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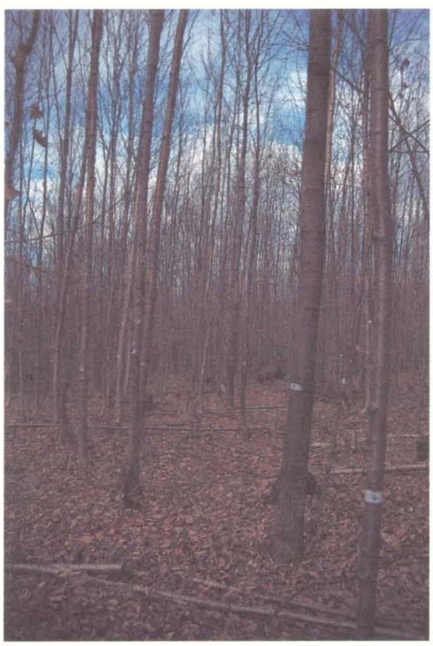
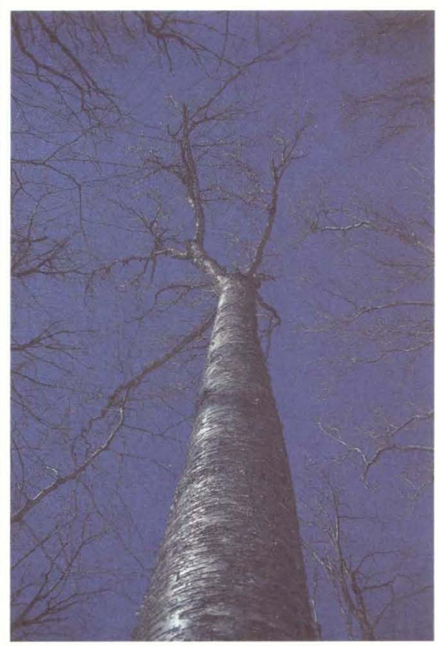
Precommercial thinning in a young sugar maple - yellow birch stand: results after 10 years

Richard Zarnovican





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Precommercial thinning in a young sugar maple - yellow birch stand: results after 10 years

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ABSTRACT

A study on the tending of young hardwood stands was initiated in 1984, near Windsor in the Eastern Townships, under an agreement between Domtar Inc. and the Canadian Forest Service. Its purpose was to evaluate the effects of silvicultural treatments on the growth and yield of the main species in sugar maple - yellow birch stands.

This paper presents the results of the impact of precommercial thinning (light from above, moderate mixed and heavy from below) on diameter and terminal growth and on the development of the three main species in a seedling stand after ten years. The study seeks to provide users with information on the management of hardwoods as regular high forest.

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RÉSUMÉ

À la suite d'une entente entre la compagnie Domtar inc. et le Service canadien des forêts, une étude sur la conduite de jeunes peuplements feuillus a été entreprise en 1984, près de Windsor en Estrie. L'objectif de cette étude est d'évaluer les effets des traitements sylvicoles sur la croissance et la production des principales essences de l'érablière à bouleau jaune.

Le travail présente les résultats de l'incidence des éclaircies précommerciales (faible par le haut, mixte modérée et forte par le bas) sur la croissance radiale et apicale et le développement des trois principales essences d'un gaulis après dix ans. Par ses résultats, l'étude vise à fournir aux utilisateurs des informations sur l'aménagement des feuillus par la méthode de la futaie régulière.

INTRODUCTION

The hardwood stands in the Eastern Townships are the result of diameter-limit cutting carried out in the 1930s and in general are formed naturally (Roberge, 1975 and 1988). Forest management therefore consisted essentially in timber harvesting, and the resulting stands were often of mediocre technological quality (Roberge, 1987). This situation prompted the creation of a research project in the early 1980s on precommercial thinning of young hardwoods. The project was carried out by the Canadian Forest Service and Domtar Inc.

Precommercial thinning is considered a treatment of choice in the tending of young hardwoods (Tubbs, 1977; Erdmann et al., 1981; Hannah, 1985; Lamson and Smith, 1987; Robitaille et al., 1990). By spacing the trees, precommercial thinning makes it possible to regulate the growth process and to concentrate stand growth on the trees with the best potential in terms of growth and quality. Through its selection effect, precommercial thinning is considered by some to be essential (Leibundgut, 1966; Tubbs, 1977; Sonderman and Brisbin, 1978; Sonderman, 1979; Schütz, 1990). This cultural operation is economically justified by the added value of the products grown (McCauley and Marquis, 1972; Mendel and Peirsol, 1977). Although the effect of release on diameter growth of hardwoods is generally considered to be beneficial (Erdmann et al., 1981; Robitaille et al., 1990; Marquis and Ernst, 1991), opinions on the intensity and nature of thinning treatments are far from unanimous.

For example, for a yellow birch seedling stand (*Betula alleghaniensis* Britton), some U.S. authors (Erdmann et al., 1981) suggest removing all stems within a radius of 3.7 m of the crop tree's stem, whereas in Quebec, Robitaille et al. (1990) suggest that the radius should not exceed 1.5 m.

Opinions are also divided on the effect of thinning on height growth and on the quality of the products grown (Kelty et al., 1987; Voorhis, 1990; von Althen et al., 1994). The tending of hardwoods is complex (Assmann, 1961; Voorhis, 1990; Zarnovican and Laberge, 1994) because the effect of thinning is not the same for all species in a mixed stand, as in the case of sugar maple - yellow birch stands (Thibault, 1986).

OBJECTIVES

The research project on precommercial thinning ties in with the management of hardwoods as regular high forest and is intended to define the tending of young seedling stands. Its objective is to evaluate the effects of precommercial thinning (nature and intensity) on the development of the main species in sugar maple - yellow birch forests, i.e., yellow birch, sugar maple (*Acer saccharum* Marsh.) and white ash (*Fraxinus americana* L.). This study covers the period between 1985 and 1995 and examines:

1 - the social dynamics of the dominant stratum;
2 - mortality of crop trees;
3 - diameter and terminal growth; and lastly,
4 - the effect of climate on the growth of birch.

SITE DESCRIPTION

The stand is located near Saint-Zacharie (lat. 45°35' N, long. 71°45' W) in Richmond county, Quebec, at an altitude of 340 m. It is a typical yellow birch seedling stand and is the result of natural regeneration after clearcutting. It forms part of the sugar maple - yellow birch domain (Thibault, 1986).

The region has a moderate, subhumid and continental climate (Proulx et al., 1987), and a 130-day growing season. The soil consists of well-drained podzols overlying heterogenous morainic material.

In 1985, the stand comprised three species: yellow birch (73%), sugar maple (19%) and white ash (7%) and it was 14 years old. It had a density of 10 025 stems per hectare, an average dbh of 3.9 cm, an average height of 7.5 m, a basal area of 14.3 m^2/ha and a total volume of 66.5 m^3/ha.

The diameter and height distributions of the stand were regular and normal (Ouellet and Zarnovican, 1988). Given the dominant height growth of the three species (Figs. 1, 2 and 3), the site index of the seedling stand is comparable to that of the sugar maple - yellow birch forest.

In silvicultural terms, the three species are distinct. Annual development in sugar maple and white ash is completed very early, whereas in yellow birch, it extends late into the season. Sugar maple and white ash are also considered to have a determinate growth form, whereas yellow birch has an indeterminate growth form (Bicknell, 1982).

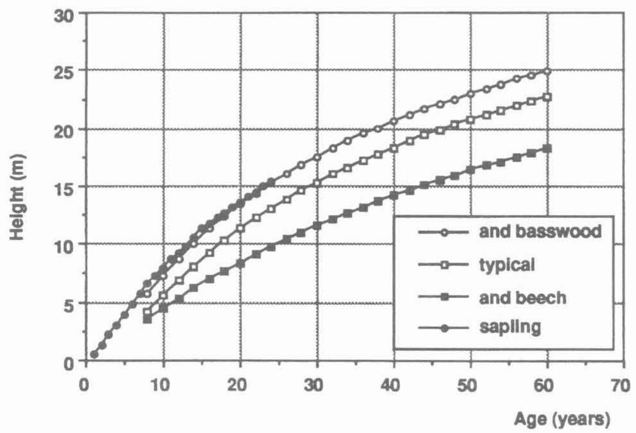

Figure 1. Height growth of yellow birch in the yellow birch - sugar maple stand.

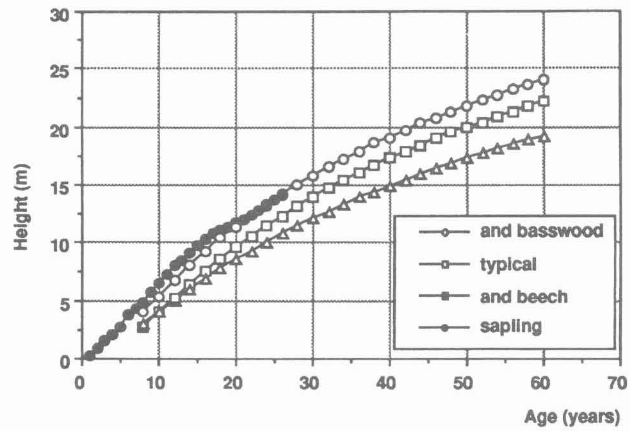

Figure 2. Height growth of sugar maple in the yellow birch - sugar maple stand.

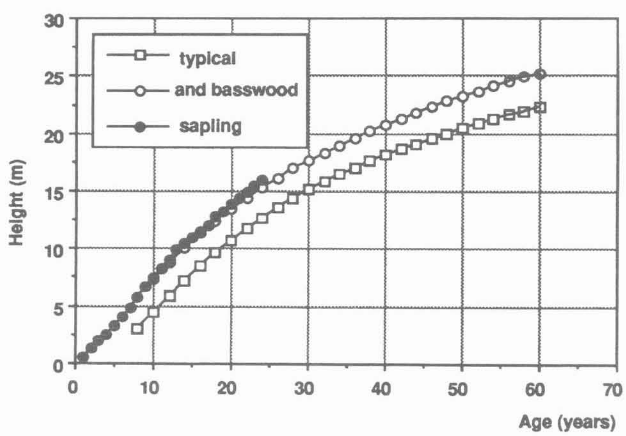

Figure 3. Height growth of white ash in the yellow birch - sugar maple stand.

METHODS AND TREATMENTS

Given the stand structure, the experiment was installed in plot 21 (Ouellet and Zarnovican, 1988). It consisted of four plots (A,B,C and D) measuring 20 m x 20 m, separated by an uncut 5-m isolation strip (Fig. 4). In the summer of 1985, live trees from the four sampling sites were numbered and located according to orthogonal coordinates and their height and dbh were measured.

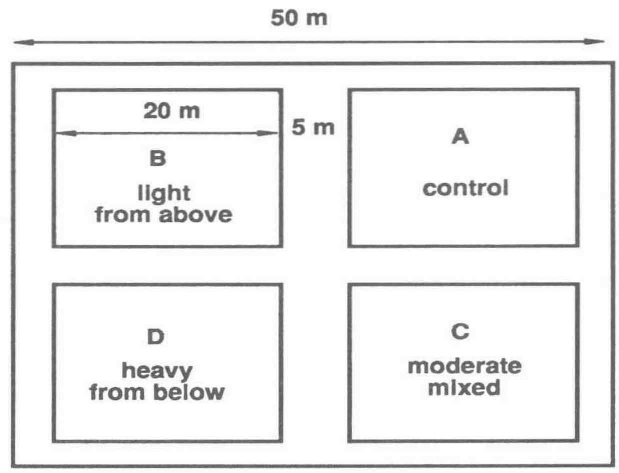

Figure 4. Design and silvicultural treatments.

The cultural role (crop tree, useful tree or harmful tree) was established on the basis of silvicultural analysis and the IUFRO classification (Ouellet and Zarnovican, 1988). Apart from the untreated control plots, three thinning treatments were applied. The first was thinning from above, based on the Danish and French thinning techniques (Vyskot et al., 1978) developed for tending hardwoods, and in which only one treatment is carried out, if necessary, for the benefit of crop trees. The second was mixed thinning, based on the qualitative thinning of Schädelin (Schütz, 1981), in which the treatment is carried out both for the benefit of crop trees and useful trees, in order to build a sufficient reserve of better candidates. The third was heavy thinning, inspired by the provincial standard in effect at the time, in which the treatment seeks regular spacing of 2 m and a residual stand of 2500 stems/ha.

The treatments were carried out on the basis of positive selection by randomly assigning one of the four treatments to each plot. Treatment without intervention was assigned to plot A, thinning from above to plot B, mixed thinning to plot C, and heavy thinning with regular spacing to plot D.

The dbh and height measurements of all trees were compiled in the fall of 1985, 1990 and 1995. The diameters were measured to the nearest millimeter at the same location on the tree, using calipers, while the height was measured to the nearest centimeter using a telescopic probe.

STATISTICAL ANALYSIS

Effect of silvicultural treatment on diameter and height growth

The effects of the silvicultural treatments on growth were evaluated using repeated-measures analysis of variance. Given the instability of the stand's social hierarchy in time, we began by considering the comparison of diameter and height increments between the two periods 1986-1990 and 1991-1995 for yellow birch crop trees (Table 1).

Table 1. Analysis of variance model for yellow birch crop trees.

Source of variation	Degrees of freedom
Thinning (E)	3
Plot (P) (E) (Error 1)	0
Trees (A) (P E) (Error 2)	111
Period (T)	1
T x E	3
T x P (E) (Error 3)	0
T x A (P E) (Error 4)	111

The analysis of variance used the "Thinning" factor with four modalities (control, light thinning from above, moderate mixed and heavy thinning from below) and the "Period" factor with two modalities (1986-1990 and 1991-1995). The dependent numeric variables are the dbh increment and the height increment.

Due to the unequal number of measurements for the three main species, we then studied the effect of thinning on trees whose height to dbh ratio was higher than the plot average. In this analysis, three factors were considered: "Thinning", "Species" and "Period" (Table 2). The "Thinning" factor has four modalities (control, light from above, moderate mixed and heavy from below), whereas the "Species" factor has three modalities (yellow birch, sugar maple and white ash) and the "Period" factor has two modalities (1986-1990 and 1991-1995).

Table 2. Analysis of variance model for the three species.

Source of variation	Degrees of freedom
Thinning (E)	3
Plot (P) (E) (Error 1)	0
Species (S)	2
E x S	6
P x S (E) (Error 2)	0
Tree (A) (S P E) (Error 3)	253
Period (T)	1
T x E	3
T x P (E) (Error 4)	0
T x S	2
T x E x S	6
T x S x P (E) (Error 5)	0
T x A (S P E) (Error 6)	253

The dependent numeric variables are the diameter increment and height increment. Since there was only one plot per silvicultural treatment, we assume that its variability is null and that the plot is confounded with the silvicultural treatment.

The normality of the distribution of the residuals ($N[0,\sigma^2]$) was tested using the Shapiro-Wilk test. This means that the diameter increment (i_d) and height increment (i_h) are also normally distributed ($N[\mu_{ij},\sigma^2]$), where μ_{ij} is the average increment in time j in plot i and σ^2 is a variance common to all thinning treatments. The homogeneity of the variance was tested using the Bartlett test. To find an optimal transformation of the data, the Box-Cox method was used (Draper and Smith, 1981). Finally, a critical threshold of 5% was used.

Fruiting and dieback of yellow birch

To test the hypothesis that fruiting in 1995 indicated a loss of growth and progressive dieback, seven pairs of yellow birch were selected near the plots that had been thinned. Each pair was composed of a yellow birch with fruiting and a yellow birch without fruiting. The paired stems were adjacent, of the same size and belonged to the same social class. Through an analysis of the stems, 14 volume growth time series were established for the period from 1983 to 1995.

By subtracting the series of the tree with fruit (iv_{af}) from the series of the tree without fruit (iv_{sf}), a new series ($dif_{as} = iv_{af} - iv_{sf}$) of differences in the increments was obtained. The effect of time on these differences (dif_{as}) was tested using repeated-measures ANOVA. If the volume increments (iv_{sf} and iv_{af}) are equal, their differences should also be equal and, as a result, the presence of fruit would not indicate dieback. If the opposite is true, the presence of fruit can be considered a sign of dieback.

Climate and volume increment of yellow birch

To determine the response function of yellow birch to climate, five time series of volume increments of dominant trees without fruit were established for the years 1980 to 1995, using the stepwise method. Each series was smoothed using the Lowess method (SYSTAT Inc., 1992) and indexed by dividing the observed volume increment by the estimated volume increment.

The indexed series represents the stationary residuals of the volume increment. On the basis of the five indexed series, an average series was established in order to measure the relationship with climate in a response function. For climate data, the monthly and standardized temperature and precipitation series of the Saint-Camille station (#702 - FR30, 12 km northeast of the stand) were used.

RESULTS

Precommercial thinning - nature and intensity

The IUFRO classification was used to evaluate the potential of the trees in each plot and to assign them a silvicultural class, i.e., crop tree, useful tree or undesirable tree. The result of the analysis (Table 3) shows the importance of the different silvicultural classes by plot and by treatment assigned. In plot A (Fig. 5), no treatment was carried out and it serves as the control. In plot B (Fig. 6), light thinning was carried out, with the g_c/g_t ratio (basal area removed from total basal area) being 11.2 %. The plot was thinned from above with the dbh_c/dbh_t ratio (ratio of the dbh of stems removed to the dbh of all stems) equal to 1.21.

Table 3. Distribution of stems by silvicultural class and treatment assigned.

Plot	Treatment assigned	Stems		
		Crop	Useful	Undesirable
A - Control	to be kept	51	235	69
	to be removed	0	0	0
	total	51	235	69
B - From above - light	to be kept	61	362	4
	to be removed	0	4	37
	total	61	366	41
C - Moderate mixed	to be kept	60	202	0
	to be removed	0	10	108
	total	60	212	108
D - From below - heavy	to be kept	45	51	0
	to be removed	0	257	48
	total	45	308	48

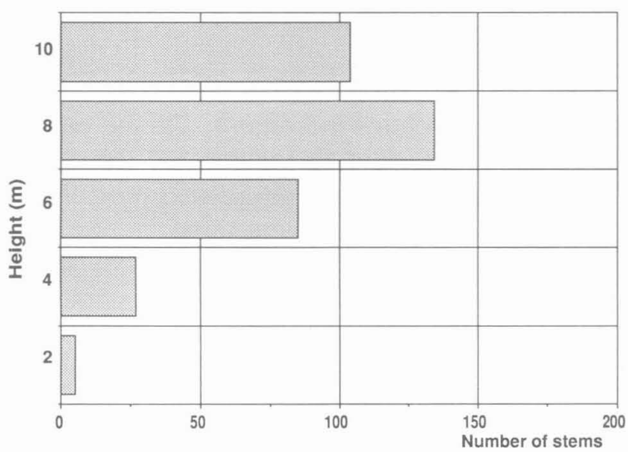

Figure 5. Distribution of stems in the control plot.

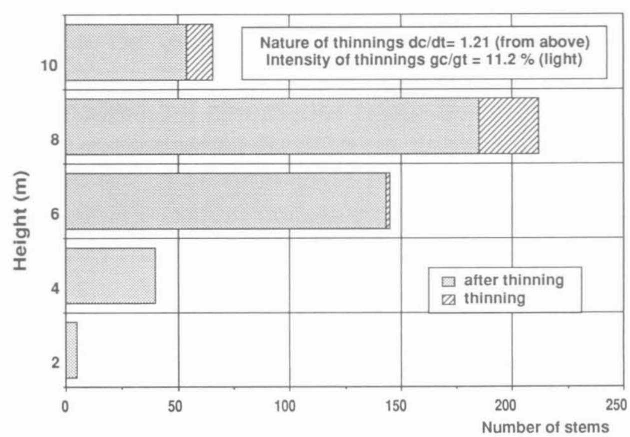

Figure 6. Distribution of stems in plot B.

In plot C (Fig. 7), moderate thinning was carried out (g_c/g_t ratio of 25.5%) in all strata (dbh_c/dbh_t ratio of 0.9), hence the adjective mixed. Finally, in plot D (Fig. 8), heavy thinning was carried out (g_c/g_t ratio of 58.7%) by removing trees in the lower strata (dbh_c/dbh_t ratio of 0.63%). It is important to bear in mind that this treatment was designed to achieve regular spacing of 2 m and a residual density of 2500 stems/ha.

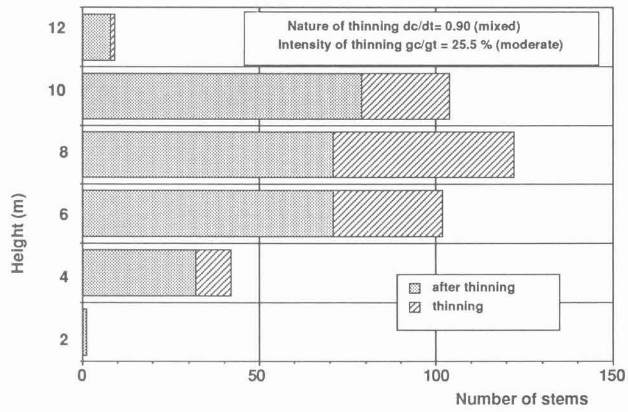

Figure 7. Distribution of stems in plot C.

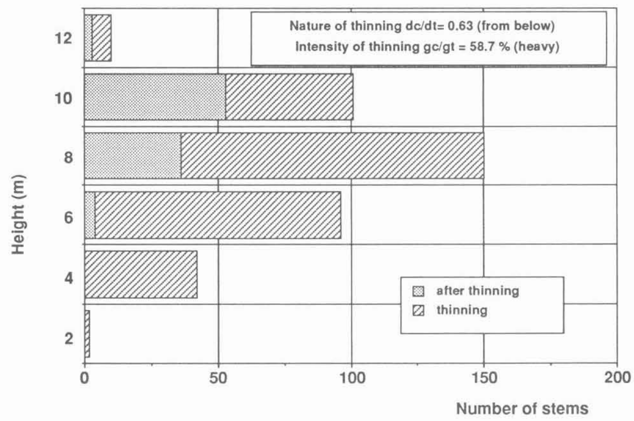

Figure 8. Distribution of stems in plot D.

Dynamics of the dominant stratum

With age, the space requirement of trees increases as they grow and their number declines, due to mortality. Although the dynamics of the lower strata are relatively well understood, those of the dominant strata are less so, due to the complexity of the dynamics of mixed stands. A knowledge of these dynamics makes it possible to evaluate the capacity of the species to withstand and adapt to disturbances, both endogenous and exogenous, which Van Miegroet (1984) calls resilience.

The changes observed in the dominant stratum between 1985 and 1995 by plot and species (Figs. 9, 10 and 11) indicate that there were few gains in social position and that the maintenance or loss of social position depended largely on the species and treatment applied. For white ash, some gains in social position (controls and heavy thinning from below) as well as maintenance of its high social position (Fig. 9) was observed. In sugar maple (Fig. 10), the maintenance of high social position varies depending on the intensity of the treatment. As for yellow birch (Fig. 11), a dramatic loss of high social position and high mortality were observed. The loss in social position and the high mortality in yellow birch raise questions about its resilience, its ecological stability and its capacity to adapt to site conditions and treatments.

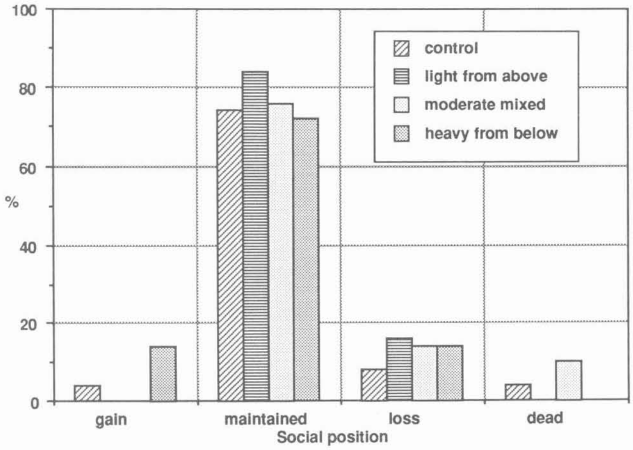

Figure 9. Dynamics of the dominant stratum between 1985 and 1995 for white ash.

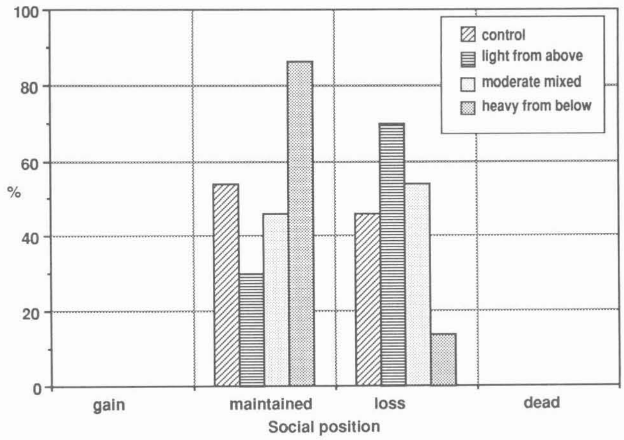

Figure 10. Dynamics of the dominant stratum between 1985 and 1995 for sugar maple.

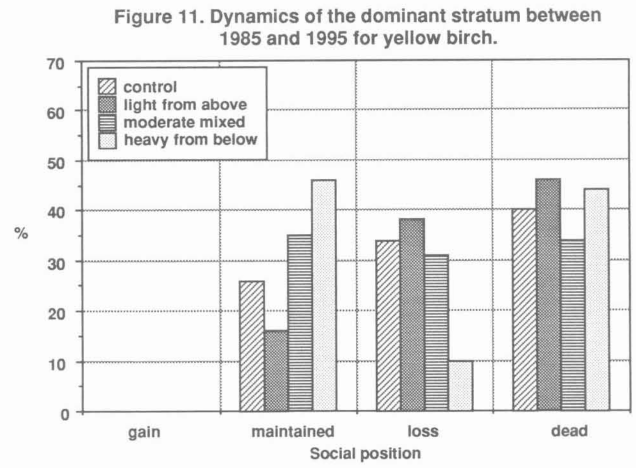

Figure 11. Dynamics of the dominant stratum between 1985 and 1995 for yellow birch.

Mortality

Following thinning from above and mixed thinning, yellow birch mortality (Fig. 12) was high, with a downward trend. In the control plot, mortality was low, with a decline in the second period. In the plot in which thinning from below was carried out, mortality was low at the beginning and high during the second period.

In the case of sugar maple (Fig. 13), a decline in mortality was observed between the first and second periods. For the first period, mortality was high in the plot to which the mixed thinning treatment was applied, lower in the plot in which thinning from above was carried out and low in the controls and plots in which thinning from below was carried out. The same downward trend was observed between the two periods for white ash (Fig. 14).

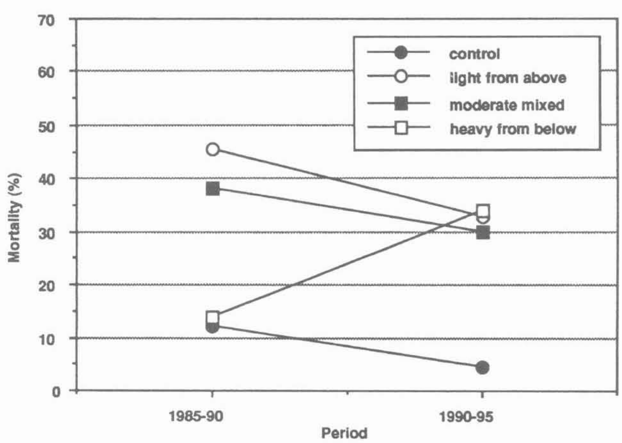

Figure 12. Mortality of yellow birch (all stems).

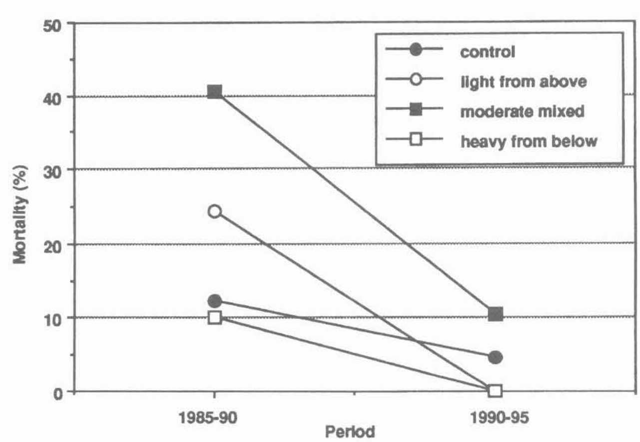

Figure 13. Mortality of sugar maple.

For the 1986-1990 period, mortality was moderate in the control and in the plot to which the mixed thinning treatment was applied, and low in the other two plots. For the 1991-1995 period, white ash mortality was very low in the plot to which the mixed thinning treatment was applied, and non-existent elsewhere. However, if we look at mortality of yellow birch crop trees (Fig. 15), we see an upward trend for all plots, with the highest rate in the plot with heavy thinning from below. This casts doubt on the merit of heavy thinning (Schober, 1987) for stabilizing the mortality of crop trees. The mortality rates of yellow birch in the seedling stand are much higher than those observed by Teck and Hilt (1990) for the northeastern U.S.

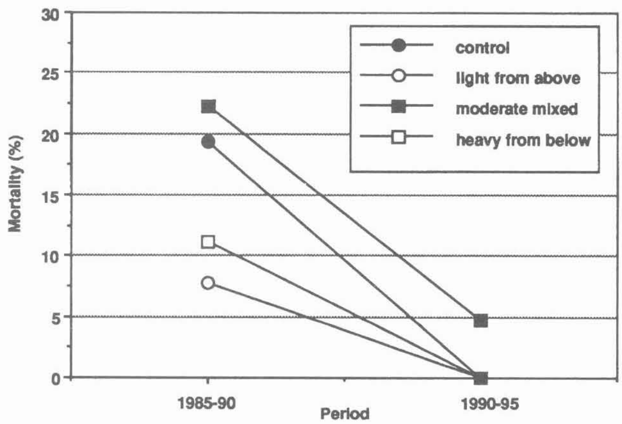

Figure 14. Mortality of white ash.

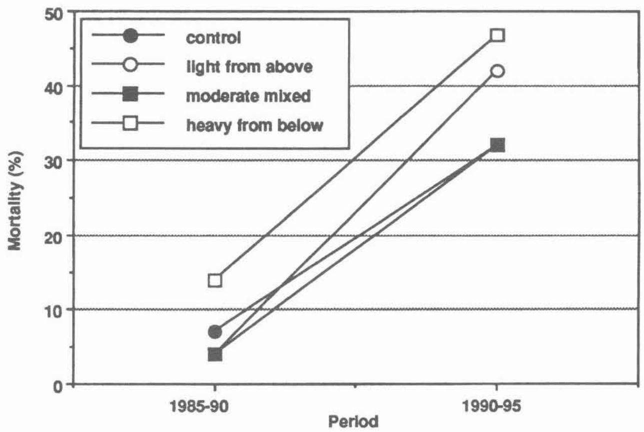

Figure 15. Mortality of yellow birch crop trees.

Effect of thinning on yellow birch crop trees

Diameter increment

The analysis of variance was performed on the 5-year mean periodic increment. The Shapiro-Wilk test confirmed the normality of the residuals for the two periods and the Bartlett test confirmed the homogeneity of the variances. The analysis of variance (Table 4) suggests that precommercial thinning had a marked effect on diameter increment (Table 5). However, the effect is not uniform for the two periods (Table 6), since the interaction (Period*Thinning) is significant.

Table 4. Test of the assumption of equality of the thinning treatments.

Source	DF	SS	MS	F	Prob>F
Thinning (E)	3	1.576	0.525	11.397	0.00000
Error (2)	111	5.115	0.046		
Total	114	6.691			

DF = degrees of freedom, SS = sum of squares, MS = mean square, Prob>F = probability of obtaining a greater statistic under H_0.

Table 5. Mean annual diameter increment (cm/year^{-1}).

Thinning-plot	n	1986-1990	1991-1995
Control	30	0.322 a	0.271 a
Light from above	30	0.352 a	0.321 a
Moderate mixed	34	0.438 b	0.302 a
Heavy from below	21	0.562 c	0.514 b

On the basis of the Tukey multiple comparison test (P = 0.05), the underlined means do not differ greatly between the periods and the means with the same letters do not differ significantly between thinnings/plots.

Diameter growth was generally lower during the second period (1991-1995) than the first (1986-1990), and the difference was more pronounced in the plot to which the moderate mixed thinning treatment was applied than in the others (Table 4). Heavy thinning from below produced the highest yields both in the first and second periods.

Table 6. Uniformity of the effect of thinnings between the two periods.

Source	DF	SS	MS	F	Prob>F
Period (T)	1	0.244	0.244	27.990	0.000
Thinning*Period	3	0.106	0.035	4.041	0.009
Error (4)	111	0.968	0.009		
Total	115	1.318			

The effect of moderate mixed thinning was significant only during the first period, while the effect of light thinning from above was not for either the first or second period. The substantial decline in diameter growth during the second period could just as well indicate the end of the effect of the treatment as the effect of other factors, such as climate.

Height increment

The Bartlett test confirmed the homogeneity of the variances and the Shapiro-Wilk test confirmed the normality of the residuals for the two periods. The analysis of variance (Table 7) suggests that thinning had a significant effect on the height increment of yellow birch crop trees (Table 8).

Table 7. Test of the assumption of equality of the treatments.

Source	DF	SS	MS	F	Prob>F
Thinning (E)	3	0.470	0.157	6.093	0.001
Error (2)	111	2.855	0.026		
Total	114	3.325			

Table 8. Mean annual height increment (m/year^{-1}).

Thinning-plot	n	1986-1990	1991-1995
Control	30	0.325 a	0.217 a
Light from above	30	0.319 a	0.214 a
Moderate mixed	34	0.334 a	0.374 b
Heavy from below	21	0.408 a	0.325 ab

On the basis of the Tukey multiple comparison test (P = 0.05), the underlined means do not differ greatly between the periods and the means with the same letters do not differ significantly between the thinnings/plots.

The increments between the two periods, however, did differ significantly (Table 9). The interaction term (Thinning*Period), although not marked, is close to the critical threshold, undoubtedly due to the change in the height increment in the plot to which the moderate mixed thinning treatment was applied.

Table 9. Test of the uniformity of the effect of thinning between the two periods.

Source	NDF	SS	MS	F	Prob>F
Period (T)	1	0.227	0.227	7.244	0.008
Thinning*Period	3	0.240	0.080	2.555	0.059
Error (4)	111	3.478	0.031		
Total	115	3.945			

The Tukey test (Table 8) suggests that the height increments are similar in the first period, whereas the same test suggests significant differences in the second period between the plot with moderate mixed thinning and the controls and the plot with light thinning from above.

The trend of height increments between the two periods is decreasing in the controls and in the plots with light thinning from above and heavy thinning from below, whereas it is increasing for moderate mixed thinning. However, only the decline in the control and in the plot with light thinning from above is significant. The decline in height growth during the second period once again raises the question of the effect of other factors.

Thinnings and growth of the main stand

To compare the effect of silvicultural treatments on the growth of the three main species (yellow birch, sugar maple and white ash), all trees having a height to dbh ratio over the average of 1985 were selected. This set of trees can be assumed to belong to the final crop (Assmann, 1961; Horne et al., 1986; Abetz, 1993).

Table 10. Relative frequencies of the selected trees (%).

Plot	Sugar maple	Yellow birch	White ash	Total
Control	3.1	27.2	5	35.3
Light from above	2.5	22	5	29.5
Moderate mixed	3.1	12.2	5	20.3
Heavy from below	3.8	9.2	1.9	14.9
Total	12.5	70.6	16.9	100

The selection of these stems was necessary because the number of crop trees varied from species to species and from plot to plot (Table 10). The relative distribution of the 186 stems of yellow birch, 33 stems of sugar maple and 46 stems of white ash as a function of silvicultural treatment is presented in Table 10.

Diameter increment

The data on the mean periodic increment of the three species by plot and period are presented in Table 11. The Shapiro-Wilk test rejects the assumption of normality of the residuals for the second period. However, the analysis of the processed data gives the same results as the analysis of raw data, which means that the latter analysis was retained.

The analysis of variance (Table 12) indicates that thinning had a significant effect on dbh increment. However, the multiple comparison indicates that diameter growth is similar for heavy thinning from below and mixed thinning, but is noticeably greater than that observed in the control and in the plot with light thinning from above.

Table 11. The dbh increment of the final crop (cm/year^{-1}).

Plot treatment	Yellow birch		White ash		Sugar maple	
	1986-1990	1991-1995	1986-1990	1991-1995	1986-1990	1991-1995
Control	0.290 a	0.227 a	0.560 a	0.669 a	<u>0.315 a</u>	<u>0.358 a</u>
Light from above	0.299 a	0.255 ab	0.479 a	0.639 a	<u>0.249 a</u>	<u>0.266 a</u>
Moderate mixed	0.449 b	0.339 b	0.648 a	0.795 a	<u>0.375 a</u>	<u>0.335 a</u>
Heavy from below	<u>0.538 b</u>	<u>0.483 c</u>	0.436 a	0.672 a	<u>0.440 a</u>	<u>0.516 a</u>

The underlined means do not differ greatly between the periods and the means with the same letters do not differ significantly between the thinnings/plots.

The last two means are also similar. The interaction term (Thinning*Species) indicates that the response of the species to the treatment is similar.

Table 12. Analysis of variance for dbh increment.

Source	DF	SS	MS	F	Prob>F
Thinning	3	1.043	0.348	5.487	0.001
Species	2	4.046	2.023	31.944	0.000
Thinning*Species	6	0.735	0.122	1.934	0.076
Error (3)	253	16.023	0.063		
Period	1	0.112	0.112	12.709	0.000
Thinning*Period	3	0.061	0.020	2.334	0.075
Species*Period	2	0.846	0.423	48.155	0.000
Thinning*Species*Period	6	0.042	0.007	0.800	0.571
Error (6)	253	2.222	0.009		
Total	265	3.283			

Diameter growth differed significantly between the species and in time (Species*Period). If we also consider the significant effect of the "Period" factor with a decline in the increment in the second period, it is important to know the individual response of the species. The study of the effect of thinning on diameter growth indicates that it was significant only in the case of yellow birch.

The decline in diameter growth (Table 11) for birch during the second period (statistically significant in the controls, plots with thinning from above and following mixed thinning) suggests that the positive effect of release was restricted to the first period only.

Thinning had no effect on the diameter growth of white ash ($p = 0.134$) or sugar maple ($p = 0.141$). However, the diameter increment in white ash increased significantly in time, whereas that of sugar maple remained unchanged (Table 11). Of the three species, white ash showed the greatest diameter increment during the two periods.

Height increment

The results of the analysis of variance for height increment (Table 13) are essentially the same as for diameter growth, with the significant effect of the silvicultural treatment.

Table 13. Analysis of variance for height increment.

Source	DF	SS	MS	F	Prob>F
Thinning	3	0.411	0.137	4.098	0.008
Species	2	1.981	0.991	29.246	0.000
Thinning*Species	6	0.322	0.054	1.583	0.152
Error (3)	253	8.570	0.034		
Period	1	0.010	0.010	0.386	0.535
Thinning*Period	3	0.104	0.035	1.307	0.273
Species*Period	2	0.452	0.226	8.533	0.000
Thinning*Species*Period	6	0.287	0.048	1.811	0.097
Error (6)	253	6.694	0.026		
Total	265	7.547			

The comparison of the means between treatments gives a similar height growth between the controls, thinning from above and thinning from below. The first two treatments (Table 14) produced different height increments than did the mixed thinning treatment, whereas the latter produced a height increment similar to that of heavy thinning from below. The interaction (Thinning*Species) is not significant.

Table 14. Height increment in the final crop (m/year^{-1}).

Plot treatment	Yellow birch		White ash		Sugar maple	
	1986-1990	1991-1995	1986-1990	1991-1995	1986-1990	1991-1995
Control	0.292 a	0.176 a	0.416 a	0.440 a	0.315 a	0.358 a
Light from above	0.290 a	0.172 a	0.487 a	0.483 a	0.249 a	0.266 a
Moderate mixed	0.335 a	0.353 ab	0.432 a	0.639 b	0.375 a	0.335 a
Heavy from below	0.404 b	0.305 b	0.460 a	0.402 a	0.440 a	0.516 a

The underlined means do not differ greatly between the periods and the means with the same letters do not differ significantly between thinnings/plots.

Height growth differed between the species and in time (Tables 13 and 14). The analysis of variance for each species indicates that thinning had a significant effect on height growth of yellow birch ($p = 0.000$) and white ash ($p = 0.009$), but had no effect on sugar maple ($p = 0.067$). We also see that height growth of the three species evolved differently in time. White ash showed the greatest height growth.

The height increment of yellow birch declined significantly between the two periods in the controls and in plots with thinning from above, whereas the decline was not great in the plot with thinning from below. Finally, the plot with mixed thinning showed an upward trend, although it was not significant. The significant effect of the thinning on terminal growth of white ash derived from the increment observed during the second period after mixed thinning. Finally, the mean height increments of sugar maple were similar for the various silvicultural treatments and in time.

These results raised the question of the effectiveness of precommercial thinning in mixed stands. As can be seen, a treatment can stimulate the growth of one species, yet be completely ineffective for another. The challenge for the forester is to find a compromise in terms of nature, intensity of treatment and age of application.

Production in total volume

After the thinning done in 1985, the total volume per plot corresponded to the residual standing volume. The highest yield was observed in the control (Fig. 16) and the lowest yield was observed in the plot with heavy thinning from below. The plot with light thinning from above and the plot with moderate mixed thinning fell between the two. The position of the plots reflects the intensity of the treatment, as expressed by the volume of wood cut.

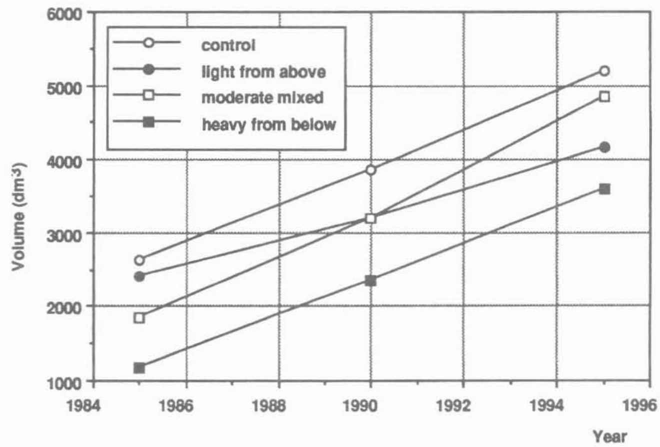

Figure 16. Total volume with bark.

We observed that, with time, the discrepancy between the control and the plot with heavy thinning from below was constant, whereas it declined for the plot with moderate mixed thinning and increased for the plot with light thinning from above. This comparison indicates that the loss in volume by cutting is not necessarily offset by the gain in volume of the residual trees, but rather by the average dbh.

For example, if we take the average dbh of the stems of crop trees in 1995, we see that if the dbh of the control is 100%, the average dbh of the plot thinned from above is 103%, that of the plot with mixed thinning is 107% and that of the plot with heavy thinning from below is 125%.

Dieback of yellow birch

In addition to high mortality, relatively abundant fruiting was observed in yellow birch during the second period. In the past, the presence of these two phenomena has been associated with dieback in yellow birch (Gross and Harnden, 1968; Kessler, 1969; Gross, 1972). Dieback seems to be a cyclical phenomenon in eastern Canada, for it has been described and identified several times since the 1930s (Pomerleau, 1953; Wall, 1983).

Associated with the presence of cryptogamic and viral diseases (Hansbrough, 1953), or with the effect of climate (Clark and Hare, 1953; Jones et al., 1993), the causes of dieback are still poorly understood (Wall, 1983). Dieback is characterized by the gradual appearance of certain symptoms on the trunk (collapse of the cambium, discoloration, lesions, mucous exudate and cankers) and crown (wilting of leaves, dying of the crowns and cankers). To test the hypothesis that fruiting indicates a loss of growth and gradual dieback, the equality of differences between volume increment with fruit and volume increment without fruit (Figs. 17 and 18) in time was tested by repeated-measures ANOVA (Table 15).

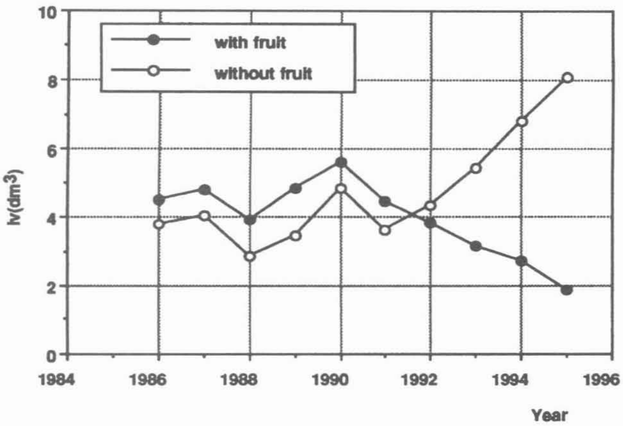

Figure 17. Volume increment of yellow birch.

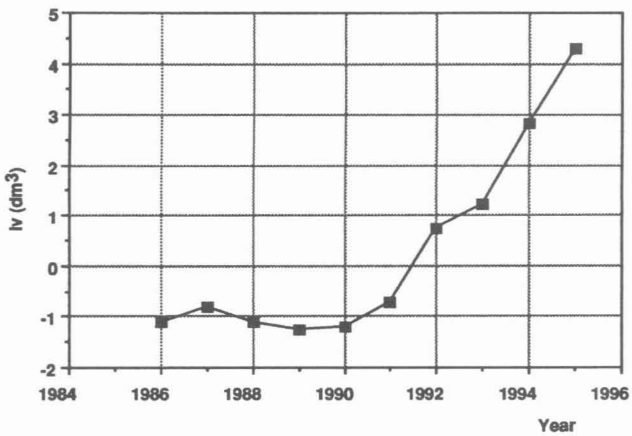

Figure 18. Differences between volume increment of yellow birch with and without fruit.

Table 15. Test of the assumption of equality of volume increment.

Source	DF	SS	MS	F	Prob>F
Time	4	147.320	36.810	7.162	0.001
Error	24	5.139			
Linear time	1	111.330	111.330	8.320	0.028
Error	6	80.265	13.378		
Quadratic time	1	35.834	35.830	9.479	0.022
Error	6	22.682	3.780		
Cubic time	1	0.013	0.013	0.005	0.946
Error	6	14.955	2.492		

Between 1986 and 1991 (Fig. 18), the differences between the volume increment of trees with and without fruit, although negative, were equal, which suggests that the trees with fruit were more productive. After 1992, these differences were positive and increased significantly.

The study of the effect of time on the equality of these differences (Table 15) indicates that they are not equal in time. According to the tests on polynomial contrasts (Table 15), the linear and quadratic components of the effect of time are significant, whereas the cubic component is not.

The evolution of trees with and without fruit was similar between 1986 and 1991, whereas since 1992, the volume increment of the trees with fruit declined continually. These results suggest that the presence of fruit is a sign of dieback in yellow birch.

Temporal relationship between volume increment and climate

Of the external factors that affect tree development, climate is undoubtedly the most important. Both the allocation in carbon and the hormonal activity of the tree are ultimately dependent on climate (Kozlowski et al., 1991). In this context, it is possible that dieback and severe mortality of yellow birch between 1991 and 1995 were caused by climate.

Although Holdaway (1987) believes that yellow birch is relatively insensitive to climatic variations, Roberge (1988) observed that the beneficial effect of thinning on yellow birch at Dudswell was offset by dieback and the high mortality rate between 1969 and 1984. Lavallée and Bard (1971) found that a high humidity rate promotes the spread of disease, coloration and stem rot in yellow birch.

To assess the response of yellow birch to the regional climate, the relationships between volume increment of yellow birch and monthly temperature and precipitation data were analyzed using the stepwise method. The results indicate that the climate during the growing season (May, June and July) plays an important role in the development of yellow birch (Fig. 19). The average temperature for this period accounted for 75% of the variations in volume increment between 1983 and 1992, while precipitation accounted for only 40%.

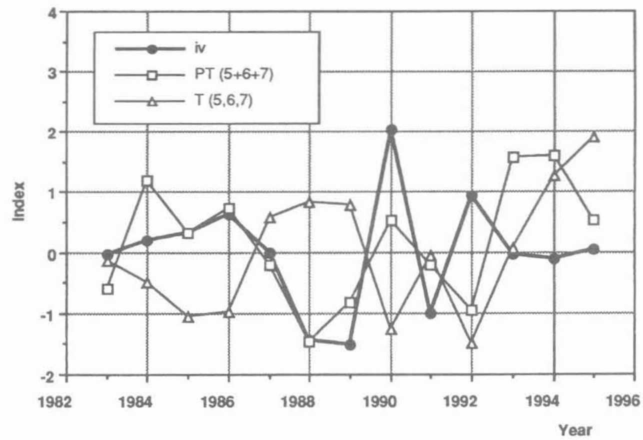

Figure 19. Relationship between volume increment (iv) of yellow birch, precipitation (PT) and mean temperature (T).

The comparison of average temperatures and precipitation (May, June and July) between 1986-1990 and 1991-1995, using a matched *t* test, revealed that the climate remained, on average, stable during the two periods. This does not mean, however, that the annual fluctuations in climate were the same during the two periods.

The two climatic factors are cyclical (Fig. 19) and the volume increment depends on the phase of these two variables. When these variables are dephased, two situations can be seen. In the first, yellow birch suffers the effect of water deficiency, as was the case in 1988 and 1989 and the volume increment is therefore below normal. In the second situation, when temperatures are cool and precipitation is higher than normal, as was the case in 1990, the volume increment is higher than normal. After 1992, the two climate factors were in phase, rainfall and temperatures were above normal and we observed dieback and less growth in yellow birch.

Although this relationship seems apparent, no definitive conclusions can be drawn since, during the period studied, climatic variables were perfectly dephased only in 1988 and 1990. To verify this relationship, we need longer series to obtain a good estimate of the dominant cycles of these series. It would then be possible to predict the years in which the highest growth rates would occur.

CONCLUSIONS

Given that the diameter and vertical distribution of the stand was regular and normal, these stands can be managed as regular high forests. The site quality of the seedling stand is comparable to the quality of sugar maple - yellow birch - basswood forest. Heavy thinning from below had a positive and sustained effect on diameter growth of yellow birch and on the average size of the stems. Moderate mixed thinning had a positive effect on height growth of yellow birch and appears to be the best compromise for tending.

Given the regional climate, yellow birch poses a high management risk and its proportion in the stand should decline. Increased efforts should therefore be focussed on the formation of mixed stands at the thicket stage, by increasing the proportion of ash, black cherry and sugar maple and by reducing the proportion of yellow birch. The climate in May, June and July appears to play a very important role in the development of yellow birch. A more exhaustive study of the relationships between climate and the yield of yellow birch is needed. To this end, longer time series will have to be established in several ecological regions.

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NOTES