Survey of the effects of forest drainage operations: (3) Climate and volume increment of black spruce and tamarack at Saint-Anaclet

Richard Zarnovican and Claude Laberge
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(3) Climate and volume increment
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ABSTRACT

A dendrochronological study of the volume increment of black spruce (*Picea mariana* [Mill.] B.S.P.) and tamarack (*Larix laricina* [Du Roi] K. Koch.) was carried out in the spruce-litter forest and the spruce-mosses forest in the drained peatland at Saint-Anaclet, near Rimouski, from 1968 to 1992. The time series of volume increment come from stem analysis and correspond to the mean of 10 black spruce trees in the spruce-litter forest and spruce-mosses forest and 5 tamarack trees in the spruce-litter forest by growth class (superior, intermediate and inferior). These series were correlated with climatic variables, monthly snowfall and rainfall and mean monthly temperatures.

The results show that the residual series for a species and a plot are synchronous between growth classes. The series of spruce in the spruce-litter forest and the spruce-mosses forest showed amplified oscillations with a complete cycle of about 7 years, while periodicity of tamarack was different, with a cycle of about 15 years.

Response functions based on multiple regressions showed a strong positive influence of rainfall (June and August) and mean temperatures (December and October) on volume increment for the species studied from 1968 to 1987.

Comparison of the climatic model with the series observed from 1988 to 1992 reveals greater than expected variations; however, the response functions for the period from 1983 to 1992 showed that these variations reflect climatic variations, in particular the effect of precipitation (June rainfall) on black spruce in the spruce-mosses forest and heat stress (mean August temperatures) on black spruce in the spruce-litter forest, while the effect of drainage was negligible or nil.

RÉSUMÉ

L'étude dendrochronologique de l'accroissement en volume de l'épinette noire (*Picea mariana* [Mill.] B.S.P.) et du mélèze laricin (*Larix laricina* [Du Roi] K. Koch.) a été effectuée dans la pessière à litière et dans la pessière à mousses de la tourbière drainée de Saint-Anaclet, près de Rimouski, de 1968 à 1992. Les séries temporelles de l'accroissement en volume proviennent de l'analyse de tiges et correspondent à la moyenne de 10 épinettes noires dans la pessière à litière et dans la pessière à mousses et de 5 mélèzes laricins dans la pessière à litière par classe de croissance (supérieure, moyenne et inférieure). Ces séries ont été corrélées avec les variables climatiques, les précipitations mensuelles de neige et de pluie et les températures mensuelles moyennes.

Les résultats démontrent que les séries résiduelles d'une essence et d'une parcelle sont synchrones entre les classes de croissance. Les séries d'épinettes dans la pessière à litière et dans la pessière à mousses présentent des oscillations amplifiées ayant un cycle complet d'environ 7 ans, alors que la périodicité du mélèze laricin est différente, avec un cycle d'environ 15 ans.

Les fonctions de réponse établies à partir des régressions multiples montrent une forte incidence positive des pluies (juin et août) et des températures moyennes (décembre et octobre) sur l'accroissement en volume des essences étudiées, pour la période de 1968 à 1987.

La comparaison du modèle climatique avec les séries observées de 1988 à 1992 indique des variations supérieures aux prévisions. Cependant, les fonctions de réponse pour la période de 1983 à 1992 démontrent que ces variations reflètent les variations climatiques et notamment l'effet des précipitations (pluie de juin) sur l'épinette noire dans la pessière à mousses et du stress thermique (températures moyennes d'août) sur l'épinette noire dans la pessière à litière, alors que l'effet du drainage est faible sinon nul.

INTRODUCTION

Growth of black spruce (*Picea mariana* [Mill.] B.S.P.) and tamarack (*Larix laricina* [Du Roi] K. Koch.) in peatlands is generally dependent on variations in the water table (Jasieniuk and Johnson 1982). In fact, in spruce-sphagnum-ericaceous forests, variations in water table constitute a major obstacle to root development and the normal functioning of the tree (Liffers and Rothwell 1987a and b).

Since these variations are positively correlated with rainfall (Dai *et al.* 1974, Munro 1984), we might conclude that high summer rainfall is the direct cause of poor tree growth. However, a study by Dang and Lieffers (1989) suggests the contrary; it is shown that radial growth in the species studied is strongly and positively correlated with summer rainfall and thus with a high water table level.

Tree development by evapotranspiration is also linked to variations in summer temperatures (Tryon and Chapin 1983, Van Cleve *et al.* 1983), and radial growth is correlated with minimum and maximum summer temperatures (Dang and Lieffers 1989). However, it should be pointed out that, while cooler temperatures promote radial growth, high temperatures appear to hinder it.

For maximum radial growth, some authors suggest an optimum water table level (Van Groenewoud 1975), while others (Päivänen and Wells 1978) speak of a biologically acceptable water table level during the active growth period.

In light of these observations, we might ask what are the real short- and medium-term effects of lowering the water table by drainage on tree growth compared to climate and climatic variations. This study was carried out in this perspective, since relations between climate and growth for the drained spruce-mosses forests had not been examined in previous studies.

This report presents a dendrochronological analysis of relations between climate and volume increment of black spruce and tamarack in drained peatlands at Saint-Anaclet, near Rimouski (Zarnovican 1989).

Work hypotheses

To determine the respective effects of climate and drainage on volume increment in a dendrochronological analysis, it was important to establish basic data taking into account the endogenous and exogenous factors of the stand.

For the purposes of this study, we consider that:

- Endogenous stand effects on volume increment of trees are attenuated by classifying trees in growth classes according to social position and strength;
- The effect of drainage on volume increment of trees is the same everywhere, since the minimum distance separating the plots from the canal exceeds 12 m;
- The individual tree effect is eliminated by using a mean series by growth class;
- The climate effect is the same in both plots, since they have similar topographical characteristics and are part of the same peatland complex.

Work objectives

The purpose of this research was to highlight the effects of climate and drainage on volume increment by:

- Assessing the synchronicity and variability of volume increment series by growth classes for black spruce and tamarack;
- Determining the effect of climatic factors on volume increment, by multiple regressions, used as response functions;
- Assessing the effect of drainage as compared with that of climate.

MATERIALS AND METHODS

Time series of volume increment

The volume increment series were derived from the analysis of stems (60 for black spruce and 15 for tamarack) harvested in the Saint-Anaclet test plots. The morphometric characteristics of trees were presented in Zarnovican and Laberge (1994), and the ecological conditions of plots were described in Zarnovican (1989).

A mean series corresponds to the mean of volume increments by year, growth class (10 values for black spruce and 5 for tamarack), species and plot (Figures 1, 2 and 3). In all, 9 series were formed, that is 6 for black spruce and 3 for tamarack, from 1968 to 1992. The use of mean series was justified, since in general, the individual series of a growth class are strongly positively correlated, although there were a few cases of non-significant correlations.

Elimination of growth trend

Study of the relations between climatic variables and volume increment using a response function requires elimination of the growth trend and the use of residual series. To do so, the trend of a growth class series was removed using a simple linear model. The linear model was chosen first because the series were relatively short with a clear linear trend (Figures 1, 2 and 3) and second, since a regression line allowed adjustment as good as second- and third-order models. The residual series of a growth class was calculated by subtracting the values of the regression line of the corresponding observed values (Figures 4, 5 and 6).

Climatic data

Monthly climatic data were divided into series for the current year (climate from January to August of the current year) and into series from the previous year (climate from September to December of the previous year). These data came from the Rimouski station (located approximately 12 km west of the drained area) and were supplied by the Direction de la météorologie of the ministère de l'Environnement du Québec.

The study of the relations between climate and volume increment covers the period from 1967 to 1992 and includes the following climatic variables:

a)   Mean minimum air temperatures in °C;

b)   Mean maximum air temperatures in °C;

c)   Mean air temperatures in °C;

d)   Snowfall in cm;

e)   Rainfall in mm.

For a direct comparison of the estimators obtained in multiple regression models, climatic data were standardized. We may thus judge the importance of an independent variable in these models using the estimator associated with it.

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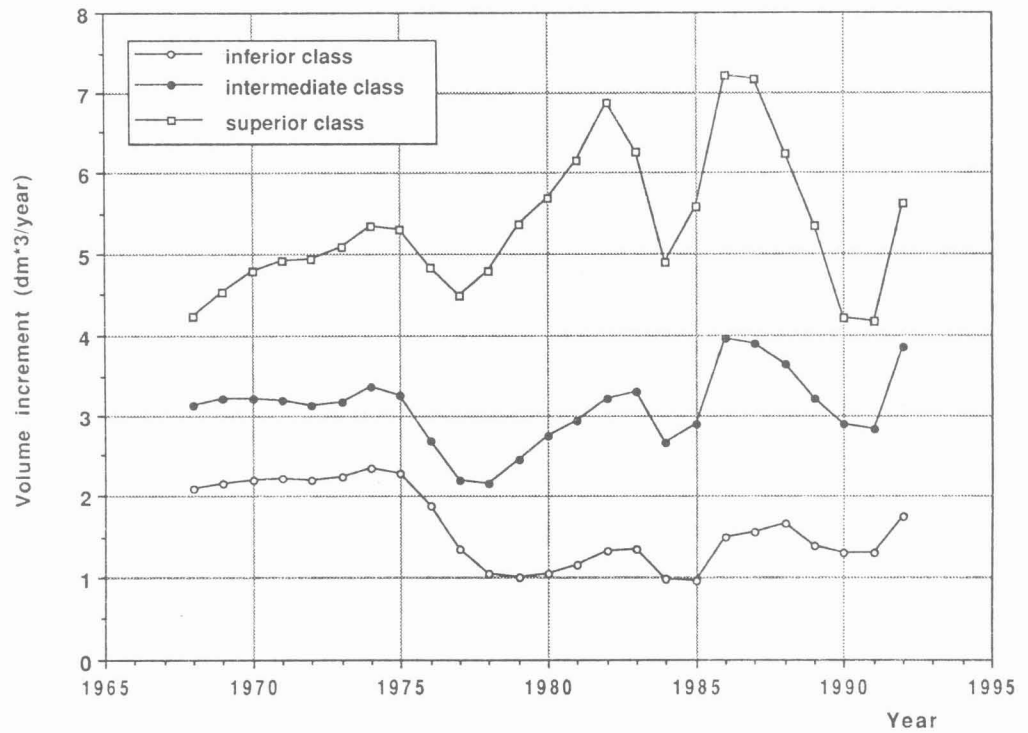
Figure 1.   Annual volume of black spruce in the spruce-litter forest, mean by growth class.
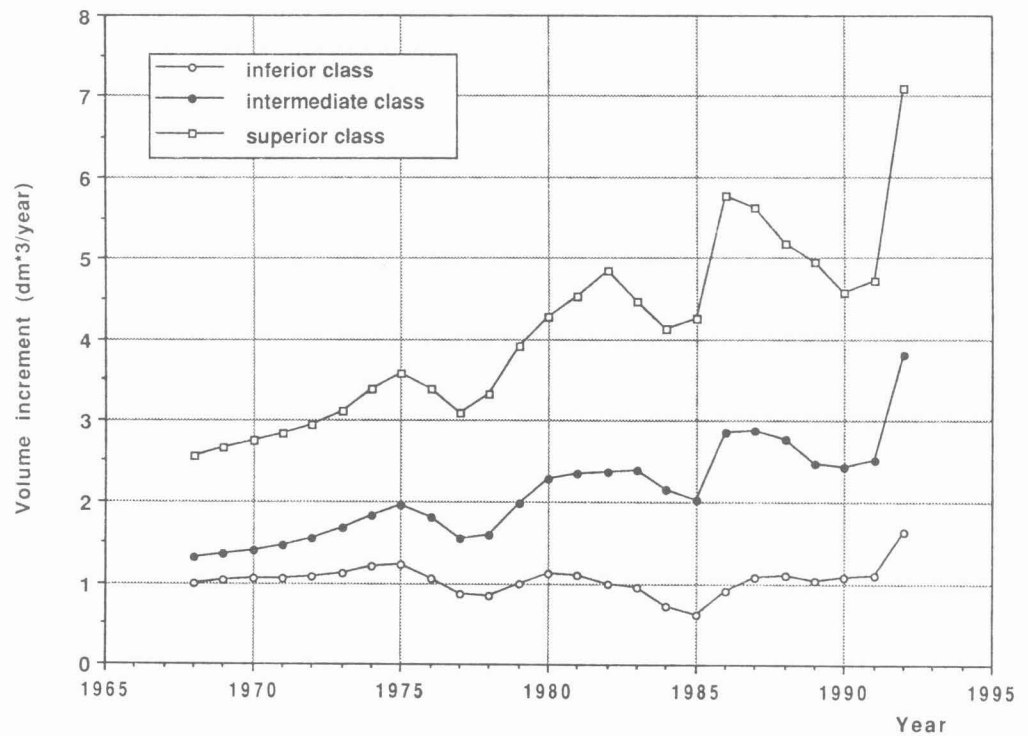
Figure 2.   Annual volume of black spruce in the spruce-mosses forest, mean by growth class.
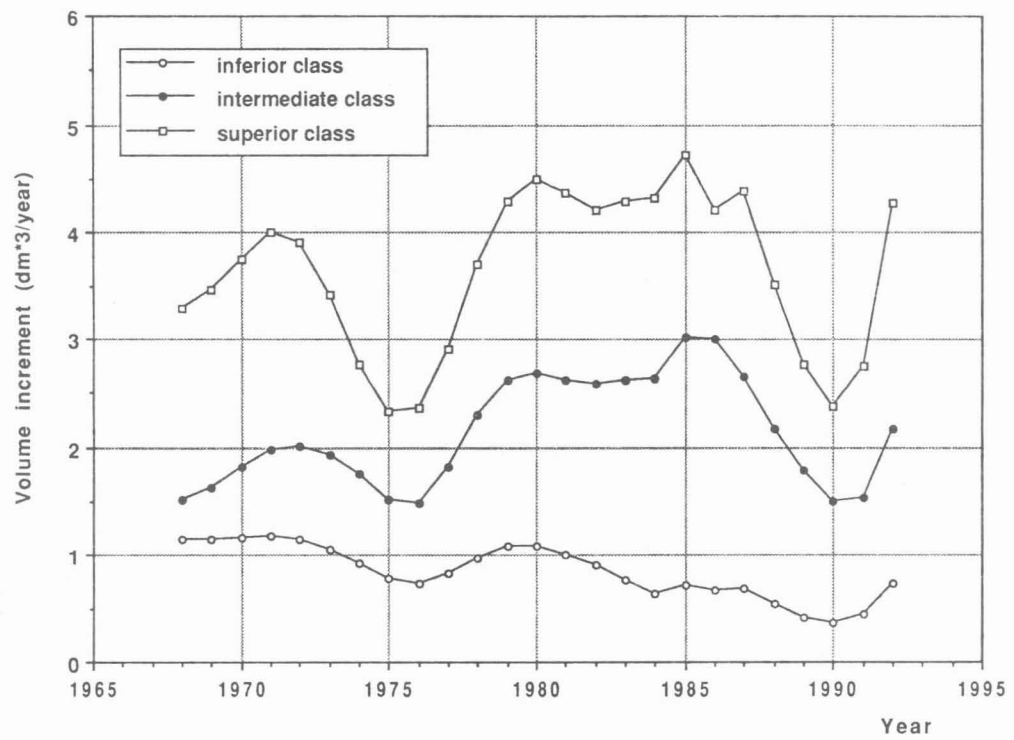
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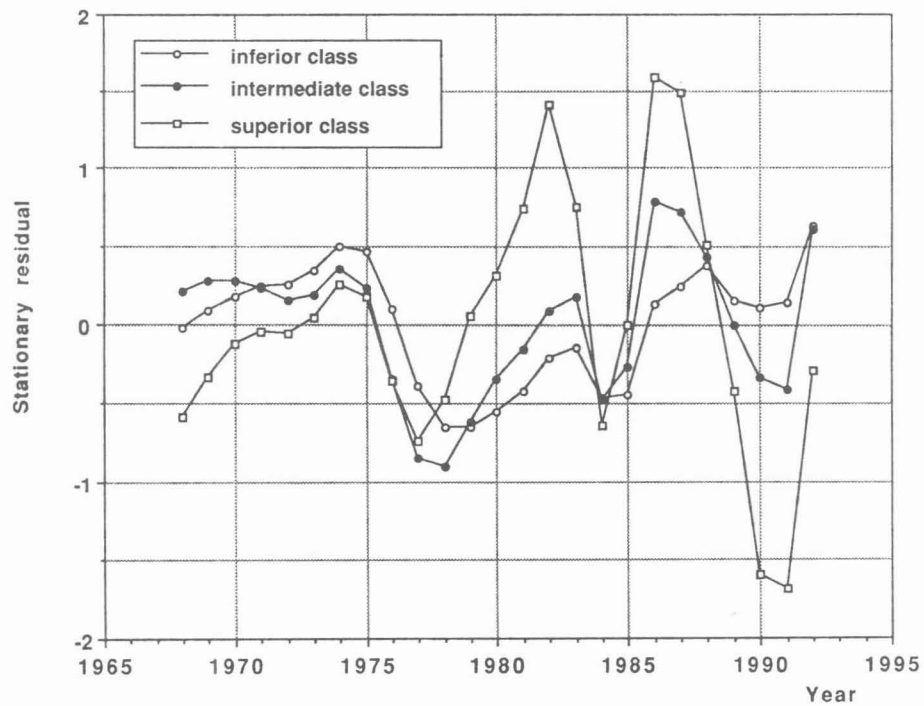
Figure 4. Residual series of black spruce in the spruce-litter forest by growth class.
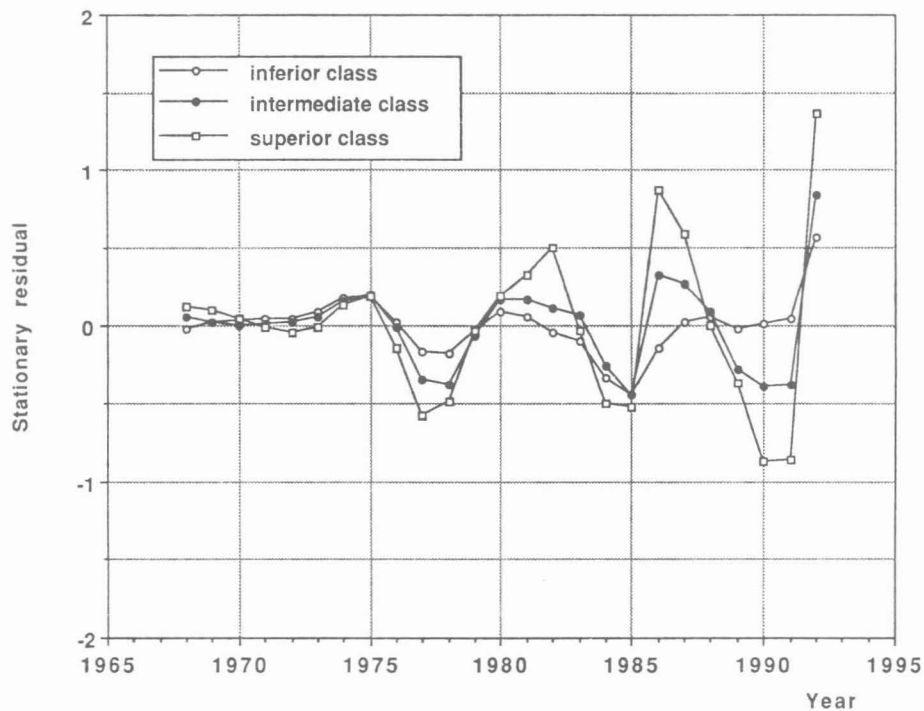
Figure 5.   Residual series of black spruce in the spruce-mosses forest by growth class.
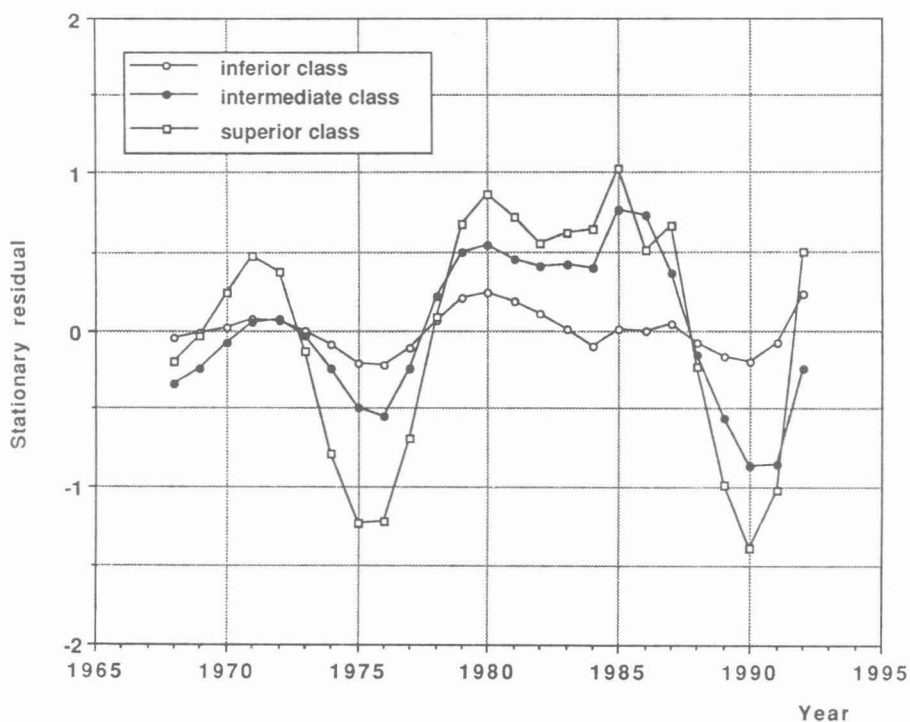
Figure 6.   Residual series of tamarack in the spruce-litter forest by growth class.

Response function

Relations between residual series and climatic variables were studied using multiple regression as a response function. The purpose of this analysis was to determine the respective share of climate and drainage in variations in volume over time. First, the best climatic model was chosen to predict the residual series of volume increment before drainage, that is from 1968 to 1987. This model was then applied to prediction of the volume increment after drainage, that is from 1988 to 1992, with a confidence interval of 95%.

Next, the segment of the residual series observed from 1988 to 1992 was compared with values of the confidence interval for the same period. We thus consider that the effect of climate is determinant when the segment of the residual series observed falls within the confidence intervals of the model, while conversely, volume increment reflects the effects of other factors, including those of drainage. To establish the best predictive model, the two following selection methods were used: the stepwise method (STEPWISE in SAS) and the R-square method (RSQUARE in SAS).

The various statistical tests were carried out using programs from the SAS Institute Inc. (1985).

RESULTS AND DISCUSSION

Synchronicity of residual series

The synchronicity of residual series was calculated by species, growth class and forest type using cross-correlations at lag zero and with one- and two-year lags. This assessment was intended to determine whether the residual series varied in the same way over time and, if so, to use only certain series in subsequent studies, namely those determined in the variability study.

Synchronicity without lag

Cross-correlations at lag zero (Table 1) indicate that:

- For a given species and plot, the residual series of growth classes are correlated positively and significantly (5%), except in the spruce-litter forest for series of spruces in the superior and inferior classes;

- In the two plots, the residual series of spruce are correlated significantly and positively, except for one combination of the superior and inferior classes;
- The series of spruces in the superior class of both plots are correlated significantly and positively with the series of tamarack in all growth classes;
- There are few significant correlations between, on the one hand, the series of spruce in the intermediate and inferior growth classes of the two plots with, on the other hand, the residual series of tamarack; when there are such correlations, the relation is negative three times out of four.

Synchronicity with lag

First-order autocorrelation coefficients with a one-year lag (Table 2) indicate that all residual series are autocorrelated, except for the residual series of spruce in the superior and intermediate classes of the spruce-mosses forest.

Second-order autocorrelation coefficients, with a two-year lag (Table 2), indicate a noteworthy decrease in positive significant correlations as well as the appearance of negative autocorrelations for spruce in the spruce-mosses forest in the superior and intermediate classes.

Study of cross-correlation coefficients showed that, in general, the greater the lag between the two series, the more likely the correlation was to decrease or disappear.

Based on these results, we may conclude that residual series were generally synchronous, that is, on average, the trees of a given species but of various growth classes behave in the same way over time with respect to volume increment.

Variability of residuals

Study of the variability of residual series was aimed at assessing the amplitude of variations in volume increment over time, by comparing variances in different residual series. However, the autocorrelation of residual series (Table 1) biases estimators of $\text{Var}(y_t)$. To obtain a more accurate estimate of the variability of residuals, we must adjust the series for the presence of autocorrelation. Assuming for the residual series a first-order autoregressive structure, as deduced from Tables 1 and 2, we obtain the following equation:

$$\text{Var}(y_t) = s^2.(1-\Phi^2)^{-1}$$

[1]

This equation gives the relation between $\text{Var}(y_t)^{0.5}$; the standard deviation of observed values (y_t); s, the intrinsic standard deviation associated with the specific variability of each observation; and Φ, the first-order autocorrelation coefficient. Table 3 presents estimators of s, obtained by calculating the standard deviations for the transformed series $(y_t - \Phi y_{t-1})$.

Equality in variances between plots, species and growth classes was calculated using the Bartlett test, and the results of its application to transformed data $(y_t - \Phi y_{t-1})$ indicate that:

- Variability increases significantly by growth classes;
- Black spruce shows greater variability in the spruce-litter forest than in the spruce-mosses forest;
- Black spruce shows greater variability than tamarack in the spruce-litter forest.

Study of the variability of residuals shows much greater amplitude and thus greater sensitivity of dominant trees to outside factors. Moreover, these results indicate that tamarack shows less sensitivity than black spruce, and that spruce is less sensitive in the spruce-mosses forest than in the spruce-litter forest. This last observation suggests the effect of the age of a stand as well as the presence of different forms of growth (Zarnovican 1992).

Table 1. Cross-correlations between residual series at lag zero by growth class and forest type

Class	TAM-litter			SPR-litter			SPR-mosses		
	inf.	int.	sup.	inf.	int.	sup.	inf.	int.	sup.
TAM-inf.	1.00	**0.64**	**0.82**	-0.32	0.07	**0.40**	0.21	**0.45**	**0.52**
TAM-int.		1.00	**0.90**	**-0.54**	0.05	**0.69**	**-0.43**	0.17	**0.34**
TAM-sup.			1.00	**-0.42**	0.15	**0.56**	-0.23	0.29	**0.43**
SPR-inf.				1.00	**0.75**	0.02	**0.67**	**0.50**	**0.36**
SPR-int.					1.00	**0.56**	0.46	**0.73**	**0.72**
SPR-sup.						1.00	0.00	**0.56**	**0.69**
SPR-inf.							1.00	**0.73**	**0.56**
SPR-int.								1.00	**0.95**
SPR-sup.									1.00

Note: Bold face type indicates a significant relation at the 5% level; SPR = black spruce; TAM = tamarack; inf. = inferior; int. = intermediate; sup. = superior.

Table 2. First- and second-order autocorrelations for residual series by forest type and growth class

Residual series		Autocorrelation	
		Order 1	Order 2
Spruce-litter forest:	tamarack		
inferior class		**0.66**	0.12
intermediate class		**0.83**	**0.48**
superior class		**0.75**	0.35
Spruce-litter forest:	black spruce		
inferior class		**0.80**	**0.48**
intermediate class		**0.59**	0.11
superior class		**0.61**	-0.04
Spruce-mosses forest:	black spruce		
inferior class		**0.58**	0.12
intermediate class		0.14	**-0.44**
superior class		0.16	**-0.45**

Note: Bold face type indicates a significant relation at the 5% level.

Table 3. Estimators of intrinsic standard deviation for transformed residual series to allow for autocorrelation

Species	Type of spruce forest	Growth class	Standard deviations $(dm^3.an^{-1})$
tamarack	litter	superior	0.50
tamarack	litter	intermediate	0.26
tamarack	litter	inferior	0.10
spruce	litter	superior	0.64
spruce	litter	intermediate	0.36
spruce	litter	inferior	0.23
spruce	mosses	superior	0.50
spruce	mosses	intermediate	0.28
spruce	mosses	inferior	0.15

In the case of spruce (Figures 4 and 5), we see that, starting in 1975, the series took the form of enlarged oscillations with a periodicity of approximately 7 years, while for tamarack (Figure 6), amplitude seems to be constant and the periodicity is about 15 years.

These results indicate that the residual series are generally synchronous and that superior classes are the most sensitive, which would justify their specific use to establish response functions.

Volume increments and climate - response function

Selection of predictive models

Due to the presence of strong correlations between different temperature variables, only mean air temperatures, snowfall and rainfall were considered in the remainder of the study.

It should be borne in mind that the predictive models were established for the period from 1968 to 1987 inclusively, so as to eliminate the period after drainage. In addition, to avoid the presence of singular matrices when using the R-square method, only 19 climatic variables were preselected according to their respective coefficients of correlation. Table 4 shows the best models, established using the R-square method. For the two series associated with spruce, the variables selected were the same, and the estimators of parameters were fairly similar. The three models included the variable associated with June rainfall.

Table 4. Multiple regression models established using the R-square method

Residual series	R^2	Explanatory climatic variables				
Black spruce spruce-litter forest	0.74	$Tm_{11}(-0.26)$	$Tm_{12}(0.58)$	$Rn_6(0.34)$	$Rn_8(0.49)$	$Sn_{12}(-0.27)$
Black spruce spruce-mosses forest	0.70	$Tm_{11}(-0.17)$	$Tm_{12}(0.36)$	$Rn_6(0.13)$	$Rn_8(0.31)$	$Sn_{12}(-0.11)$
Tamarack spruce-litter forest	0.66	$Tm_6(-0.26)$	$Tm_7(0.49)$	$Tm_{10}(0.53)$	$Rn_6(0.40)$	

Note: Numbers in subscript correspond to months of the year; Tm = mean temperature; Rn = rain; Sn = snow.

In the case of the stepwise method, the best predictive model was chosen using 32 climatic variables and the result is shown in Table 5. The model selection procedure was carried out with a 10% level, which implies that variables must be significant at the 10% level to be introduced into the model and must remain significant at this level to be maintained in the model.

The models associated with the stepwise method (Table 5) are quite different from the R-square method (Table 4). Moreover, the results of these two methods show little correspondence between the models of the two series of spruce, which nevertheless show good

synchronicity. Given these observations, the models associated with the R-square method were chosen.

Table 5. Multiple regression models established using the stepwise method

Residual series	R^2	Explanatory climatic variables				
Black spruce spruce-litter forest	0.47	$Rn_6(0.40)$	$Rn_{12}(0.27)$			
Black spruce spruce-mosses forest	0.54	$Tm_1(0.17)$	$Tm_8(-0.26)$	$Rn_{12}(0,14)$		
Tamarack spruce-litter forest	0.78	$Tm_3(0.34)$	$Tm_6(-0.48)$	$Tm_7(0,43)$	$Tm_{10}(0,48)$	$Sn_{10}(-0,23)$

Note: Numbers in subscript correspond to months of the year; Tm = mean temperature; Rn = rain; Sn = snow.

Analysis of models

Black spruce - spruce-litter forest

The model chosen by the R-square method explains 74% of residual variations in volume increment, with 5 climatic variables. This model is presented in Table 6, and its performance in predicting volume increment of spruce in the spruce-litter forest is illustrated in Figure 7. Since all the climatic variables were standardized, the value of estimators makes it possible to determine the importance of predictive variables. The most important variables are thus rainfall in June and August of the current year and mean temperature in December of the previous year.

Validation of model

The Durbin-Watson test failed to yield conclusions (at the 5% level) regarding the significance of the autocorrelation of residuals. Nonetheless, the low value of the first-order autocorrelation coefficient of residuals (0.21) results in no major problems in setting out relevant conclusions for subsequent studies; we will thus not waste time trying to eliminate all traces of autocorrelation.

Study of residuals showed that only the year 1983 presented a standardized residual greater than 2 in absolute terms. As well, the study of influential values using Cook's

statistic showed that 1983 was the most influential year in determining estimators, and several other years had only a moderate influence.

Table 6. Climatic model of black spruce in the spruce-litter forest from 1968 to 1987

Variable	Estimator	T for H_o Estim = 0	Prob > T
Intercept	0.20	2.14	0.050
Tm_{11}	-0.26	-2.57	0.022
Tm_{12}	0.58	3.94	0.002
Rn_6	0.34	3.15	0.007
Rn_8	0.49	3.57	0.003
Sn_{12}	-0.27	-2.71	0.017
Coefficient of determination: 0.74			

Note: Numbers in subscript correspond to months of the year; Tm = mean temperature; Rn = rain; Sn = snow.
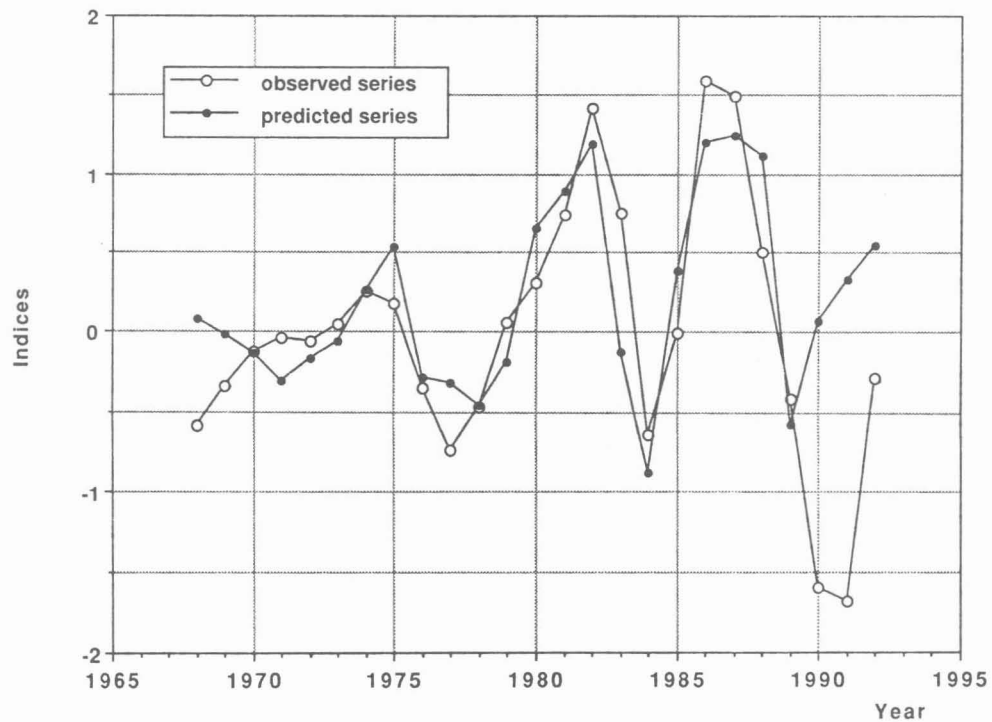

Figure 7. Predicted and observed residual series for black spruce in the spruce-litter forest.

However, to ensure that the year 1983 was not the only one to determine the model, a second regression was carried out without taking into account the year 1983. The results of this regression indicate that the percentage of explained variance increased to 84%, that the estimators of parameters remain significant at the 5% level (Tm_{11} = -0.28; Tm_{12} = 0.62; Rn_6 = 0.39; Rn_8 = 0.56 and Sn_{12} = -0.22), and that the values of estimators are consistent with those shown in Table 6. Therefore, the presence of the year 1983 did not significantly affect our conclusions regarding the model presented in Table 6, which justified the use of this model without restriction for the following treatments.

Black spruce - spruce-mosses forest

The model chosen as a predictive one includes 5 variables and was established using the R-square method. With this model, 70% of variations in the residual series can be explained. The model is shown in Table 7 and its performance is illustrated in Figure 8. It will be seen that the most important variables are the mean temperature in December of the previous year and August rainfall for the current year.

Validation of model

The Durbin-Watson test failed to yield conclusions regarding the autocorrelation of residuals at the 5% level. Note that it was previously indicated in Table 2 that the residual series was not autocorrelated.

The study of residuals showed that only the standardized residual for 1985 was greater than 2. Study of influential values using Cook's statistic showed that 1985 was the most influential year in determining estimators, but that several other years had a moderate influence. To ensure that the year 1985 did not significantly affect the model, a second regression was performed without considering that year. The results of this regression indicated that the percentage of variance explained increased to 85% (Tm_{11} = -0.15; Tm_{12} = 0.36; Rn_6 = 0.13; Rn_8 = 0.32; Sn_{12} = -0.15), that the estimators of parameter were all significant at the 5% level, and that the values of estimators were consistent with those in Table 7. The spruce-mosses forest model was not significantly affected by the year 1985 and is quite adequate as a response function.

Table 7. Climatic model of black spruce in the spruce-mosses forest from 1968 to 1987

Variable	Estimator	T for H_o Estim = 0	Prob > T
Intercept	0.05	0.89	0.389
Tm_{11}	-0.17	-2.85	0.013
Tm_{12}	0.36	4.25	0.001
Rn_6	0.13	2.14	0.050
Rn_8	0.31	3.88	0.002
Sn_{12}	-0.11	-2.01	0.064
Coefficient of determination: 0.70			

Note: Numbers in subscript correspond to months of the year; Tm = mean temperature; Rn = rain; Sn = snow.
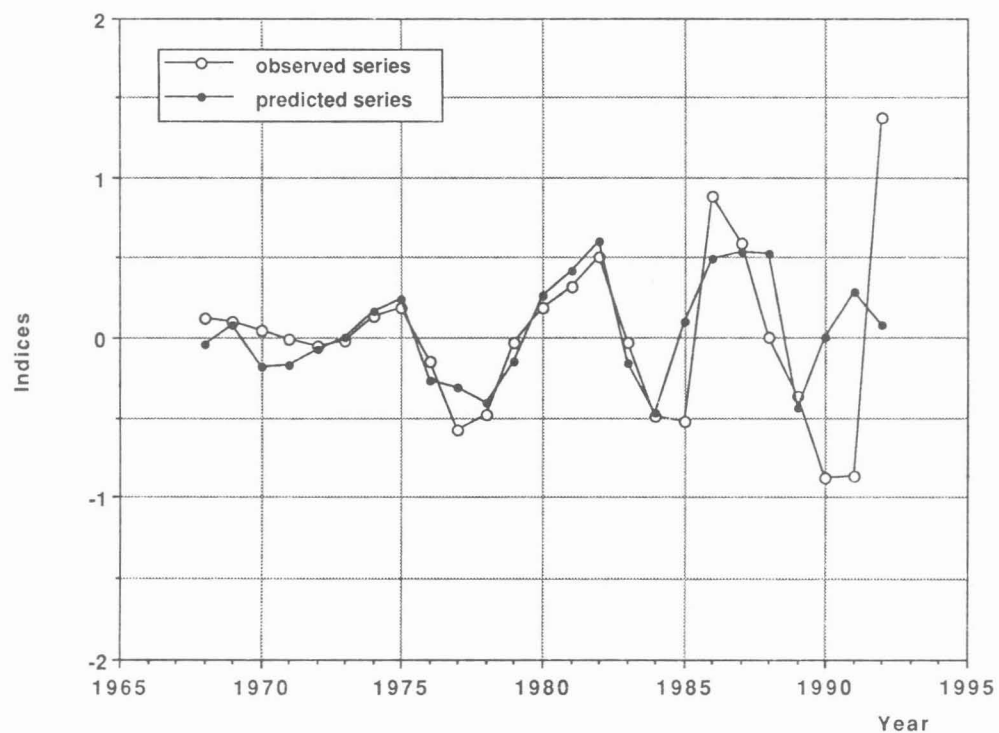
Figure 8. Predicted and observed residual series for black spruce in the spruce-mosses forest.

Tamarack - spruce-litter forest

The model with 5 variables selected using the stepwise method (at the 10% level) makes it possible to explain 78% of variations, while that obtained with the R-square method with 4 variables explains 66% of them. Despite the slightly lower percentage of variance explained, the model obtained using the R-square method was chosen as the response

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function in order to maintain some continuity with models associated with the two series of spruce. Table 8 summarizes this model, while Figure 9 presents the predicted and observed series. The most important variables were mean temperatures for October of the previous year and July of the current year and rainfall in June of the current year.

Table 8. Climatic model of tamarack in the spruce-litter forest from 1968 to 1987

Variable	Estimator	T for H_o Estim = 0	Prob > T
Intercept	0.18	1.78	0.096
Rn_6	0.40	2.63	0.019
Tm_6	-0.26	-1.90	0.076
Tm_7	0.49	3.36	0.004
Tm_{10}	0.53	3.65	0.002
Coefficient of determination: 0.66			

Note: Numbers in subscript correspond to months of the year; Tm = mean temperature; Rn = rain; Sn = snow.
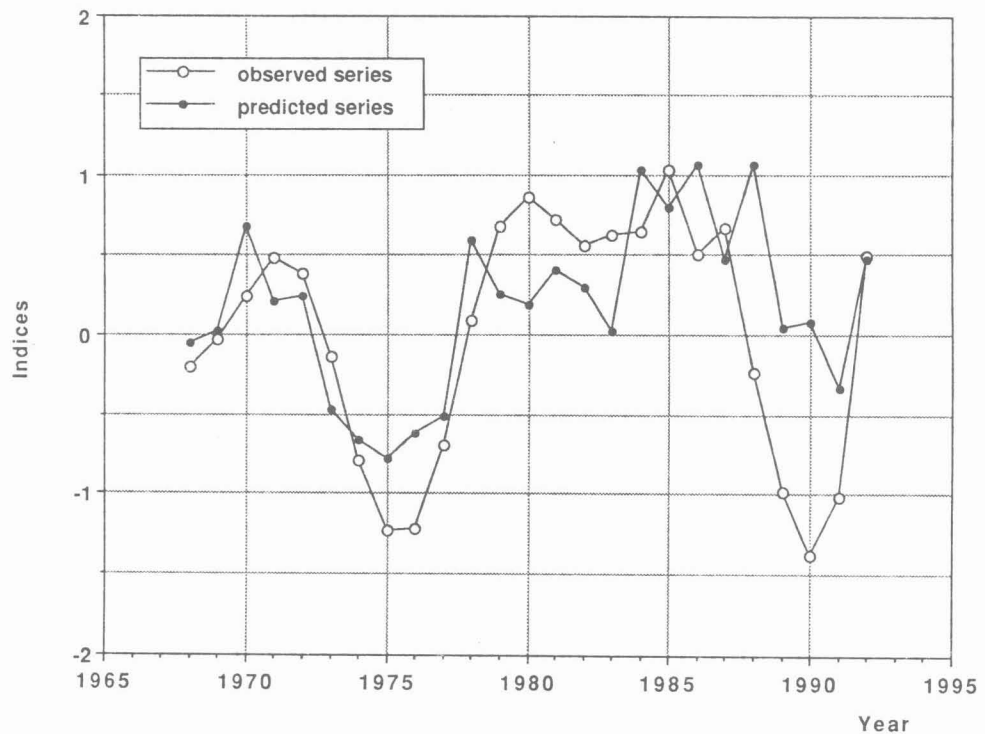

Figure 9. Predicted and observed residual series for tamarack in the spruce-litter forest.

Validation of model

Based on the Durbin-Watson test, autocorrelation of residuals is not significant at the 5% level. The autocorrelation present in the residual series (obtained after elimination of the trend) is thus eliminated by the climatic variables. Study of residuals showed no standardized residual greater than 2, in absolute value, while study of influential values using Cook's statistic failed to identify a highly influential year in determining estimators. The model shown in Table 8 was therefore used without restriction.

Volume increments, climate and drainage

To arrive at an informed conclusion regarding the true effect of drainage over the past five years, we used climatic models (Tables 6, 7 and 8) to predict residual series for the period from 1988 to 1992. As mentioned previously, the effect of drainage on volume increment will be judged on the behaviour of the residual series observed, based on the 95% confidence interval of the model. In the case of black spruce in the spruce-litter forest (Figure 10), the residual variations in volume increment followed the limits of the model, except in 1990 and 1991. For those years, the decrease in volume increment exceeded the lower limit of the model. The situation was similar for black spruce in the spruce-mosses forest (Figure 11). However, in addition to the significant decreases in volume increment recorded in 1990 and 1991, there was a significant increase in 1992. In the case of tamarack (Figure 12), residual variations fell below the lower limit of the model in 1990. Looking at Figures 10, 11 and 12, we see that variations in volume increment recorded from 1987 to 1992 were different from those seen from 1968 to 1988, which might be due to drainage, but also to a specific climate cycle. However, since the series of spruce show synchronous, enlarged oscillations (Figures 10 and 11) as early as 1975, it is unlikely that these fluctuations were the result of drainage.

In the case of tamarack, the oscillation of the residual series does not enlarge over time and the complete cycle is approximately 15 years. To properly understand the effect of climate on the behaviour of tamarack, we believe it is necessary to establish a much longer residual series.

Finally, to determine the effect of climate on volume increment of spruce (complete 7-year cycle) during the greatest amplitude (from 1983 to 1992), a multiple regression was carried out between the residual series and the climatic variables of the models, as described in Tables 6 and 7. In the case of black spruce in the spruce-litter forest, variations in volume

over the past ten years are statistically linked to climatic variations in August (Figure 13), since they make it possible to explain 96% of them. However, the most important effect comes from the mean August temperature, which alone explains 81% of variations in volume increment (Figure 14). With respect to black spruce in the spruce-mosses forest, the results show that variations in volume depend on June rainfall and April snows (Figure 15), which explain 91% of the variations. However, June rainfall seems to have had a determining effect on volume increment over the past ten years, since it was responsible for 81% of the variations (Figure 16). The dominant effect of June rains along with August temperatures on growth of black spruce in the communities studied confirms the conclusions of Dang and Lieffers (1989).

In the spruce-litter forest, the critical period appears only in August, probably due to the absence of lower strata, and apparently corresponds to stress caused by high temperatures, while in the spruce-mosses forest, the critical period appears earlier and is linked to June rainfall. This was probably due to the great abundance of hypnaceous mosses, which, by interception and evapotranspiration (Busby *et al.* 1978), increase moisture stress and speed up the beginning of the critical period for black spruce.
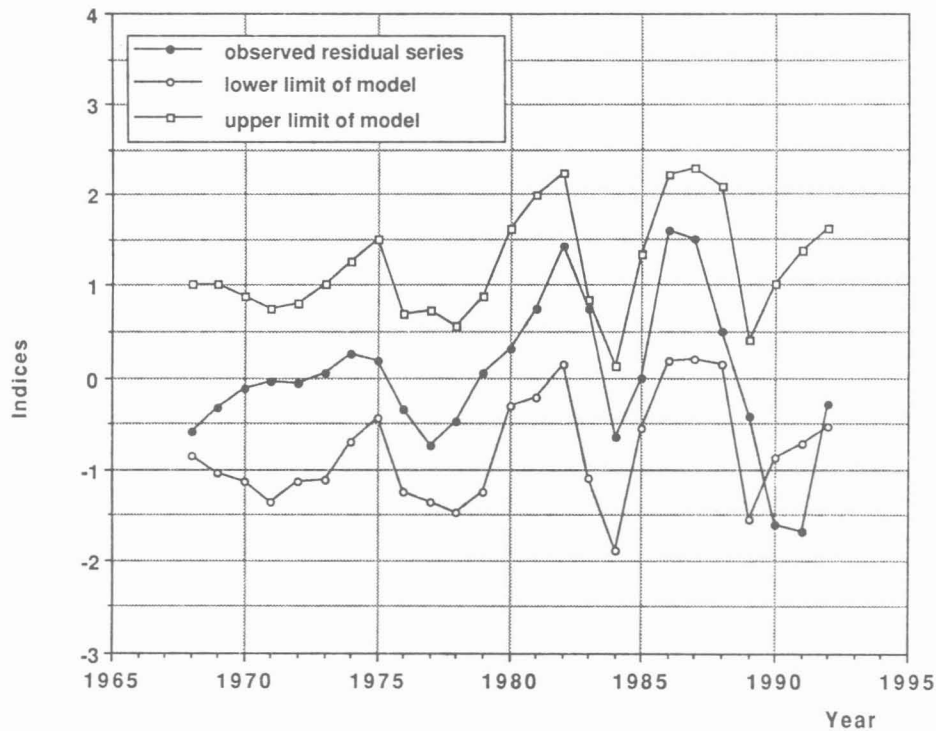

Figure 10. Residual series of black spruce in the spruce-litter forest and 95% confidence interval of climatic model.
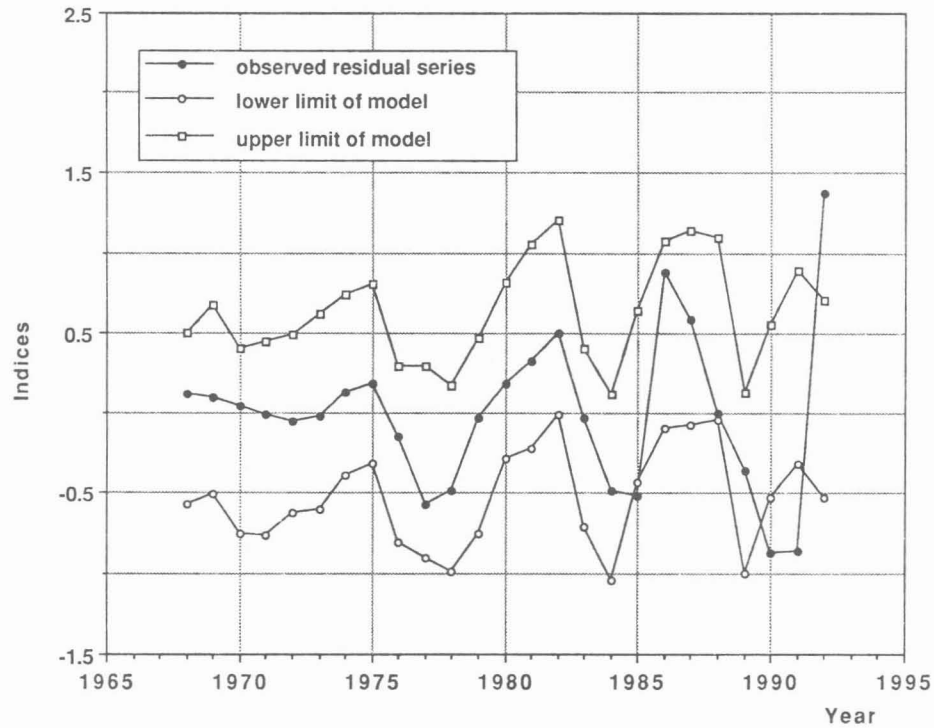
Figure 11. Residual series of black spruce in the spruce-mosses forest and 95% confidence interval of climatic model.
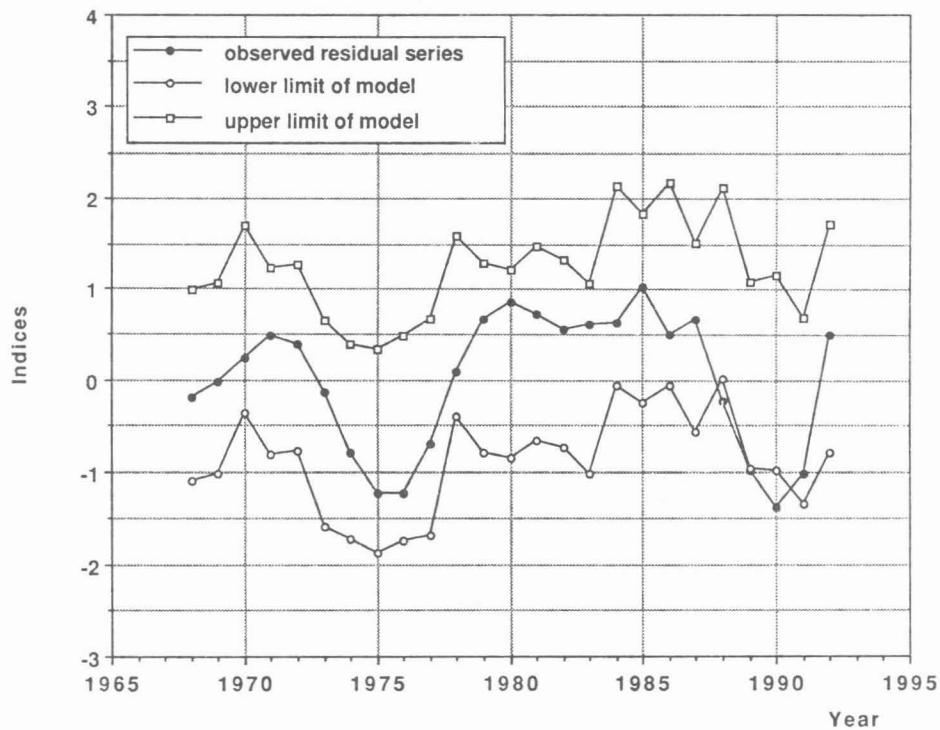

Figure 12. Residual series of tamarack in the spruce-litter forest and 95% confidence interval of climatic model.
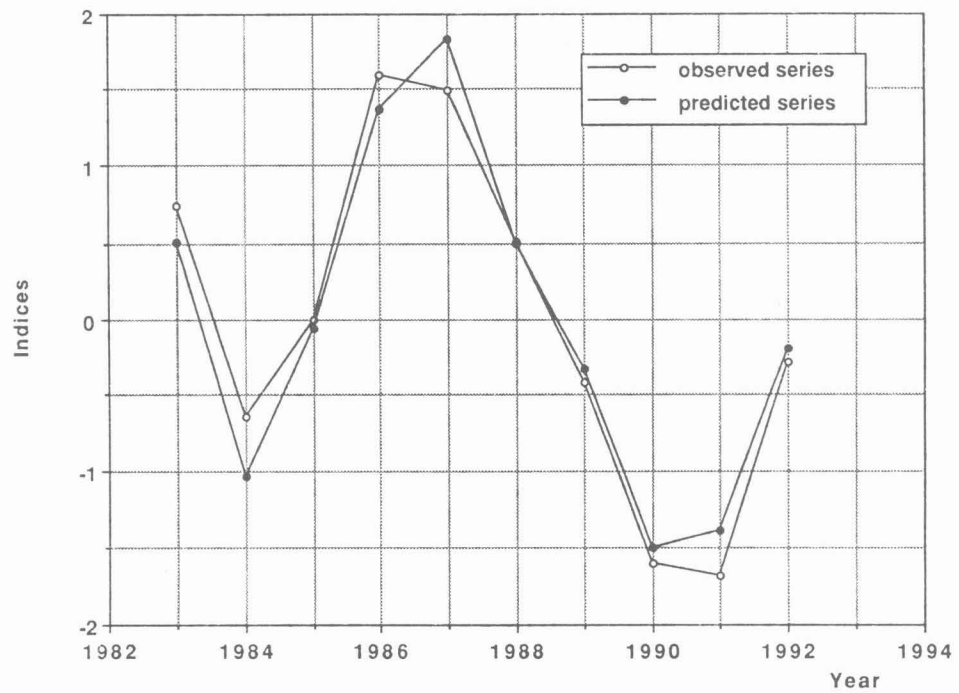
Figure 13. Predicted and observed residual series for black spruce in the spruce-litter forest from 1983 to 1992.
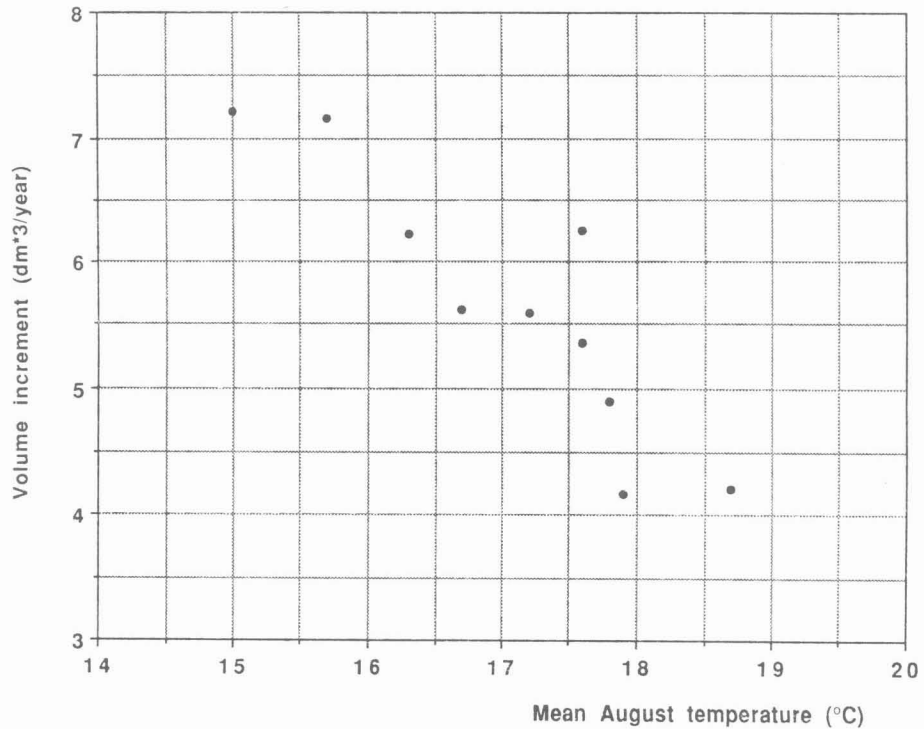

Figure 14. Annual volume of black spruce in the spruce-litter forest by mean August temperature from 1983 to 1992.
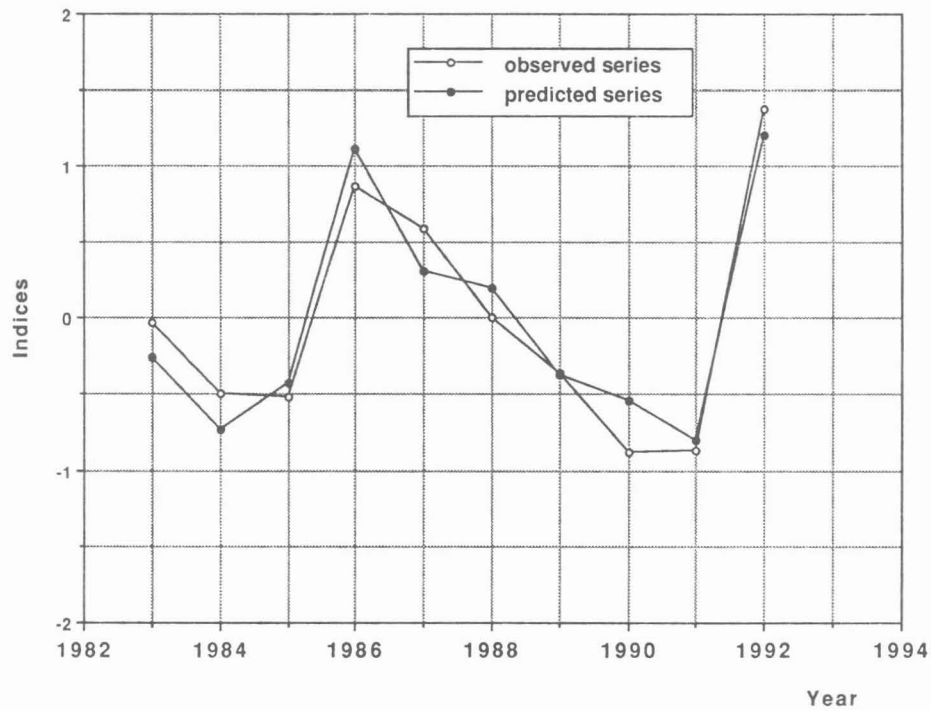
Figure 15. Predicted and observed residual series for black spruce in the spruce-mosses forest from 1983 to 1992.
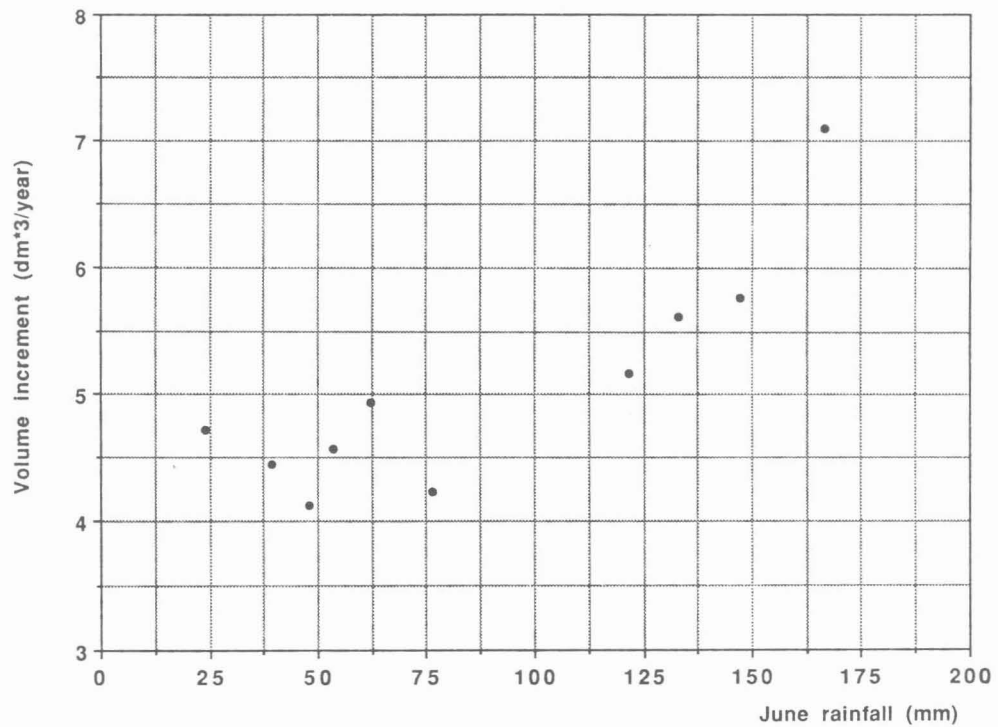

Figure 16. Annual volume of black spruce in the spruce-mosses forest by June rainfall from 1983 to 1992.

The results obtained raise the question of the validity of drainage in this type of spruce forest and its true effect on yield. The strong correlations between residual series and climatic variables for the highest growth period tend to indicate that the effect of drainage on the volume increment was negligible or nil.

Dominant black spruce in the spruce-litter forest shows variability and is thus more sensitive to exogenous factors than tamarack and spruce in the spruce-mosses forest. However, despite the fact that the dominant spruce in the spruce-mosses forest are 82 years old, they are still physiologically very active.

In comparison with normal yield tables, the site index of the two spruce forests is comparable with that of spruce forests on mineral soils (Zarnovican 1989 and 1992). Considering that these were physiologically active and productive stands, appropriate silvicultural treatment might have improved the quality of the stand and the timber produced and might have yielded better results than drainage.

CONCLUSION

Time series of volume increment for black spruce and tamarack in the spruce-litter and spruce-mosses forests are synchronous and the variability of these series is directly related to the social hierarchy of the trees within the stand.

The black spruce series shows enlarged oscillations in a 7-year cycle, with the greatest amplitude of the cycle occurring between 1985 and 1992. In the case of tamarack, the periodicity is different, with a 15-year cycle.

For the period from 1968 to 1987, the response function of black spruce in the spruce-litter forest was associated with the June and August rainfall, as well as with the mean temperature in December of the previous year. As well, for the same period, the response function for black spruce in the spruce-mosses forest emphasized the synchronicity with spruce in the spruce-litter forest by association with the August rainfall and the mean December temperature of the previous year. Finally, the response function of tamarack is associated with June rainfall and the mean July and October temperatures of the previous year.

The multiple regression for the period when the greatest amplitude was observed, i.e. between 1983 and 1992, confirms the determining effect of climatic variables on volume

increment. We should mention in particular the effect of mean August temperature on spruce in the spruce-litter forest, as well as June rainfall on black spruce in the spruce-mosses forest. Given the importance of climate, the effect of drainage on this growth appears to be either negligible or nil, at least in the context of this study.

ACKNOWLEDGEMENTS

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