Survey of the effects of forest drainage operations: (2) Effect of drainage on black spruce and tamarack growth at Saint-Anaclet

Richard Zarnovican and Claude Laberge

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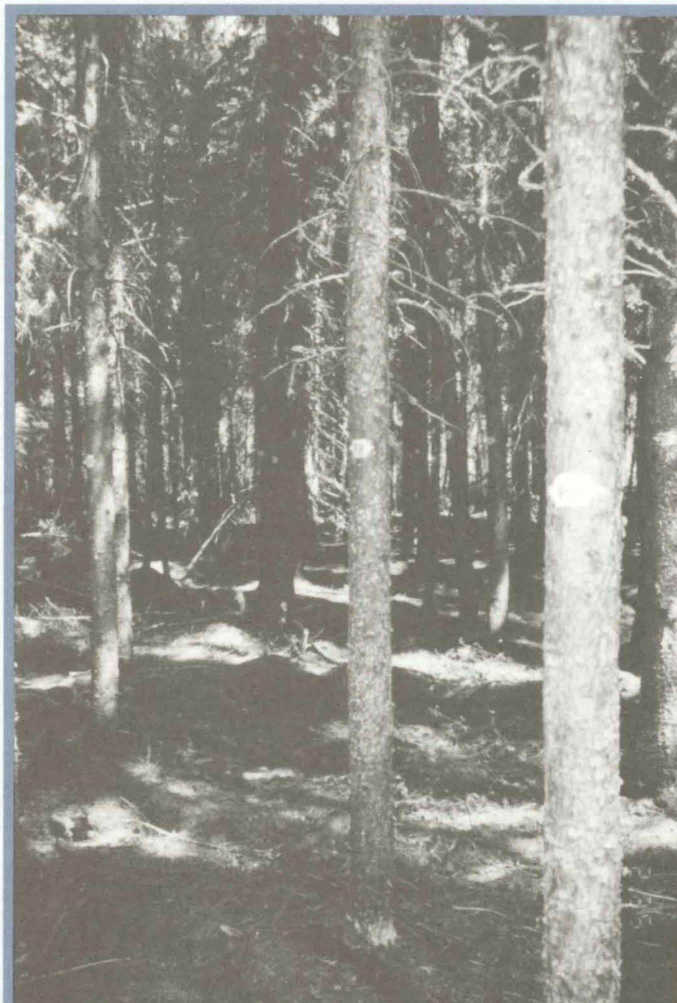

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TABLE OF CONTENTS

Page

LIST OF TABLES v

LIST OF FIGURES vi

ABSTRACT vii

RÉSUMÉ viii

INTRODUCTION 1
- Work hypotheses 1
- Work objectives 1

MATERIALS AND METHODS 2
- Experimental design 2
- Experimental factors 4
- Choice of experimental design 4
- Linear model used 5

RESULTS AND DISCUSSION 7
- Production of the experimental plots 7
  - Spruce-litter forest 7
  - Spruce-mosses forest 8
- Description of the trees under study 11
- Growth and drainage 13
  - Diameter increment 13
    - Comparison of plots 13
    - Comparison of species 13

TABLE OF CONTENTS
(cont'd)

Page

Height increment 15
Comparison of plots 15
Comparison of species 17
Form factor 17
Comparison of plots 17
Comparison of species 17
Volume increment 18
Comparison of plots 18
Comparison of species 22

CONCLUSION 22

ACKNOWLEDGEMENTS 24

LITERATURE CITED 24

LIST OF TABLES

Page

Table 1. Expected mean squares for the linear model relative to treatment (A), plot (B), class (C) and tree (D) factors, fixed (F) or random (R) effect. 6

Table 2. Excepted mean squares for the linear model relative to treatment (A), species (B), class (C) and tree (D) factors, fixed (F) or random (R) effect. . 7

Table 3. Composition of the experimental plot of the spruce-litter forest, by basal area (dm^2). 8

Table 4. Production of the experimental plot of the spruce-litter forest, from 1987 to 1992. 8

Table 5. Composition of the experimental plot of the spruce-mosses forest, by basal area (dm^2). 10

Table 6. Production of the experimental plot of the spruce-mosses forest, from 1987 to 1992. 10

Table 7. Dendrometric characteristics of the trees analyzed. 12

Table 8. Changes in the growth of black spruce and tamarack as the result of drainage, by forest community and growth class. 23

LIST OF FIGURES

Page

Figure 1. Location of the study area. 3

Figure 2. Volume distribution by dbh class in 1987 and 1992 in the spruce-litter forest. 9

Figure 3. Volume distribution by dbh class in 1987 and 1992 in the spruce-mosses forest. 9

Figure 4. Diameter increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class. 14

Figure 5. Apical increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class. 16

Figure 6. Form factor (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class. 19

Figure 7. Volume increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class. 20

Figure 8. Mean black spruce volume increment series in the spruce-litter forest. . . 21

Figure 9. Mean black spruce volume increment series in the spruce-mosses forest. . 21

ABSTRACT

This report presents the assessment of the effect of drainage on the growth of black spruce (*Picea mariana* [Mill.] B.S.P.) and tamarack (*Larix laricina* [Du Roi] K. Koch) in the spruce-mosses and spruce-litter forests located at Saint-Anaclet, near Rimouski, Quebec.

In the absence of control plots, the effect of drainage was assessed from time data using the analysis of variance with repeated measurements. The time data correspond to the means of the increments (radial, apical and volume) and to the means of the form factors before and after drainage, which are determined using stem analysis. The study also includes the assessment of the ligneous production of the experimental plots, which was done by comparing inventories after 5 years.

Comparison of the inventories results in very interesting net annual increment rates for basal area and volume. On the basis of height growth, the spruce-litter forest is comparable to Vézina and Linteau's class II and Plonski's class 1. The site index of the spruce-mosses forest is comparable to Vézina and Linteau's class IV and Plonski's class 3.

Analysis of variance does not make it possible to assign to the drainage operations any positive and statistically significant effects on the growth of the 2 species in the 2 forest types under study. In fact, the results show nonsignificant or negative effects for the different increments of the spruce-litter forest. In the spruce-mosses forest, it is found that after drainage, there is a statistically significant increase in radial and apical growths in all growth classes, whereas the effect of drainage on volume increment is nonsignificant.

RÉSUMÉ

Le présent rapport présente l'évaluation de l'effet du drainage sur la croissance de l'épinette noire (*Picea mariana* [Mill.] B.S.P.) et du mélèze laricin (*Larix laricina* [Du Roi] K. Koch) dans la pessière à mousses et dans la pessière à litière situées à Saint-Anaclet, près de Rimouski, Québec.

En l'absence des parcelles témoins, l'effet du drainage a été évalué à partir de données temporelles à la suite d'une analyse de variance à mesures répétées. Les données temporelles correspondent aux moyennes des accroissements (radial, apical et volumique) et aux moyennes des coefficients de forme, avant et après le drainage, qui sont établies au moyen de l'analyse des tiges. L'étude comprend également l'évaluation de la production ligneuse des parcelles expérimentales qui a été effectuée après la comparaison des inventaires au terme de 5 ans.

La comparaison des inventaires donne comme résultats des taux annuels nets en surface terrière et en volume très intéressants. Au plan de la croissance en hauteur, la pessière à litière se compare à la classe II de Vézina et Linteau et à la classe 1 de Plonski. Quant à l'indice de site de la pessière à mousses, il est comparable à celui de la classe IV de Vézina et Linteau et à celui de la classe 3 de Plonski.

L'analyse de variance ne permet pas d'attribuer au drainage des effets positifs et statistiquement significatifs sur la croissance des deux essences dans les deux groupements étudiés. En effet, les résultats montrent des effets non significatifs ou négatifs pour les différents accroissements de la pessière à litière. Dans la pessière à mousses, on constate qu'après le drainage, il y a une augmentation statistiquement significative des croissances radiale et apicale dans toutes les classes de croissance, alors que l'effet du drainage sur l'accroissement volumique est non significatif.

INTRODUCTION

In the context of private woodlot management in the Lower St. Lawrence and Gaspé regions, the technical committee of the Canadian Forest Service - Quebec Region, Rimouski, had several wooded areas drained. The objective of this was to lower the water table by means of drainage channels in order to improve conditions for tree growth.

In 1987, the technical committee gave us the mandate of evaluating the effect of drainage on growth and yield. The first stage in this mandate consisted in describing the ecological conditions and yield parameters of the main forest types at Saint-Anaclet and Cabano, and in establishing permanent plots in the most productive forest types in order to carry out periodic inventories for 5 years.

The results of the first stage made it possible to establish 2 experimental plots in the spruce-mosses and spruce-litter forests in order to carry out the 5-year measurements (Zarnovican 1989), in addition to characterizing station fertility and black spruce (BS) (*Picea mariana* [Mill.] B.S.P.) volume growth (Zarnovican 1990 and 1991).

The second stage in the mandate involved studying the growth and yield of black spruce and tamarack (TL) (*Larix laricina* [Du Roi] K. Koch), before and after drainage, in order to assess the effect of lowering the water table after 5 years.

From this perspective, this work studies the effect of drainage on the main measurement information of the tree through analysis of variance using the linear model.

Work hypotheses

To determine the respective role of drainage in the determinism governing tree growth, the following hypotheses were advanced:

1) The reaction of trees as regards their production is similar when they belong to the same growth class (Horne et al. 1986).
2) Growth conditions after drainage are similar throughout the plot, as the minimum distance of trees from the drainage channel is 12 m (Seppälä 1972).

Work objectives

Given the resources available to us, the time allotted and the progress of the drainage operations, the objectives pursued for this study were as follows:

1) To assess the 5-year production of the 2 experimental plots by comparing inventories;
2) To assess the changes that occurred in black spruce growth due to drainage, by forest type (spruce-litter and spruce-mosses forests) and by growth class;
3) To assess the changes that occurred in tamarack growth due to drainage in the spruce-litter forest, by growth class.

MATERIALS AND METHODS

Experimental design

In accordance with the recommendations of the technical committee, the 5-year monitoring was carried out at Saint-Anaclet in two 15-m by 20-m random selected experimental plots in the spruce-litter and spruce-mosses forests (Figure 1).

Considering the tree classification systems (Assman 1970, Leibundgut 1956) and the variability in radial growth of spruce in the spruce-mosses forest (Zarnovican 1991), 3 growth classes were used: superior, intermediate and inferior. All the living trees in the 2 plots were numbered and classified according to the following criteria:

- The tree's position in the social hierarchy of the stand, as expressed by height;
- The tree's vigor or vitality, as expressed by the size of the tree and the volume of its green crown.

A 5-year measurement was carried out in the experimental plots. Comparison of the inventories made it possible to determine the main production parameters: mortality, and gross and net periodic increments in basal area and volume. To compare the black spruce site index with the tables of Vézina and Linteau (1968) and Plonski (1981), the dominant height from stem analysis was used.

The effect of drainage on 5-year growth was determined after comparison of the means of the annual increments before drainage with the means of the annual increments after drainage. Comparison of repeated measurements was necessary because of the absence of any undrained area in the drained complex. The mean annual increments were determined for each growth class from the analysis of 10 randomly selected black spruce trees from 2 plots and 5 tamarack trees from the spruce-litter forest.

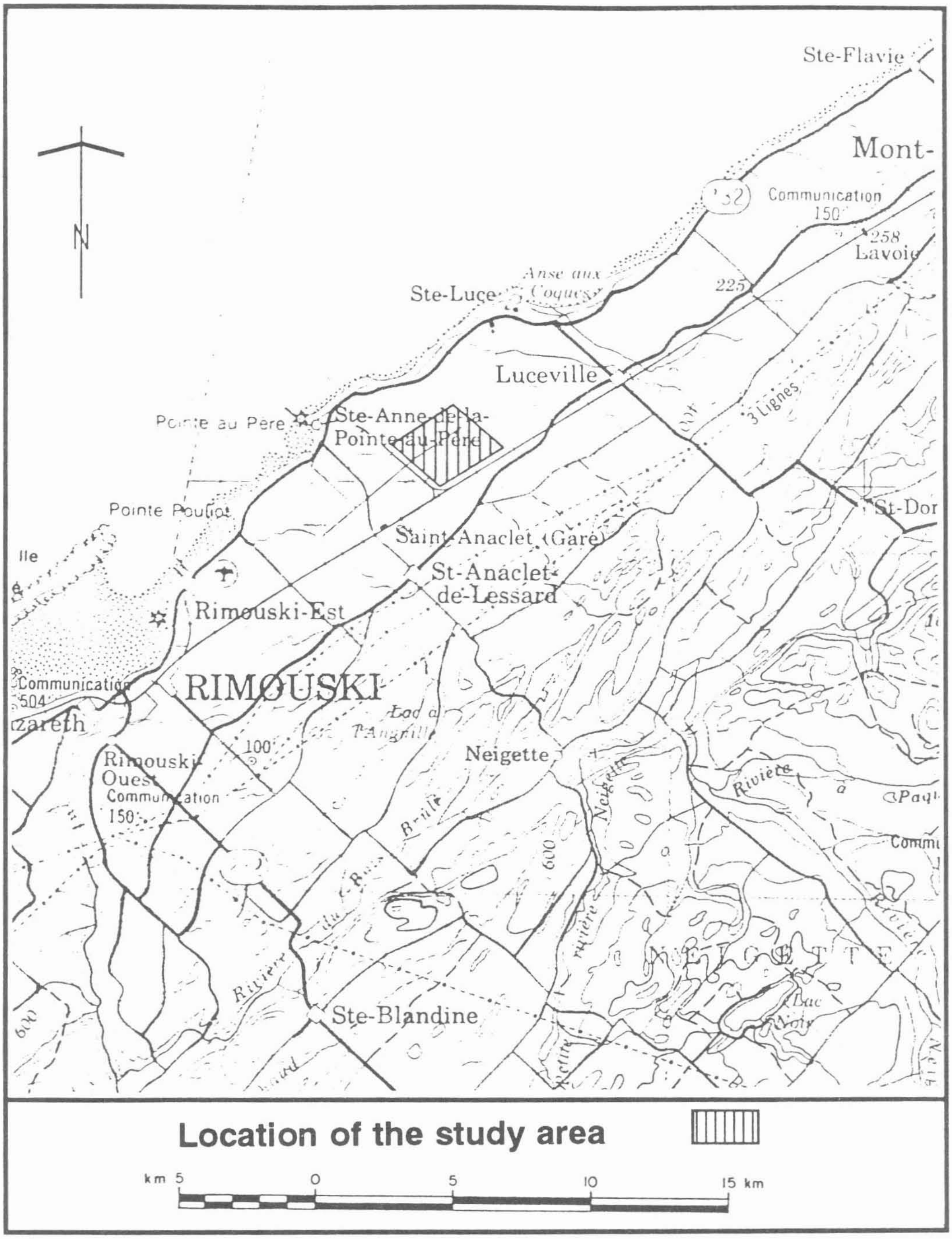

Figure 1. Location of the study area.

Experimental factors

The statistical analysis is based on analysis of variance, and the various factors studied are as follows:

- Treatment, 2 modalities (before and after drainage);
- Plot, 2 modalities for black spruce (spruce-mosses and spruce-litter forests), 1 modality for tamarack (spruce-litter forest);
- Growth class, 3 modalities (inferior, intermediate, superior);
- Species, 2 modalities (black spruce and tamarack);
- Tree, 10 modalities for black spruce and 5 for tamarack.

This description of the factors already makes it possible to formulate certain observations about possible analyses. The comparison of the plots can be done only with black spruce. The study of the species uses a non-balanced design, as the number of trees per species is different. In addition, the presence of 2 plots of black spruce but only one of tamarack must be taken into consideration during the analysis. The treatment, class and species factors are fixed-effect, whereas the other factors are random-effect. The numerical dependent variables are determined by stem analysis and are the means of the increments in diameter ($cm.yr^{-1}$), height ($m.yr^{-1}$) and volume ($dm^3.yr^{-1}$) as well as the means of the form factors.

Choice of experimental design

The experimental design was determined by the cost of gathering samples and the resources allotted by the technical committee. The selection of trees is stratified random, with certain restrictions: an equal number of trees in each growth class while avoiding opening up the stand. This experimental design recognizes that:

- The trees are nested within the growth classes (a tree belongs to only one class, so there is no tree x class interaction);
- The classes are nested within the plots (the definition of the classes is peculiar to each plot, so there is no class x plot interaction);
- The trees represent blocks for which we have 2 measurements (before and after drainage); these measurements are therefore not independent;
- The trees (blocks) represent replicates; it is therefore impossible to compare them.

Linear model used

To meet the objectives of the analysis, the following linear model was chosen:

$$y_{ijklm} = m + t_i + b_j + d_{k(j)} + l_{l(jk)} + (tb)_{ij} + (td)_{ik(j)} + (tl)_{il(jk)} + e_{(ijkl)m} \quad [1]$$

where m = the general mean; t_i = the effect associated with the treatment (i = 1 = before and i = 2 = after); b_j = the effect of the jth plot (in the study of black spruce only); $d_{k(j)}$ = the effect of the kth class within the jth plot, $l_{l(jk)}$ = the effect of the lth tree within the kth class and the jth plot; $(tb)_{ij}$ = the interaction between treatment and plot; $(td)_{ik(j)}$ = the interaction between treatment and class; $(tl)_{il(jk)}$ = the interaction between treatment and tree; $e_{(ijkl)m}$ = the error term.

It should be noted that the other interaction terms cannot be included in the model, since the factors are nested. Table 1 presents the expected mean squares that make it possible to construct adequate tests for the different hypotheses in the case of the black spruce (plot factor present).

Study of the expected mean squares shows that for testing:

- The effect of treatment (A), the statistic $F_1 = MS_A/MS_{AB}$ must be used, where MS_{AB} represents the mean squares for the interaction between time (A) and plot (B);
- The effect of plot (B), the statistic $F_2 = MS_B/MS_D$ must be used, where MS_D represents the mean squares for the tree factor (D);
- The effect of class (C), the statistic $F_3 = MS_C/MS_D$ must be used, where MS_D represents the mean squares for the tree factor (D);
- The treatment x plot interaction (AB), the statistic $F_4 = MS_{AB}/MS_{AC}$ must be used, where MS_{AC} represents the mean squares for the interaction between time (A) and class (C);
- The treatment x class interaction (AC), the statistic $F_5 = MS_{AC}/MS_{AD}$ must be used, where MS_{AD} represents the mean squares for the interaction between time (A) and tree (D). Since no replicate other than the tree block is present in the analysis, it is impossible to estimate the value of MS_e and, for that very reason, it is impossible to test the tree factor and the treatment x tree interaction.

Table 1. Expected mean squares for the linear model relative to treatment (A), plot (B), class (C) and tree (D) factors, fixed (F) or random (R) effect.

Factor	F 2 i	R 2 j	F 3 k	R 10 l	R 1 m	E(MS):	Expected mean squares
A : τ_i	0	2	3	10	1	$E(MS_A)$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 30\sigma^2_{\tau\beta} + 60\Sigma\,(\tau_i)^2$
B : β_j	2	1	3	10	1	$E(MS_B)$	$= \sigma^2 + 2\sigma^2_{\lambda} + 60\sigma^2_{\beta}$
C : $\delta_{k(j)}$	2	1	0	10	1	$E(MS_C)$	$= \sigma^2 + 2\sigma^2_{\lambda} + 10\Sigma\,(\delta_k)^2$
D : $\lambda_{l(jk)}$	2	1	1	1	1	$E(MS_D)$	$= \sigma^2 + 2\sigma^2_{\lambda}$
AB : $(\tau\beta)_{ij}$	0	1	3	10	1	$E(MS_{AB})$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 30\sigma^2_{\tau\beta}$
AC : $(\tau\delta)_{ik(j)}$	0	1	0	10	1	$E(MS_{AC})$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 5\Sigma\Sigma\,((\tau\delta)_{ik})^2$
AD : $(\tau\lambda)_{il(jk)}$	0	1	1	1	1	$E(MS_{AD})$	$= \sigma^2 + \sigma 2_{\lambda}$
E : $e_{(ijkl)m}$	1	1	1	1	1	$E(MS_E)$	$= \sigma^2$

For comparing the species, the plot factor is replaced by the species factor in model 1. Since the species factor is fixed-effect and the parcel factor is random-effect, the test changes. Table 2 presents the expected mean squares in the presence of the species factor. To test the different hypotheses, all the tests remain identical to those associated with Table 1, except in the case of the time factor, where the statistic F_1 is replaced by $F_1 = MS_A/MS_{AD}$, where MS_{AD} represents the expected mean squares for the interaction between time (A) and tree (D) factors. The homogeneity of the variances was always tested, and when this hypothesis was rejected, the variables were transformed. In the presence of a significant interaction, the analysis of variance was carried out for each of the modalities of the factors. The different statistical tests were carried out using the software from the SAS Institute Inc. (1985), with a critical level of 5%.

Table 2. Expected mean squares for the linear model relative to treatment (A), species (B), class (C) and tree (D) factors, fixed (F) or random (R) effect.

Factor	F 2 i	R 2 j	F 3 k	R 7.5 1	R 1 m	E(MS):	Expected mean squares
A : τ_i	0	2	3	7.5	1	$E(MS_A)$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 45\Sigma\,(\tau_i)^2$
B : β_j	2	0	3	7.5	1	$E(MS_B)$	$= \sigma^2 + 2\sigma^2_{\lambda} + 45\Sigma\,(\beta_j)^2$
C : $\delta_{k(j)}$	2	1	0	7.5	1	$E(MS_C)$	$= \sigma^2 + 2\sigma^2_{\lambda} + 7.5\Sigma\,(\delta_k)^2$
D : $\lambda_{l(jk)}$	2	1	1	1	1	$E(MS_D)$	$= \sigma^2 + 2\sigma^2_{\lambda}$
AB : $(\tau\beta)_{ij}$	0	0	3	7.5	1	$E(MS_{AB})$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 11.25\Sigma\Sigma\,((\tau\beta)_{ij})^2$
AC : $(\tau\delta)_{ik(j)}$	0	1	0	7.5	1	$E(MS_{AC})$	$= \sigma^2 + \sigma^2_{\tau\lambda} + 3.75\Sigma\Sigma\,((\tau\delta)_{ik})^2$
AD : $(\tau\lambda)_{il(jk)}$	0	1	1	1	1	$E(MS_{AD})$	$= \sigma^2 + \sigma 2_{\lambda}$
E : $e_{(ijkl)m}$	1	1	1	1	1	$E(MS_E)$	$= \sigma^2$

RESULTS AND DISCUSSION

Production of the experimental plots

Spruce-litter forest

In the composition of the spruce-litter forest, we find 5 species (Table 3). However, in terms of basal area, the stand is made up of 3 main species: black spruce, tamarack and eastern white cedar (EWC) (*Thuja occidentalis* L.). Comparison of the 2 inventories (Table 4) indicates mortality of 7 stems, concentrated mainly in the small diameters. This table also shows that the net annual rate of growth in basal area was 1.786% and in volume 2.487%. From the standpoint of distribution of volume by diameter class (Figure 2), we find that the volume increased in the higher classes, except for the 14-cm class, while in the classes under 12 cm, there was a decrease in the volume production of the spruce-litter forest. From the standpoint of height growth, this plot is comparable to Vézina and Linteau's class II and Plonski's class 1.

Table 3. Composition of the experimental plot of the spruce-litter forest, by basal area (dm^2).

Year	Species					
	BS	TL	EWC	BF	PCH	Total
1987	82.83	25.48	8.13	1.10	1.83	119.37
(%)	69	21	7	1	2	
1992	90.17	27.66	9.01	0.82	2.04	129.70
(%)	70	21	7	0.5	1.5	

Note: BF = balsam fir (*Abies balsama* [L.] Koch); PCH = pin cherry (*Prunus pennsylvanica* L. fil.).

Table 4. Production of the experimental plot of the spruce-litter forest, from 1987 to 1992.

Year	Age (years)	$d_{o.b.}$ (cm)	h (m)	$g_{o.b.}$ (dm^2)	$v_{o.b.}$ (dm^3)	n
1987	49	11.81	10.7	116.44	7531.6	103
1992	54	12.74	11.4	126.84	8468.2	96
Net increment				10.40	936.6	
Mortality				2.79	155.97	7
Gross increment				13.19	1092.5	
Net annual rate (%)				1.786	2.487	

Note: $d_{o.b.}$ = diameter outside bark; h = height; $g_{o.b.}$ = basal area outside bark; $v_{o.b.}$ = volume outside bark; n = number of trees.

Spruce-mosses forest

The stand on the experimental plot consists of black spruce and tamarack, with a marked dominance by the former (Table 5). Comparison of the inventories (Table 6) shows mortality of 3 stems and a net annual rate of 1.452% in basal area and 2.279% in volume outside bark.

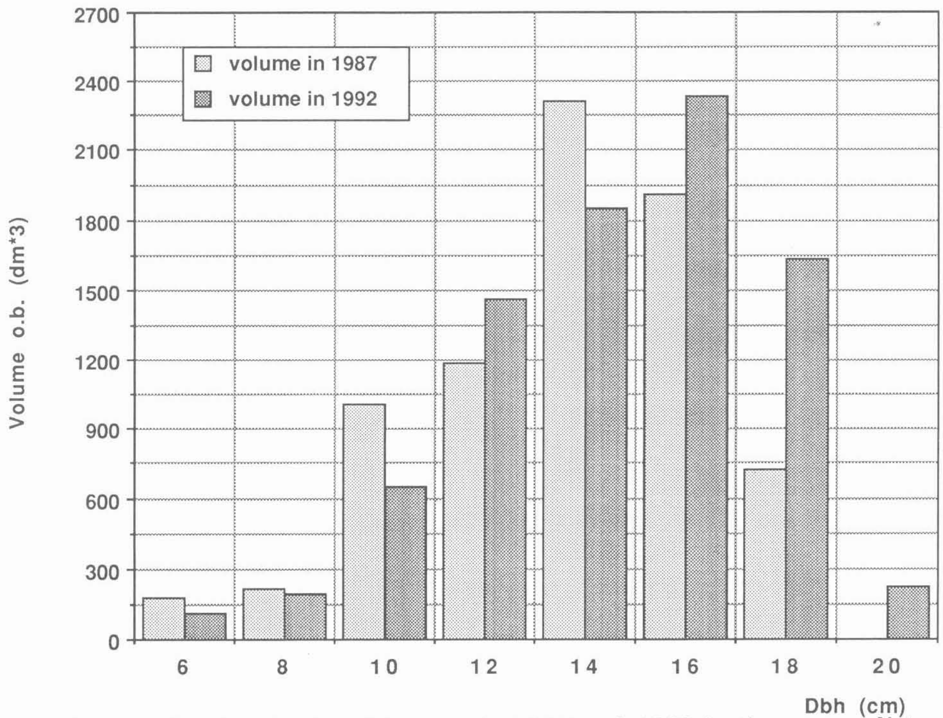

Figure 2. Volume distribution by dbh class in 1987 and 1992 in the spruce-litter forest.

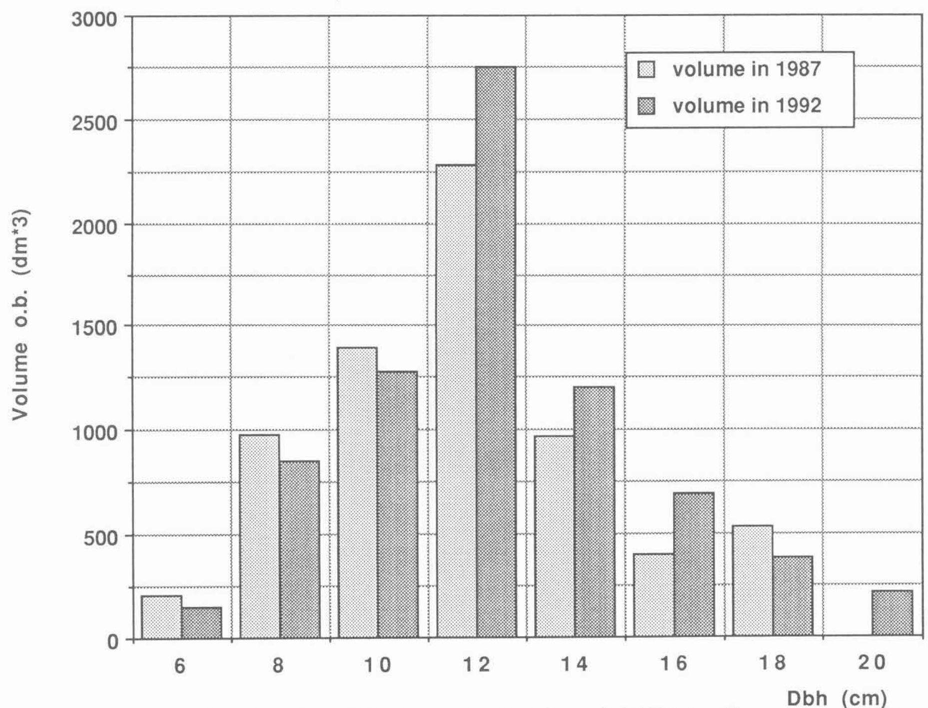

Figure 3. Volume distribution by dbh class in 1987 and 1992 in the spruce-mosses forest.

The volume distribution for the 2 inventories (Figure 3) confirms that for the spruce-litter forest, the volume of the classes under 12 cm diminished, but for those over that size, it increased, except for the 18-cm class. The spruce-mosses forest shows a standing volume less considerable than that of the spruce-litter one; the same is observed for the basal area, mean dbh and mean height of the stand. In addition, the annual volume yield is less important when these data are compared with those in the tables. This forest type is comparable to Vézina and Linteau's class IV and Plonski's class 3.

Table 5. Composition of the experimental plot of the spruce-mosses forest, by basal area (dm^2).

Year	Species		Total
	BS	TL	
1987	98.30	8.13	106.43
(%)	92	8	
1992	104.66	9.50	114.16
(%)	92	8	

Table 6. Production of the experimental plot of the spruce-mosses forest, from 1987 to 1992.

Year	Age (years)	$d_{o.b.}$ (cm)	h (m)	$g_{o.b.}$ (dm^2)	$v_{o.b.}$ (dm^3)	n
1987	77	10.35	10.4	106.43	6766.7	119
1992	82	10.86	10.9	114.16	7537.8	116
Net increment				7.73	771.1	
Mortality				2.98	205.0	3
Gross increment				10.71	976.1	
Net annual rate (%)				1.452	2.279	

Note: $d_{o.b.}$ = diameter outside bark; h = height; $g_{o.b.}$ = basal area outside bark; $v_{o.b.}$ = volume outside bark; n = number of trees.

Finally, it should be emphasized that volume outside bark was calculated with two-entry local tariffs. The accuracy of the tariffs, based on a sample of 60 trees, was ±4.2% with a bias of +0.005% for black spruce. For tamarack, the accuracy was ±5.2% and the bias +0.081% calculated from a sample of 15 trees. Taking into account that the biases are negligible and that the relative errors in the increments are equal to the known errors of the volumes, i.e. those of the tariffs, and that they are equal for both inventories, it is then possible to give an order of magnitude to the increment errors (Kramer and Akça 1987) according to the following formula:

$$e_{iv} = \pm (e_{im} . V_m . \sqrt{2})/n.(V_2 - V_1) \quad [2]$$

In this equation, e_{iv} corresponds to the error in increment; e_{im}, to the weighted quadratic mean of the tariff errors; V_m represents the quadratic mean of the 2 volumes; n, the 5-year period; V_2, the 1992 volume and V_1, the 1987 volume.

The error in volume increment is ±10.8% in the spruce-litter forest, and ±11.3% in the spruce-mosses one.

Description of the trees under study

To assess the effect of lowering the water table on tree growth, an analysis was carried out on 75 stems. This made it possible to determine the means of the dendrometric variables before and after drainage. The main statistics characterizing the felled stems are summarized in Table 7. Analysis of variance of the morphometric characteristics of the stem and crown confirmed that there exist statistically significant differences between the growth classes for black spruce and tamarack in both communities. This analysis also indicates that the morphometry of the tamarack is different from that of the black spruce in the spruce-litter forest. Finally, there are no significant differences between the age of the trees of the 2 species and that of the 3 growth classes in the spruce-litter forest and in the spruce-mosses one. However, it is obvious that the mean age of the trees on the 2 plots differ significantly.

Table 7. Dendrometric characteristics of the trees analyzed.

Forest type	Spruce-litter forest						Spruce-mosses forest		
Species	black spruce			tamarack			black spruce		
Growth class	sup.	int.	inf.	sup.	int.	inf.	sup.	int.	inf.
Stem:									
age (years)	54*	55	53	52	53	52	83	82	81
	1.7**	2.1	1.9	1.3	1.5	1.1	2.7	3.5	3.1
$dbh_{o.b.}$ (cm)	18.2	14.5	11.5	16.8	13.0	9.3	16.8	12.5	9.9
	1.0	0.8	0.6	0.5	0.4	0.2	1.8	0.5	0.8
h (m)	14.0	13.0	11.5	13.9	12.2	11.3	13.7	12.1	11.0
	0.6	0.8	0.7	0.8	0.6	0.7	1.0	0.5	0.8
$v_{o.b.}$ (dm^3)	195	118	67	157	88	42	167	84	49
	20	17	8	11	15	5	42	7	10
form factor	0.536	0.547	0.565	0.510	0.539	0.544	0.542	0.563	0.571
	0.012	0.022	0.025	0.027	0.022	0.025	0.027	0.019	0.026
h/dbh	0.774	0.893	1.001	0.824	0.941	1.223	0.817	0.967	1.118
	0.055	0.043	0.079	0.043	0.072	0.052	0.047	0.058	0.073
Crown:									
width (m)	2.0	1.6	1.3	2.2	1.8	1.3	2.0	1.5	1.1
	0.3	0.2	0.2	0.3	0.4	0.1	0.3	0.2	0.1
length (m)	7.9	6.2	4.6	6.0	4.5	3.4	6.9	5.2	4.1
	1.2	1.3	0.9	1.1	1.0	0.5	1.2	1.0	1.1

Note: * = arithmetic mean; ** = standard deviation; sup. = superior; int. = intermediate; inf. = inferior; $dbh_{o.b.}$ = diameter at breast height outside bark; h = height; $v_{o.b.}$ = volume outside bark.

Growth and drainage

Diameter increment

Comparison of plots

Comparison of the variances using the Bartlett test showed the inequality of the variances at the 5% level and the necessity of transforming variables ($X^{0.5}$) in order to obtain valid conclusions about the significance of the interaction terms.

When analyzing these terms, we note a strong interaction between the growth-class and treatment factors ($F_{4.54}$ = 7.74, Prob > F = 0.007), and a significant interaction between the plot and treatment factors ($F_{1.54}$ = 3.90, Prob > F = 0.007). These conclusions justified analyses of variance for each plot.

In the spruce-litter forest (Figure 4A), the term of interaction between the class and treatment factors is always significant ($F_{2.27}$ = 6.65, Prob > F = 0.005), making analysis of variance for each growth class necessary. The results for the classes indicate a significant decrease, at the 5% level, in diameter growth for the superior class only.

In the spruce-mosses forest (Figure 4A), the term of interaction between the class and treatment factors is no longer significant ($F_{2.27}$ = 0.46, Prob > F = 0.634), so we can conclude that the effect of drainage is the same for all growth classes on this plot. The test on the class factor ($F_{2.27}$ = 22.57, Prob > F = 0.000) indicates that the diameter increment is significantly different from one growth class to the next, whereas the test on the treatment factor ($F_{1.27}$ = 6.12, Prob > F = 0.020) shows that the diameter increment increased significantly after drainage.

Comparison of species

Comparison of the species in the spruce-litter forest shows (Figure 4B) that the 2 species do not react in the same way to drainage in their radial growth (significant interaction between the species and treatment factors, Prob > F = 0.026). Also, the effect of drainage is not the same from one growth class to the next (significant interaction between the class and treatment factors, Prob > F = 0.0003).

The results of the analysis of variance for each growth class indicate that:

- There is a decrease in radial growth after drainage ($F_{1.13}$ = 26.10, Prob > F = 0.0002) in spruce and tamarack of the superior class, and this decrease is similar for both species ($F_{1.13}$ = 0.86, Prob > F = 0.370);

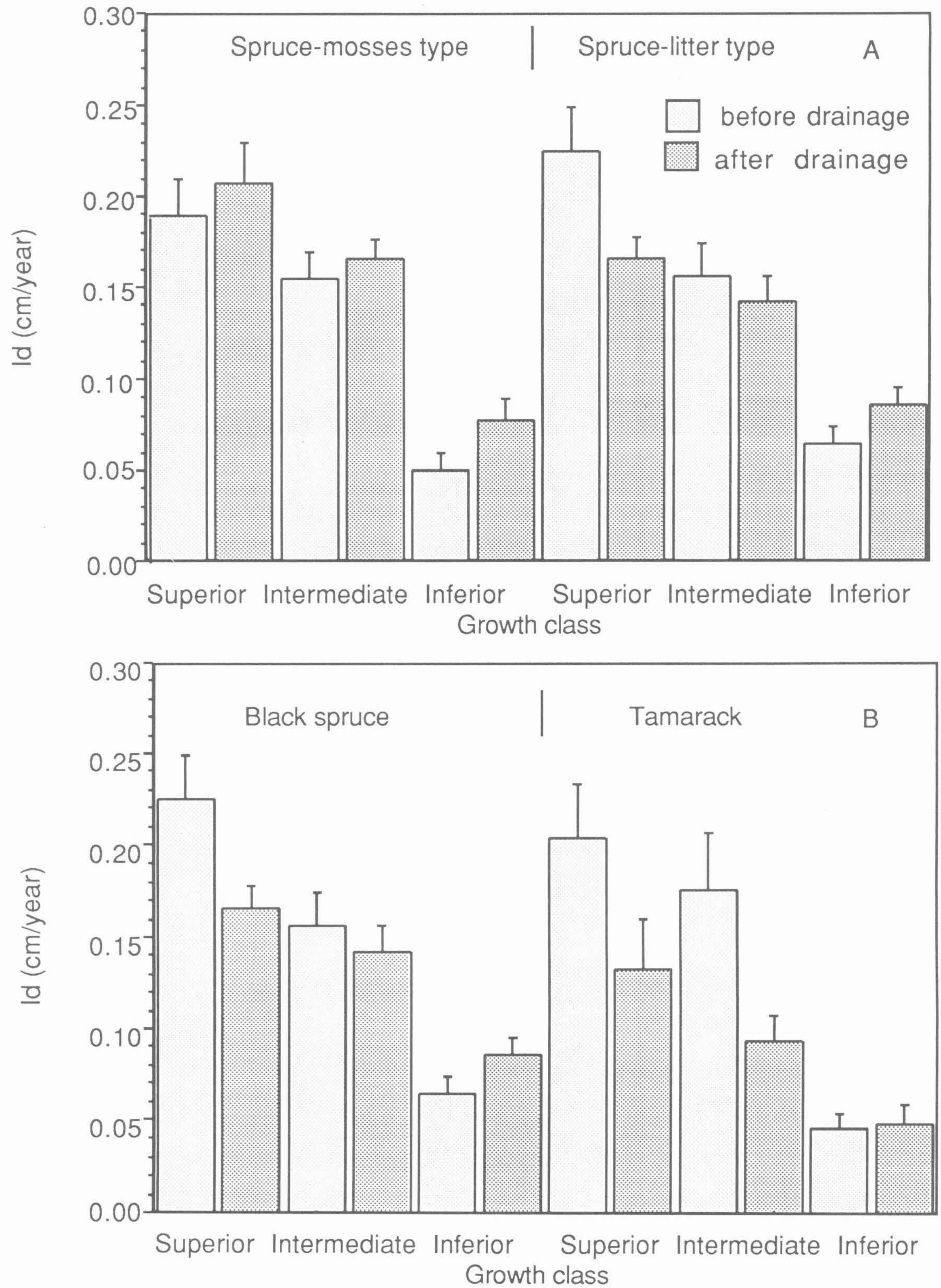

Figure 4. Diameter increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class.

- The radial growth in the spruce and tamarack of the intermediate class differs after drainage; we note a significant decrease in tamarack, whereas there is no significant change in black spruce;
- There is no significant change in the radial growth of spruce and tamarack in the inferior class ($F_{1.13}$ = 1.65, Prob > F = 0.221). However, we find that the diameter increment in spruce is significantly greater than the diameter increment in tamarack (Figure 4B).

Height increment

Comparison of plots

The Bartlett test confirms the homogeneity of the variances in apical growth in the different combinations of modalities of the factors. Study of interactions by analysis of variance for the plot, class and treatment factors leads to the following conclusions:

- There is no significant interaction between the treatment and class factors, which means that the effect of drainage on apical growth is the same for all growth classes;
- There exists a significant interaction between the treatment and plot factors, which means a significantly different effect of drainage on height growth between the 2 plots, whence the need for an analysis of variance for each plot.

In the spruce-litter forest (Figure 5A), the test on the class factor ($F_{2.27}$ = 0.61, Prob > F = 0.553) shows that the height increment is the same in all growth classes, whereas the test on the treatment factor ($F_{1.27}$ = 0.61, Prob > F = 0.443) indicates that there is no change in height growth after drainage.

In the spruce-mosses forest (Figure 5A), we conclude once again that the height increment is the same for all growth classes ($F_{2.27}$ = 1.76; Prob > F = 0.192). However, the test on the treatment factor ($F_{1.27}$ = 60.31, Prob > F = 0.000) shows that the height increment changes very significantly after drainage. We then note an increase in height increment from 0.11 $m.yr^{-1}$ before drainage to 0.17 $m.yr^{-1}$ after drainage.

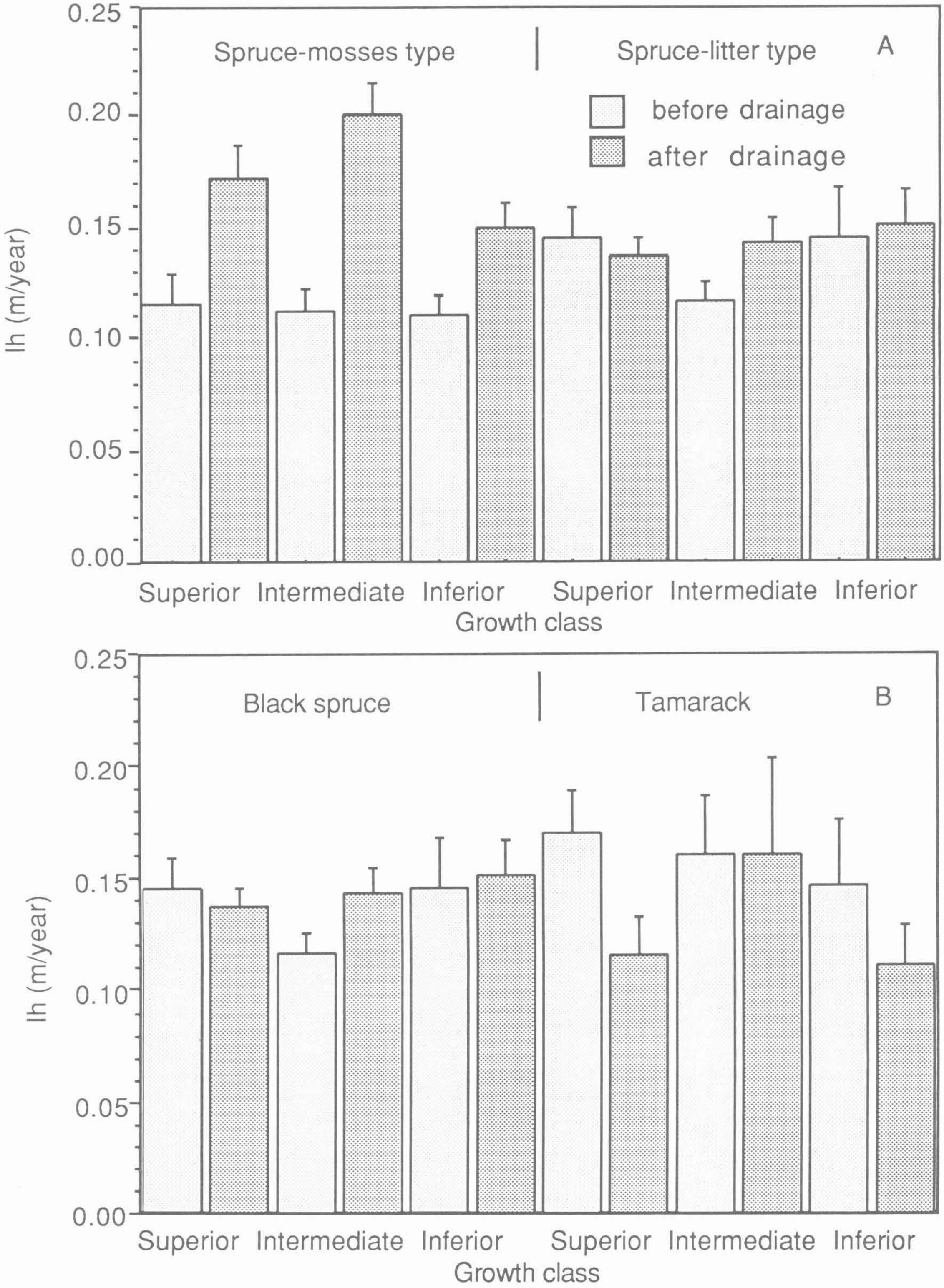

Figure 5. Apical increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class.

Comparison of species

Comparison of species with regard to apical growth in the spruce-litter forest (Figure 5B) shows no significant change, which means that the height increment is the same before and after drainage, for both species and all 3 growth classes.

Form factor

Comparison of plots

Comparison of the variances of the form factors by means of the Bartlett test indicates that they are equal in the different combinations of modalities of the factors. It is thus possible to study the interactions for the plot, class and treatment factors. The results of the analysis of variance show that:

- There is no significant interaction between the treatment and plot factors ($F_{1.54}$ = 0.12, Prob > F = 0.727), which means that the effect of drainage (Figure 6A) on the form factor is the same in the 2 plots;
- There is a significant interaction between the treatment and class factors ($F_{4.54}$ = 4.33, Prob > F = 0.004), so that an analysis of variance for each growth class is required in order to adequately verify the behavior of the form factor after drainage.

The analysis of variance of the form coefficient for the 3 growth classes indicates that:

- There is a significant increase in the form factor after drainage for the superior class, and the form factor is not significantly different from one plot to the other;
- There is also a significant increase in the form factor after drainage for the intermediate class, and the form factor is not always significantly different from one plot to the other;
- After drainage, the form factor of the trees in the inferior class did not change significantly, and it is similar for the 2 plots.

Comparison of species

Comparison of the form factors for the species in the spruce-litter forest (Figure 6B) shows that the 2 species did not react in the same way to drainage, significant interaction between species and treatment (Prob > F = 0.0001). Also, the effect of drainage is different from one growth class to another, as the interaction between the class and treatment factors is significant (Prob > F = 0.0277). Finally, because of the significant interaction between species and treatment factors for each growth class, an analysis of variance was carried out for each combination of the species and class factors.

The results of these analyses make it possible to conclude that the form factor of the tamarack in the superior class shows no significant change after drainage, whereas an increase in form factor after drainage at the 5% level was already detected in black spruce for this growth class. However, when we study only the spruce-litter forest, the increase for black spruce is only significant at the 10% level. No significant change after drainage was detected in the form factor for the intermediate and inferior classes.

Volume increment

Comparison of plots

First, the Bartlett test detected the inequality of variances between growth classes, which required a transformation for the volume increment. The results of the analysis of variance indicate a significant interaction (Prob. > F = 0.005) between plot and treatment for the volume increment after drainage in the 2 spruce forests. We find (Figure 7A) that in the spruce-litter forest, there was a decrease in volume increment, whereas in the spruce-mosses forest, there was an increase. Separate analyses of variance were therefore carried out for each plot, so that we could draw adequate conclusions.

In the spruce-litter forest, the homogeneity of the variances is accepted, and the analysis of variance indicates a significant interaction (Prob > F = 0.006) between the class and treatment factors. In the spruce-mosses forest, logarithmic transformation was used to homogenize the variance, and the analysis of variance shows that the interaction between class and treatment is also significant (Prob > F = 0.0276).

These conclusions led us to study the effect of drainage for each growth class. The results of this analysis show that in the spruce-litter forest, the decrease in volume increment is significant at the 5% level for the superior class only, whereas in the spruce-mosses forest, the increase is significant at the 5% level only for the inferior class. It should be noted, however, that in the spruce-mosses forest, there is an increase of approximately 0.4 $dm^3.yr^{-1}$ for the 3 growth classes, but the inequality of the variances leads to a significant result only when the variance is least.

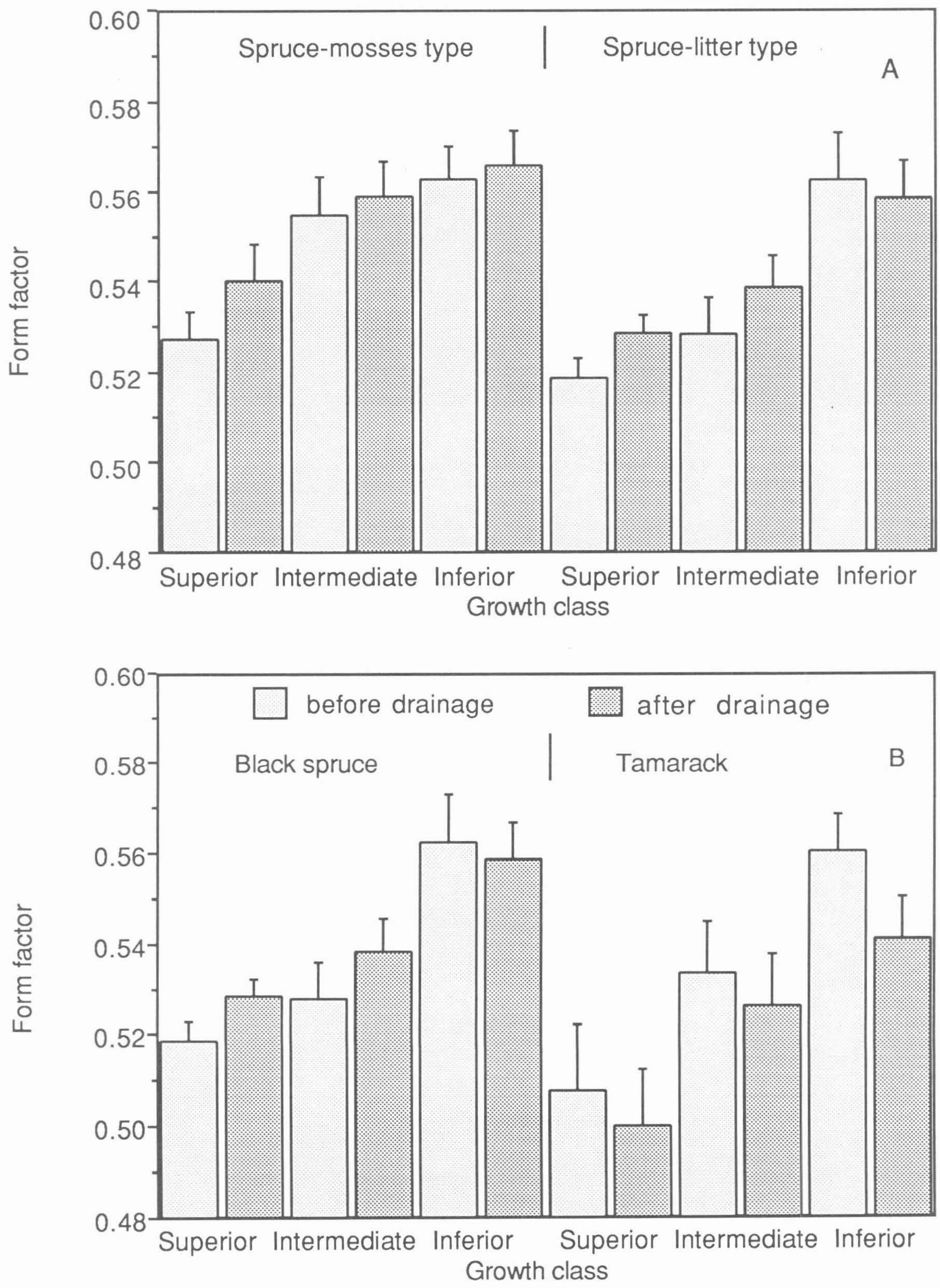

Figure 6. Form factor (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class.

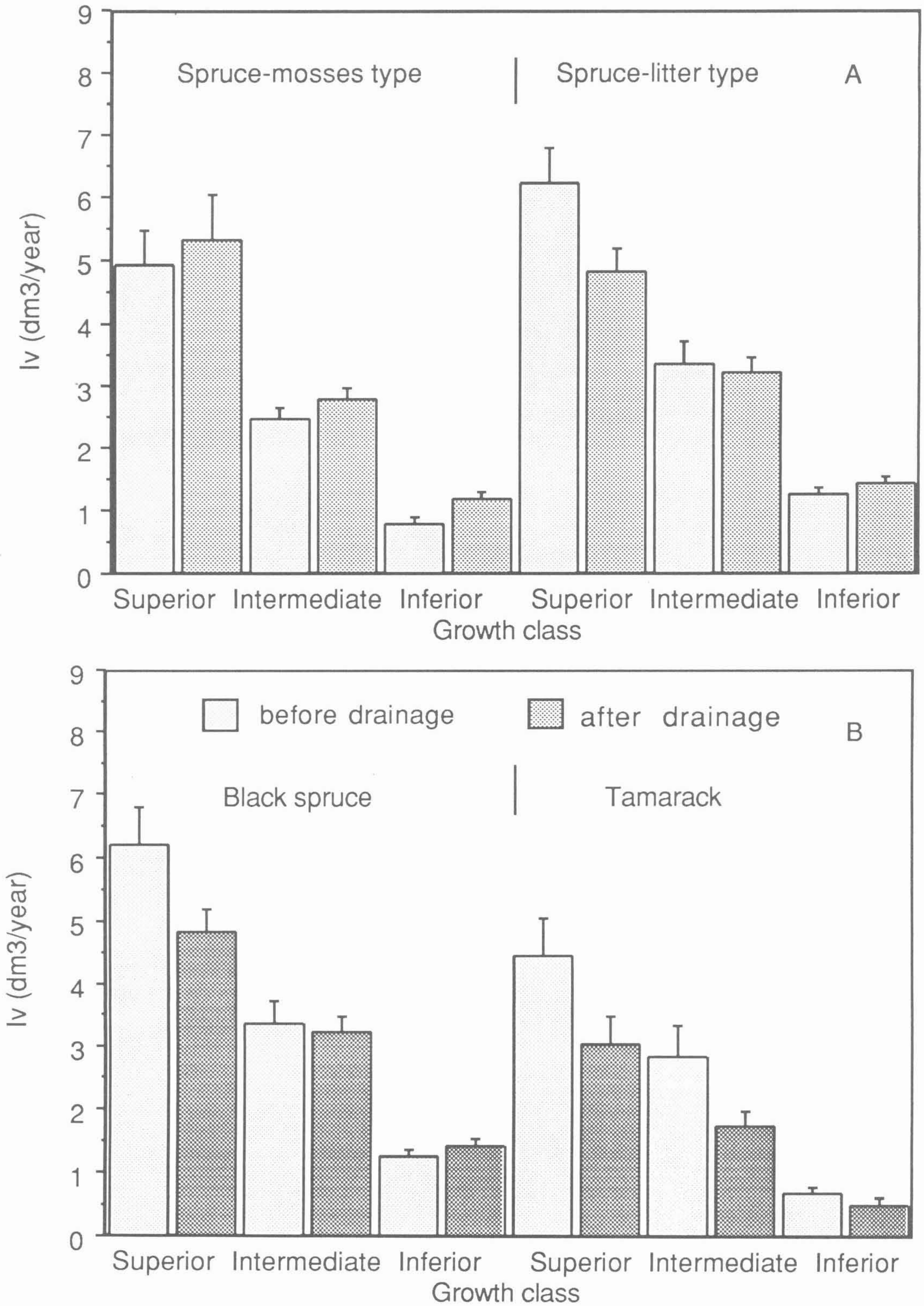

Figure 7. Volume increment (mean and standard error) of black spruce by forest type (A) and of black spruce and tamarack in the spruce-litter forest (B) before and after drainage by growth class.

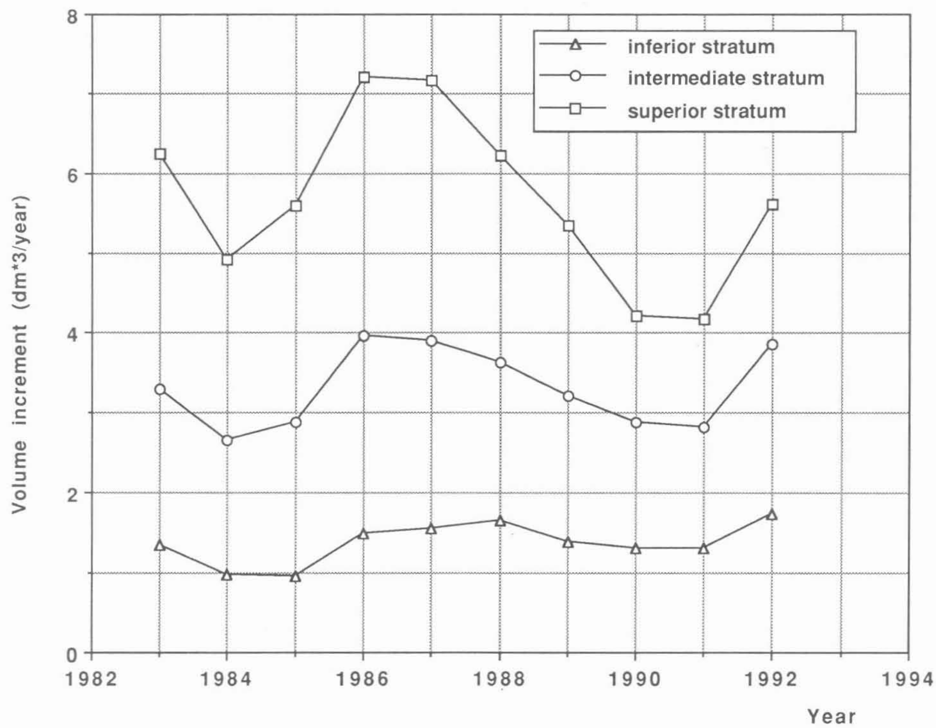

Figure 8. Mean black spruce volume increment series in the spruce-litter forest.

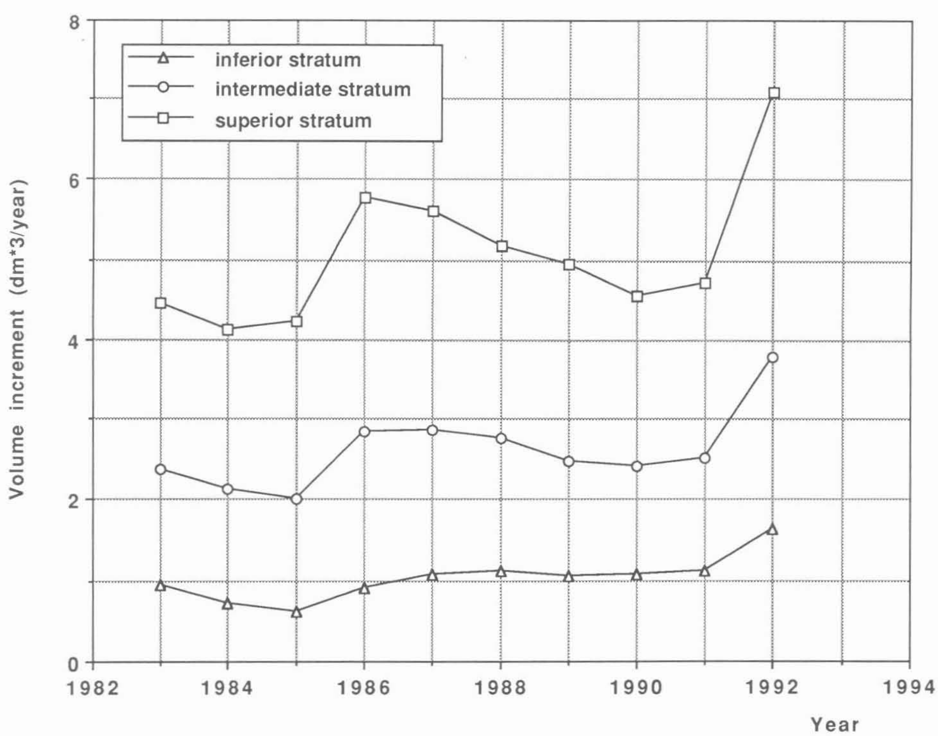

Figure 9. Mean black spruce volume increment series in the spruce-mosses forest.

Comparison of species

Comparison of the volume increments in the spruce-litter forest shows (Figure 7B) that the reaction of the 2 species after drainage is the same: a significant decrease at the 5% level in volume increment in the superior class of both species.

CONCLUSION

Comparison of the inventories of the 2 experimental plots indicates that the spruce-litter forest is more productive than the spruce-mosses forest. The 54-year-old spruce-mosses forest yielded a net annual rate of 1.786% in basal area and 2.487% in volume outside bark. In terms of growth in dominant height, this forest type is comparable to Vézina and Linteau's class II and Plonski's class 1.

The 82-year-old spruce-mosses forest yielded a net annual rate of 1.452% in basal area and 2.279% in volume ouside bark. Station fertility in terms of growth in dominant height is comparable to Vézina and Linteau's class IV and Plonski's class 3.

Comparison of growth before drainage with growth after drainage does not make it possible to draw clear and unambiguous conclusions about the effect of drainage on yield.

According to the summary of the analyses of variance (Table 8), volume increment diminished significantly in the spruce-litter forest, while the statistically significant increase in volume in the spruce-mosses forest only occurred in the inferior class.

It should be noted, however, that for all growth classes, radial and apical growth of black spruce improved in the spruce-mosses forest.

Several possible explanations for the volume-yield results after drainage can be listed. For example, we know that black spruce, like tamarack, under certain conditions, has superficial root development (under 40 cm) and lateral root development (Strong and La Roi 1983, Lieffers and Rothwell 1987). Also, the plagiotropic rhizogenesis of black spruce, often marked by partial reiteration of the lateral axes (Zarnovican 1989), could have confined this species to lowering of the water table by drainage.

We can also mention the species' reaction time to drainage. Although it is generally quite rapid (Trottier 1985), it is possible that under the conditions in the plots studied, the reaction time of black spruce and tamarack is much longer.

Table 8. Changes in the growth of black spruce and tamarack as the result of drainage, by forest community and growth class.

Variable	Growth class superior	Growth class intermediate	Growth class inferior
Spruce-litter forest: black spruce			
volume ($dm^3.yr^{-1}$)	*⇓	N.S.	N.S.
dbh ($cm.yr^{-1}$)	*⇓	N.S.	N.S.
height ($m.yr^{-1}$)	N.S.	N.S.	N.S.
form factor	*⇑	*⇑	N.S.
Spruce-litter forest: tamarack			
volume ($dm^3.yr^{-1}$)	*⇓	N.S.	N.S.
dbh ($cm.yr^{-1}$)	*⇓	*⇓	N.S.
height ($m.yr^{-1}$)	N.S.	N.S.	N.S.
form factor	N.S.	N.S.	N.S.
Spruce-mosses forest: black spruce			
volume ($dm^3.yr^{-1}$)	N.S.	N.S.	*⇑
dbh ($cm.yr^{-1}$)	*⇑	*⇑	*⇑
height ($m.yr^{-1}$)	*⇑	*⇑	*⇑
form factor	*⇑	*⇑	N.S.

N.S. = non-significant (0.05); * ↑ = significant and positive; * ↓ = significant and negative.

Moreover, we can ask ourselves whether drainage was an appropriate treatment, considering the fact that the water table in the soil profile of both plots lay below 60 cm during the growing season in 1987. This is markedly deeper than the biological standard suggested by Päivänen and Wells (1978), which is 30 to 50 cm for the active growing period.

Finally, it is quite possible that the effect of drainage, if any, was masked by much more important factors such as climatic factors, which would have imposed a specific cyclical variation on the growth of the trees. It seems to us that the effect of climate is the most probable factor, when we examine the time series of increments for the last 10 years (Figures 8 and 9) with a quite obvious and synchronous periodicity. But to verify these hypotheses, it is necessary to carry out a dendrochronological study, which goes beyond the bounds of this study.

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