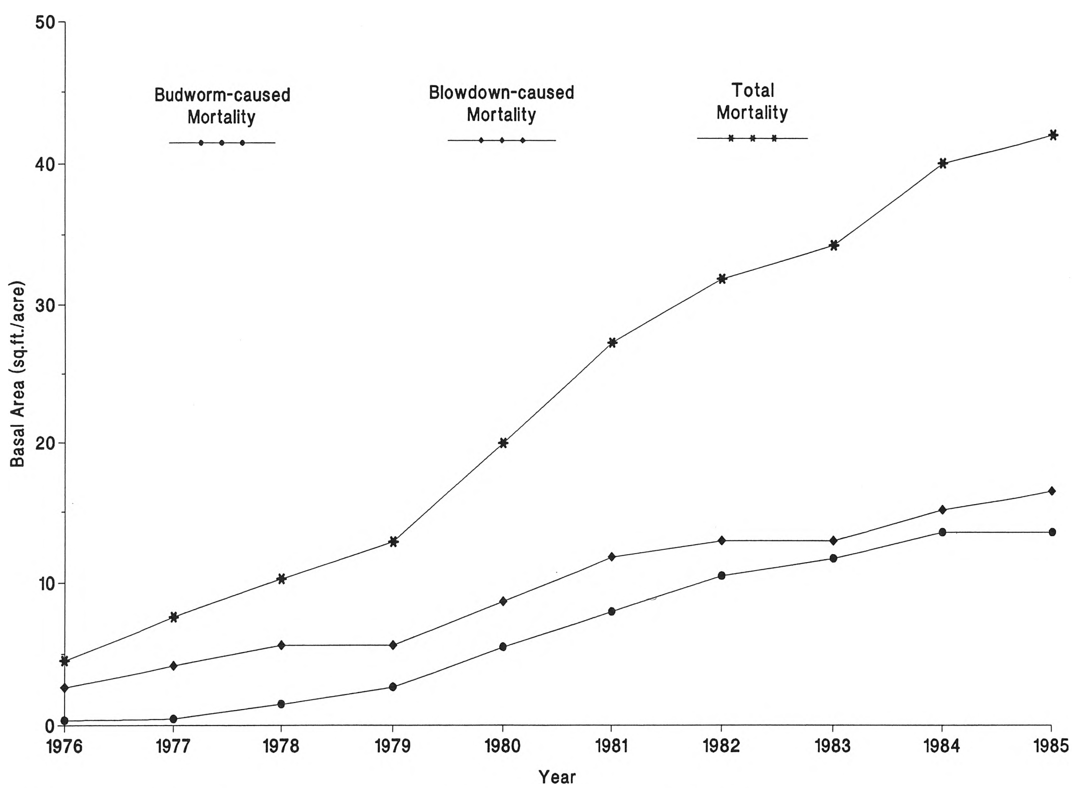

Figure 25.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 9-inch mean stand-diameter class.

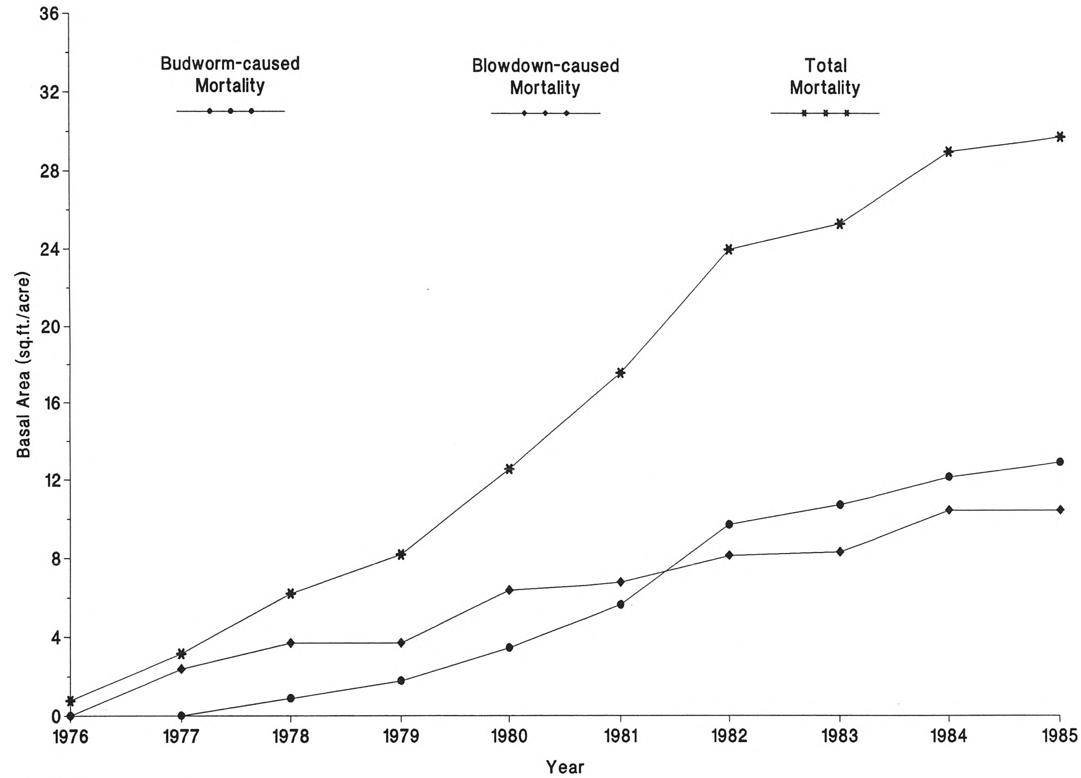

Figure 26.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 10-inch mean stand-diameter class.

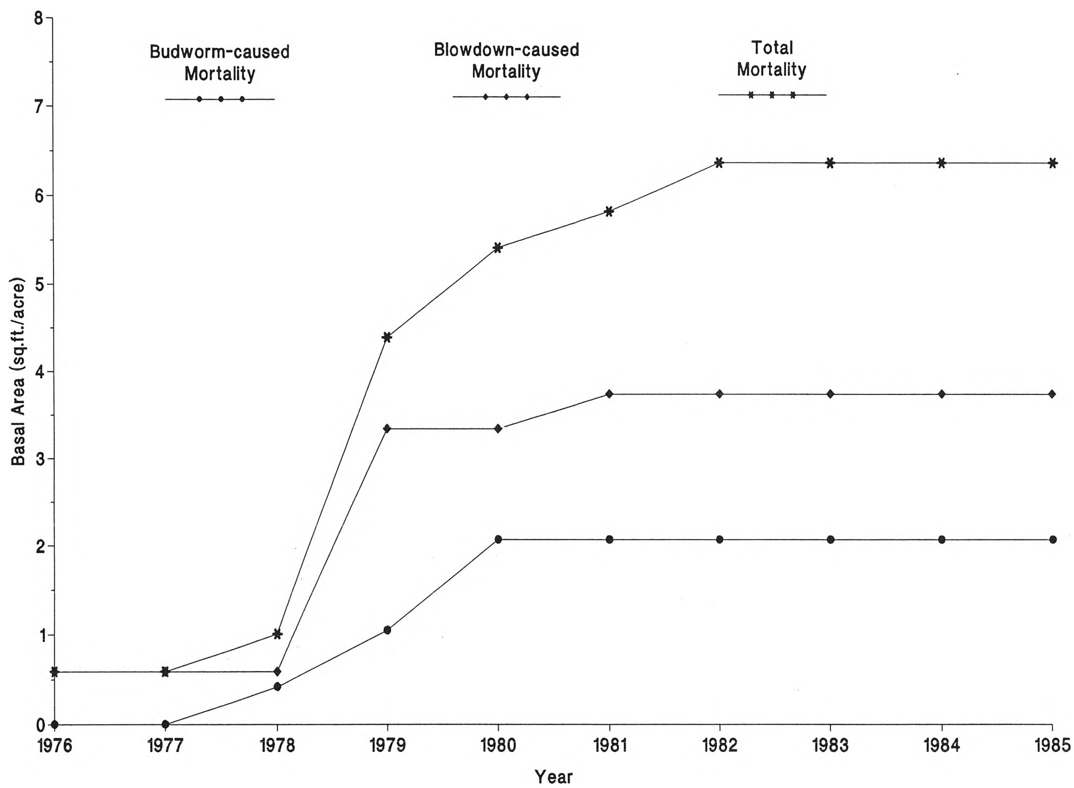

Figure 27.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 20-ft^2 basal-area class.

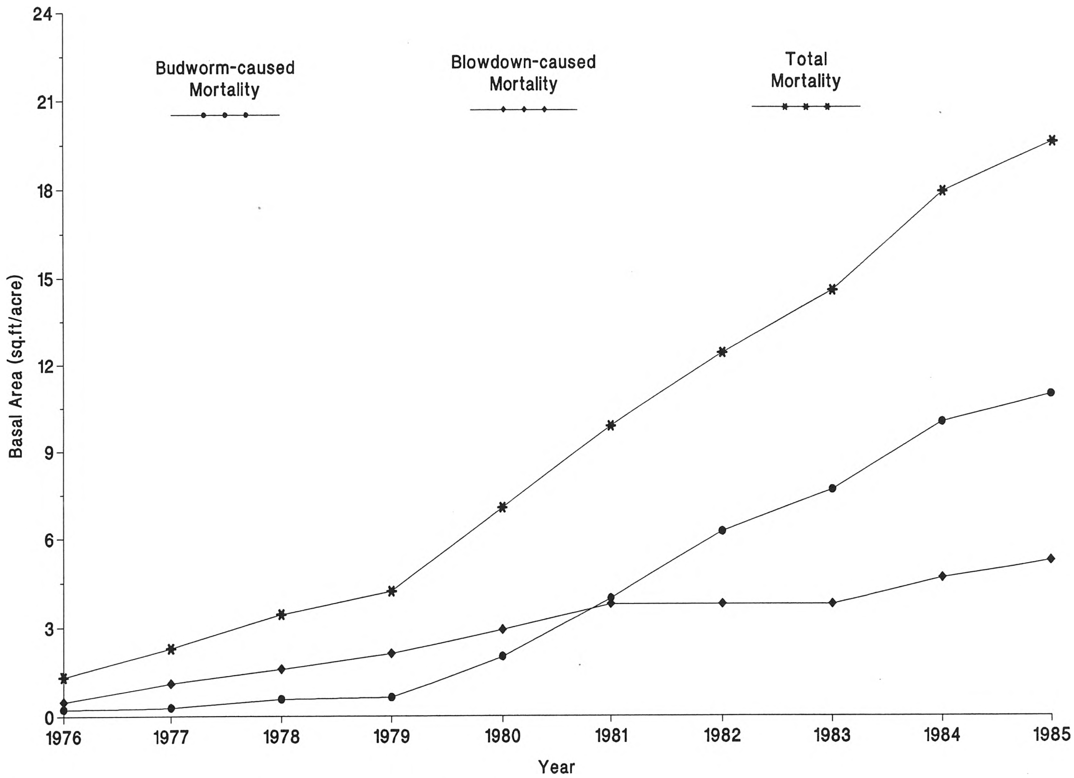

Figure 28.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 60-ft^2 basal-area class.

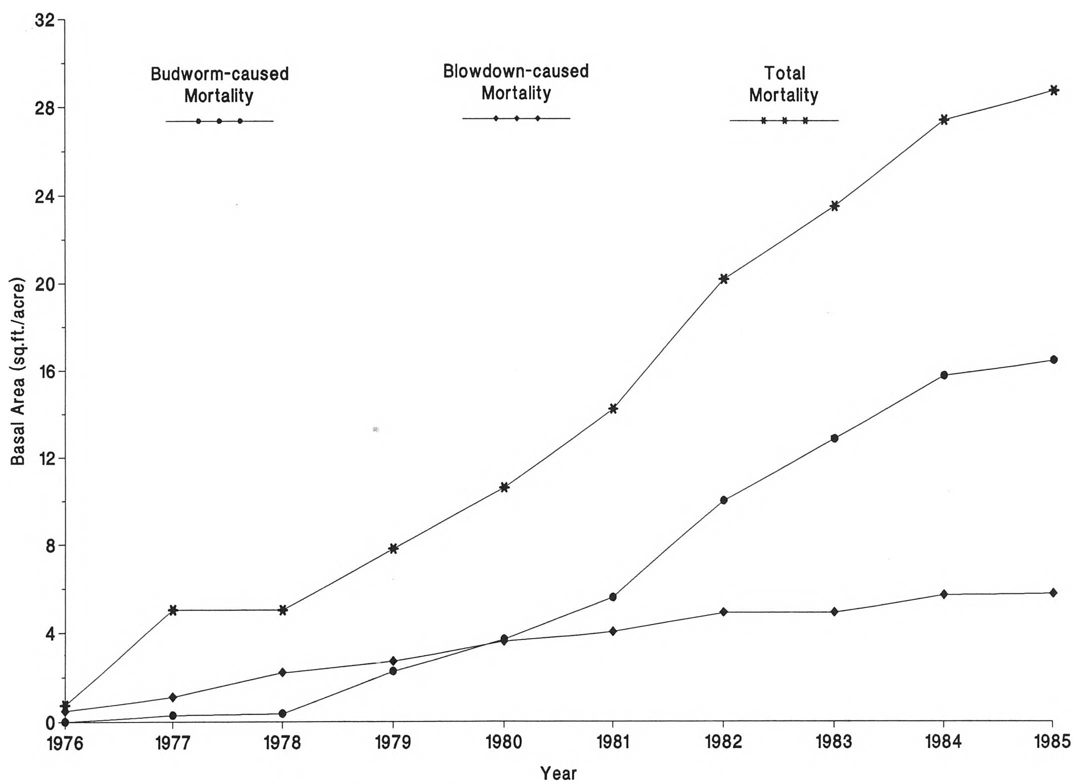

Figure 29.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 100-ft^2 basal-area class.

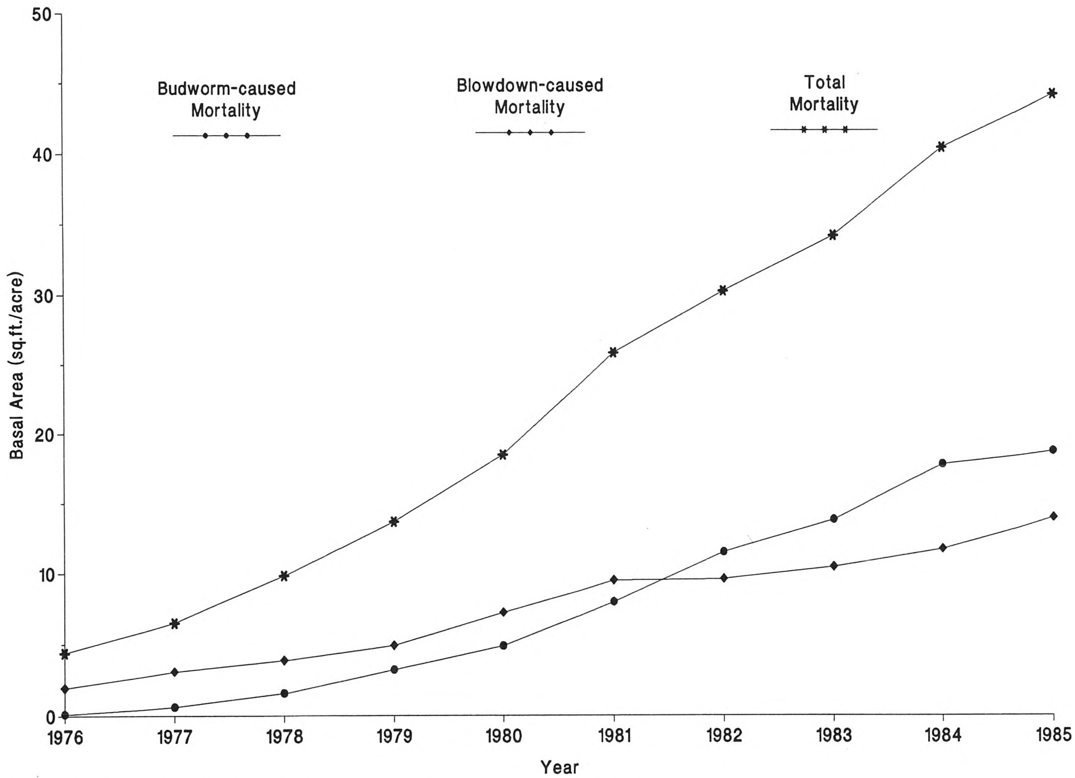

Figure 30.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 140-ft^2 basal-area class.

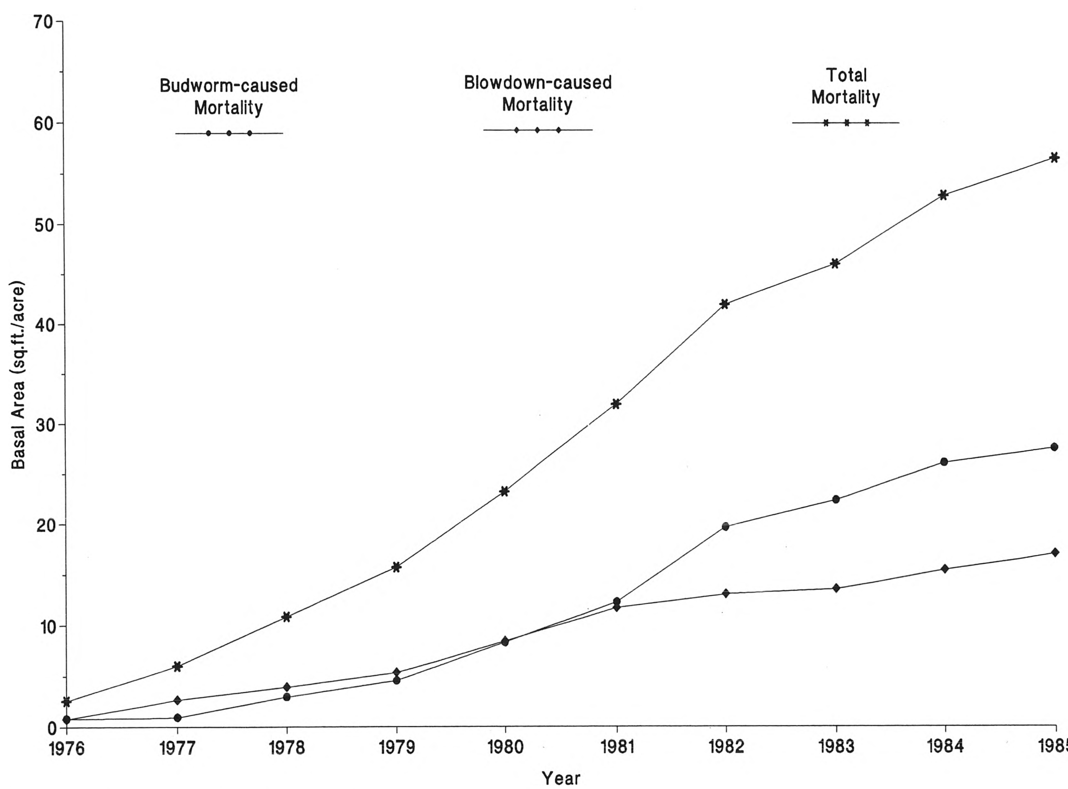

Figure 31.—Budworm-caused, blowdown-caused, and total cumulative mortality in softwood stands in 1976 through 1985 for 180-ft^2 basal-area class.

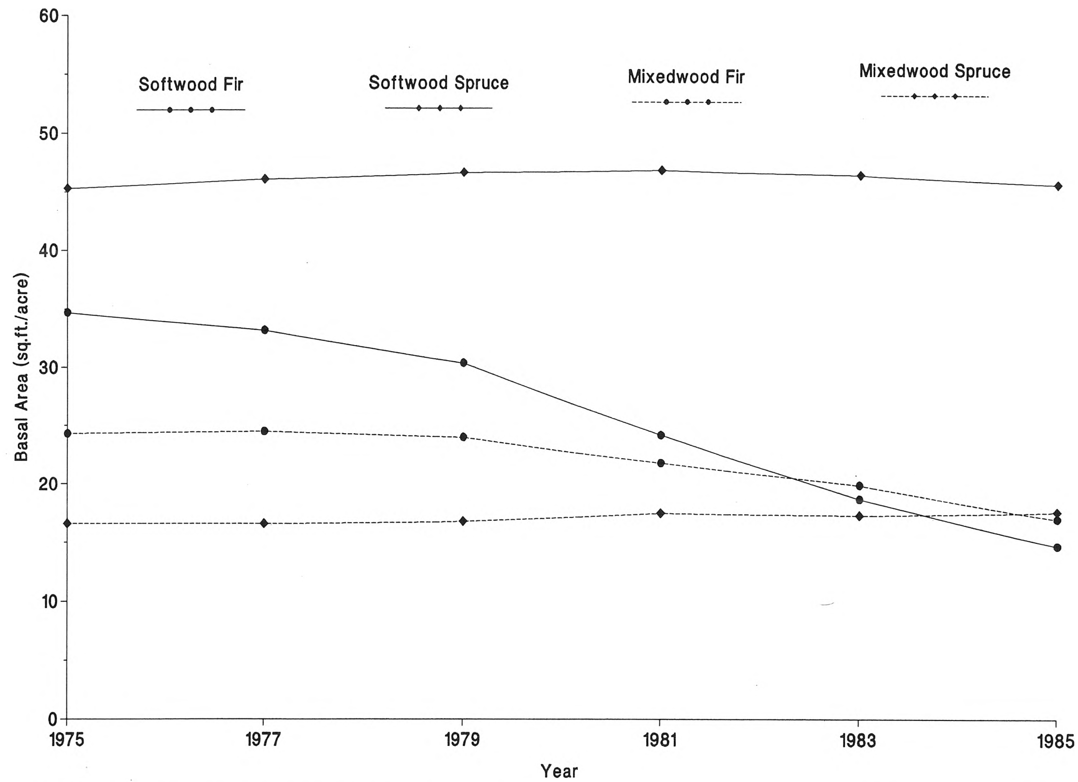

Figure 32.—Biennial live basal area of spruce and fir in softwood and mixedwood stands in 1975 through 1985.

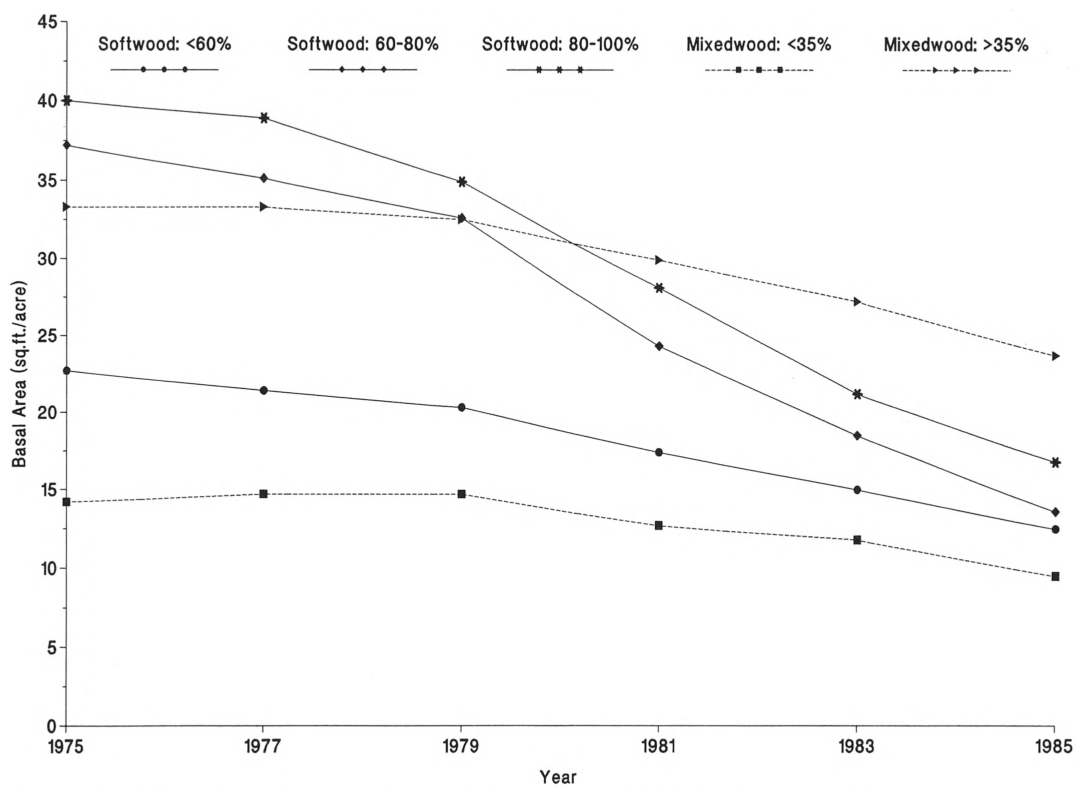

Figure 33.—Biennial live basal area balsam fir in 1975 through 1985 by host-composition class.

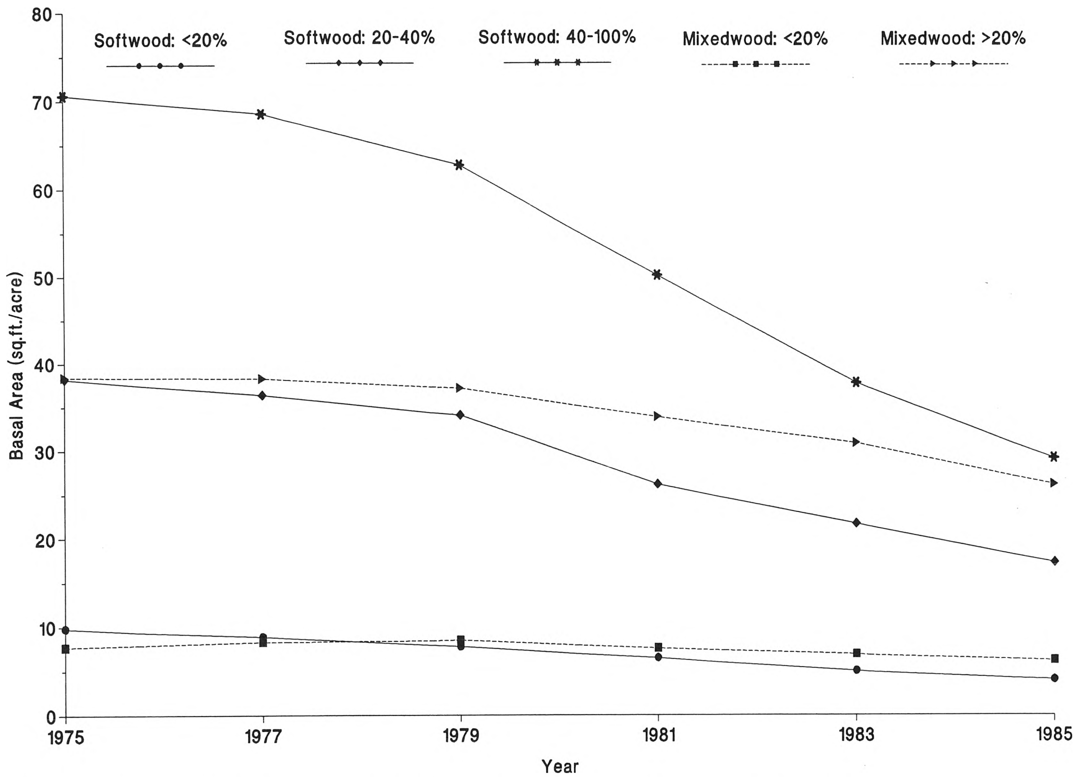

Figure 34.—Biennial live basal area of balsam fir in 1975 through 1985 by fir-composition class.

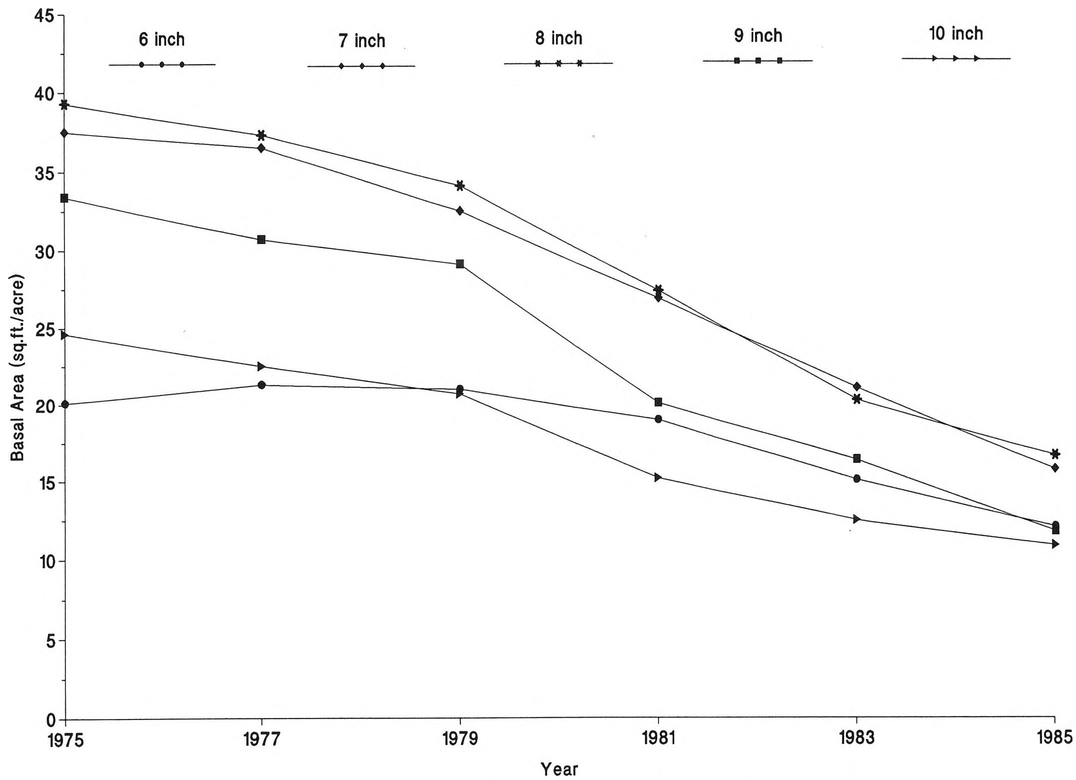

Figure 35.—Biennial live basal area of balsam fir in 1975 through 1985 by mean stand-diameter class—softwood.

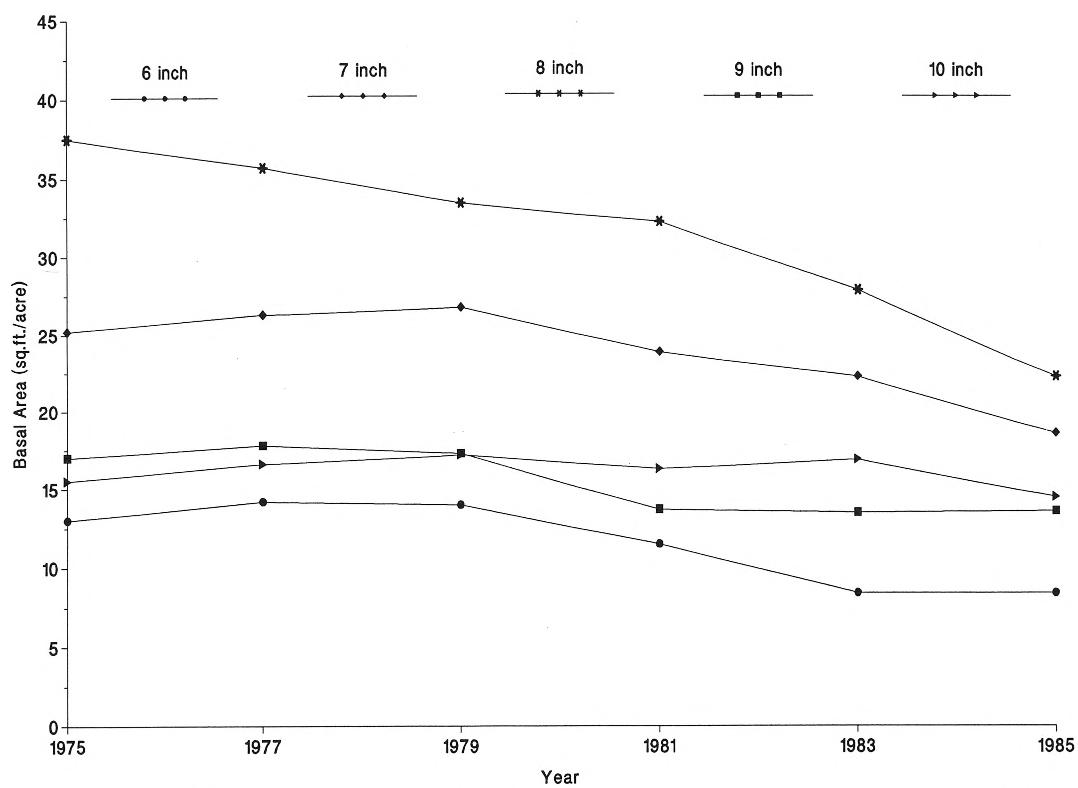

Figure 36.—Biennial live basal area of balsam fir in 1975 through 1985 by mean stand-diameter class—mixedwood.

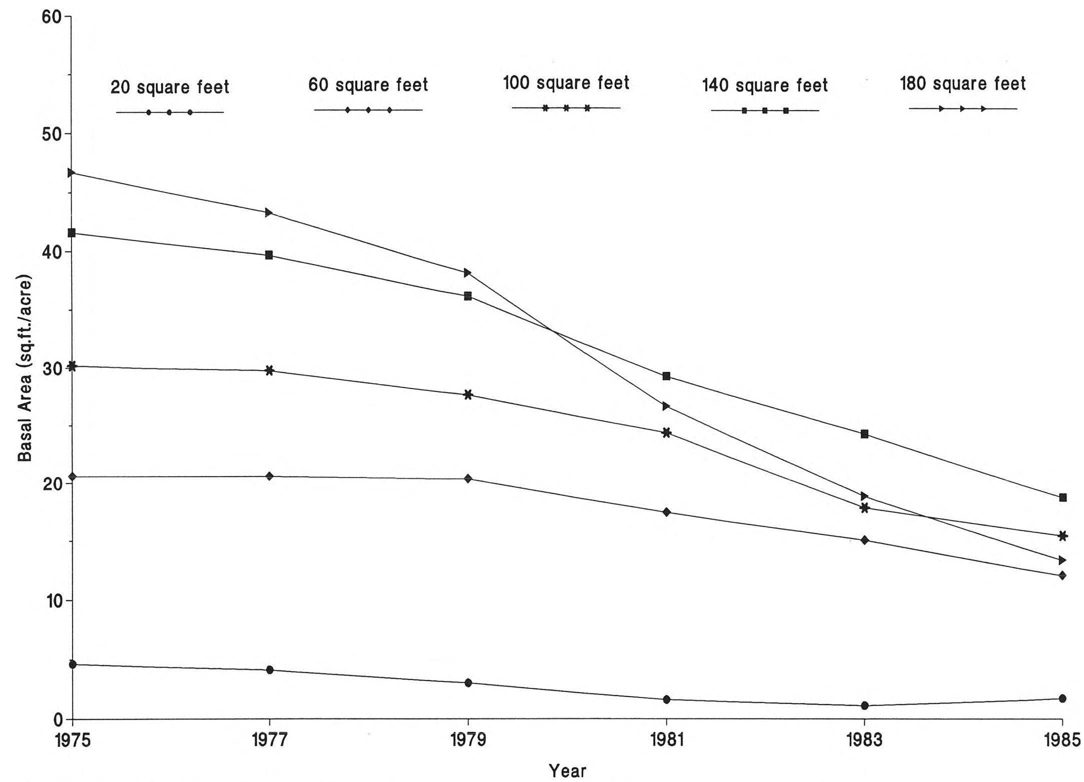

Figure 37.—Biennial live basal area of balsam fir in 1975 through 1985 by basal-area class—softwood.

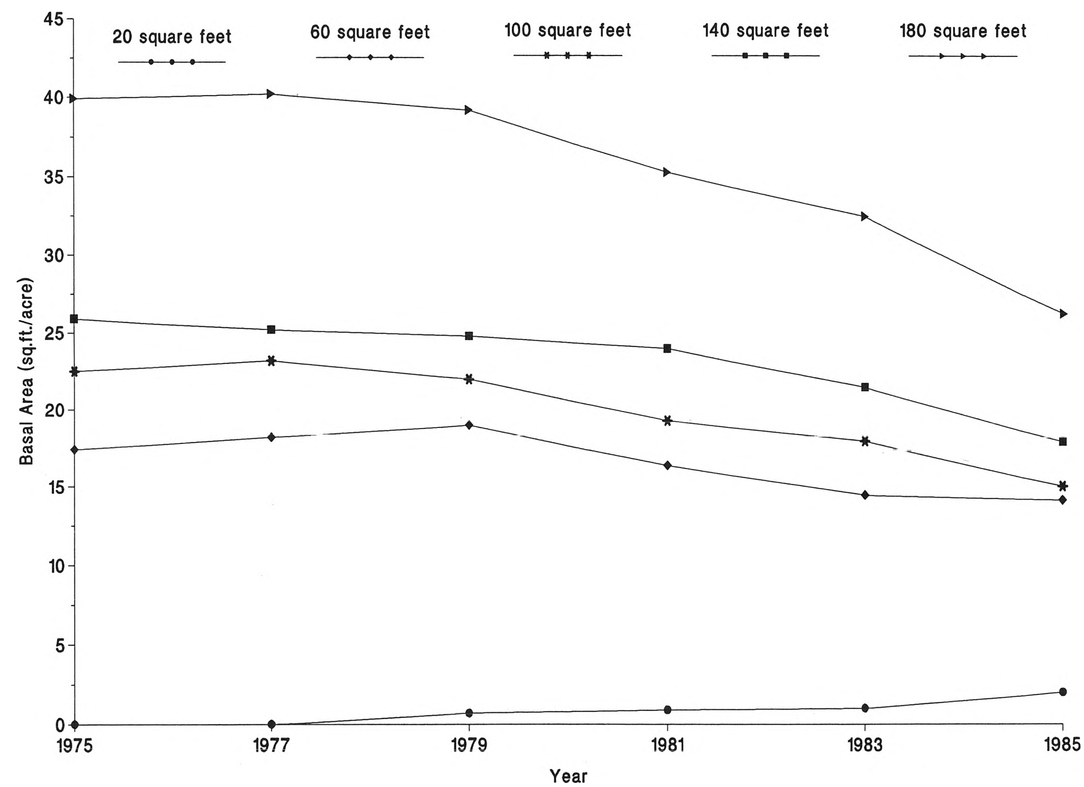

Figure 38.—Biennial live basal area of balsam fir in 1975 through 1985 by basal-area class—mixedwood.

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Solomon, Dale S.; Brann, Thomas B. 1992. **Ten-year impact of spruce budworm on spruce-fir forests of Maine.** Gen. Tech. Rep. NE-165. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 44 p.

Annual measurements from 1975 to 1985 on 278 Maine spruce-fir plots infested by the spruce budworm were analyzed by forest type, density, host-species composition, diameter, and percent fir or spruce composition classes to determine impact on growth and mortality. In 1985, balsam fir, one-fourth of the initial 1975 basal area per acre, had 50 percent mortality in mixedwood and 75 percent in softwood types. Spruce mortality was 3 times higher in the softwood than in the mixedwood type. Balsam fir mortality increased with increasing basal-area density with the heaviest losses occurring 2 years earlier in the highest density stands. Heaviest losses in the mixedwood stands usually occurred about 4 years after those in the softwood stands.

Keywords: Spruce budworm, mortality, balsam fir, spruce, growth

Headquarters of the Northeastern Forest Experiment Station is in Radnor, Pennsylvania. Field laboratories are maintained at:

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