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# Dynamics of field-layer vegetation and tree growth in young *Pinus sylvestris* and *Picea abies* stands on microsites in Swedish Lapland

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# Abstract

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Dynamics of field-layer vegetation, and the growth of planted, pure and mixed stands of Scots pine and Norway spruce in relation to microsite conditions, were studied during 31 years from planting, on a high-altitude site with a harsh climate in Swedish Lapland. Observations were made on 360 circular sample plots on a 6-ha site. Plots had a 3-m radius, and were laid out in a systematic pattern over the site. Site conditions were assessed separately for every individual plot, then related to tree survival and mortality, height and height increment of single trees, and stand volume on individual sample plots. Tree survival, height and height increment of single trees, and stand volume, were correlated with the cover of various species of field-layer vegetation, fertilisation, frost hollows, logging residues and stump occurrence at the local level of 3-m circular plots, for single-species stands and for a species mixture. Norway spruce was more sensitive to site conditions than Scots pine, as shown by clear effects of microsite conditions on height and volume growth. Some species of field-layer vegetation at the sites were also studied, with regard to their distribution in space and development over time.



*Keywords: boreal forests, mixed stand yield, Norway spruce, Scots pine, site variability, field-layer vegetation*



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# Dynamics of field-layer vegetation and tree growth in young *Pinus sylvestris* and *Picea abies* stands on microsites in Swedish Lapland

## Introduction

Several studies of microsites, and their importance to stand establishment and early tree growth, especially with regard to both site preparation (*e.g*. Bärring, 1965, Söderström, 1976; Lähde, 1978; Pohtila & Pohjola, 1983; Martinsson, 1985) and topography (*e.g*. Ydgren, 1972; Sinko & Nilsson, 1976; Hagner, 1989), have been made. Hagner (1989) states that survival and early growth are affected by a vast number of environmental factors, often on a micro-scale that is overlooked by the forester. Hagner contends that, to obtain the deeper understanding necessary to develop better scarification equipment, and to prevent large-scale destructive manipulation of forest ground, studies of microsite effects must be further refined. Furthermore, such investigations should be carried out not on young stands alone, but on stands of all ages, over a wide range of microenvironments, and should include mixed stands.

Erefur (2005) has reviewed some literature dealing with effects of local conditions (gap) for tree establishment and growth.

The present investigation is a contribution to research on the multifacetted impact of micro-environmental conditions. A forest yield experiment was analysed on the basis of data collected 13, 20 and 31 years after establishment by planting. The primary aim of the experiment was to test the hypothesis that mixed stands of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), growing in a certain range of site quality, give a higher volume yield than the average of pure stands (Jonsson, 1962).

The data were collected to elucidate key factors that affect yield, such as the susceptibility of the tree species to microsite conditions, both during stand establishment (Jonsson, 1999) and in the early growth phase. The data were used to correlate plant/tree survival and mortality, height increment and volume growth of Scots pine and Norway spruce trees in pure and mixed stands, with the cover of various species of field-layer vegetation (including grasses and dwarf shrubs), fertilisation, frost hollows, logging residues, and stump occurrence, at the local scale of circular plots with 3-m radius (microsites).

The tree species mixture was also considered, together with the distribution in space and development over time of field-layer vegetation.

## Materials and Methods

### Geographical location, climatic conditions and experimental site

The experimental site is in the municipality of Arjeplog, at Lilla Laxsjön, in Swedish Lapland (65º58´N, 18º23´E), on a north-facing slope 510–535 m above sea-level (a.s.l.). In this area, the vertical distance of the site below the generalised tree limit on a northern slope is *ca*. 75 m for Scots pine and *ca*. 125 m for Norway spruce (Kullman & Hofgaard, 1987). The local climate is continental, and extremely cold compared to Swedish conditions generally (Hägglund & Lundmark, 1982). The average slope gradient is 7º.

The nearest meteorological station is at Arjeplog, 428 m a.s.l., *ca*. 25 km W of the experimental site. Between the years 1951–1980, the mean annual air temperature at Arjeplog was –0.5 ºC, and the mean temperatures for June, July and August were 10.5 ºC, 13.2 ºC and 11.5 ºC, respectively (Eriksson, 1982). The mean annual precipitation was 520 mm for the same period, and the mean precipitation for June, July and August was 50, 80 and 73 mm, respectively (uncorrected values); the corrected mean annual precipitation was 620 mm (Eriksson, 1983).

At the experimental site, the mean temperature from June to August probably was 0.5 ºC lower than that for Arjeplog (Odin *et al.,* 1990). According to Odin *et al*. (1983), the duration of the growing season at the site is estimated at *ca*. 130 days (threshold temperature 5 ºC). On average, the growing season begins around 15 May, and ends around 20 September. The total temperature sum is *ca*. 600 units, obtained by summing days with a mean diurnal temperature >5 ºC (with an approximate correction for continentality).

The soil moisture status at the site is mesic. The soil is morainal, with particle sizes 20–6 mm, 6–2 mm and <2 mm comprising 9%, 11% and 80%, respectively.

The original stand at the site was mainly old Norway spruce. According to the classification of Hägglund & Lundmark (1977, 1982) the site indices, assessed by means of site properties, are T16 and G14, *i.e*. the dominant height for 100-year-old Scots pine and Norway spruce stands is expected to be 16 m and 14 m, respectively.

### Experimental design and denotations

The experiment was laid out in ten randomised blocks, each including three 30×40 m parcels with 5-m borders (*i.e*. 30 parcels in all), to a total area of 6 ha. Three treatment levels: a pure Scots pine stand ('PI' in Jonsson (1999); here 'Pine stand'), a pure Norway spruce stand ('SP' in Jonsson (1999); here 'Spruce stand') and a stand with Scots pine and Norway spruce in equal numbers ('MI' in Jonsson (1999); here 'Mixed stand'), were randomly assigned to the parcels within each block. All stands were established with bare-root seedlings.

All observations were made on 360 individual circular plots, each of radius 3 m. Twelve such plots were laid out systematically in each parcel. In the present paper, the statistical analysis was applied at the level both of circular plots (microsites) and of parcels.

In what follows, the 30×40 m parcels are denoted 'parcels' and the circular plots of radius 3 m are denoted simply 'plots'.

## Recapitulation of treatments and observations

Results from the experiment, and detailed information from its inception up to 1995, as regards the provenance of the planting stock, silvicultural measures, observations on the field-layer vegetation and on the stand, are reported in Jonsson (1999).

### Silvicultural measures

Clearfelled, 1972/73. Soil scarification by means of the TTS-harrow, 1974. Stand establishment with bare-root seedlings, 1975.

### Field-layer vegetation

The following information is available for analysis of the state and dynamics of the field-layer vegetation:

In 1988, the percentage cover of total *Deschampsia flexuosa* (L.) Trin., lush (*i.e.* blue-green and vigorous) *D. flexuosa* and bilberry (*Vaccinium myrtillus* L.) was estimated on all plots, but not that of crowberry (*Empetrum hermaphroditum* Hagerup). Cover was recorded separately for each individual plot.

In 1995, the cover of total *D. flexuosa*, lush *D. flexuosa*, bilberry, cowberry (*V. vitis-idaea* L.) and (for the first time) crowberry, was recorded on all 360 plots.

In 2007, the cover of total *D. flexuosa*, lush *D. flexuosa*, bilberry, cowberry and crowberry, was recorded on all 360 plots.

### Tree stand

The following information is available for analysis of the state and dynamics of the tree stand:

In 1988, several observations were made on live seedlings and trees, and recorded for individual plots. The number of dead seedlings and trees was also recorded.

On each plot, the following were measured and recorded: (1) stumps, with respect to the number of stumps with diameter >15 cm, (2) the occurrence and depth of frost hollows, and (3) the cover of logging residues, which were concentrated into four straight, parallel strips over the research area, each strip being 3–6 m broad.

In 1994, all living trees were measured with respect to height in 1994 and five years earlier, and recorded by species for individual plots.

In 2006, the same measurements were made as in 1994 (Jonsson, 1999). Thus, tree height in 2006 and five years earlier, and breast-height diameter (DBH), were recorded by species for individual plots.

### Fertilisation

In 1994, half of each parcel (‘sub-parcel’) was fertilised. Thus after 1994, there were two equal subsamples of plots: unfertilised and fertilised, which are separately identified in the data. In the records from 1988, the designations ‘unfertilised’ and ‘fertilised’ were applied in order to distinguish between the samples, even though this is strictly incorrect, because both were unfertilised at the time. It should be borne in mind that material designated as ‘1988’ and ‘2007’, without distinction, refers to both samples in the years in question. Fertiliser composition and dosage are given in Jonsson (1999).

### Previous stand

The previous stand consisted of old Norway spruce. Its importance to the field-layer and to tree growth was studied in the present paper. For this purpose, the occurrence of stumps, *i.e.* the number of stumps >15 cm in diameter, was recorded on every individual plot.

## Statistical model

In the present study, the following mixed covariance model was employed. This is referred to as 'the Mixed model'.

$$y_{ijk} = \mu + \alpha_i + b_j + (\alpha b)_{ij} + \beta_1 \cdot x_{ijk} + \beta_2 \cdot x^2_{ijk} + e_{ijk}$$

where

$y_{ijk}$ = the dependent variable (e.g. percentage cover)

$i$ = treatment (pine, spruce, mixed stand)

$j$ = block

$k$ = plot within treatment × block

$\alpha_i$ = fixed treatment effects

$b_j$ = random block effects

$(\alpha b)_{ij}$ = random interactions treatment × block

$\beta_1, \beta_2$ = coefficients for the covariates (independent variables) $x_{ijk}$, $x^2_{ijk}$

$e_{ijk}$ = independent $N(0, \sigma^2)$

For numerical analysis of the data according to the above model, a program from the statistical package Minitab /Release 14 was used, *viz.* ANOVA/General Linear Model.

Note that this program employs the normalisation customary in the mathematical theory for such models,

$$\sum \alpha_i = 0; \text{ e.g. } \alpha_{Pine\ stand} + \alpha_{Spruce\ stand} + \alpha_{Mixed\ stand} = 0.$$

To test whether a true parameter value equals 0, the F-test (or *t*-test) is used and the result is judged by the p-value. By the above normalisation, this tests whether the effect of the treatment Pine stand differs from the mean of the treatments (grand mean); the same applies to the treatments Spruce and Mixed stand. When data from only two treatments are analysed (*e.g.* Pine stand and Mixed stand), the difference in the effect of these treatments can readily be calculated. It is twice the value calculated by the program and with the same p-value as the calculated value.

The program calculates the difference between the treatment means (two or three) and the grand mean, all adjusted for the values of the covariate, *i.e.* the estimated value of the $\alpha_i$. The estimated values are reported in the present paper together with their p-values, for testing whether single $\alpha_i$ equals zero. For these tests, the program treats block effects as fixed, not random. This implies that the conclusions drawn from the p-values are valid only within the experiment, and cannot be extended to a wider population. This is especially to be noted.

The error rate in these tests is per test. For pairwise comparisons among three treatments, Tukey's test was applied, implying a familywise error rate, but still with fixed block effects. When there is significance according to a 5% significance level, this is reported.

In a variance analysis approach, we would consider the block effects as random (see the Mixed model), testing hypotheses also for a wider population. The p-values obtained in this case do not in general show significance, and are not reported here.

### Causal interpretation

The Mixed model yields statistical results (covariates-correlations), which are not strictly causal relationships. The models on which the analysis is based are, however, founded in biological knowledge and assessments, hence the statistical results should be capable of biological interpretation. The author has therefore elected to interpret the results causally, and to make statements about causation on the basis of the statistical results. The aim of the study was to acquire knowledge about biological effects.

# Results

## Field-layer

### Denotations

In this section, cover is expressed in the functions in *per cent* of the area; in other sections it is expressed as decimal degree of cover (see the table heads).

The reference, *e.g.* Table 15a:f1, denotes function 1 in Table 15a. When a p-value is given as 0.000***, it strictly refers to the p-value p<0.001***.

In the present study, lush *D. flexuosa*, crowberry and bilberry are hypothetically regarded as species that indicate site quality; hence they are called 'indicator species'.

## Dynamics of field-layer

An overview of the dynamics of the field-layer is given in Table 1 and Figure 1a. A distinction is made between unfertilised plots and plots fertilised in 1994. Note that fertiliser had not yet been applied in 1988; thus all plots were then unfertilised.

### Lush D. flexuosa

From Table 2, Figure 2a and Table 4:f1, it may be seen that the cover of lush *D. flexuosa* in 1988 increased with the number of recorded stumps/ plot with diameter >15 cm, up to *ca*. 2.5 stumps/ plot (*i.e. ca*. 900 stumps $ha^{-1}$), beyond which there was a slight decrease. In that year, the percentage cover was on average 13% in relation to the number of stumps. Seven years later, in 1995, cover on the unfertilised section of the parcels was only 1%. On the fertilised section, it was on average 12% (Table 2 and Figure 2b); fertiliser was applied in the preceding year. The effect of fertilisation increased markedly with the cover of lush *D. flexuosa* in 1988, as shown in Table 3, Figure 3b and Table 4:f3.

When they occur contiguously, lush *D. flexuosa* and crowberry are each other's opposite. Table 3, Figure 4a and Table 6:f4 show how the occurrence of lush *D. flexuosa* decreased with increasing cover of crowberry, when they were growing close together on the plots (and *vice versa*; see below).

When the effect of crowberry was taken into account, the cover of lush *D. flexuosa* in 2007 was highly significantly higher in the Pine stand, and lower in the Spruce stand, than the mean for the experiment (Table 6:f4).

The p-value for the difference between the cover in the Pine stand and the Spruce stand was 0.000***, while the p-value for the difference between the Spruce stand and the Mixed stand was 0.016*.

### 'Total D. flexuosa'

The cover of 'total *D. flexuosa*' in 1988 increased with the number of stumps (Table 2, Figure 2c); seven years later, this relationship had disappeared. The mean cover on the plots in 1988 was 27%. On the unfertilised section of the parcels it was 29% in 1995, and on the fertilised section 40% (Table 1).

Table 3 and Figure 3c show that the more lush *D. flexuosa* there was in 1988, the more 'total *D. flexuosa*' there was in 1995. Table 3 and Figure 4b show that the cover of 'total *D. flexuosa*' in 1988 decreased with an increase in the occurrence of crowberry in 1995; Table 6:f3 shows the same relationship for these species in 2007.

When the effect of crowberry was taken into account, the cover of total *D. flexuosa* in 2007 was highly significantly higher in the Pine stand, and lower in the Spruce stand, than the mean for the experiment (Table 6:f3).

The p-value for the difference between the cover in the Pine stand and the Spruce stand was 0.000***.

### Crowberry

Table 2, Figure 2a and Table 4:f2 show that the cover of crowberry in 1995 decreased with increasing number of stumps per plot. On average, it was 10% relative to the number of stumps (11% on unfertilised and 9% on fertilised plots).

The same relationship is evident from Table 2, Figure 5a and Table 6:f1, *i.e.* that the cover of crowberry in 2007 decreased with increasing number of stumps per plot. On average, it was 29% on both unfertilised and fertilised plots (Table 1).

The cover of crowberry in 1995 decreased with increasing cover of lush *D. flexuosa* in 1988 (Table 3, Figure 3a and Table 4:f4). Table 5a, Figure 5b and Table 6:f2 show the same relation for crowberry in 2007 *vs.* lush *D. flexuosa* in 1988.

When the effect of stumps and lush *D. flexuosa*, respectively, in 1988 was taken into account, the cover of crowberry in 2007 was highly significantly higher in the Spruce stand, and lower in the Mixed stand, than the mean for the experiment (Tables 6:f1 and f2).

The p-value for the difference between the cover in the Spruce stand and that in the Mixed stand was 0.000*** (Table 6:f1) and 0.005** (Table 6:f2).

Figure 1b shows the cover of crowberry in 2007 by blocks and treatments. Mean cover on the plots was 28% (SD 17%) in the Pine stand, 33% (SD 15%) in the Spruce stand and 26% (SD 18%) in the Mixed stand. The difference between the Spruce stand and the Mixed stand was almost significant ($p = 0.063$); in this variance analysis, the block effect was treated as random.

### Bilberry

No relationship could be seen between the cover of bilberry in 1988 or 1995, and the number of stumps (Table 2 and Figure 2d). The cover of bilberry was on average 41% in 1988, and 31% in 1995 (Table 1).

The cover of bilberry in both 1988 and 1995 decreased with increasing cover of lush *D. flexuosa* in 1988 (Table 3 and Figure 3d; Tables 4:f5 and 4:f6); the decrease in 1995 was smaller.

The relationship between bilberry and crowberry changed with time. The cover of bilberry in 1988 increased with increasing cover of crowberry in 1995 (Table 3, Figure 4c and Table 4:f7). From Table 3 and Figure 4d, it is evident that this relationship did not persist in 1995.

The cover of bilberry in 2007 decreased with increasing cover of crowberry in 2007 (Table 5b, Figure 5c and Table 6:f5).

With an increase in the cover of crowberry between 1995 and 2007, there was a parallel decrease in the cover of bilberry, as shown by Table 5c, Figure 5d and Table 6:f6. This is especially noticeable.

### Cowberry

The cover of cowberry was on average 2% in 1995 and 5% in 2007.

## Tree numbers and mortality

Unfortunately, there was no seedling inventory immediately after the establishment of the experiment in 1975, which hinders analysis of the development of the tree population from the beginning. However, an attempt was made to reconstruct the initial situation in 1975 (Table 7).

A further weakness is that recording of the tree population in 1988 did not differentiate between pine and spruce, although the species of dead seedlings was recorded at that time.

The intended plant spacing was 1.5×2.5 m, which should give 2667 plants $ha^{-1}$. In Tables 3 and 4 in Jonsson (1999), the information in Table 7 of the present paper was taken from the 1988 inventory. According to this, the reconstructed number of plants in 1975 was 2623 plants $ha^{-1}$ as an average for the treatments, *i.e.* only 2% fewer than the intended number.

On the basis of the reconstructed total number of plants (Table 7) and information on living plants both in that table and in Table 9 and Figure 6, the development of the number of living plants and trees was analysed (Table 8). Figure 6 shows the development of the number of undamaged and slightly damaged trees at the inventories in 1994 and 2006, assorted by blocks and treatments.

### Mortality

During the period 1994–2006, mainly spruce died. In that period, in the whole experiment, 24 pines and 276 spruce $ha^{-1}$ died (Table 9).

Mortality among spruces in particular was studied. The study showed (Table 10) that mortality significantly decreased with increasing cover of lush *D. flexuosa*, but significantly increased with increasing cover of crowberry.

### Plots without trees in 2006

Some plots were treeless in 2006 (blank plots). The probability of that was analysed by Sören Holm (see Acknowledgements), by means of binary logistic regression.

The investigated variable was categorical, with two classes: 1 if the plot lacked trees, and 0 if trees were present. Binary logistic regression investigates the probability that $y = 1$, denoted $P(y = 1)$. This probability is considered to depend on various background variables, such as block, treatment, cover of various species, *etc*.

In binary logistic regression, the model usually has the following form:

$$P(y_i = 1) = \frac{e^{\alpha + \beta \cdot x_i + \ldots}}{1 + e^{\alpha + \beta \cdot x_i + \ldots}}, \quad (1)$$

where $x_i$, *etc*., is the value of the background variables (continuous or categorical, converted into indicator variables). The parameters $\alpha$ and $\beta$, *etc*., are estimated by the Maximum Likelihood method. The estimated values of these parameters, inserted into the right-hand side of (1), give estimated values of $P(y = 1)$.

### Tested variables without frost hollows

Of several tested variables, bilberry gave the only clear result. A high cover of bilberry in 1988 (Bilberry88— analogous notation for other plant species and years), gave a lower probability of a blank plot; the β-coefficient for cover was –0.0425 and $p = 0.005$**. With simultaneous use of the cover of both Bilberry95 and Crowberry95, the β-coefficient was 0.0465 for the latter variable, which was almost significantly different from 0 ($p = 0.061$). For Bilberry95, the β-coefficient was –0.0891, and $p = 0.005$**.

In other words, when the cover of bilberry increased, the probability of a blank plot decreased, whereas it increased with increasing cover of crowberry.

### Frost hollows

It is well known (*e.g.* Andersson, 1968) that frost kills tree seedlings. Of 360 plots, three were classified as marked frost hollows. All three were also blank plots. The estimated probability of a blank plot is thus 1 for such plots.

For the remaining 357 plots, the indicator variable 'slight frost hollow' was tested together with other variables by means of logistic regression. The β-coefficient for 'slight frost hollow' differed strongly from 0; the coefficient was 2.1851 and p was 0.000***. Of the other variables, Bilberry88 was again the variable that demonstrably differed from 0; the coefficient was –0.0352 and p = 0.032*.

For a 'slight frost hollow', the probability of a blank plot increased strongly, whereas it decreased with increasing cover of bilberry.

It was also found that most of the 'slight frost hollows' affected the treatment Pine stand (17 of 25 were 'marked' or 'slight').

## Tree height in 2006 and height increment

### Analysis of variance of tree height and height increment by parcels and treatments

As noted above, all trees on plots were measured in 2006 with respect to breast-height diameter, height and height increment during the preceding five years. Data were recorded for individual trees, assorted by species on each plot (Table 11).

From these data, parcel mean height and mean height increment were calculated by tree species. Four different parcel means were calculated:

(1) Arithmetic mean for trees >1.3 m tall;

(2) Diameter-weighted mean for trees >1.3 m tall (Figures 7 a-d);

(3) Basal-area weighted mean for trees >1.3 m tall; and

(4) Arithmetic mean of the height of the tallest tree and the largest 5-year height increment, by species and plot, denoted plot maximum height and plot maximum height increment, respectively; here representing the arithmetic means of trees >0 m tall.

Table 11 shows the arithmetic means of these types of parcel mean for the various treatments. The parcel means are the basis for the analysis of variance, which estimates the p-values for differences between treatment means.

The table shows throughout for the various types of calculated parcel mean, that

- the mean height of pine was greater in pure stands than in mixed stands, although the difference was only slightly significant;
- the mean height of spruce was greater in mixed than in pure stands, with slight significance for the diameter-weighted parcel mean;
- the mean height increment of pine was greater in pure than in mixed stands, with considerable significance for differences in the arithmetic and diameter-weighted means;
- the mean height increment of spruce was greater in mixed than in pure stands, with considerable significance for differences in arithmetic and diameter-weighted parcel means.

### Studies at plot level of diameter-weighted mean height and mean height increment vs. the cover of indicator species

The larger and more vigorous trees on the plots were of particular interest, since they will form the future stand. Particular emphasis was placed on such trees, by using the DBH of each tree as a weight when calculating mean height and height increment.

Thus, diameter-weighted mean height and height increment were calculated by species for trees >1.3 m tall in different strata; such strata were based on the cover per plot of indicator species of the field-layer (see above). The values of these height characters are shown by species and stands, in relation to lush *D. flexuosa* in 1988 in Table 12 and Figure 8; in relation to crowberry in 1995 in Table 13 and Figure 9; and in relation to bilberry in 1988 in Table 14 and Figure 10.

The tables and figures show that diameter-weighted mean height and diameter-weighted mean height increment:

- increased slightly in pine with increasing cover of lush *D. flexuosa*;
- increased strongly in spruce with increasing cover of lush *D. flexuosa*;
- decreased slightly in pine with increasing cover of crowberry and bilberry; and
- decreased strongly in spruce with increasing cover of crowberry and bilberry.

These results were applicable to all types of treatment.

### Plot-level studies of height and height increment of individual trees with the Mixed model

*Variables*

In these studies, the maximum height of trees by species in 2006, and the largest 5-year height increment by plots, were used. These characters are of especial interest to forestry. The number of pines and spruces refers to the year 2006.

Because effects on tree growth are expected to be multiplicative ('percentage'), a logarithmic model was chosen for the analysis. This implies that the dependent variable, and some independent variables, were logarithmic in the mixed regression model (natural logarithm).

*Cover*

In the following analyses made with the Mixed model, cover is expressed as the decimal degree of cover (not percentage) of each plot.

*Indexed independent variables for analysis of the fertiliser effect*

Some indexed independent variables were used to study the interaction between the cover of indicator species and fertilisation. Thus, one variable consists of the cover per plot (in a certain year) for the unfertilised sub-parcels, with a similar variable for the fertilised sub-parcels. In this way, the fertiliser effect can be differentiated according to the cover of various species of the field-layer.

Alternative indexed independent variables and their β-coefficients were either separate

(V1) $\beta_{unfertilised} \,.\, cover_{unfertilised} + \beta_{fertilised} \,.\, cover_{fertilised}$

or, with treatment 'unfertilised' as reference,

(V2) $\beta_0 \,.\, cover + \beta_{1,fertilised} \,.\, cover_{fertilised}$

In the latter case, $\beta_0$ is the coefficient for unfertilised sub-parcels, and $\beta_{1,fertilised}$ is the difference between the coefficients for fertilised and unfertilised, permitting a test to be made for a non-zero difference.

In what follows, results are reported in terms of the first alternative. Where there is significance according to $p \leq 0.05$ for $\beta_{1,fertilized}$, this is reported.

### Independent variables for analysis of the effects of stand establishment and productive capacity

The height of the tallest tree per plot, as well as the largest tree-height increment per plot— but principally, stand volume— may be regarded as a function of tree establishment and survival (No. of trees in 2006) and of the productive capacity ('site quality') of each plot. According to this, two different analytical regression models can be distinguished:

(V3) dependent variable = f(*E, B*) =
$\beta_{\text{No. trees}}$ · No. of trees + $\beta_{\text{site quality}}$ · site quality

(V4) dependent variable = f(*E, B*) =
$\beta_{\text{(establishment, site quality)}}$ · site quality,

where the dependent variable is one of the abovementioned growth characteristics; *E* is establishment and *B* is site quality.

In the first model (V3), establishment/survival is specified by the number of pines or spruces in 2006; $\beta_{\text{No.trees}}$ is the effect of the number of trees of the appropriate species. In the second model (V4), the effect of establishment/survival is incorporated in $\beta_{\text{(establishment, site quality)}}$ for the site quality variable; the effect of both establishment/survival and site quality is included in this β-coefficient. The term 'site quality' expresses the intrinsic site productive capacity and any fertilisation applied. The intrinsic site quality is indicated by certain species of the field-layer ('indicator species'; see above).

### Utilised observations on species of the field-layer vegetation

As noted above, the cover of various species in the field layer was recorded on several occasions. In 1988, 1995 and 2007, total *D. flexuosa*, lush *D. flexuosa*, bilberry and cowberry were recorded on all 360 plots. In 1995 and 2007, crowberry was also recorded.

Analyses were also made on the basis of these observations

- in 1988 for lush *D. flexuosa*, for crowberry in 1995 and for bilberry in 1988 or
- in 1988 for lush *D. flexuosa* and in 2007 for crowberry and bilberry.

The cover of lush *D. flexuosa* in 1988 was used throughout these analyses, because this species, which is sensitive to fertilisation, was not then affected by fertiliser, which was first applied in 1994. Thus, the occurrence of lush *D. flexuosa* indicates microsites unaffected by fertiliser in 1988, both on entirely unfertilised sub-parcels, and on sub-parcels which were later fertilised. This is of importance to the analyses, as will appear below.

For reasons of space, mainly results based on simultaneously observed sets of variables in 1988 for lush *D. flexuosa* and bilberry, and for crowberry in 1995, are reported here. These observations fall in the middle of the experimental period thus far. The results from the years in question were in good agreement with those for lush *D. flexuosa* in 1988, and those for crowberry and bilberry in 2007.

### Functions for maximum tree height and maximum tree height increment

In these studies, as already noted, the height of the tallest tree and the largest 5-year height increment by species per plot were used as dependent variables, after transformation to their natural logarithms. These variables were then related to block (random) and treatment (fixed), and plotwise to independent variables (covariates), in the Mixed model.

Height and height increment of pine were studied in Pine and Mixed stands, and of spruce in Spruce and Mixed stands. The results are shown in Tables 15(a-f).

### Variable: Tree number

The probability of finding a taller maximum height tree of a species, and a larger maximum height increment, is greater on plots with many trees than on plots with few trees (statistical effect). There are more pine trees in the Pine stand than in the Mixed stand, and more spruce trees in the Spruce stand than in the Mixed stand. In all relevant functions in Table 15(a-f), the p-value was 0.000*** for the β-coefficients for ln [No. pines per plot] and ln [No. spruces per plot], respectively.

### Pine stand and Spruce stand vs. Mixed stand

Case (1). In functions for height and height increment which contain ln [No. pines per plot] and ln [No. spruces per plot], respectively, as independent variable, the α-values for the Pine stand *vs*. the Mixed stand were consistently positive, but weak, with p-values between 0.115 and 0.278 (Tables 15a:f3 and 15d:f3). For the Spruce stand *vs*. the Mixed stand, they were consistently negative, with p-values between 0.011** and 0.140 (Tables 15d:f4 and 15e:f2).

Case (2). In functions in which ln [No. pines per plot] and ln [No. spruces per plot] were not present as independent variables, the α-values for the Pine stand *vs*. the Mixed stand were consistently positive, with p-values between 0.004** and 0.008** (Tables 15b:f1 and 15d:f1). For the Spruce stand *vs*. the Mixed stand, they were consistently positive, but weak, with p-values between 0.404 and 0.821 (Tables 15f:f2 and 15b:f2).

In Case (1) above, the statistical effect was eliminated, leaving only the treatment effect. This implies that height and height increment were slightly greater in the Pine stand than in the Mixed stand, *cf*. Table 11. In contrast, for spruce, height and height increment were significantly lower in the Spruce stand than in the Mixed stand (Table 11).

In Case (2) above, the positive statistical effect was added to the treatment effects according to Case (1). This resulted in the overall effect for pine being significantly greater (**) in the Pine stand than in the Mixed stand. For spruce in the Spruce stand, the statistical effect was positive, but the treatment effect in relation to the Mixed stand was negative, which led to a very weak overall effect.

It should again be pointed out that the comparison was made with the grand mean of the treatment effects.

### Lush D. flexuosa in 1988

As mentioned above, indexed variables were used to differentiate possible fertiliser effects. Thus, one variable for lush *D. flexuosa* in 1988 consists of the cover per plot on the unfertilised sub-parcels, and a similar variable of cover per plot on the fertilised sub-parcels (see *e.g*. Table 15b).

The β-coefficients for these variables for pine in the Pine and the Mixed stand were consistently weak, with non-significant p-values.

The β-coefficients for these variables for spruce in the Spruce stand and the Mixed stand were consistently strongly positive, with significant p-values. The $\beta_{fertilised}$-coefficients were consistently larger than the $\beta_{unfertilised}$-coefficients; in Table 15c:f4, the difference between these coefficients was significant, p-value 0.05*, and in Table 15e:f4, the p-value was 0.073.

### Crowberry 1995 and 2007

Indexed variables, similar to those for lush *D. flexuosa* above, were used.

The β-coefficients for these variables for pine in the Pine stand and the Mixed stand were consistently negative, with non-significant p-values, with the exception of the $\beta_{unfertilised}$-coefficients in Table 15a:f3 (p-value 0.025*) and Table 15b:f1 (p-value 0.023*).

The β-coefficients for these variables for spruce in the Spruce stand and the Mixed stand were consistently strongly negative, with significant p-values. The $\beta_{fertilised}$-coefficients were consistently larger than the $\beta_{unfertilised}$-coefficients in all functions; in Table 15d:f2; the difference between these coefficients was significant, with p-value 0.046*.

### Bilberry

The β-coefficients for these variables for pine in the Pine stand and the Mixed stand were negative, with non-significant p-values, with the exception of the $\beta_{unfertilised}$-coefficient in Table 15a:f1 (p-value 0.048*).

The β-coefficients for these variables for spruce in the Spruce stand and the Mixed stand were likewise negative, with non-significant p-values.

### Logging residues

It should be noted that the strips of logging residues covered 5% of the area, and affected only 57 (*i.e.* 16%) of the 360 plots. The mean cover of logging residues on the 57 plots was 30% (SD 20%); the median value of cover was also 30%.

The β-coefficients for the variable (*logging residues*)$^2$ for pine in the Pine stand and Mixed stand were negative, with non-significant p-values in both regression models, where ln [No. pines per plot] as independent variable was present or absent, respectively (Tables 15(a-d)).

The β-coefficients for the variable (*logging residues*)$^2$ for spruce in the Spruce and Mixed stand were strongly positive.

In functions which contained ln [No. spruce per plot], but not bilberry, as independent variable, significance for $\beta_{(logging\ residues)^2}$ was consistently strong (p-value 0.000*** or 0.001***).

In functions which did not contain ln [No. spruce per plot] and bilberry as independent variables, $\beta_{(logging\ residues)^2}$ was weakly positive (p-values between 0.093 and 0.400).

### Stump frequency

The β-coefficients for this variable (No. stumps per plot) for pine in the Pine stand and Mixed stand were positive, with significant p-values in the regression models which contained ln [No. pines per plot] as independent variable (Tables 15b:f3 and 15d:f3).

The β-coefficients for this variable for spruce in the Spruce stand and the Mixed stand were positive, with strongly significant p-values in the regression model which contained ln [No. spruces per plot] as independent variable (Tables 15b:f4 and 15d:f4).

## Stand volume in 2006

### Stand volume at parcel level

*Volume determination of individual trees*

As noted above, DBH and height were measured on all trees on all plots in 2006, and recorded individually and by species and plot. The volume of each such tree was estimated as follows:

- for trees of DBH <51 mm, according to Andersson's volume functions (Andersson, 1954) for pine and spruce, respectively, in northern Sweden,
- for trees of DBH >50 mm, according to Brandel's volume functions for Pine – northern Sweden: Function 100-01 (Table 1211 in Brandel, 1990)Spruce – northern Sweden: Function 100-01 (Table 1221 in Brandel, 1990).

Tree volumes thus calculated were summed by plots, by species and DBH strata and in total for each plot. Parcel volumes were then calculated from these data, assorted by species and DBH strata and for treatments as a whole (Table 16a and Figure 11a).

*Comparison of certain stand volumes in 2006*

In Table 16a, the difference in the total stand volume on bark (o.b.) between the Pine stand and the Mixed stand (34.1 and 28.6 m$^3$ ha$^{-1}$, respectively), gave a p-value of 0.430. This was calculated on the basis of an analysis at parcel level, comprising 2×10 parcel volumes.

The total stand volume of spruce (o.b.) was approximately equal in the Spruce stand and the Mixed stand (7.6 and 8.3 m$^3$ ha$^{-1}$, respectively). Total stand volume (o.b.) for trees with DBH <51 mm was 1.2 m$^3$ ha$^{-1}$ in the Spruce stand, and 0.7 m$^3$ ha$^{-1}$ in the Mixed stand. From the analysis of variance, the difference was significant, with a p-value of 0.003**. This was calculated on the basis of an analysis at parcel level, comprising 2×10 parcel values.

Thus, in the Spruce stand, 16% of spruce volume consisted of trees of DBH <51 mm, while in the Mixed stand, the corresponding volume was only 8%.

*Stand volume by parcels vs. cover of indicator species*

Table 16b shows that stand volume and cover of crowberry per parcel were consistently negatively correlated in 2007. The β-coefficients for this variable varied between –3.239 in f9 and –4.217 in f3, the p-value in the former being 0.027* and in the latter, 0.046*. The functions are based on 30 and 20 parcel values, respectively.

The correlation with lush *D. flexuosa* in 1988 was positive in the Spruce stand and the Mixed stand, but not significant. In f7, the β-coefficient was 2.943 and the p-value 0.076.

*Basal-area weighted mean diameter and mean tree volume*

The larger is the stand volume of a tree species, the larger are its basal-area weighted mean diameter and arithmetic mean volume for trees of DBH >0 mm. Both of these characters were significantly smaller for spruce in the Spruce stand than in the Mixed stand (Table 16c).

*The structure of tree volume*

The volume structure for pines with DBH >0 mm was rather similar in the Pine stand and the Mixed stand: the arithmetic mean volume (o.b.) was 35.5 and 33.6 $dm^3$ (SD 22.2 and 21.7 $dm^3$, respectively; Table 16d).

The corresponding volume for spruce was 51% greater in the Mixed stand than in the Spruce stand: 10.4 and 6.9 $dm^3$ (SD 15.1 and 11.3 $dm^3$, respectively).

### Plot-level studies of stand volume per plot vs. cover of indicator species

Mean stand volume per plot in 2006 *vs.* lush *D. flexuosa* is reported in Table 17 and Figure 12, and *vs.* crowberry in 1995 in Table 18 and Figure 13.

The tables and figures show that, with increasing cover of lush *D. flexuosa*, stand volume per plot

- showed no trend in the Pine stand;
- increased strongly in the Spruce stand;
- increased strongly in the Mixed stand; and

with increasing cover of crowberry

- decreased markedly in the Pine stand;
- decreased slightly in the Spruce stand;
- decreased markedly in the Mixed stand.

### Plot-based studies of stand volume per plot according to the Mixed model

These studies were carried out similarly to those for height and height increment. The term 'spruce proportion' means 'spruce numerical proportion' (decimal).

(1) Table 19a reports stand volume per plot in 2006 in relation to certain variables, according to the following two regression models:

*(a)* without ln [No. trees per plot] and Spruce proportion per plot *vs.* cover of an indicator species on fertilised and unfertilised parcels, respectively; and

*(b)* as *(a)* above, but including both ln [No. trees per plot] and Spruce proportion per plot as independent variables.

As expected, ln [No. trees per plot] and Spruce proportion per plot in 2006 were strongly correlated with the dependent variable (p-value 0.000).

For the Pine stand, ln [stand volume per plot] and the corresponding cover of the studied indicator variables were not significantly correlated on unfertilised or fertilised parcels.

By contrast, for the Spruce stand there were strong correlations:

- both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for lush *D. flexuosa* in 1988 were strongly positive (p-value 0.000***);
- $\beta_{fertilised}$ was consistently larger than $\beta_{unfertilised}$ (see f2 and f5);
- both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for crowberry in 1995 were strongly negative (p-value 0.002** and 0.003** in f8, and 0.002** and 0.079 in f11);
- both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for bilberry in 1988 were strongly negative (p-value 0.000*** in f14 and f17).

In the Mixed stand too, there were strong correlations:

• both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for lush *D. flexuosa* in 1988 were strongly positive (p-value 0.004** and 0.263 in f3, and 0.000*** in f6);

• both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for crowberry in 1995 were strongly negative (p-value 0.000***); in these cases, the difference between $\beta_{unfertilised}$ and $\beta_{fertilised}$ was highly significant (p-value 0.000*** in f9 and f12);

• both $\beta_{unfertilised}$ and $\beta_{fertilised}$ for bilberry in 1988 were strongly negative (p-value 0.011** and 0.001*** in f15 and 0.000*** in f18).

(2) In Table 19(b-e), stand volume per plot in relation to certain independent variables was analysed according to the following regression models:

*(a)* ln [No. trees per plot] and Spruce proportion per plot in 2006, cover of indicator species on both fertilised and unfertilised parcels, cover of logging residues and treatments as independent variables;

*(b)* as *(a)*, but excluding Spruce proportion per plot as an independent variable;

*(c)* as *(a)*, but excluding both ln [No. trees per plot] and Spruce proportion per plot as independent variables;

*(d)* including ln [No. trees per plot], Spruce proportion per plot, No. stumps per plot, cover of logging residues, fertilisation and treatments as independent variables.

In this case also, ln [No. trees per plot] and Spruce proportion per plot were variables with a strong predictive ability (p-value 0.000***).

For the Pine stand, other tested independent variables were non-significant in all functions.

In the Spruce stand and the Mixed stand, the β-coefficients for the cover of indicator species were highly significant, with the exception of bilberry in 1988 and 2007 (Tables 19b:f2 and 19d:f2), which were therefore excluded from other functions. $\beta_{unfertilised}$ and $\beta_{fertilised}$ for cover of lush *D. flexuosa* in 1988 were positive, the latter being consistently larger.

$\beta_{unfertilised}$ and $\beta_{fertilised}$ for cover of crowberry in 1995 and 2007 were, in contrast, negative; $\beta_{fertilised}$ was always largest, except for $\beta_{fertilised}$ in 2007 in some functions (Tables 19d:f2 and 19d:f4).

In Table 19c:f4, the difference between $\beta_{unfertilised}$ and $\beta_{fertilised}$ was significant (p-value 0.037*).

*Logging residues*

In the Pine stand, $\beta_{(logging\ residues)^2}$ was consistently positive, but not significant.

In the Spruce stand, $\beta_{(logging\ residues)^2}$ was strongly positive (p-value 0.000*** to 0.002**) in functions which contained ln [No. trees per plot] and Spruce proportion per plot as independent variables. In functions from which those variables were excluded, $\beta_{(logging\ residues)^2}$ was not significant.

*No. stumps per plot*

As noted above, the number of stumps with diameter >15 cm was recorded on all plots. As Table 19c:f5 shows, the β-coefficient for such stumps was not significant in the Pine stand (p-value 0.214).

In the Spruce stand, however, it was highly significant (p-value 0.000***), as appears from Table 19c:f6.

*Example of the effect on total volume yield in 2006*

In Table 19f, estimates are given for the Spruce stand and the Mixed stand, of the effect on total volume yield in 2006 of indicator species, fertilisation and logging residues.

## Discussion & Conclusions

Biological conditions on the future experimental area were radically altered by clearfelling. The conditions thus created also changed gradually with time. The biological status of microsites also varied across the experimental area. The present paper deals with the dynamics of various plant species on these microsites, among them, trees.

### Field-layer

The vegetation of the field-layer before clearfelling is carried through to the freshly exposed area, while at the same time, other species appear. Conditions on the clearfelled area favour some plants, but disfavour others. Some plants are more competitive than others on the clearfelled site. Consequently, the occurrence of the various plant species changes with time: the field-layer vegetation is dynamic.

### Stumps and nutrients

Some conditions on the microsite can be related, *via* the stumps, to conditions before clearfelling. Figure 2a and Tables 4:f1 and 4:f2 show that the more stumps (diameter >15 cm) there were on a plot, the greater was the cover of lush *D. flexuosa* in 1988, and the less crowberry there was in 1995. In 1995, there was no such relationship between unfertilised lush *D. flexuosa*, and the number of stumps (Figure 2b); the cover of unfertilised lush *D. flexuosa* decreased from 12% in 1988, to 1% in 1995 (Table 1).

Figures 1, 2b and 3b and Table 4:f3 show that the cover of lush *D. flexuosa* increased markedly on sub-parcels fertilised a year earlier. In 1988, the cover of lush *D. flexuosa* was as great, on average, as that on fertilised sub-parcels in 1995.

This can be interpreted as indicating that lush *D. flexuosa* reflects a good supply of nutrients from tree litter, and that the natural supply of nutrients declines with time. Lush *D. flexuosa* thus indicates sites within the experimental area which have a good nutrient supply.

No observations were made on crowberry in 1988, probably because that species occurred sparsely. A cursory examination of the remainder of the original stand adjacent to the clearfelled area, revealed no crowberry; the stand is dominated by bilberry.

According to Lagerberg (1948), crowberry is a species characteristic of poor soils, and is markedly light-demanding. It is therefore natural for crowberry to colonise nutrient-poor sites on open clearfelled areas. Tables 4:f2 and 6:f1 and Figures 2a and 5a show how the cover of crowberry in 1995 and 2007 decreased as the number of stumps increased, *i.e.* with increased nutrient status. Crowberry thus indicates poor microsites within the experiment.

Figure 2d shows that the cover of bilberry in 1988 and 1995, in relation to the number of stumps, was rather even. Bilberry thus appears not to be sensitive to variations in nutrient supply in the soil of the experiment.

The cover of total *D. flexuosa* in 1988 increased with the number of stumps (Figure 2c). Seven years later there was no such relationship, which may indicate that the natural supply of nutrients had decreased with time, as already noted.

### Cover of other species *vs.* lush *D. flexuosa*

Where they occur together, crowberry and lush *D. flexuosa* are each other's opposites, as shown by Figures 3a and 5b and Tables 4:f4 and 6:f2. The greater was the cover of lush *D. flexuosa* on plots, the smaller was the cover of crowberry on the same plot. *D. flexuosa* is favoured by nutrient-rich sites within the experiment, where it out-competes crowberry, which is more competitive on nutrient-poor sites (see below).

Figure 3b and Table 3 show that the cover of lush *D. flexuosa* was considerably greater in the year following fertilisation, on fertilised than on unfertilised sub-parcels. It also had a faster rate of increase relative to total *D. flexuosa* on fertilised than on unfertilised sub-parcels.

This might be interpreted as indicating that fertilisation has a greater effect on sites of higher nutrient status.

The cover of bilberry decreased both with time and with increasing cover of lush *D. flexuosa* (Figure 3d and Table 3). Thus, lush *D. flexuosa* appears to be competitive also in relation to bilberry.

### Cover of other plant species *vs.* crowberry

The greater was the cover of crowberry, the less was that of lush *D. flexuosa* and total *D. flexuosa* (Table 3, Tables 6:f3 and 6:f4; Figures 4a and b), which agrees well with the relationship between these species, noted above.

The cover of bilberry changed in relation to that of crowberry over time. In 1988, scarcely any crowberry was visible on the research area. At that time, bilberry expanded onto areas that later were colonised by crowberry (Table 4:f7 and Figure 4c). As crowberry successively expanded, the occurrence of bilberry declined (Figure 4d), until in 2007 it had decreased greatly relative to the increased occurrence of crowberry (Table 6:f5 and Figure 5c).

The change in the occurrence of bilberry relative to that of crowberry in the years 1995–2007 is noteworthy. As the cover of crowberry increased, that of bilberry decreased (Tables 5c and 6:f6; Figure 5d).

This might be explained by conditions on the open clearfelled area, which disfavoured bilberry, but favoured crowberry. However, crowberry can also have an allelopathic effect (Zackrisson & Nilsson 1992, Nilsson 1994).

However, the relationship of both crowberry and bilberry with microsite is complex. Where original stand density was high (numerous stumps), the ground would have been shady, disfavouring crowberry, irrespective of nutrient status. Numerous inconspicuous crowberry plants must nevertheless have been present in the original stand, to make possible its subsequent vegetative expansion.

Bilberry, on the other hand, tolerates low light intensity in forest stands, and can survive clear-felling thanks to its extensive rhizome. It can therefore expand rapidly in the early stages of stand establishment. This is a transient phase, later curtailed by higher frost incidence on open areas. Crowberry has a far greater frost tolerance, whereas bilberry is limited to areas where snow lies longest (*cf*. Nilsson & Sandberg, 1982; Carlsson *et al.* , 1999).

### Cover of some indicator species in 2007 *vs.* treatment

When the effect of some factors had been eliminated, the cover of crowberry in 2007 was significantly higher in the Spruce stand than the mean for the experiment. In the Mixed stand its cover was significantly lower (Table 6).

When the effect of crowberry had been eliminated, the cover of *D. flexuosa* was significantly lower in the Spruce stand than the mean for the experiment. In the Pine stand it was significantly higher (Table 6).

The Spruce stand was sparsely stocked, and consequently received a smaller input of nutrients from the tree litter, and more light to the ground, than other treatments. As remarked above, it was therefore natural for crowberry to colonise such nutrient-poor and light areas. The lower occurrence of lush *D. flexuosa* in the Spruce stand than the average for the experiment, also indicates a poorer nutrient status.

Both of these circumstances indicate a poorer nutrient status in 2007 (nutrient degeneration) in the Spruce stand, compared to other treatments.

### Tree numbers and mortality

Table 9 shows that a large number of spruces died during the period 1994–2006; 26% in the Spruce stand and 20% in the Mixed stand. At the beginning of the period, the median height/height of the shortest tree for spruce, was 77/15 cm in the Spruce stand, and 93/13 cm in the Mixed stand.

It has been shown above that the height and height increment of spruce is strongly negatively correlated with the cover of crowberry. The greater the cover of crowberry, the greater is spruce mortality (Table 10).

No observations were made on dead trees in 2006. The subjective impression from field observations was, however, that only spruces shorter than the median height had died, following attacks by *Lophophacidium hyperboreum*. The occurrence of crowberry, which inhibits height growth, may thus indirectly be the cause of the substantial mortality of spruces in the snow-cover.

An increased cover of crowberry increases the probability of blanks, as shown above. This may be caused by the allelopathic activity of crowberry. An increased cover of bilberry, on the other hand, reduces the probability of blanks; this may depend either on the modifying effect of bilberry on the severe local climate (lower radiative heat loss), or on the association between bilberry and the depth and duration of snow-cover.

In an earlier paper, Jonsson (1999) describes and analyses in detail plant survival/mortality in the establishment phase of this experiment (*op. cit.*, Table 11 for an overview). Those results show that Scots pine is more sensitive to site conditions during the stand establishment phase than is Norway spruce— having both lower survival rates and more obviously negative correlations with adverse conditions. The results of the present study show a plant survival of 61% in the Pine stand during the establishment phase (the first 13 years), 89% in the Spruce stand and 77% in the Mixed stand (Table 8).

In the later stages of stand development, spruce was the more vulnerable (Table 9). For the entire period (1975–2006), survival in the experiment was 42% in the Pine stand, 59% in the Spruce stand and 59% in the Mixed stand (Table 8). This is in good agreement with the results of Remröd & Strömberg (1974), Hagner (1989) and Fries (1991).

### Parcel-level study of the mixed-stand effect on tree height and height increment

In an earlier study of a similar experiment, Jonsson (2001) obtained results for height increment that agreed well with those of the present study.

Jonsson (2001) distinguished between three developmental phases in that study (on a site with site index T27— *i.e.* dominant pine height at age 100 years would be 27 m). These stages are summarised here:

(1). Up to stand age 15 years, and at a dominant tree height of *ca.* 5 m for pine and *ca.* 2 m for spruce in mixed stands, there were no differences in dominant height, as compared to the species in pure stands (Table 2; Jonsson, 2001).

(2). During the following years, however, the height increment of dominant spruce trees in mixed stands was significantly greater than that of spruce in pure stands. This resulted in a significantly greater dominant height for spruce in mixed stands (Table 2, Figure 2; Jonsson, 2001). No such differences were found for pine.

Thus, at the early stage of tree development, and before crown closure, there was a favourable, ecological mixed-stand effect on the height growth of spruce. Jonsson argued that the taller pines in mixed stands provided a better growth climate for the shorter, sheltered spruces.

(3). However, the pines continued to grow faster in both height and diameter than the spruces, which resulted in dense, mixed stands with pine trees as dominant and spruce as co-dominant or suppressed. In the crown layer of mixed stands, there was less competition for light than in the crown layer of pure pine stands, owing to the smaller number of dominant trees in mixed stands. Weaker competition for nutrients resulted in a larger DBH for pine trees in mixed stands; weaker competition for light resulted in a lower height for dominant pine trees ($p = 0.087$) in mixed than in pure pine stands (Table 1, Figure 1; Jonsson, 2001).

Overall, Jonsson (2001) concluded that his study may show a mild etiolation effect, as a result of competition for light in the crown layer.

The present study falls within development stages (2) and (3) above. In Table 11, both mean height and mean height increment of pine were greater in the Pine stand than in the Mixed stand, although the significance of the differences was weak. In all cases, the mean height and mean height increment of spruce were greater in the Mixed stand than in the Spruce stand, with some notable significance levels, especially as regards height increment (*cf*. point (2) above).

### Plot-level study of the mixed-stand effect on tree height and height increment

Tables 12-14 and Figures 8-10 show similarly, that diameter-weighted mean height and mean height increment for pine were greater in the Pine stand than in the Mixed stand; and for spruce, that diameter-weighted mean height and mean height increment were greater in the Mixed than in the Spruce stand.

### Plot-level study of the mixed-stand effect on maximum height and maximum height increment

In Table 15(a-e), with ln [No. trees per plot] as the independent variable, it appears that the height and height increment of pine were consistently greater in the Pine stand than in the Mixed stand, although significance levels were low. For spruce, height and height increment were consistently lower in the Spruce stand than in the Mixed stand, sometimes with moderate significance.

In functions from which ln [No. trees per plot] as an independent variable was absent, the effect (statistical effect) of tree numbers is included in the $\beta$-coefficients for the Pine stand and the Spruce stand, respectively. Mixed-stand effects were not isolated in these functions (see above).

In summary, it may be stated that:

• the height increment of spruce is favoured at a stage of canopy closure in Mixed stand , such that the dominant pines shelter the spruces, but do not yet suppress them;

• the height increment of pine is greater in the Pine stand because of the higher degree of canopy closure; in consequence, greater competition for light. This results in etiolation of pine.

### Tree height and height increment *vs.* indicator species, fertilisation and number of stumps

The correlation between height and height increment of pine, and the indicator species lush *D. flexuosa*, crowberry and bilberry, was remarkably weak. Fertilisation had no demonstrable effect. Pine is apparently insensitive to the site characteristics indicated by these indicator species, as also to fertilisation. There was, however, a positive correlation between the height and height increment of pine, and the number of stumps of diameter >15 cm per plot (Tables 15b:f3 and 15d:f3).

In contrast, spruce is extremely sensitive to these site characteristics. Its height and height increment are strongly and positively correlated with the cover of lush *D. flexuosa*, as also with fertilisation and the number of stumps per plot.

However, the height and height increment of spruce are strongly and negatively correlated with the cover of crowberry. In this context, the negative correlation with fertilisation is remarkable; it implies that the greater was the cover of crowberry in 1995, the more negative was the effect of fertilisation. The explanation of this may be that, the more crowberry there was on a plot in 1995, the poorer was the soil (crowberry's typical niche). Trees are optimally adapted to natural sites and to the nutrient regime there. On a markedly nutrient-poor site, fertilisation can serve as a shock to the trees, with a consequent growth reduction.

In 2007, the cover of crowberry was three times that in 1995. Its expansion in the interval may partly have taken place over less nutrient-poor microsites (plots), which give a positive fertiliser effect on the height and height increment of spruce, similar to that of microsites with lush *D. flexuosa*.

The negative and positive effects of fertilisation described here, cause the β-coefficients for the cover of crowberry in 2007 not to differ materially from the corresponding coefficients for unfertilised crowberry (Tables 15e:f3 and 15e:f4).

### Tree volume at parcel level

Table 16d shows that mean tree volume for pine was 33.6 $dm^3$ (o.b.) in the Mixed stand in 2006, and 35.5 $dm^3$ (o.b.) in the Pine stand. This difference was, however, not significant.

The corresponding figure for spruce was 10.4 $dm^3$ (o.b.) in the Mixed stand and 6.9 $dm^3$ (o.b.) in the Spruce stand. The difference is highly significant (p-value 0.001).

The conclusion is that, in 2006, pines in the Pine stand and Mixed stand at the age in question had developed rather similarly. In a similar experiment (Jonsson, 2001), however, the basal-area weighted mean volume of pine was 30% greater in the Mixed stand than in the Pine stand; stand age in that experiment was 43 years, and site index was T27.

In summary, the following conclusions may be drawn as regards tree volume:

• that mean tree volume of pine at the age in question differed little between the Pine and the Mixed stand in 2006. It is, however, to be expected that tree volume of pine will later become larger in the Mixed than in the Pine stand, when nutrient competition between trees increases; in the Mixed stand, the density of dominant pines is lower.

• that the volume increment of spruce is favoured at a stage when stand density in the Mixed stand is such, that the dominant trees shelter the spruces, but do not yet suppress them.

The larger the stand volume of a species, the greater is the mean tree volume of that species (Tables 16c:f3 and 16c:f4); this relationship is highly significant. This possibly indicates that good mutual shelter in young stands can favour tree growth. It may also depend on differences in site quality. In the Spruce stand, the mean volume of spruce was highly significantly lower than that in the Mixed stand.

### Stand volume at parcel level *vs.* indicator species

The parcel stand volume in 2006 was negatively and significantly correlated with the cover of crowberry in 2007 (Table 16b); such a relationship is also evident in Table 18 and Figure 13.

The correlation with lush *D. flexuosa* in 1988 was notably weakly positive in Table 16b, but not for the Pine. In Table 17 and Figure 12, the positive relationship with lush *D. flexuosa* in 1988 was clear, but even here, with the exception of the Pine stand.

The conclusion to be drawn from this, is that stand volume is smaller on microsites which have a high cover of crowberry, and larger on those where there is a high cover of lush *D. flexuosa*. In the case of crowberry, the cause of this may be either a lower soil nutrient content, or allelopathy; whereas in the case of lush *D. flexuosa*, the cause is probably a better nutrient supply.

### Stand volume on plots

None of the functions in Tables 19(a-e) showed a demonstrable effect on stand volume in the Pine stand in 2006, of lush *D. flexuosa* in 1988 or of crowberry in 1995 and 2007. In contrast, they had a large effect on stand volume in the Spruce stand and the Mixed stand. When present together with these indicator species, bilberry had no effect.

As in the case of tree height and height increment, stand volume in 2006 in the Spruce stand and the Mixed stand was positively and significantly correlated with lush *D. flexuosa* in 1988. Fertilisation had a further positive effect.

Crowberry, however, had a significant negative effect, which furthermore was reinforced by fertilisation at the degree of cover recorded in 1995. At the degree of cover recorded in 2007, there was only a small difference in stand volume between unfertilised and fertilised plots where crowberry was present, in functions containing ln [No. trees per plot] and Spruce proportion as independent variables (Table 19d:f4).

The explanation of the latter phenomenon appears to be the same as for height and height increment; the more crowberry there was on a plot in 1995, the poorer was the soil. The cover of crowberry in the experiment was three times larger in 2007 than in 1995. Its expansion in the interval may in part have extended over less nutrient-poor microsites (plots), which would result in a positive fertiliser effect on the height and height increment of spruce, similar to that on sites with lush *D. flexuosa*. These negative and positive effects, respectively, of fertilisation have the consequence that the β-coefficient for the cover of fertilised crowberry in 2007 did not differ substantially from the corresponding coefficient for unfertilised crowberry (Table 19d:f4).

In functions from which ln [No. trees per plot] and Spruce proportion as independent variables were absent (Table 19e:f4), there was, however, a notable difference in stand volume between unfertilised and fertilised crowberry. In this case, both the establishment and the survival of the trees are included in the estimated effect, which implies that the total effect on stand volume is estimated by unfertilised and fertilised crowberry, respectively. As was noted above, the higher was the cover of crowberry, the greater was the mortality of spruce.

### Calculated effects

In Table 19f, an estimate is given of the effect on the volume yield of the Spruce stand and the Mixed stand in 2006, of indicator species, fertilisation and logging residues. This is based on the mean values for cover, given in Table 1.

The estimates must be regarded as approximate. They are admittedly based on significant β-values, but the p-values for these test only whether the true β-value = 0. The p-values give no information about the precision of the β-values, *i.e.* in estimating the effects on volume yield.

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Their help is gratefully acknowledged.

# Appendices

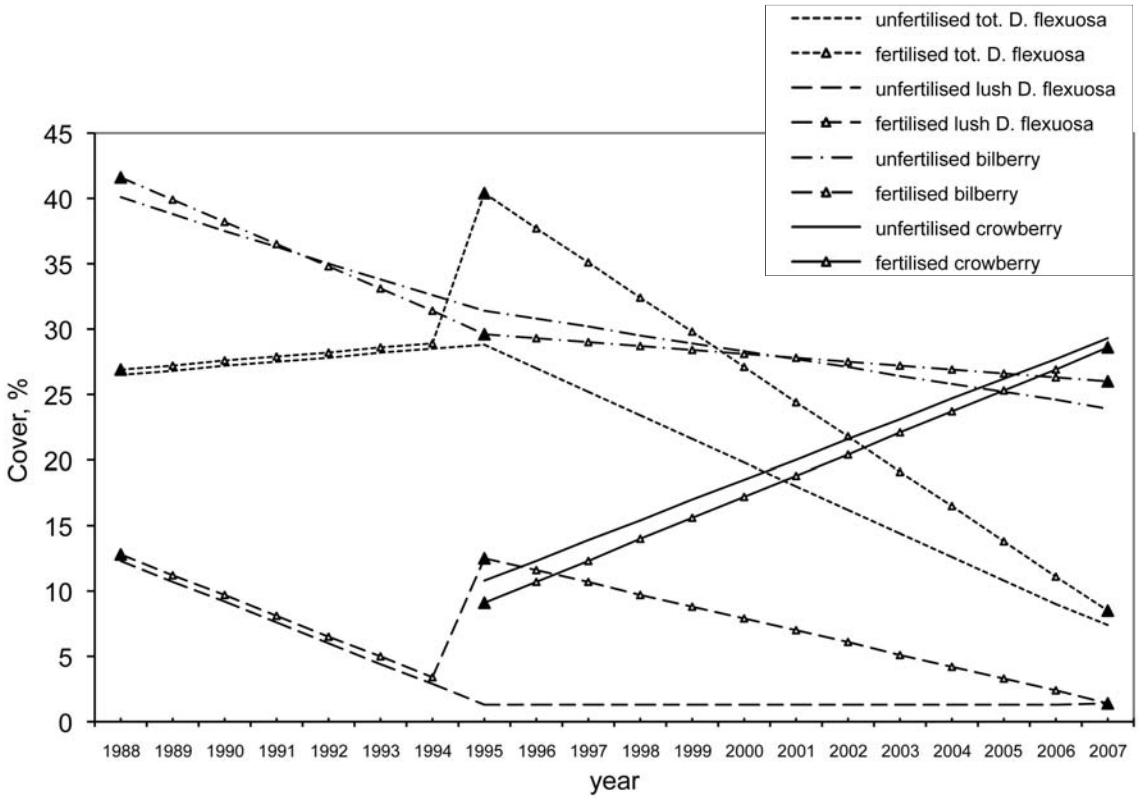


*Fig. 1a. Dynamics of the field-layer vegetation. Mean cover of the major species of the field-layer on plots at different times. Observations were made in 1988, 1995 and 2007; fertiliser was applied in 1994.*

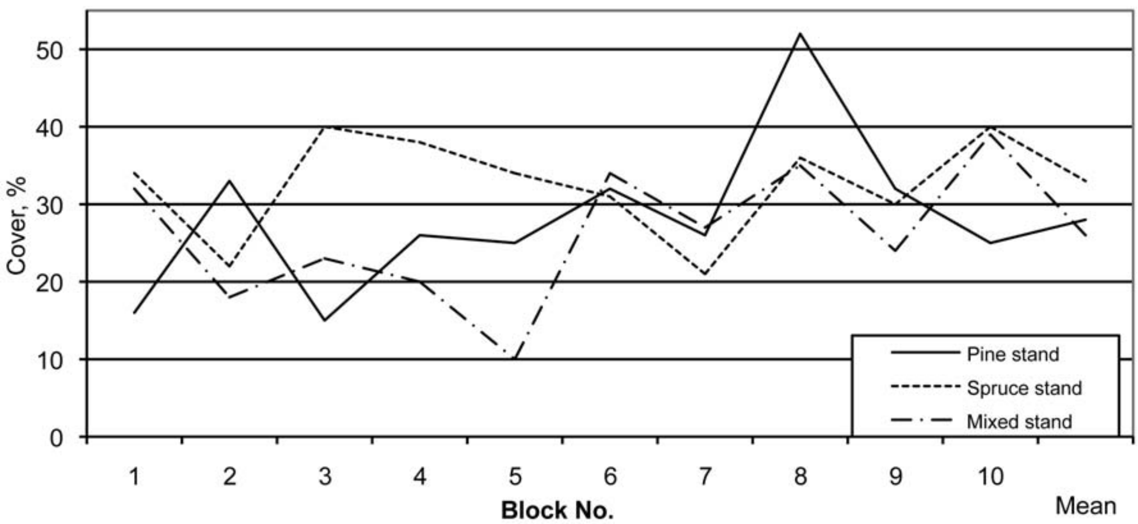


*Fig. 1b. Cover of crowberry in 2007.*

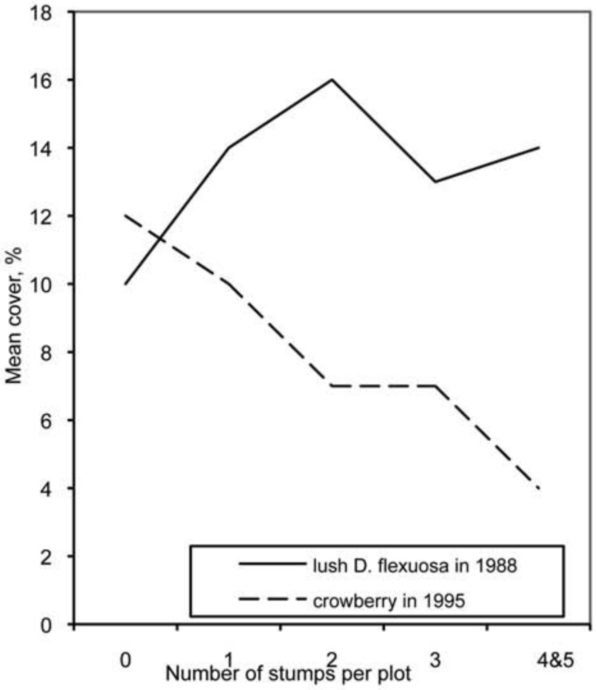


*Fig. 2a. Mean cover of lush D. flexuosa in 1988 and crowberry in 1995 vs. number of stumps per plot.*

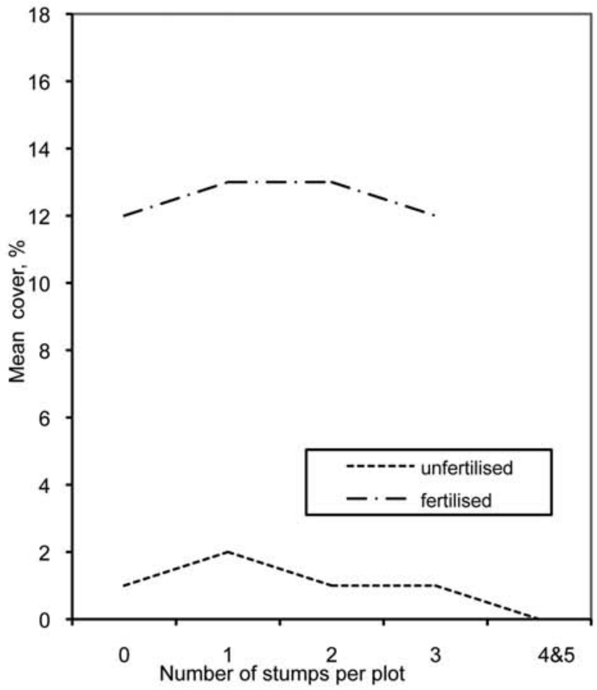


*Fig. 2b. Mean cover of lush D. flexuosa in 1995 vs. number of stumps per plot.*

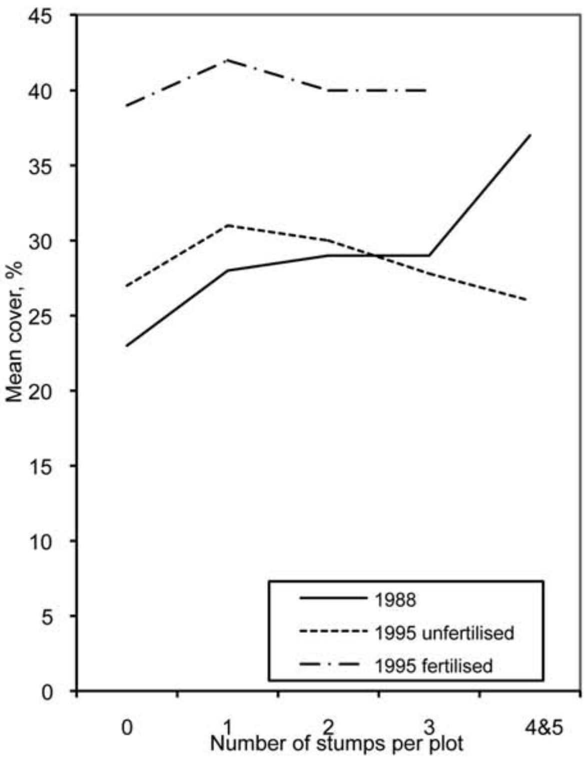


*Fig. 2c. Mean cover of total D. flexuosa in 1988 and 1995 vs. number of stumps per plot.*

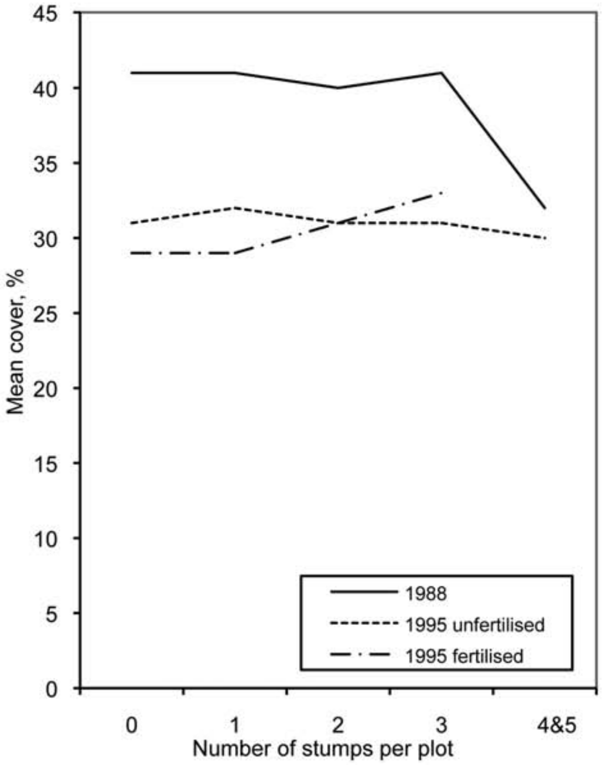


*Fig. 2d. Mean cover of bilberry in 1988 and 1995 vs. number of stumps per plot.*

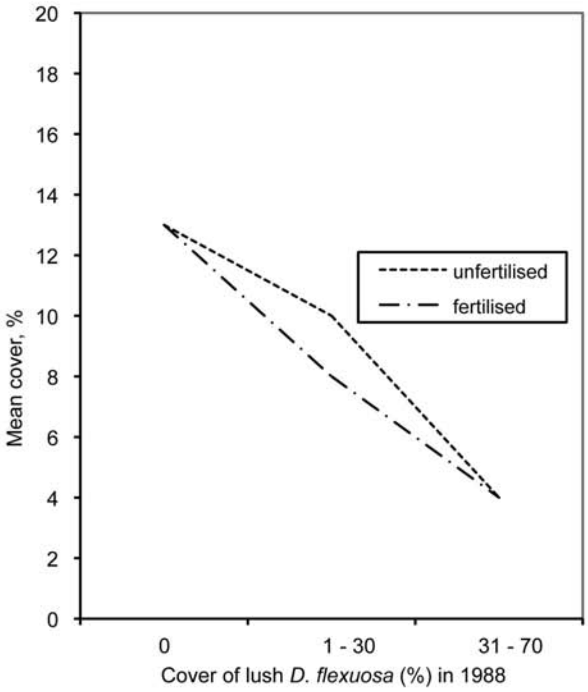


*Fig. 3a. Mean cover of crowberry in 1995 vs. cover (in intervals) of lush D. flexuosa in 1988.*

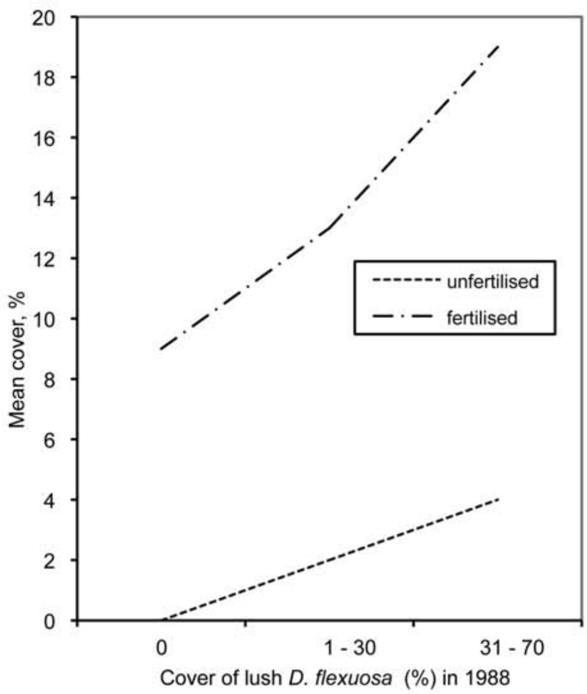


*Fig. 3b. Mean cover of lush D. flexuosa in 1995 vs. cover (in intervals) of lush D. flexuosa in 1988.*

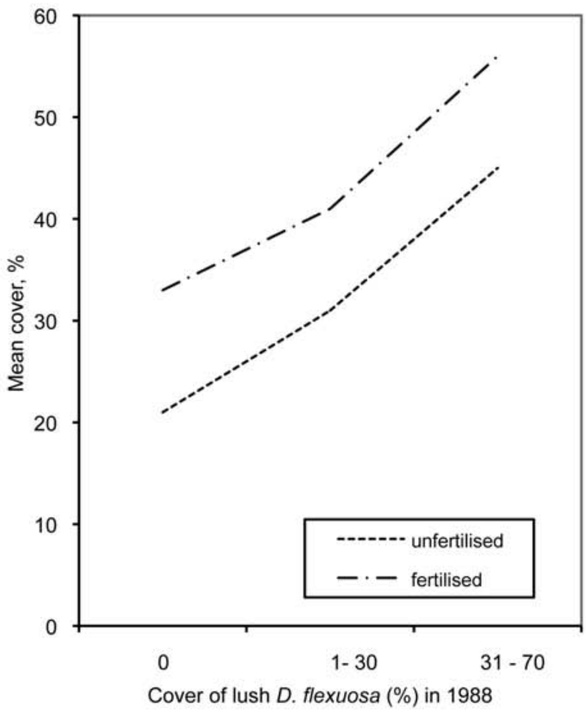


*Fig. 3c. Mean cover of total D. flexuosa in 1995 vs. cover (in intervals) of lush D. flexuosa in 1988.*

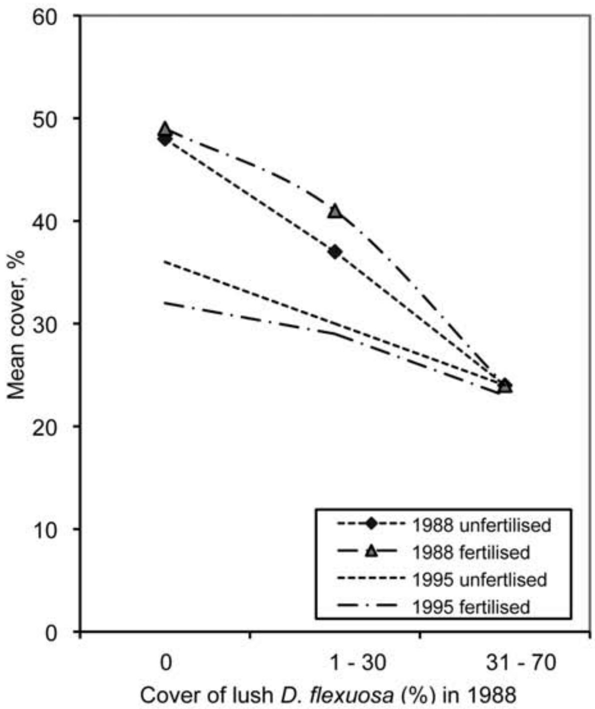


*Fig. 3d. Mean cover of bilberry in 1988 and 1995 vs. cover (in intervals) of lush D. flexuosa in 1988.*

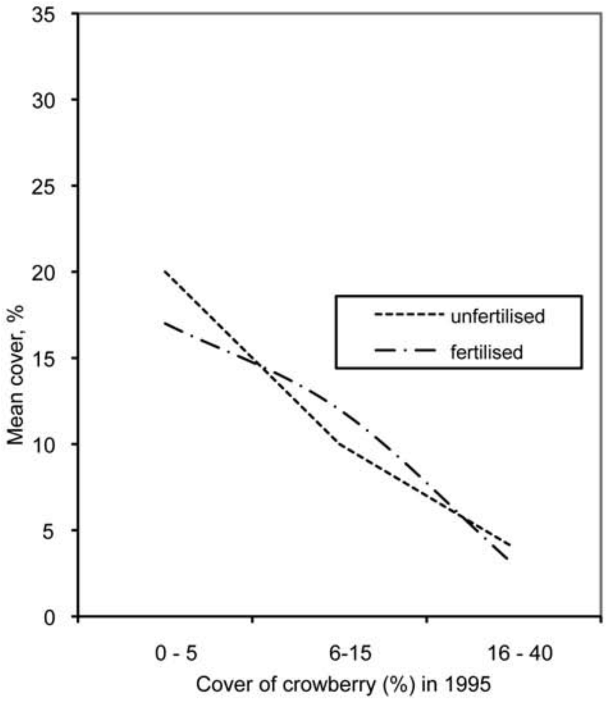


*Fig. 4a. Mean cover of lush D. flexuosa in 1988 vs. cover (in intervals) of crowberry in 1995.*

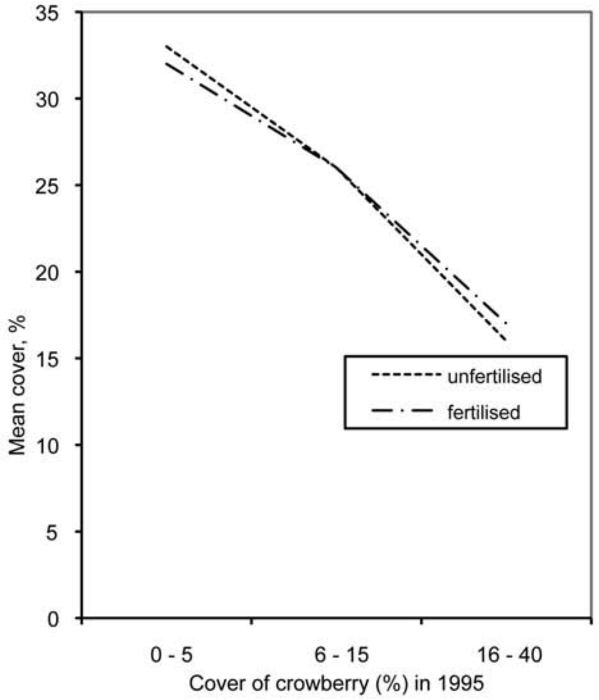


*Fig. 4b. Mean cover of total D. flexuosa in 1988 vs. cover (in intervals) of crowberry in 1995.*

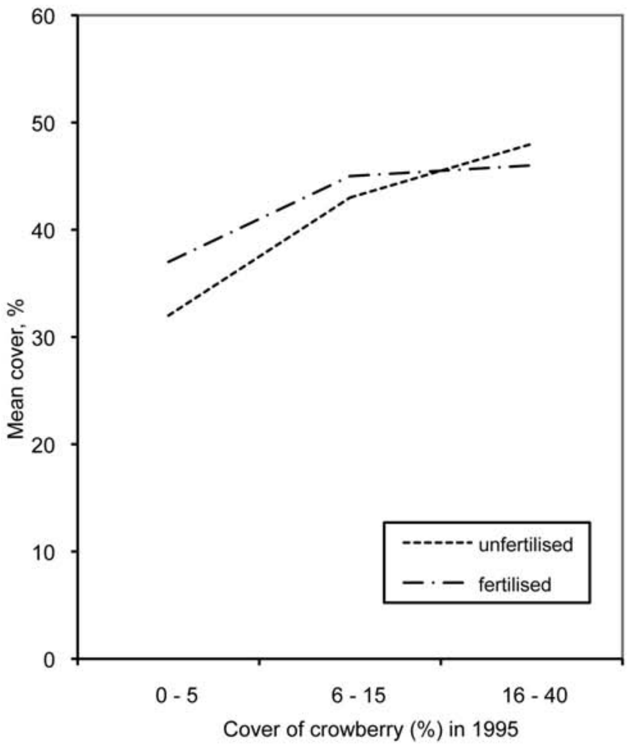


*Fig. 4c. Mean cover of bilberry in 1988 vs. cover (in intervals) of crowberry in 1995.*

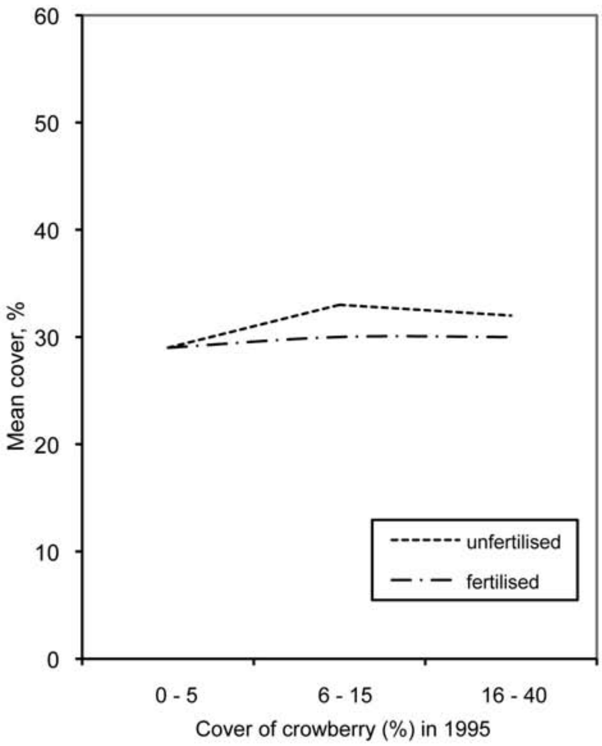


*Fig. 4d. Mean cover of bilberry in 1995 vs. cover (in intervals) of crowberry in 1995.*

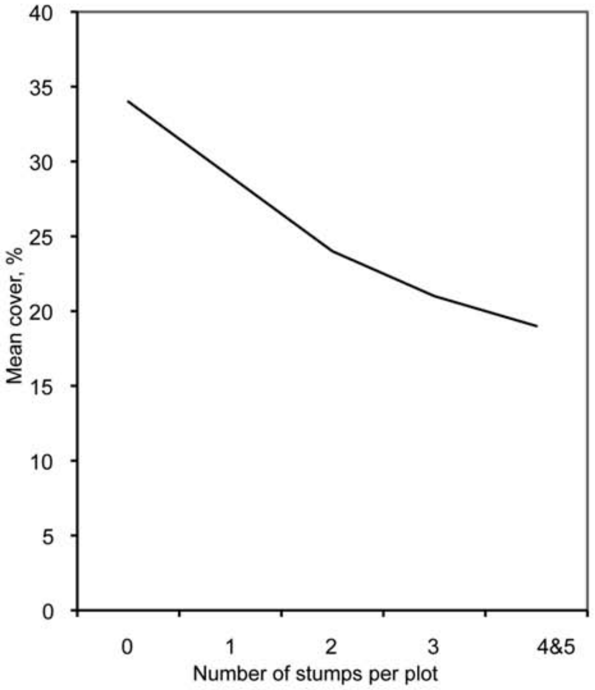


*Fig. 5a. Mean cover of crowberry in 2007 vs. number of stumps per plot.*

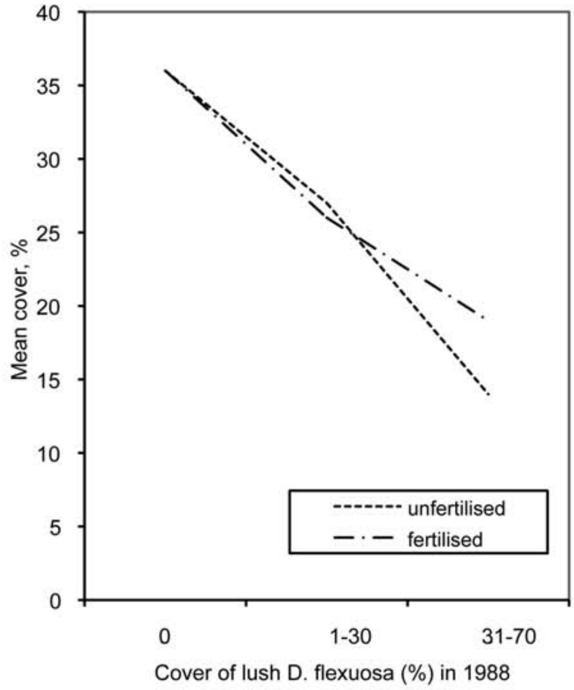


*Fig. 5b. Mean cover of crowberry in 2007 vs. cover (in intervals) of lush D. flexuosa in 1988.*

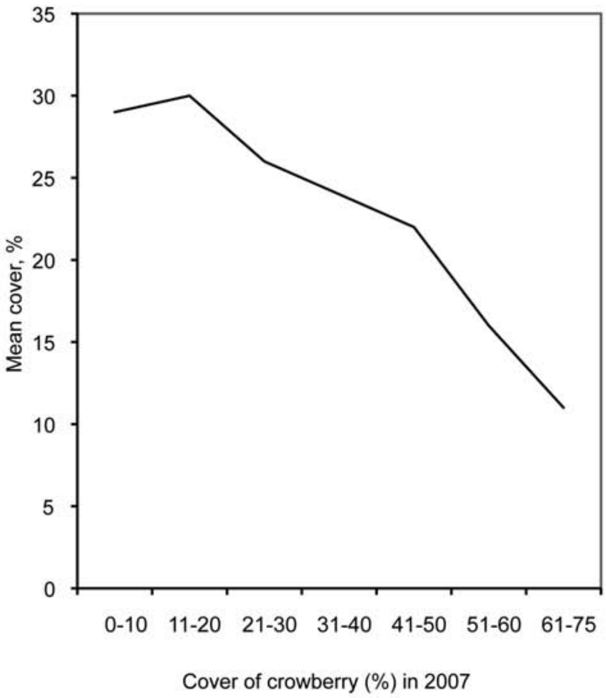


*Fig. 5c. Mean cover of bilberry in 2007 vs. cover (in intervals) of crowberry in 2007.*

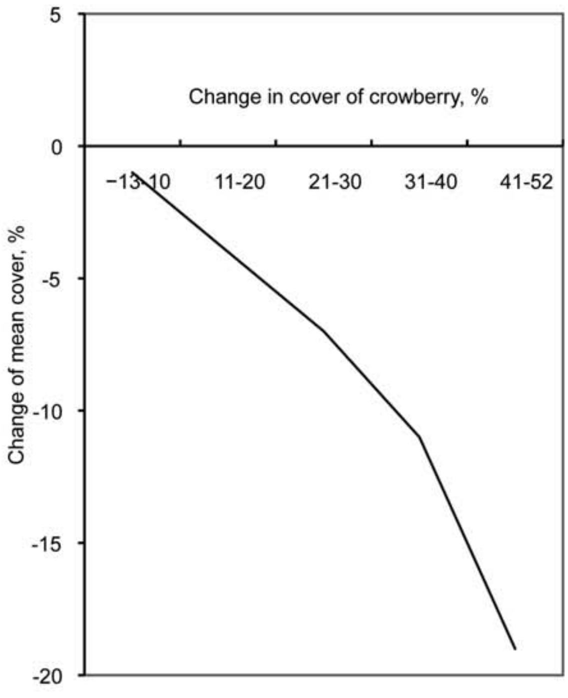


*Fig. 5d. Change in mean cover of bilberry between 1995 and 2007 vs. change (in intervals) in cover of crowberry during the same period.*

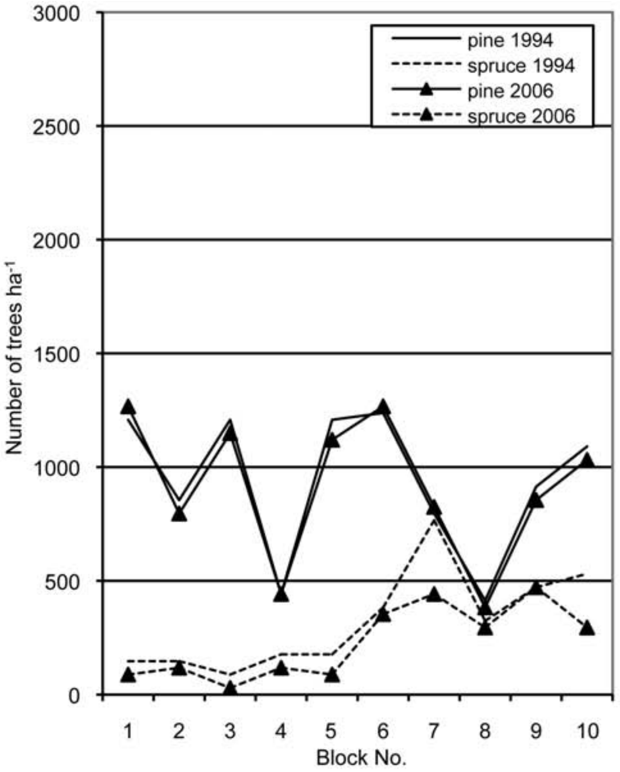


*Fig. 6a. Number ha-1 of undamaged and slightly damaged trees in the Pine stand.*

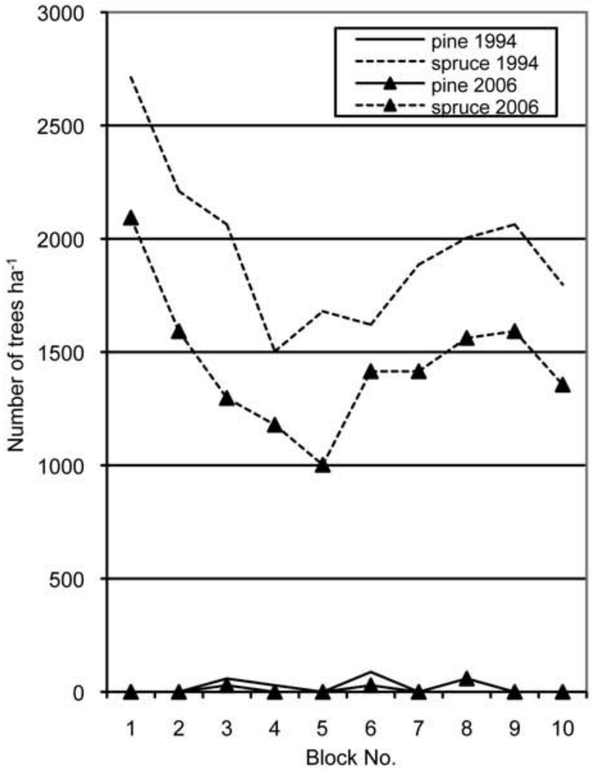


*Fig. 6b. Number ha-1 of undamaged and slightly damaged trees in the Spruce stand.*

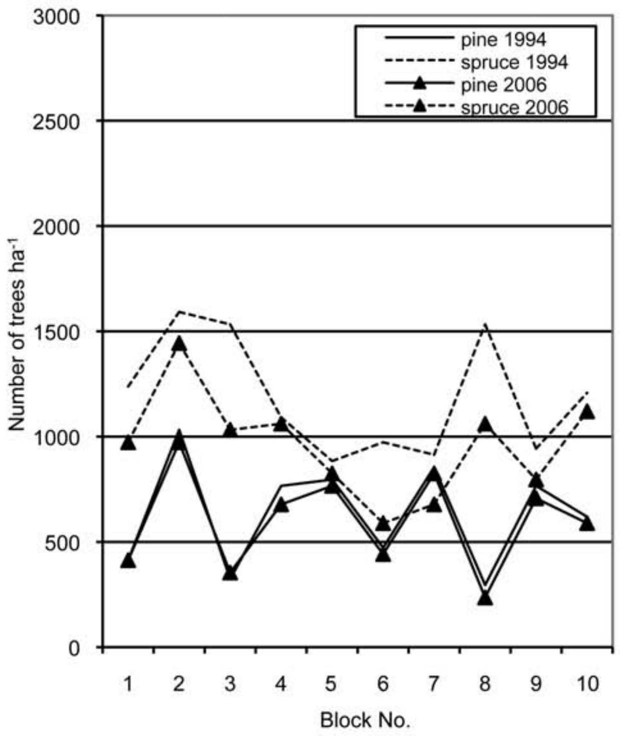


*Fig. 6c. Number ha-1 of undamaged and slightly damaged trees in the Mixed stand.*

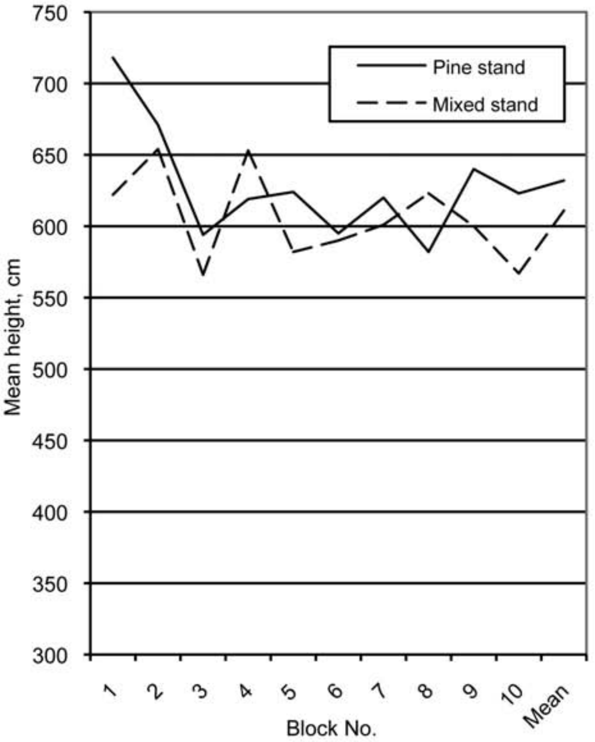


*Fig. 7a. Diameter-weighted mean height of pine in 2006 in the Pine stand and the Mixed stand, respectively.*

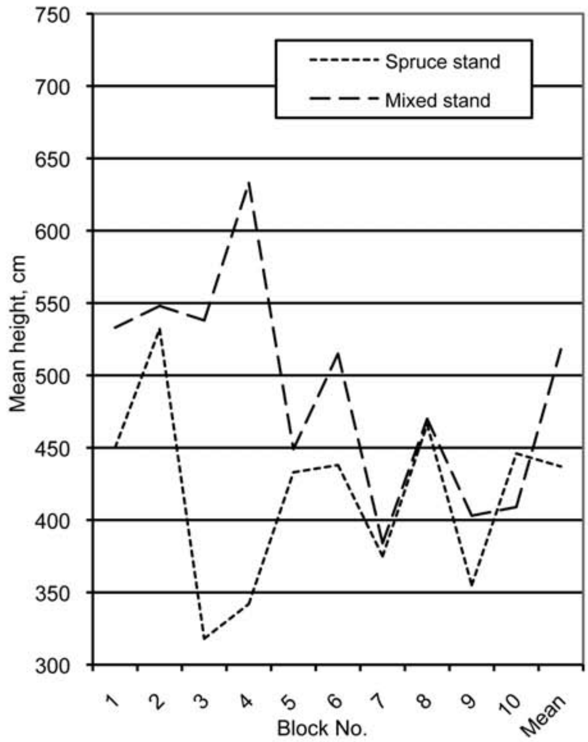


*Fig. 7b. Diameter-weighted mean height of spruce in 2006 in the Spruce stand and the Mixed stand, respectively.*

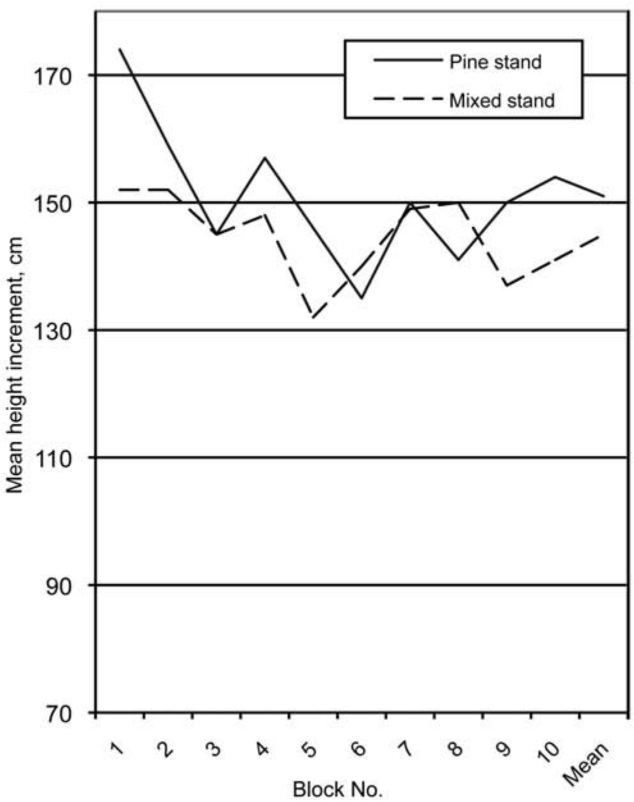


*Fig. 7c. Diameter-weighted mean height increment of pine in the Pine stand and the Mixed stand, respectively.*

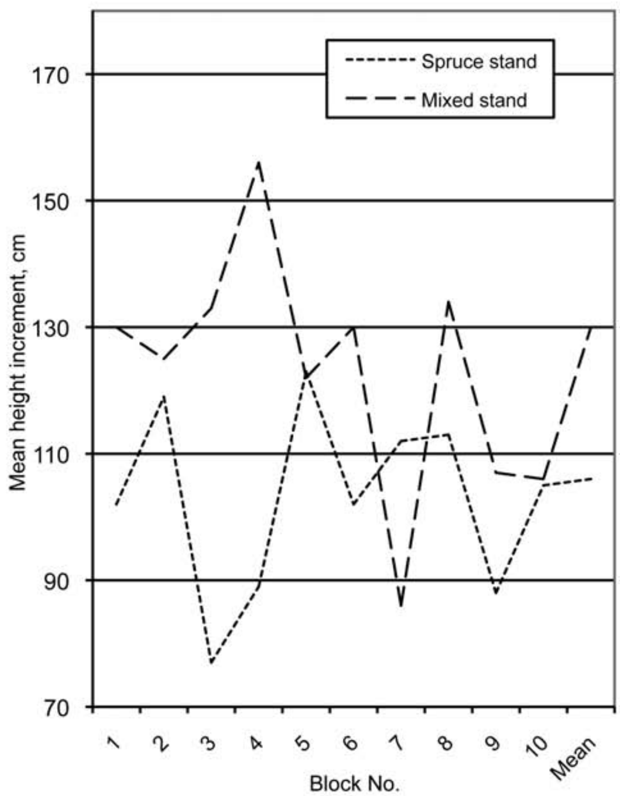


*Fig. 7d. Diameter-weighted mean height increment of spruce in the Spruce stand and the Mixed stand, respectively.*

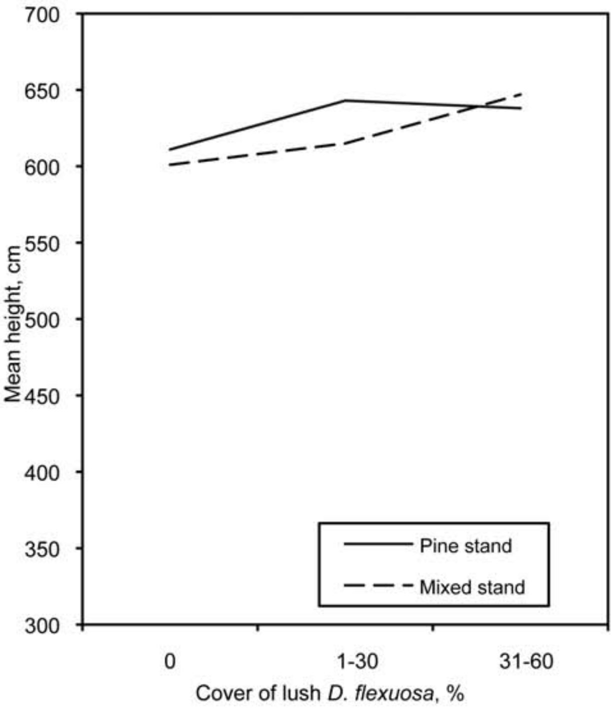


*Fig. 8a. Diameter-weighted mean height of pine in 2006 for various degrees of cover of lush D. flexuosa in 1988 in the Pine stand and the Mixed stand, respectively.*

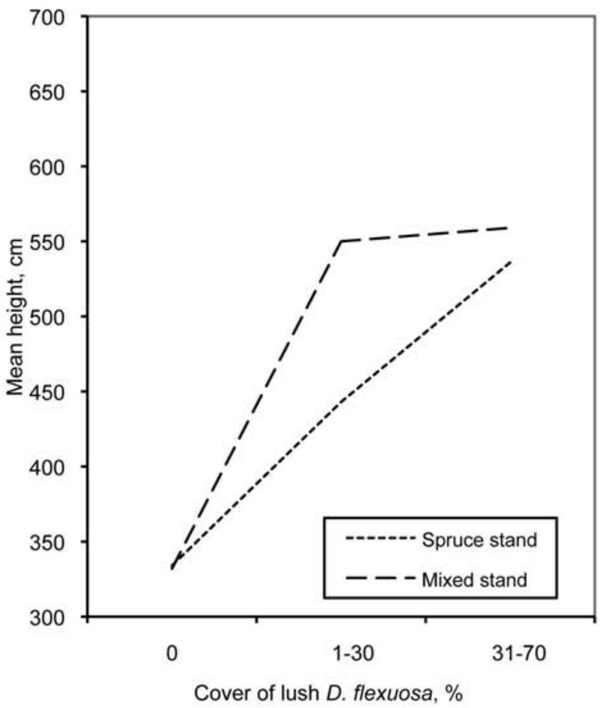


*Fig. 8b. Diameter-weighted mean height of spruce in 2006 for various degrees of cover of lush D. flexuosa in 1988 in the Spruce stand and the Mixed stand, respectively.*

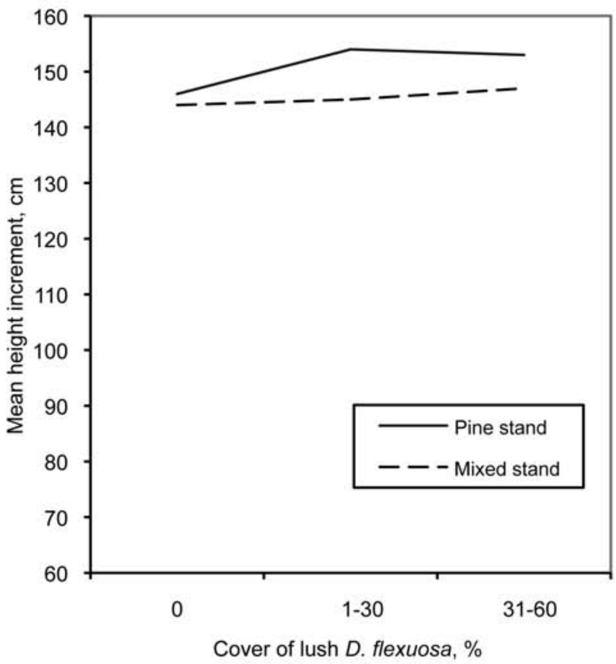


*Fig. 8c. Diameter-weighted mean height increment of pine for various degrees of cover of lush D. flexuosa in 1988 in the Pine stand and the Mixed stand, respectively.*

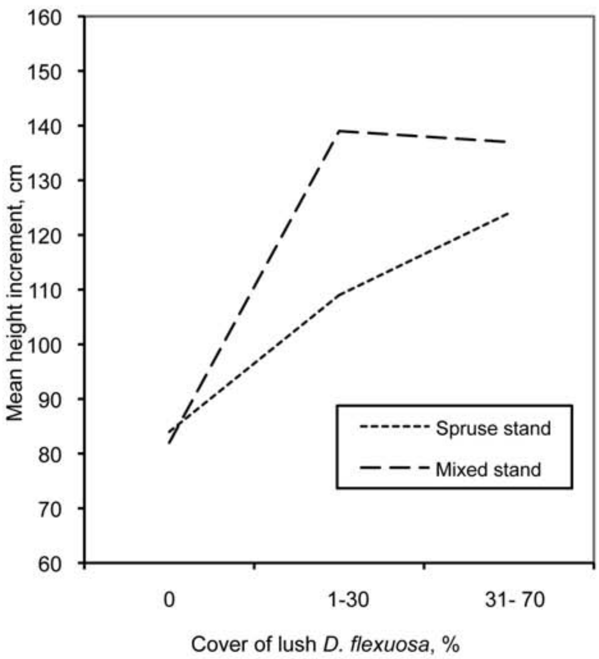


*Fig. 8d. Diameter-weighted mean height increment of spruce for various degrees of cover of lush D. flexuosa in 1988 in the Spruce stand and the Mixed stand, respectively.*

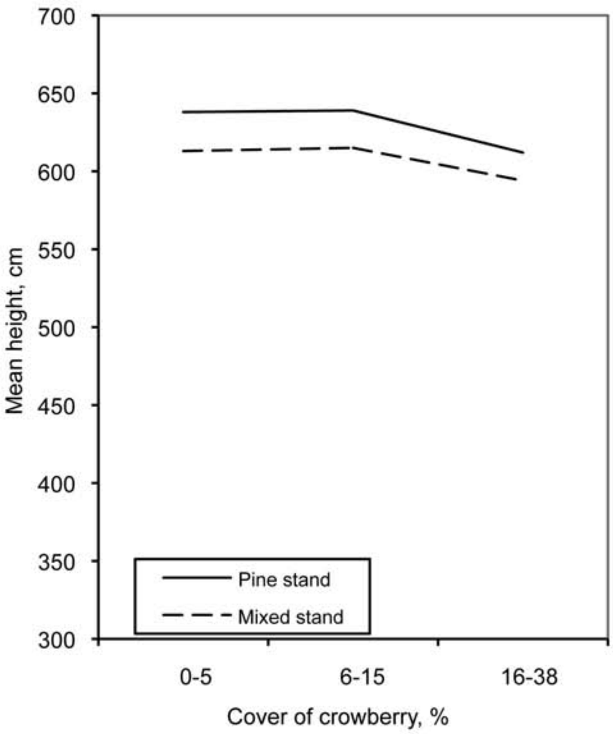


*Fig. 9a. Diameter-weighted mean height of pine in 2006 for various degrees of cover of crowberry in 1995 in the Pine stand and the Mixed stand, respectively.*

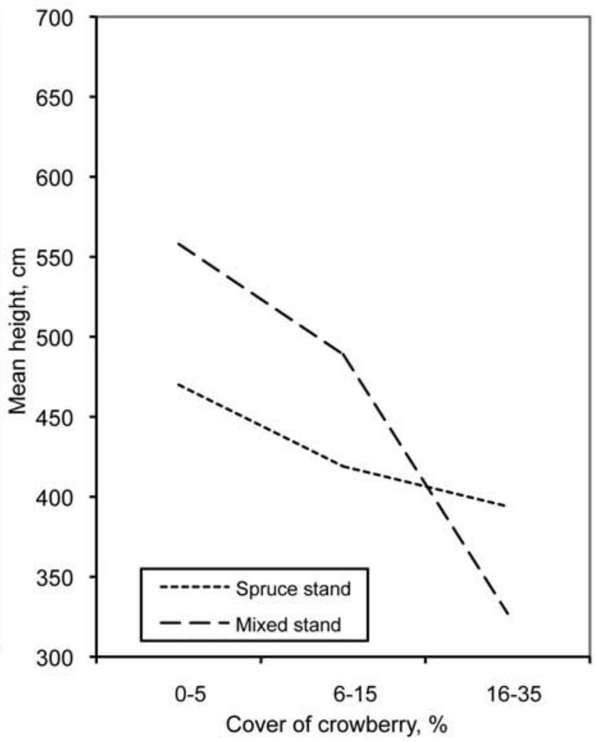


*Fig. 9b. Diameter-weighted mean height of spruce in 2006 for various degrees of cover of crowberry in 1995 in the Spruce stand and the Mixed stand, respectively.*

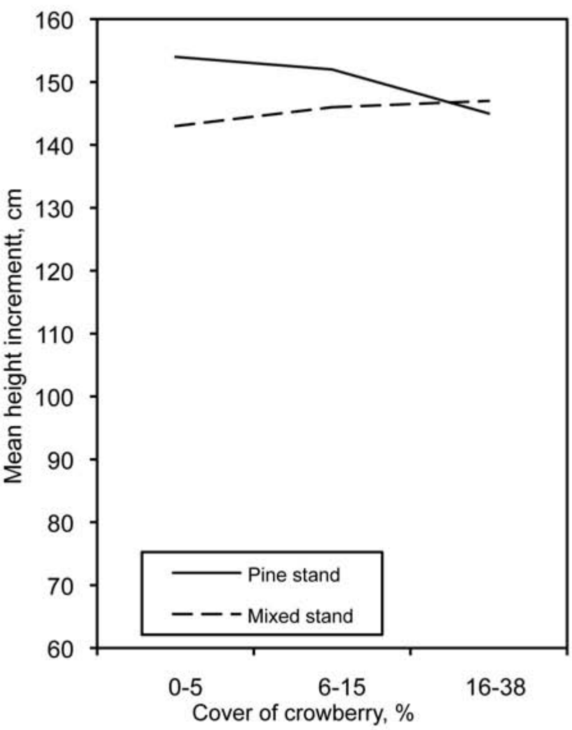


*Fig. 9c. Diameter-weighted mean height increment of pine for various degrees of cover of crowberry in 1995 in the Pine stand and the Mixed stand, respectively.*

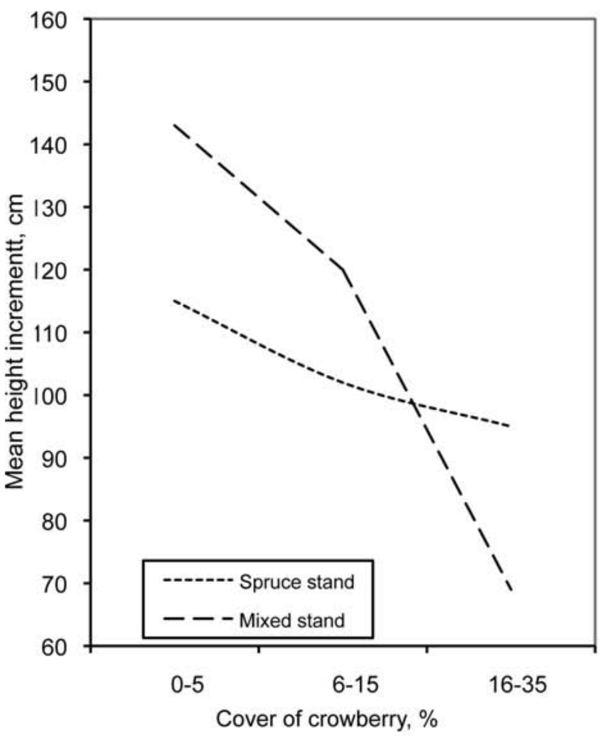


*Fig. 9d. Diameter-weighted mean height increment of spruce for various degrees of cover of crowberry in 1995 in the Spruce stand and the Mixed stand, respectively.*

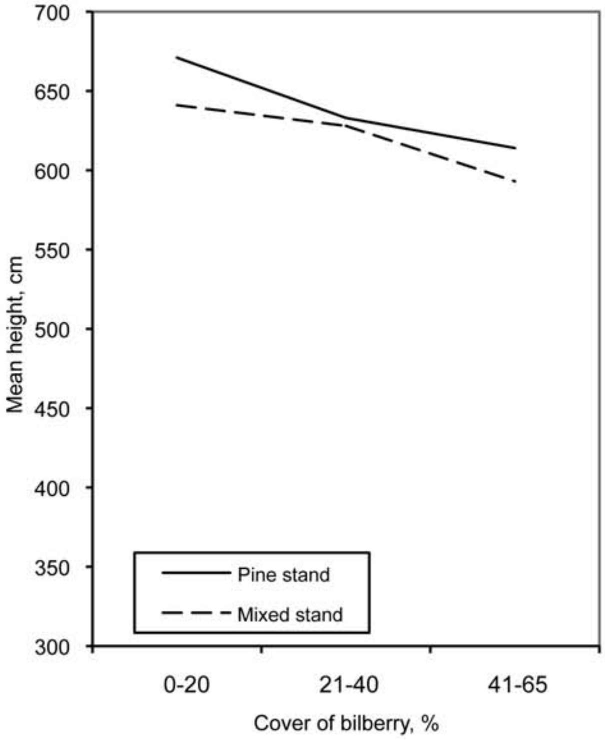


*Fig. 10a. Diameter-weighted mean height of pine in 2006 for various degrees of cover of bilberry in 1988 in the Pine stand and the Mixed stand, respectively.*

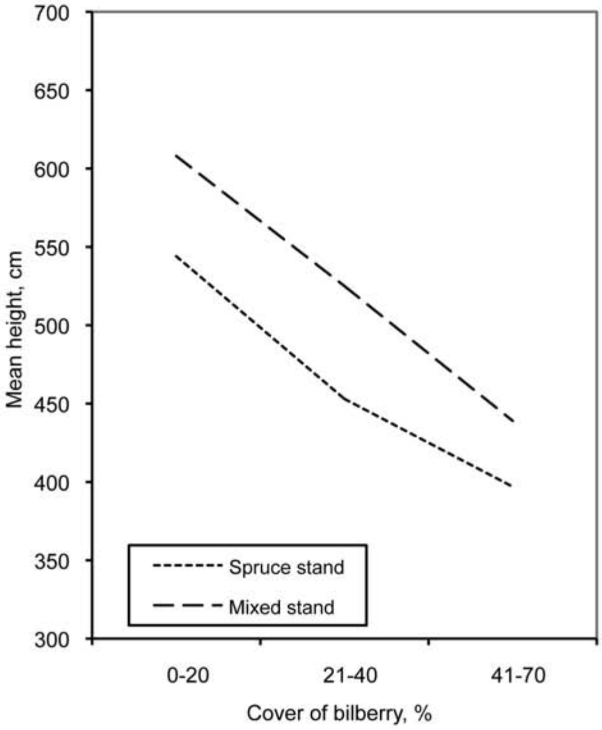


*Fig. 10b. Diameter-weighted mean height of spruce in 2006 for various degrees of cover of bilberry in 1988 in the Spruce stand and the Mixed stand, respectively.*

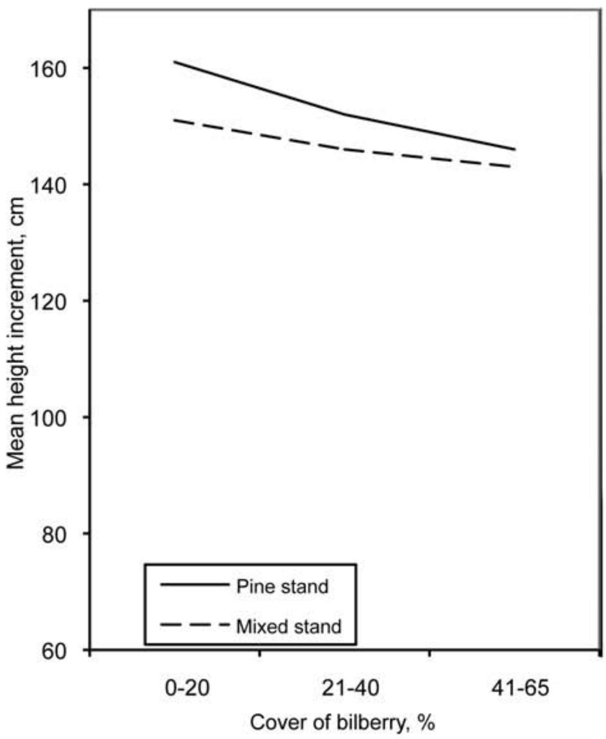


*Fig. 10c. Diameter-weighted mean height increment of pine for various degrees of cover of bilberry in 1988 in the Pine stand and the Mixed stand, respectively.*

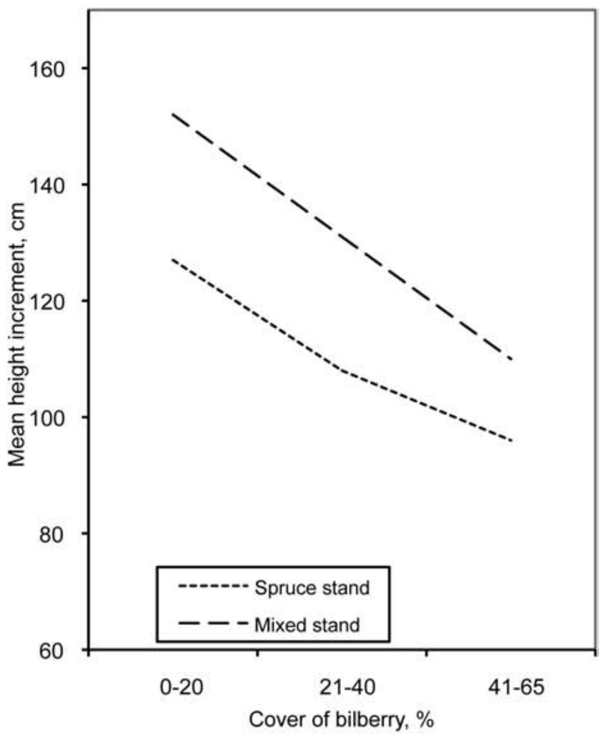


*Fig. 10d. Diameter-weighted mean height increment of spruce for various degrees of cover of bilberry in 1988 in the Spruce stand and the Mixed stand, respectively.*

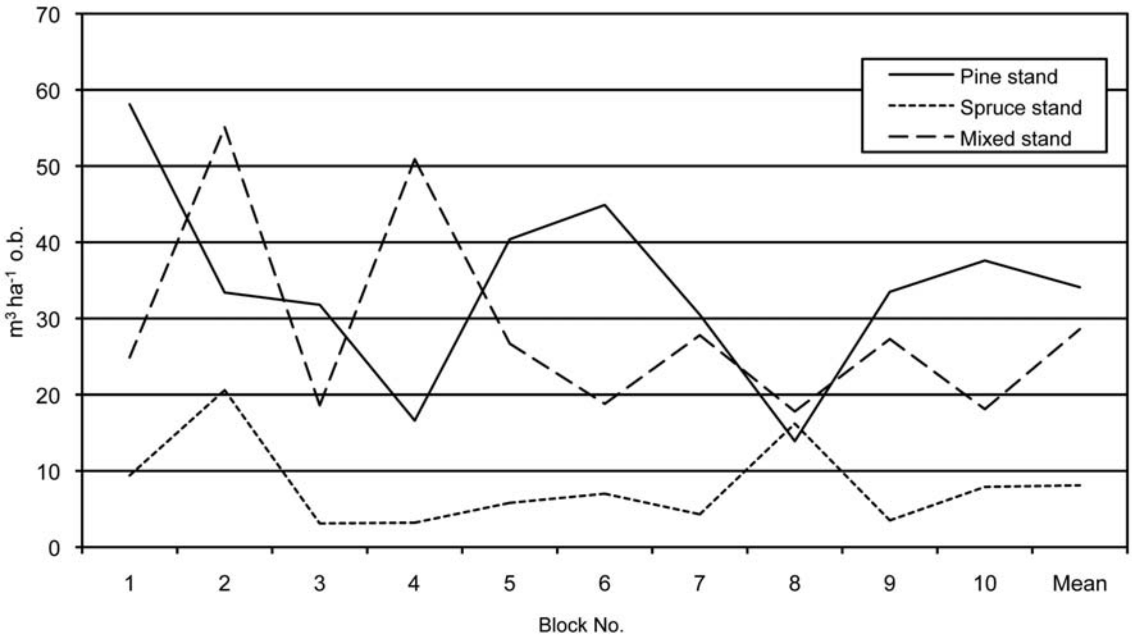


*Fig. 11a. Total stand volume in 2006.*

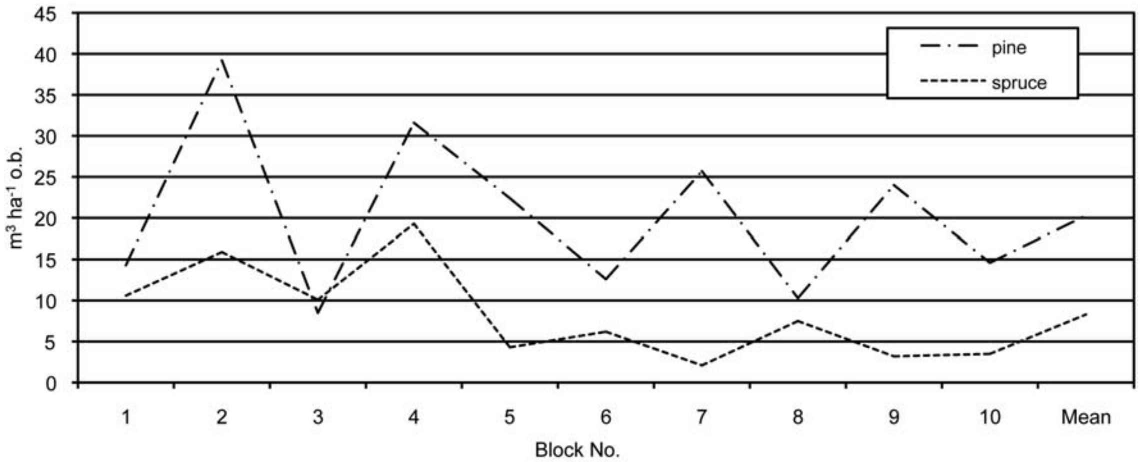


*Fig. 11b. Stand volume of pine and spruce, respectively, in the Mixed stand in 2006.*

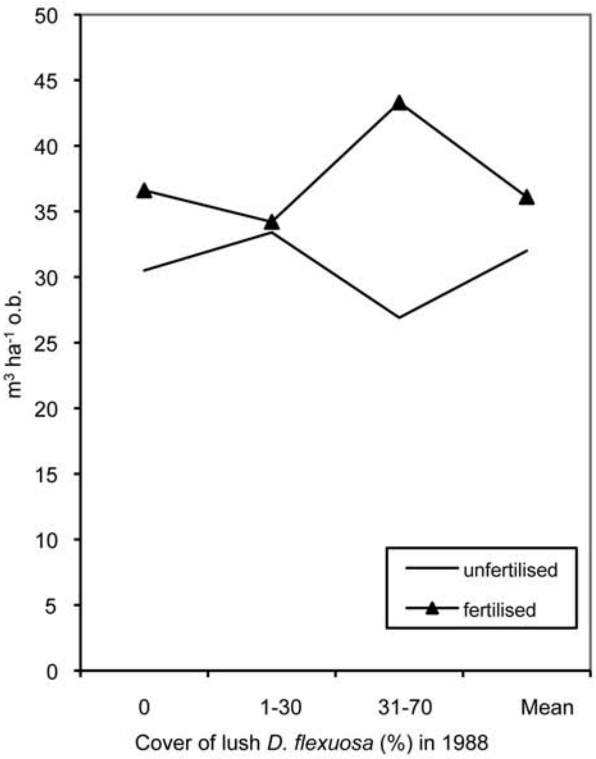


*Fig. 12a. Mean stand volume per plot in the Pine stand in 2006 vs. lush D. flexuosa in 1988.*

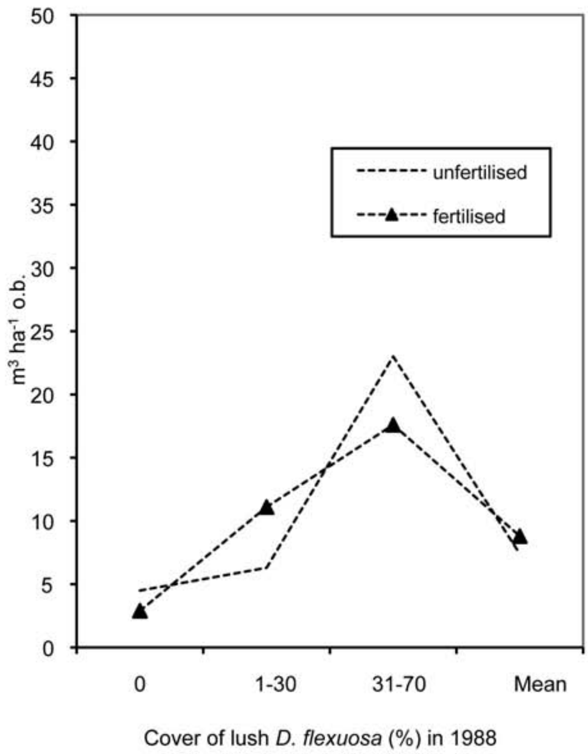


*Fig. 12b. Mean stand volume per plot in the Spruce stand in 2006 vs. lush D. flexuosa in 1988.*

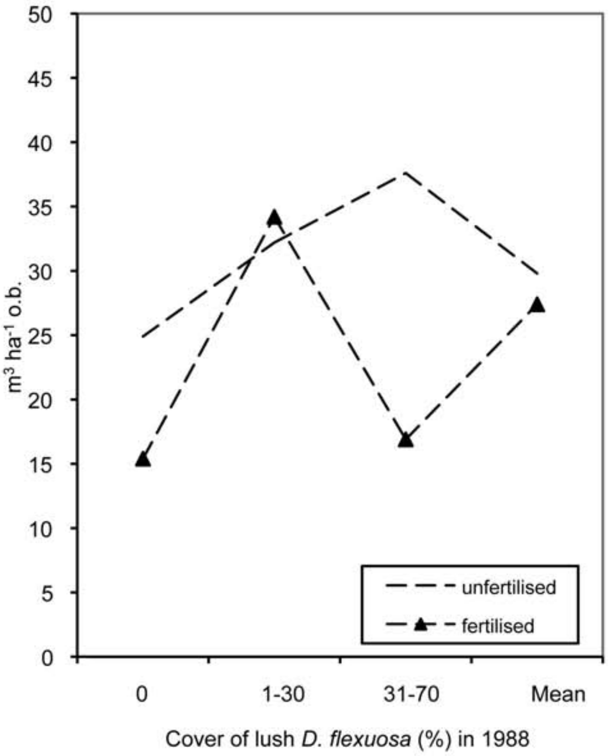


*Fig. 12c. Mean stand volume per plot in the Mixed stand in 2006 vs. lush D. flexuosa in 1988.*

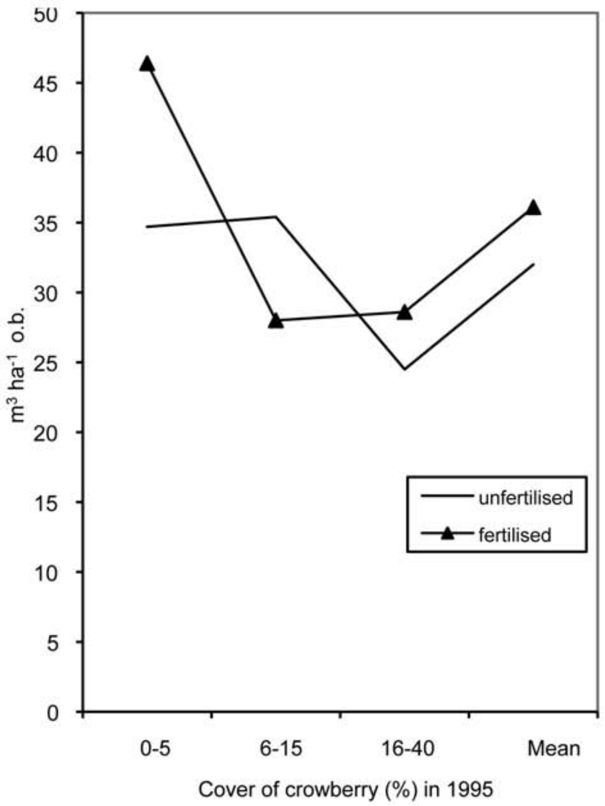


*Fig. 13a. Mean stand volume per plot in the Pine stand in 2006 vs. crowberry in 1995.*

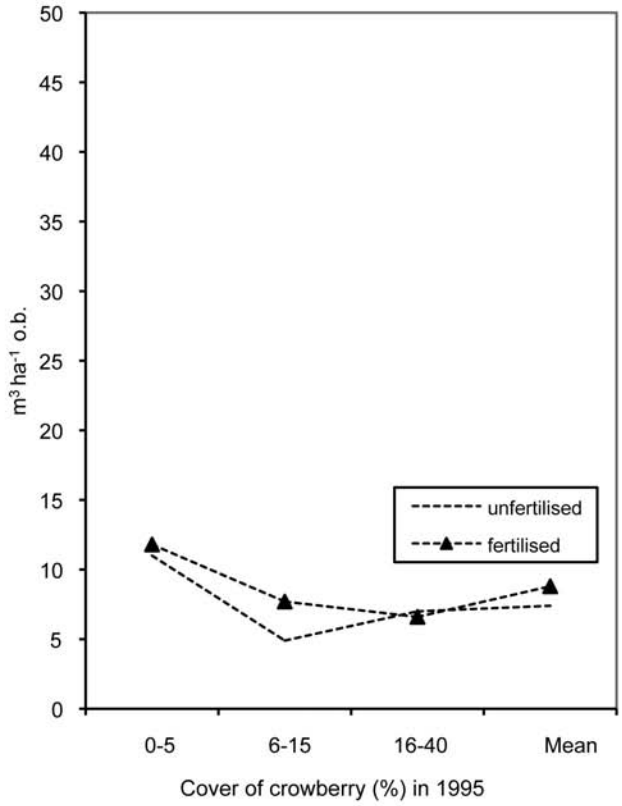


*Fig. 13b. Mean stand volume per plot in the Spruce stand in 2006 vs. crowberry in 1995.*

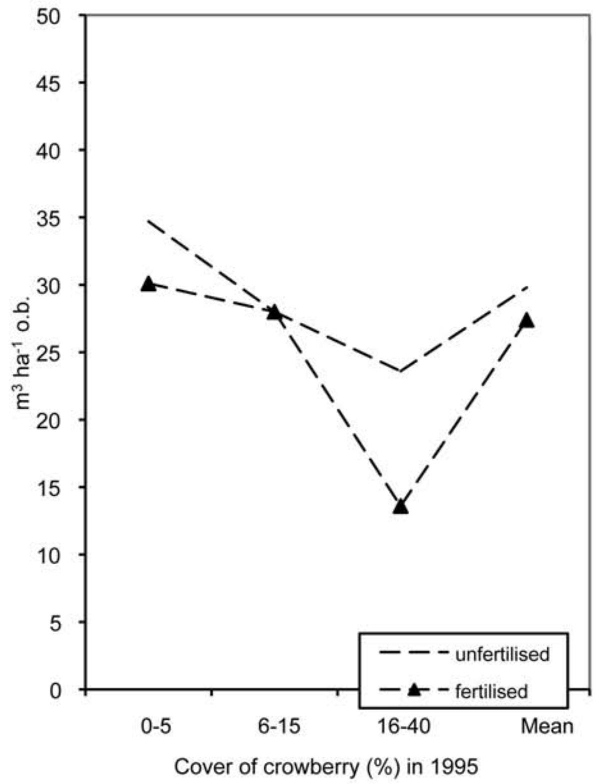


*Fig. 13c. Mean stand volume per plot in the Mixed stand in 2006 vs. crowberry in 1995.*

*Table 1. Degree of cover (%) of the major species of the field-layer on plots at various times. Observations were made in 1988, 1995 and 2007; fertiliser was applied in 1994. UF = unfertilised F = fertilised*

| Year/ statistics | Total *D. flexuosa* | | Lush *D. flexuosa* | | Bilberry | | Crowberry | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **UF** | **F** | **UF** | **F** | **UF** | **F** | **UF** | **F** |
| **1988** | | | | | | | | |
| Mean | 27 | 27 | 12 | 13 | 40 | 42 | – | – |
| Std. dev. | 16 | 16 | 15 | 14 | 16 | 15 | – | – |
| Minimum | 5 | 5 | 0 | 0 | 4 | 3 | – | – |
| Maximum | 75 | 85 | 70 | 60 | 65 | 70 | – | – |
| **1994** | **Fertilisation** | | | | | | | |
| **1995** | | | | | | | | |
| Mean | 29 | 40 | 1 | 12 | 31 | 30 | 11 | 9 |
| Std. dev. | 12 | 11 | 3 | 8 | 9 | 8 | 9 | 8 |
| Minimum | 8 | 15 | 0 | 1 | 5 | 8 | 0 | 0 |
| Maximum | 70 | 70 | 20 | 45 | 60 | 60 | 40 | 35 |
| **2007** | | | | | | | | |
| Mean | 7 | 8 | 1 | 1 | 24 | 26 | 29 | 29 |
| Std. dev. | 7 | 8 | 3 | 2 | 10 | 13 | 17 | 18 |
| Minimum | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 1 |
| Maximum | 40 | 50 | 20 | 20 | 65 | 70 | 75 | 70 |

*Table 2. Mean degree of cover (%) of different species of the field-layer in relation to the number of stumps with diameter > 15 cm.*

| No. Stumps/plot | No. plots | Lush *D. flexuosa* in 1988, % | Total *D. flexuosa* in 1988, % | Bilberry in 1988, % | Crowberry in 1995, % | Crowberry in 2007, % |
|---|---|---|---|---|---|---|
| 0 | 135 | 10 | 23 | 41 | 12 | 34 |
| 1 | 127 | 14 | 28 | 41 | 10 | 29 |
| 2 | 63 | 16 | 29 | 40 | 7 | 24 |
| 3 | 27 | 13 | 29 | 41 | 7 | 21 |
| 4–5 | 8 | 14 | 37 | 32 | 4 | 19 |
| 0–5 | 360 | 13 | 27 | 41 | 10 | 29 |
| | | Fig. 2a | Fig. 2c | Fig. 2d | Fig. 2a | Fig. 5a |
| | | **Lush *D. flexuosa* in 1995, %** | **Total *D. flexuosa* in 1995, %** | **Bilberry in 1995, %** | **Crowberry in 1995, %** | **Crowberry in 2007, %** |
| | | | | **Unfertilised** | | |
| 0 | 66 | 1 | 27 | 31 | 14 | 34 |
| 1 | 63 | 2 | 31 | 32 | 10 | 30 |
| 2 | 30 | 1 | 30 | 31 | 8 | 22 |
| 3 | 13 | 1 | 28 | 31 | 9 | 27 |
| 4–5 | 8 | 0 | 26 | 30 | 4 | 19 |
| 0–5 | 180 | 1 | 29 | 31 | 11 | 29 |
| | | | | **Fertilised 1994** | | |
| 0 | 69 | 12 | 39 | 29 | 10 | 33 |
| 1 | 64 | 13 | 42 | 29 | 10 | 28 |
| 2 | 33 | 13 | 40 | 31 | 7 | 25 |
| 3 | 14 | 12 | 40 | 33 | 5 | 15 |
| 4–5 | – | – | – | – | – | – |
| 0–5 | 180 | 12 | 40 | 30 | 9 | 29 |
| | | Fig. 2b | Fig. 2c | Fig. 2d | | |

*Table 3. Mean degree of cover (%) of different species of the field-layer in relation to lush D. flexuosa in 1988 and crowberry in 1995*

| Reference species: Lush *D. flexuosa* 1988 No. plots | | Interval % | Mean % | Lush *D. flexuosa* 1995, % | Total *D. flexuosa* 1995, % | Crowberry 1995, % | Bilberry 1995, % |
|---|---|---|---|---|---|---|---|
| 70 | Unfertilised | 0 | 0 | 0 | 21 | 13 | 36 |
| 56 | Fertilised | | 0 | 9 | 33 | 13 | 32 |
| 92 | Unfertilised | 1 – 30 | 15 | 2 | 31 | 10 | 30 |
| 106 | Fertilised | | 14 | 13 | 41 | 8 | 29 |
| 18 | Unfertilised | 31 – 70 | 45 | 4 | 45 | 4 | 24 |
| 18 | Fertilised | | 45 | 19 | 56 | 4 | 23 |
| 180 | Unfertilised | 0 – 70 | 12 | 1 | 29 | 11 | 31 |
| 180 | Fertilised | | 13 | 12 | 40 | 9 | 30 |
| | | | | Fig. 3b | Fig. 3c | Fig.3a | Fig. 3d |

| Reference species: Crowberry 1995 No. plots | | Interval % | Mean % | Lush *D. flexuosa* 1988, % | Total *D. flexuosa* 1988, % | Bilberry 1988, % | Bilberry 1995, % |
|---|---|---|---|---|---|---|---|
| 64 | Unfertilised | 0 – 5 | 3 | 20 | 33 | 32 | 29 |
| 77 | Fertilised | | 2 | 17 | 32 | 37 | 29 |
| 76 | Unfertilised | 6 – 15 | 10 | 10 | 26 | 43 | 33 |
| 71 | Fertilised | | 10 | 12 | 26 | 45 | 30 |
| 40 | Unfertilised | 16 – 40 | 25 | 4 | 16 | 48 | 32 |
| 32 | Fertilised | | 23 | 3 | 17 | 46 | 30 |
| 180 | Unfertilised | 0 – 40 | 11 | 12 | 27 | 40 | 31 |
| 180 | Fertilised | | 9 | 13 | 27 | 42 | 30 |
| | | | | Fig. 4a | Fig. 4b | Fig. 4c | Fig. 4d |

*Table 4. Functions for the cover (%) of*
*(f1) lush D. flexuosa in 1988 and (f2) crowberry in 1995, respectively, vs. number of stumps per plot (stumps with diameter > 15 cm)*
*(f3) fertilised lush D. flexuosa in 1995 vs. lush D. flexuosa in 1988*
*(f4) crowberry in 1995 vs. lush D. flexuosa in 1988*
*(f5) bilberry in 1988 vs. lush D. flexuosa in 1988*
*(f6) bilberry in 1995 vs. lush D. flexuosa in 1988 and*
*(f7) bilberry in 1988 vs. crowberry in 1995*

| Function | Dependent variable | Independent variable | β | p-value | Standard deviation | $R^2$ |
|---|---|---|---|---|---|---|
| **f1** | Lush *D. flexuosa* 1988 *cf.* Fig. 2a | **Constant**<br>No. stumps<br>(No. stumps)$^2$ | 9.514<br>4.947<br>−0.950 | 0.000***<br>0.005**<br>0.079 | 13.107 | 0.18 |
| **f2** | Crowberry 1995 *cf.* Fig. 2a | **Constant**<br>No. stumps | 11.506<br>−1.548 | 0.000***<br>0.000*** | 7.393 | 0.24 |
| **f3** | Fertilised lush *D. flexuosa* 1995 *cf.* Fig. 3b | **Constant**<br>Lush *D. flexuosa* 1988 | 10.283<br>0.174 | 0.000***<br>0.000*** | 7.280 | 0.25 |
| **f4** | Crowberry 1995 *cf.* Fig. 3a | **Constant**<br>Lush *D. flexuosa* 1988 | 12.851<br>−0.233 | 0.000***<br>0.000*** | 6.897 | 0.34 |
| **f5** | Bilberry 1988 *cf.* Fig. 3d | **Constant**<br>Lush *D. flexuosa* 1988 | 48.207<br>−0.584 | 0.000***<br>0.000*** | 10.940 | 0.49 |
| **f6** | Bilberry 1995 *cf.* Fig. 3d | **Constant**<br>Lush *D. flexuosa* 1988 | 33.548<br>−0.243 | 0.000***<br>0.000*** | 6.824 | 0.39 |
| **f7** | Bilberry 1988 *cf.* Fig. 4c | **Constant**<br>Crowberry 1995 | 34.673<br>0.624 | 0.000***<br>0.000*** | 12.570 | 0.33 |

*Table 5a. Mean cover (%) of crowberry in 2007 vs. mean cover of D. flexuosa in 1988*

| Reference species: Lush *D. flexuosa* 1988 | | | | Crowberry 2007, % |
|---|---|---|---|---|
| No. plots | | Interval, % | Mean, % | |
| 70 | Unfertilised | 0 | 0 | 36 |
| 56 | Fertilised | | 0 | 36 |
| 92 | Unfertilised | 1 - 30 | 15 | 27 |
| 106 | Fertilised | | 14 | 26 |
| 18 | Unfertilised | 31 - 70 | 45 | 14 |
| 18 | Fertilised | | 45 | 19 |
| 180 | Unfertilised | 0 - 70 | 12 | 29 |
| 180 | Fertilised | | 13 | 29 |
| | | | | Fig. 5b |

*Table 5b. Mean cover of bilberry in 2007 vs. mean cover of crowberry in 2007*

| Reference species: Crowberry 2007 | | | Bilberry 2007, % |
|---|---|---|---|
| No. plots | Interval, % | Mean, % | |
| 68 | 0-10 | 6 | 29 |
| 61 | 11-20 | 16 | 30 |
| 75 | 21-30 | 27 | 26 |
| 79 | 31-40 | 37 | 24 |
| 37 | 41-50 | 48 | 22 |
| 30 | 51-60 | 57 | 16 |
| 10 | 61-75 | 66 | 11 |
| | | | Fig. 5c |

*Table 5c. Mean change in cover between 1995 and 2007 of bilberry vs. mean change in cover of crowberry during the same period (status in 2007 minus status in 1995)*

| Change in Crowberry cover 1995 – 2007 | | | Change in Bilberry cover 1995 – 2007, % |
|---|---|---|---|
| No. plots | Interval, % | Mean, % | |
| 103 | −13-10 | 4 | −1 |
| 105 | 11-20 | 16 | −4 |
| 86 | 21-30 | 25 | −7 |
| 43 | 31-40 | 35 | −11 |
| 23 | 41-52 | 45 | −19 |
| | | | Fig. 5d |

*Table 6. Functions for correlation between*
*(f1)– f(5) the cover (%) of various species in the field-layer in 2007 and*
*(f6) the change in cover (%) of bilberry between 1995 and 2007 vs. the change in cover of crowberry during the same period (status in 2007 minus status in 1995)*

| Function | Dependent variable | Independent variable | β or α | p-value | Standard deviation | $R^2$ |
|---|---|---|---|---|---|---|
| **f1** | Crowberry 2007 | Constant | 32.623 | 0.000*** | 14.925 | 0.24 |
| | | No. stumps >15 cm | −3.595 | 0.000*** | | |
| | *cf.* Fig. 5a | Pine stand | −0.623 | 0.576 | | |
| | | Spruce stand | 3.948 | 0.000*** | | |
| | | Mixed stand | −3.324 | 0.003** | | |
| **f2** | Crowberry 2007 | Constant | 35.834 | 0.000*** | 13.535 | 0.37 |
| | | Lush *D. flexuosa* 1988 | −0.548 | 0.000*** | | |
| | *cf.* Fig. 5b | Pine stand | −0.029 | 0.977 | | |
| | | Spruce stand | 2.756 | 0.007** | | |
| | | Mixed stand | −2.727 | 0.007** | | |
| **f3** | Total *D. flexuosa* 2007 | Constant | 11.833 | 0.000*** | 5.616 | 0.46 |
| | | Crowberry 2007 | −0.134 | 0.000*** | | |
| | | Pine stand | 1.652 | 0.000*** | | |
| | | Spruce stand | −1.643 | 0.000*** | | |
| | | Mixed stand | −0.009 | 0.983 | | |
| **f4** | Lush *D. flexuosa* 2007 | Constant | 2.324 | 0.000*** | 2.094 | 0.37 |
| | | Crowberry 2007 | −0.032 | 0.000*** | | |
| | | Pine stand | 0.599 | 0.000*** | | |
| | | Spruce stand | −0.678 | 0.000*** | | |
| | | Mixed stand | 0.079 | 0.615 | | |
| **f5** | Bilberry 2007 | Constant | 32.122 | 0.000*** | 10.183 | 0.24 |
| | | Crowberry 2007 | −0.247 | 0.000*** | | |
| | *cf.* Fig. 5c | Pine stand | −1.598 | 0.036* | | |
| | | Spruce stand | 0.428 | 0.579 | | |
| | | Mixed stand | 1.170 | 0.128 | | |
| **f6** | Change in bilberry 1995–2007 | Constant | −0.425 | 0.564 | 9.367 | 0.20 |
| | | (Change in crowberry 1995–2007)$^2$ | −0.0098 | 0.000*** | | |
| | *cf.* Fig. 5d | Pine stand | −0.517 | 0.463 | | |
| | | Spruce stand | 0.958 | 0.177 | | |
| | | Mixed stand | −0.442 | 0.528 | | |

*Table 7. Reconstruction of the total number of plants ha$^{-1}$ at establishment in 1975*

| Type of plant | Pine stand | Mixed stand | Spruce stand |
|---|---|---|---|
| Total number of pine and spruce plants with favourable survival prognosis | 1482 | 1913 | 2072 |
| Total number of pine and spruce plants with unfavourable survival prognosis | 183 | 109 | 130 |
| Dead plants | 1076 | 618 | 286 |
| Total number of all plants | 2741 | 2640 | 2488 |
| Mean number of all plants | | 2623 | |
| Total number of all plants in relation to mean number of all plants | 1.05 | 1.01 | 0.95 |

*Table 8. No. of living plants and trees in relation to the reconstructed total number of plants at the establishment of the experiment*

| Type of plant | Pine stand | Mixed stand | Spruce stand |
|---|---|---|---|
| Reconstructed total number of all plants 1975, % | 100 | 100 | 100 |
| Total number of pine and spruce plants in 1988 (with favourable or unfavourable survival prognosis), % | 61 | 77 | 89 |
| Undamaged and slightly damaged trees 1994 , % | 46 | 69 | 80 |
| Undamaged and slightly damaged trees 2006, % | 42 | 59 | 59 |

*Table 9. No. trees ha$^{-1}$ and tree height (cm) for undamaged and slightly damaged trees in 1994 and 2006. Height in 1994 refers to height at the beginning of that year,* i.e. *excluding the 1994 current shoot; and height in 2006 refers to the end of that year,* i.e. *including the 2006 current shoot*

| **Statistical information** | **Pine stand** | | **Spruce stand** | | **Mixed stand** | |
|---|---|---|---|---|---|---|
| | **Pine** | **Spruce** | **Pine** | **Spruce** | **Pine** | **Spruce** |
| | | | **Year 1994** | | | |
| No. trees ha$^{-1}$ | 937 | 321 | 24 | 1954 | 634 | 1191 |
| Standard deviation of No. trees/parcel | 313 | 217 | 33 | 347 | 248 | 276 |
| Arithmetic mean tree height, cm | 265 | 98 | 148 | 98 | 258 | 119 |
| Standard deviation of individual trees | 66 | 80 | 157 | 73 | 69 | 84 |
| Median tree height, cm | 267 | 67 | 98 | 77 | 259 | 93 |
| Maximum tree height, cm | 445 | 350 | 454 | 469 | 427 | 455 |
| Minimum tree height, cm | 96 | 11 | 6 | 15 | 26 | 13 |
| | | | **Year 2006** | | | |
| No. trees ha$^{-1}$ | 914 | 230 | 12 | 1450 | 598 | 958 |
| Standard deviation of No. trees/parcel | 315 | 161 | 21 | 293 | 233 | 247 |
| Arithmetic mean tree height, cm | 600 | 304 | 439 | 269 | 583 | 331 |
| Standard deviation of individual trees | 115 | 191 | 243 | 175 | 111 | 213 |
| Median tree height, cm | 610 | 273 | 346 | 223 | 595 | 368 |
| Maximum tree height, cm | 890 | 750 | 790 | 870 | 900 | 905 |
| Minimum tree height, cm | 175 | 41 | 273 | 34 | 260 | 37 |
| | | | **Period 1994–2006** | | | |
| No. dead trees ha$^{-1}$ | 23 | 91 | 12 | 504 | 36 | 233 |
| No. dead trees, % | 2 | 28 | 50 | 26 | 6 | 20 |

*Table 10. Mortality functions with 'No. dead spruces per plot during the period 1994–2006' as dependent variable. Note: plots with 0 spruces in 1994 are not included; decimal degree of cover*

| **Function No. and independent variable** | **Spruce- and Mixed stand** | | | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| Function No. | f1 | | f2 | |
| Constant | −0.2589 | 0.468 | 0.1591 | 0.471 |
| (No. spruces 1994)$^2$ | 0.0243 | 0.000*** | 0.0237 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | −2.0463 | 0.006** | −2.0565 | 0.003** |
| Fertilised lush *D. flexuosa*88 | −1.2923 | 0.101 | −1.2068 | 0.114 |
| Unfertilised crowberry07 | 2.0332 | 0.004** | 1.5379 | 0.008** |
| Fertilised crowberry07 | 2.0489 | 0.001*** | 1.5340 | 0.004** |
| Unfertilised bilberry07 | 0.8752 | 0.332 | – | – |
| Fertilised bilberry07 | 0.8443 | 0.243 | – | – |
| Logging residues | 0.9125 | 0.196 | – | – |
| Spruce stand | 0.0485 | 0.508 | 0.0392 | 0.591 |
| $R^2$ | 0.43 | | 0.43 | |
| Standard deviation | 0.9932 | | 0.9924 | |
| No. observations | 233 | | | |

*Table 11. Analysis of variance for parcel mean heights in 2006 and parcel mean height increments; plot maximum height is based on the height of the tallest tree and plot maximum height increment on the largest 5-year height increment by species per plot. The mean of the parcel heights, and of 5-year height increments, is for undamaged trees > 1.3 m tall; but > 0 m for plot maximum height and plot maximum height increment*

| Treatment | Tree species | Average of parcel mean heights | | | |
|---|---|---|---|---|---|
| | | Arithmetic | Diameter-weighted | Basal-area weighted | Plot maximum |
| **Pine** stand | Pine | 607 | 629 | 645 | 662 |
| **Spruce** stand | Spruce | 322 | 416 | 494 | 398 |
| **Mixed** stand | Pine | 581 | 606 | 624 | 627 |
| | Spruce | 363 | 488 | 569 | 437 |

| Treatment | Tree species | Average of parcel mean height increments | | | |
|---|---|---|---|---|---|
| | | Arithmetic | Diameter-weighted | Basal-area weighted | Plot maximum |
| **Pine** stand | Pine | 149 | 151 | 153 | 160 |
| **Spruce** stand | Spruce | 79 | 103 | 122 | 104 |
| **Mixed** stand | Pine | 140 | 145 | 148 | 152 |
| | Spruce | 91 | 123 | 143 | 113 |

Analyses of variance

| Treatment | Tree species | p-values for parcel mean heights | | | |
|---|---|---|---|---|---|
| | | Arithmetic | Diameter-weighted | Basal-area weighted | Plot maximum |
| **Pine** stand | Pine | 0.117 | 0.109 | 0.120 | 0.112 |
| **Mixed** stand | Pine | | | | |
| **Spruce** stand | Spruce | 0.098 | 0.056(*) | 0.086 | 0.298 |
| **Mixed** stand | Spruce | | | | |

| Treatment | Tree species | p-values for parcel mean height increments | | | |
|---|---|---|---|---|---|
| | | Arithmetic | Diameter-weighted | Basal-area weighted | Plot maximum |
| **Pine** stand | Pine | 0.043* | 0.061 | 0.090 | 0.124 |
| **Mixed** stand | Pine | | | | |
| **Spruce** stand | Spruce | 0.041* | 0.046* | 0.093 | 0.352 |
| **Mixed** stand | Spruce | | | | |

*Table 12. Diameter-weighted mean height in 2006, and mean 5-year height increment for trees > 1.3 m tall, for various degrees of cover of lush D. flexuosa in 1988*

| Reference species: Lush *D. flexuosa* 1988 | | | | Mean cover, % | | Diameter-weighted mean height, cm | | Diameter-weighted mean height increment, cm | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | No. trees | Cover Interval, % | Mean, % | Crowberry 1995 | Bilberry 1988 | Pine | Spruce | Pine | Spruce |
| **Pine** | 89 | 0 | 0 | 12 | 45 | 611 | – | 146 | – |
| stand | 161 | 1-30 | 14 | 10 | 35 | 643 | – | 154 | – |
| | 22 | 31-60 | 47 | 4 | 26 | 638 | – | 153 | – |
| **Spruce** | 117 | 0 | 0 | 12 | 46 | – | 334 | – | 84 |
| stand | 186 | 1-30 | 14 | 9 | 43 | – | 443 | – | 109 |
| | 50 | 31-70 | 48 | 4 | 26 | – | 536 | – | 124 |
| **Mixed** | 69 | 0 | 0 | 10 | 50 | 601 | – | 144 | – |
| stand | 116 | 1-30 | 15 | 9 | 40 | 615 | – | 145 | – |
| | 8 | 31-50 | 39 | 5 | 26 | 647 | – | 147 | – |
| | 70 | 0 | 0 | 11 | 50 | – | 331 | – | 82 |
| | 151 | 1-30 | 16 | 8 | 37 | – | 550 | – | 139 |
| | 40 | 31-50 | 41 | 5 | 21 | – | 559 | – | 137 |
| | | | | | | Fig. 8a | Fig. 8b | Fig. 8c | Fig. 8d |

*Table 13. Diameter-weighted mean height in 2006, and mean 5-year height increment for trees >1.3 m tall, for various degrees of cover of crowberry in 1995*

| **Reference species: Crowberry 1995** | | | | **Mean cover, %** | | **Diameter-weighted mean height, cm** | | **Diameter-weighted mean height increment, cm** | |
|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **No. trees** | **Cover Interval, %** | **Cover Mean, %** | **Lush *D. flexuosa* 1988** | **Bilberry 1988** | **Pine** | **Spruce** | **Pine** | **Spruce** |
| **Pine** | 125 | 0–5 | 2 | 17 | 31 | 638 | – | 154 | – |
| stand | 85 | 6–15 | 10 | 10 | 44 | 639 | – | 152 | – |
| | 62 | 16–38 | 26 | 4 | 42 | 612 | – | 145 | – |
| **Spruce** | 131 | 0–5 | 3 | 21 | 37 | – | 470 | – | 115 |
| stand | 164 | 6–15 | 10 | 11 | 45 | – | 419 | – | 102 |
| | 58 | 16–35 | 21 | 6 | 41 | – | 394 | – | 95 |
| **Mixed** | 85 | 0–5 | 3 | 11 | 42 | 613 | – | 143 | – |
| stand | 80 | 6–15 | 10 | 12 | 42 | 615 | – | 146 | – |
| | 28 | 16–35 | 25 | 4 | 50 | 594 | – | 147 | – |
| | 116 | 0–5 | 3 | 18 | 33 | – | 558 | – | 143 |
| | 119 | 6–15 | 11 | 15 | 40 | – | 489 | – | 120 |
| | 26 | 16–35 | 24 | 3 | 51 | – | 327 | – | 69 |
| | | | | | | Fig. 9a | Fig. 9b | Fig. 9c | Fig. 9d |

*Table 14. Diameter-weighted mean height in 2006, and mean 5-year height increment for trees >1.3 m tall, for various degrees of cover of bilberry in 1988*

| **Reference species: Bilberry 1988** | | | | **Mean cover, %** | | **Diameter-weighted mean height, cm** | | **Diameter-weighted mean height increment, cm** | |
|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **No. trees** | **Cover Interval, %** | **Cover Mean, %** | **Lush *D. flexuosa* 1988** | **Crowberry 1995** | **Pine** | **Spruce** | **Pine** | **Spruce** |
| **Pine** | 56 | 0–20 | 14 | 21 | 6 | 671 | – | 161 | – |
| stand | 83 | 21–40 | 31 | 16 | 10 | 633 | – | 152 | – |
| | 133 | 41–65 | 52 | 6 | 12 | 614 | – | 146 | – |
| **Spruce** | 34 | 0–20 | 12 | 32 | 6 | – | 544 | – | 127 |
| stand | 142 | 21–40 | 35 | 20 | 9 | – | 453 | – | 108 |
| | 177 | 41–70 | 53 | 6 | 10 | – | 397 | – | 96 |
| **Mixed** stand | 15 | 0–20 | 14 | 28 | 3 | 641 | – | 151 | – |
| | 73 | 21–40 | 35 | 14 | 9 | 628 | – | 146 | – |
| | 105 | 41–70 | 53 | 6 | 10 | 593 | – | 143 | – |
| | 44 | 0–20 | 14 | 34 | 3 | – | 608 | – | 152 |
| | 108 | 21–40 | 34 | 17 | 9 | – | 525 | – | 131 |
| | 109 | 41–70 | 53 | 6 | 10 | – | 438 | – | 110 |
| | | | | | | Fig. 10a | Fig. 10b | Fig. 10c | Fig. 10d |

*Table 15a. Functions with ln [maximum tree height (cm) per plot] as dependent variable. Note: plots without relevant tree species are not included; decimal degree of cover*

| **Function No. & independent variable** | **Pine in Pine stand & Mixed stand** | | **Spruce in Spruce stand & Mixed stand** | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| **Function No.** | **f1** | | **f2** | |
| Constant | 6.4935 | 0.000*** | 5.6086 | 0.000*** |
| ln [No. pines per plot] | 0.0952 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.3556 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.0954 | 0.461 | 0.9808 | 0.006** |
| Fertilised lush *D. flexuosa*88 | −0.1178 | 0.368 | 1.4093 | 0.000*** |
| Unfertilised Crowberry95 | −0.2404 | 0.272 | −1.1141 | 0.056* |
| Fertilised Crowberry95 | −0.3748 | 0.113 | −2.0772 | 0.003** |
| Unfertilised Bilberry88 | −0.2518 | 0.048* | −0.4602 | 0.221 |
| Fertilised Bilberry88 | −0.1327 | 0.271 | −0.1732 | 0.629 |
| (Logging residues)$^2$ | −0.3073 | 0.142 | 1.5477 | 0.010** |
| Pine stand | 0.0164 | 0.163 | – | – |
| Spruce stand | – | – | −0.0545 | 0.080 |
| $R^2$ | 0.24 | | 0.47 | |
| Standard deviation | 0.148 | | 0.433 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 6.4066 | 0.000*** | 5.4622 | 0.000*** |
| ln [No. pines per plot] | 0.0980 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.3504 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.1632 | 0.166 | 1.0919 | 0.000*** |
| Fertilised lush *D. flexuosa*88 | 0.0035 | 0.976 | 1.6331 | 0.000*** |
| Unfertilised Crowberry95 | −0.4254 | 0.025* | −1.5084 | 0.003** |
| Fertilised Crowberry95 | −0.2879 | 0.177 | −1.7146 | 0.006** |
| (Logging residues)$^2$ | −0.1810 | 0.337 | 1.7796 | 0.001*** |
| Pine stand | 0.0184 | 0.115 | – | – |
| Spruce stand | – | – | −0.0570 | 0.067 |
| $R^2$ | 0.23 | | 0.47 | |
| Standard deviation | 0.149 | | 0.433 | |
| No. observations | 193 | | 228 | |

*Table 15b Functions with ln [maximum tree height (cm) per plot] as dependent variable. Note: plots without relevant tree species are not included; decimal degree of cover*

| **Function No. & independent variable** | **Pine in Pine stand & Mixed stand** | | **Spruce in Spruce stand & Mixed stand** | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| **Function No.** | **f1** | | **f2** | |
| Constant | 6.4908 | 0.000*** | 5.8749 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.1508 | 0.228 | 1.3352 | 0.000*** |
| Fertilised lush *D. flexuosa*88 | −0.0548 | 0.659 | 1.7456 | 0.000*** |
| Unfertilised Crowberry95 | −0.4587 | 0.023* | −1.7059 | 0.002** |
| Fertilised Crowberry95 | −0.2751 | 0.225 | −2.2653 | 0.001*** |
| (Logging residues)$^2$ | −0.2781 | 0.163 | 0.9431 | 0.093 |
| Pine stand | 0.0344 | 0.004** | – | – |
| Spruce stand | – | – | 0.0072 | 0.821 |
| $R^2$ | 0.13 | | 0.37 | |
| Standard deviation | 0.158 | | 0.473 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 6.3395 | 0.000*** | 5.1498 | 0.000*** |
| ln [No. pines per plot] | 0.0905 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.4441 | 0.000*** |
| No. stumps | 0.0352 | 0.003** | 0.1014 | 0.001*** |
| Logging residues | 0.0649 | 0.443 | 1.9076 | 0.000*** |
| Fertiliser | 0.0122 | 0.573 | 0.1298 | 0.042* |
| Pine stand | 0.0132 | 0.246 | – | – |
| Spruce stand | – | – | −0.0828 | 0.014* |
| $R^2$ | 0.24 | | 0.39 | |
| Standard deviation | 0.148 | | 0.468 | |
| No.observations | 193 | | 228 | |

*Table 15c. Functions with ln [maximum tree height increment (cm) per plot] as dependent variable. Note: plots without relevant tree species are not included; decimal degree of cover*

| Function No. & independent variable | Pine in Pine stand & Mixed stand | | Spruce in Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | β or α | p-value | β or α | p-value |
| **Function No.** | **f1** | | **f2** | |
| Constant | 5.0382 | 0.000*** | 4.0997 | 0.000*** |
| ln [No. pines per plot] | 0.0943 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.5000 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | −0.0937 | 0.488 | 0.8454 | 0.059 |
| Fertilised lush *D. flexuosa*88 | −0.0909 | 0.505 | 1.5934 | 0.001*** |
| Unfertilised Crowberry95 | −0.1893 | 0.407 | −1.4772 | 0.044* |
| Fertilised Crowberry95 | −0.3055 | 0.215 | −3.0817 | 0.001*** |
| Unfertilised Bilberry88 | −0.1179 | 0.373 | −0.4177 | 0.377 |
| Fertilised Bilberry88 | −0.0572 | 0.648 | −0.1741 | 0.699 |
| (Logging residues)$^2$ | −0.3321 | 0.128 | 1.9432 | 0.010** |
| Pine stand | 0.0161 | 0.190 | – | – |
| Spruce stand | – | – | −0.0706 | 0.072 |
| $R^2$ | 0.21 | | 0.42 | |
| Standard deviation | 0.154 | | 0.545 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 4.9987 | 0.000*** | 3.9616 | 0.000*** |
| ln [No. pines per plot] | 0.0955 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.4959 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | −0.0641 | 0.597 | 0.9552 | 0.009** (a) |
| Fertilised lush *D. flexuosa*88 | −0.0332 | 0.784 | 1.7956 | 0.000*** |
| Unfertilised Crowberry95 | −0.2815 | 0.150 | −1.8139 | 0.004** |
| Fertilised Crowberry95 | −0.2584 | 0.241 | −2.7773 | 0.000*** |
| (Logging residues)$^2$ | −0.2760 | 0.157 | 2.1614 | 0.001*** |
| Pine stand | 0.0170 | 0.160 | – | – |
| Spruce stand | – | – | −0.0728 | 0.062 |
| $R^2$ | 0.22 | | 0.42 | |
| Standard deviation | 0.154 | | 0.544 | |
| No. observ ations | 193 | | 228 | |

Note: (a) p-value = 0.05* for the difference between $\beta_{\text{unfertilised lush D. flexuosa88}}$ and $\beta_{\text{fertilised lush D. flexuosa88}}$

*Table 15d. Functions with ln [maximum tree height increment (cm) per plot] as dependent variable. Note: plots without relevant tree species are not included; decimal degree of cover*

| Function No. & independent variable | Pine in Pine stand & Mixed stand | | Spruce in Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | β or α | p-value | β or α | p-value |
| **Function No.** | **f1** | | **f2** | |
| Constant | 5.0807 | 0.000*** | 4.5457 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | −0.0762 | 0.552 | 1.2997 | 0.001*** |
| Fertilised lush *D. flexuosa*88 | −0.0901 | 0.480 | 1.9548 | 0.000*** |
| Unfertilised Crowberry95 | −0.3140 | 0.128 | −2.0934 | 0.003** (a) |
| Fertilised Crowberry95 | −0.2460 | 0.290 | −3.5568 | 0.000*** |
| (Logging residues)$^2$ | −0.3706 | 0.071 | 0.9776 | 0.174 |
| Pine stand | 0.0325 | 0.008** | – | – |
| Spruce stand | – | – | 0.0180 | 0.660 |
| $R^2$ | 0.13 | | 0.28 | |
| Standard deviation | 0.162 | | 0.607 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 4.9316 | 0.000*** | 3.5551 | 0.000*** |
| ln [No. pines per plot] | 0.0912 | 0.000*** | – | – |
| ln [No. spruces per plot] | – | – | 0.5988 | 0.000*** |
| No. stumps | 0.0236 | 0.054(*) | 0.1295 | 0.001*** |
| Logging residues | −0.0377 | 0.665 | 2.2127 | 0.000*** |
| Fertiliser | 0.0223 | 0.317 | 0.1074 | 0.175 |
| Pine stand | 0.0127 | 0.278 | – | – |
| Spruce stand | – | – | −0.1060 | 0.011(**) |
| $R^2$ | 0.23 | | 0.34 | |
| Standard deviation | 0.152 | | 0.580 | |
| No. observations | 193 | | 228 | |

Note: (a) p-value = 0.046* for the difference between $\beta_{\text{unfertilised crowberry95}}$ and $\beta_{\text{fertilised crowberry95}}$

*Table 15e. Functions with ln [maximum tree height (cm) per plot] and ln [maximum tree height increment (cm) per plot], respectively, as dependent variable for spruce in the Spruce and the Mixed stand. Note: plots without relevant tree species are not included; decimal degree of cover*

| **Function No. & independent variable** | **Dependent variable: ln [plotmaxheight] (cm)** | | **Dependent variable: ln [plotmaxheightincrement] (cm)** | |
|---|---|---|---|---|
| | **β or α** | **p-värde** | **β or α** | **p-värde** |
| **Function No.** | **f1** | | **f2** | |
| Constant | 5.5264 | 0.000*** | 4.0725 | 0.000*** |
| ln [No. spruces per plot] | 0.3541 | 0.000*** | 0.4960 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.1258 | 0.001*** | 0.9570 | 0.019* |
| Fertilised lush *D. flexuosa*88 | 1.5279 | 0.000*** | 1.6458 | 0.000*** |
| Unfertilised Crowberry 07 | −0.7220 | 0.022* | −0.9399 | 0.017* |
| Fertilised Crowberry 07 | −0.6695 | 0.019* | −1.1288 | 0.002** |
| Unfertilised Bilberry 07 | −0.1154 | 0.774 | −0.1401 | 0.781 |
| Fertilised Bilberry 07 | 0.0244 | 0.940 | 0.0561 | 0.889 |
| (Logging residues)$^2$ | 1.6121 | 0.005** | 1.8685 | 0.010** |
| Spruce stand | −0.0487 | 0.128 | −0.0591 | 0.140 |
| $R^2$ | 0.46 | | 0.42 | |
| Standard deviation | 0.438 | | 0.548 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 5.5186 | 0.000*** | 4.0704 | 0.000*** |
| ln [No. spruces per plot] | 0.3525 | 0.000*** | 0.4935 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.0853 | 0.000*** | 0.8965 | 0.017* (a) |
| Fertilised lush *D. flexuosa*88 | 1.5588 | 0.000*** | 1.6890 | 0.000*** |
| Unfertilised Crowberry07 | −0.7595 | 0.005** | −1.0007 | 0.003** |
| Fertilised Crowberry 07 | −0.6387 | 0.011** | −1.0938 | 0.001*** |
| (Logging residues)$^2$ | 1.6319 | 0.003** | 1.8860 | 0.007** |
| Spruce stand | −0.0487 | 0.126 | −0.0591 | 0.138 |
| $R^2$ | 0.47 | | 0.42 | |
| Standard deviation | 0.436 | | 0.545 | |
| No. observations | | 228 | | |

Note: (a) p-value = 0.073 for the difference between $\beta_{\text{unfertilised lush } D. flexuosa88}$ and $\beta_{\text{fertilised lush } D. flexuosa88}$

*Table 15f. Functions with ln [maximum tree height (cm) per plot] and ln [maximum tree height increment (cm) per plot], respectively, as dependent variable for spruce in the Spruce stand and the Mixed stand,. Note: plots without relevant tree species are not included; decimal degree of cover*

| **Function No. & independent variable** | **Dependent variable: ln [plotmaxheight] (cm)** | | **Dependent variable: ln [plotmaxheightincrement] (cm)** | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| **Function No.** | **f1** | | **f2** | |
| Constant | 5.9560 | 0.000*** | 4.6826 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.2957 | 0.000*** | 1.1910 | 0.004** |
| Fertilised lush *D. flexuosa*88 | 1.6749 | 0.000*** | 1.8516 | 0.000*** |
| Unfertilised Crowberry07 | −0.8760 | 0.003** | −1.1636 | 0.002** |
| Fertilised Crowberry07 | −0.8876 | 0.001*** | −1.4421 | 0.000*** |
| (Logging residues)$^2$ | 0.7307 | 0.209 | 0.6245 | 0.400 |
| Spruce stand | 0.0184 | 0.573 | 0.0348 | 0.404 |
| $R^2$ | 0.37 | | 0.28 | |
| Standard deviation | 0.475 | | 0.607 | |
| **Function No.** | **f3** | | **f4** | |
| Constant | 5.1498 | 0.000*** | 3.5551 | 0.000*** |
| ln [No. spruces per plot] | 0.4441 | 0.000*** | 0.5988 | 0.000*** |
| No. stumps | 0.1014 | 0.001*** | 0.1295 | 0.001*** |
| Logging residues | 1.9076 | 0.000*** | 2.2127 | 0.000*** |
| Fertiliser | 0.1298 | 0.042* | 0.1074 | 0.175 |
| Spruce stand | −0.0828 | 0.014* | −0.1060 | 0.011(**) |
| $R^2$ | 0.39 | | 0.34 | |
| Standard deviation | 0.468 | | 0.580 | |
| No. observations | | 228 | | |

*Table 16a. Mean stand volume $m^3ha^{-1}$ o.b. in 2006, by species and DBH strata and for the treatments as a whole*

| Block | Treatment | DBH < 51 mm | | DBH > 50 mm | | DBH > 0 mm | | DBH > 0 mm |
|---|---|---|---|---|---|---|---|---|
| | | Pine | Spruce | Pine | Spruce | Pine | Spruce | Pine + Spruce |
| Block mean | **Pine stand** | 0.1 | 0.2 | 32.6 | 1.1 | 32.7 | 1.4 | 34.1 |
| | **Spruce stand** | 0 | 1.2 | 0.5 | 6.3 | 0.5 | 7.6 | 8.1 |
| | **Mixed stand** | 0.1 | 0.7 | 20.2 | 7.6 | 20.3 | 8.3 | 28.6 |
| Standard deviation | **Pine stand** | 0.1 | 0.2 | 12.7 | 0.9 | 12.8 | 0.1 | 12.8 |
| | **Spruce stand** | 0.03 | 0.3 | 1.4 | 5.4 | 1.5 | 5.4 | 5.9 |
| | **Mixed stand** | 0.1 | 0.3 | 10.0 | 5.8 | 10.0 | 5.7 | 13.5 |
| Proportion, % | **Pine stand** | 0.3 | 0.6 | 96 | 3 | 96 | 4 | 100 |
| | **Spruce stand** | 0.1 | 15 | 6 | 78 | 6 | 94 | 100 |
| | **Mixed stand** | 0.3 | 2 | 71 | 27 | 71 | 29 | 100 |

*Table 16b. Parcelwise functions for ln [stand volume $m^3ha^{-1}$ o.b.] in 2006 as dependent variable*

| Function No. & independent variable | Pine stand & Mixed stand | | | | | |
|---|---|---|---|---|---|---|
| | β or α | p-value | β or α | p-value | β or α | p-value |
| **Function No.** | **f1** | | **f2** | | **f3** | |
| Constant | 3.260 | 0.000 | 4.287 | 0.000*** | 4.794 | 0.000*** |
| Lush *D. flexuosa*88 | 0.764 | 0.774 | – | – | −2.148 | 0.393 |
| Crowberry07 | – | – | −3.409 | 0.050* | −4.217 | 0.046* |
| Pine stand | 0.088 | 0.440 | 0.129 | 0.169 | 0.148 | 0.140 |
| $R^2$ | 0.00 | | 0.20 | | 0.19 | |
| Standard deviation | 0.481 | | 0.375 | | 0.379 | |
| No. observations | | | 20 | | | |

| Function No. & independent variable | Spruce stand & Mixed stand | | | | | |
|---|---|---|---|---|---|---|
| | β or α | p-value | β or α | p-value | β or α | p-value |
| **Function No.** | **f4** | | **f5** | | **f6** | |
| Constant | 2.009 | 0.000*** | 3.688 | 0.001*** | 3.030 | 0.005** |
| Lush *D. flexuosa*88 | 4.761 | 0.106 | – | – | 4.246 | 0.126 |
| Crowberry07 | – | – | −3.792 | 0.151 | −3.273 | 0.172 |
| Spruce stand | −0.646 | 0.000*** | −0.570 | 0.003** | −0.544 | 0.003** |
| $R^2$ | 0.71 | | 0.69 | | 0.75 | |
| Standard deviation | 0.479 | | 0.497 | | 0.444 | |
| No. observations | | | 20 | | | |

| Function No. & independent variable | Pine stand, Spruce stand & Mixed stand | | | | | |
|---|---|---|---|---|---|---|
| | β or α | p-value | β or α | p-value | β or α | p-value |
| **Function No.** | **f7** | | **f8** | | **f9** | |
| Constant | 2.499 | 0.000*** | 3.958 | 0.000*** | 3.625 | 0.000*** |
| Lush *D. flexuosa*88 | 2.943 | 0.076 | – | | 1.450 | 0.349 |
| Crowberry07 | – | – | −3.761 | 0.006** | −3.239 | 0.027* |
| Pine stand | 0.547 | 0.000*** | 0.558 | 0.000*** | 0.543 | 0.000*** |
| Spruce stand | −0.938 | 0.000*** | −0.849 | 0.000*** | −0.844 | 0.000*** |
| Mixed stand | 0.391 | 0.006** | 0.292 | 0.022* | 0.302 | 0.020* |
| $R^2$ | 0.69 | | 0.76 | | 0.76 | |
| Standard deviation | 0.486 | | 0.427 | | 0.428 | |
| No. observations | | | 30 | | | |

*Table 16c. Parcelwise functions for basal-area weighted mean diameter (mm) and mean tree volume ($dm^3$ o.b.) in 2006 for trees >0 mm DBH vs. stand volume ($m^3ha^{-1}$ o.b.). Each function is based on 20 observations (parcel values)*

| Function | Dependent variable | Independent variable | β or α | p-value | Standard deviation | $R^2$ |
|---|---|---|---|---|---|---|
| f1 | **Pine stand and Mixed stand** | | | | | |
| | Basal-area-weighted mean diameter of pine, mm | Constant | 110.640 | 0.000*** | 6.988 | 0.43 |
| | DBH >0 mm | Stand volume of pine, $m^3ha^{-1}$ o.b. | 0.422 | 0.050* | | |
| | mm | Pine stand | −1.369 | 0.499 | | |
| f2 | **Spruce stand and Mixed stand** | | | | | |
| | Basal-area-weighted mean diameter of spruce, mm | Constant | 54.069 | 0.000*** | 11.274 | 0.56 |
| | DBH >0 mm | Stand volume of spruce, $m^3ha^{-1}$ o.b. | 3.550 | 0.003** | | |
| | mm | Spruce stand | −5.879 | 0.049* | | |
| f3 | **Pine stand and Mixed stand** | | | | | |
| | Mean volume of pine >0 mm in DBH | Constant | 24.634 | 0.000*** | 3.192 | 0.72 |
| | | Stand volume of pine, $m^3ha^{-1}$ o.b. | 0.357 | 0.003** | | |
| | $dm^3$ o.b. | Pine stand | −1.211 | 0.207 | | |
| f4 | **Spruce stand and Mixed stand** | | | | | |
| | Mean volume of spruce >0 mm in DBH | Constant | 1.432 | 0.024* | 0.826 | 0.96 |
| | | Stand volume of spruce, $m^3ha^{-1}$ o.b. | 0.821 | 0.000*** | | |
| | $dm^3$ o.b. | Spruce stand | −1.237 | 0.000*** | | |

*Table 16d. Mean volume ($dm^3$ o.b.) in 2006 for trees with DBH >0 mm*

| Statistical data | Pine stand | | Spruce stand | | Mixed stand | |
|---|---|---|---|---|---|---|
| | Pine | Spruce | Pine | Spruce | Pine | Spruce |
| Arithmetic mean tree volume $dm^3$ o.b. | 35.5 | 7.4 | 43.5 | 6.9 | 33.6 | 10.4 |
| No. trees $ha^{-1}$ | 313 | 62 | 4 | 369 | 205 | 270 |
| Standard deviation of mean tree volume | 22.2 | 10.6 | 75.5 | 11.3 | 21.7 | 15.1 |
| Median tree volume | 31.3 | 3.4 | 8.2 | 2.5 | 30.7 | 3.5 |
| Maximum tree volume | 147.5 | 54.0 | 156.5 | 84.2 | 107.2 | 96.8 |
| Minimum tree volume | 0.7 | 0.3 | 1.2 | 0.3 | 1.0 | 0.2 |

*Table 17. Mean stand volume per plot (m³ha⁻¹ o.b.) in 2006 vs. cover of D. flexuosa in 1988*

| **Pine stand** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Reference species: lush *D. flexuosa* 1988** | | **Cover, %** | | **Mean No. stems/plot (No. ha$^{-1}$)** | **Mean volume/plot, m$^3$ha$^{-1}$ (o.b.)** | | |
| **No. plots** | | **Interval** | **Mean** | | **Pine** | **Spruce** | **Pine + Spruce** |
| 17 | Unfertilised | 0 | 0 | 1394 | 30.0 | 0.5 | 30.5 |
| 1 | Fertilised | | 0 | 1415 | 34.9 | 1.7 | 36.6 |
| 38 | Unfertilised | 1-30 | 15 | 977 | 32.3 | 1.1 | 33.4 |
| 3 | Fertilised | | 15 | 1186 | 32.0 | 2.2 | 34.2 |
| 5 | Unfertilised | 31-70 | 46 | 778 | 26.9 | 0 | 26.9 |
| 8 | Fertilised | | 46 | 973 | 42.3 | 1.0 | 43.3 |
| 60 | Unfertilised | 0-70 | 13 | 1079 | 31.2 | 0.8 | 32.0 |
| 60 | Fertilised | | 14 | 1226 | 34.2 | 1.9 | 36.1 |

| **Spruce stand** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Reference species: lush *D. flexuosa* 1988** | | **Cover, %** | | **Mean No. stems/plot (No. ha$^{-1}$)** | **Mean volume/plot, m$^3$ha$^{-1}$ (o.b.)** | | |
| **No. plots** | | **Interval** | **Mean** | | **Pine** | **Spruce** | **Pine + Spruce** |
| 29 | Unfertilised | 0 | 0 | 1634 | 2.1 | 2.4 | 4.5 |
| 21 | Fertilised | | 0 | 1229 | 0 | 2.9 | 2.9 |
| 24 | Unfertilised | 1-30 | 13 | 1488 | 0 | 6.3 | 6.3 |
| 34 | Fertilised | | 13 | 1415 | 0 | 11.1 | 11.1 |
| 7 | Unfertilised | 31-70 | 49 | 1667 | 0 | 23.0 | 23.0 |
| 5 | Fertilised | | 42 | 1627 | 0 | 17.6 | 17.6 |
| 60 | Unfertilised | 0-70 | 14 | 1580 | 1.0 | 6.4 | 7.4 |
| 60 | Fertilised | | 11 | 1368 | 0 | 8.8 | 8.8 |

| **Mixed stand** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Reference species: lush *D. flexuosa* 1988** | | **Cover, %** | | **Mean No. stems/plot (No. ha$^{-1}$)** | **Mean volume/plot, m$^3$ha$^{-1}$ (o.b.)** | | |
| **No. plots** | | **Interval** | **Mean** | | **Pine** | **Spruce** | **Pine + Spruce** |
| 24 | Unfertilised | 0 | 0 | 1650 | 22.9 | 2.0 | 24.9 |
| 17 | Fertilised | | 0 | 1331 | 13.9 | 1.5 | 15.4 |
| 30 | Unfertilised | 1-30 | 18 | 1674 | 21.2 | 11.0 | 32.2 |
| 38 | Fertilised | | 15 | 1517 | 23.9 | 10.3 | 34.2 |
| 6 | Unfertilised | 31-70 | 38 | 1827 | 15.3 | 22.3 | 37.6 |
| 5 | Fertilised | | 45 | 1273 | 3.4 | 13.6 | 16.9 |
| 60 | Unfertilised | 0-70 | 13 | 1680 | 21.3 | 8.5 | 29.8 |
| 60 | Fertilised | | 13 | 1444 | 19.3 | 8.1 | 27.4 |

*Table 18. Mean stand volume per plot ($m^3ha^{-1}$ o.b.) in 2006 vs. cover of crowberry in 1995*

**Pine stand**

| Reference species: Crowberry 1995 | | | | | Mean volume/plot, $m^3ha^{-1}$ (o.b.) | | |
|---|---|---|---|---|---|---|---|
| No. plots | | Cover, % Interval | Cover, % Mean | Mean No. stems/plot (No. $ha^{-1}$) | Pine | Spruce | Pine + Spruce |
| 21 | Unfertilised | 0–5 | 2 | 1280 | 34.4 | 0.2 | 34.7 |
| 26 | Fertilised | | 3 | 1265 | 45.0 | 1.5 | 46.4 |
| 22 | Unfertilised | 6–15 | 10 | 1045 | 34.2 | 1.2 | 35.4 |
| 20 | Fertilised | | 10 | 1238 | 24.8 | 3.2 | 28.0 |
| 17 | Unfertilised | 16–40 | 25 | 874 | 23.4 | 1.1 | 24.5 |
| 14 | Fertilised | | 26 | 1137 | 27.8 | 0.8 | 28.6 |
| 60 | Unfertilised | 0–40 | 12 | 1079 | 31.2 | 0.8 | 32.0 |
| 60 | Fertilised | | 10 | 1226 | 34.2 | 1.9 | 36.1 |

**Spruce stand**

| Reference species: Crowberry 1995 | | | | | Mean volume/plot, $m^3ha^{-1}$ (o.b.) | | |
|---|---|---|---|---|---|---|---|
| No. plots | | Cover, % Interval | Cover, % Mean | Mean No. stems/plot (No. $ha^{-1}$) | Pine | Spruce | Pine + Spruce |
| 20 | Unfertilised | 0–5 | 3 | 1627 | 0 | 11.0 | 11.0 |
| 19 | Fertilised | | 3 | 1340 | 0 | 11.8 | 11.8 |
| 27 | Unfertilised | 6–15 | 11 | 1585 | 0.2 | 4.7 | 4.9 |
| 30 | Fertilised | | 10 | 1450 | 0 | 7.6 | 7.7 |
| 13 | Unfertilised | 16–40 | 23 | 1496 | 4.3 | 2.7 | 7.0 |
| 11 | Fertilised | | 20 | 1190 | 0 | 6.6 | 6.6 |
| 60 | Unfertilised | 0–40 | 11 | 1580 | 1.0 | 6.4 | 7.4 |
| 60 | Fertilised | | 10 | 1368 | 0 | 8.8 | 8.8 |

**Mixed stand**

| Reference species: Crowberry 1995 | | | | | Mean volume/plot, $m^3ha^{-1}$ (o.b.) | | |
|---|---|---|---|---|---|---|---|
| No. plots | | Cover, % Interval | Cover, % Mean | Mean No. stems/plot (No. $ha^{-1}$) | Pine | Spruce | Pine + Spruce |
| 23 | Unfertilised | 0–5 | 3 | 1645 | 22.4 | 12.2 | 34.7 |
| 32 | Fertilised | | 2 | 1337 | 19.8 | 10.3 | 30.1 |
| 27 | Unfertilised | 6–15 | 10 | 1795 | 20.0 | 8.0 | 28.0 |
| 21 | Fertilised | | 10 | 1566 | 21.6 | 6.4 | 28.0 |
| 10 | Unfertilised | 16–40 | 26 | 1415 | 22.2 | 1.4 | 23.6 |
| 7 | Fertilised | | 21 | 1566 | 10.6 | 3.0 | 13.6 |
| 60 | Unfertilised | 0–40 | 10 | 1680 | 21.3 | 8.5 | 29.8 |
| 60 | Fertilised | | 7 | 1444 | 19.3 | 8.1 | 27.4 |

*Table 19a. Functions with ln [stand volume per plot ($dm^3$ o.b.)] as dependent variable. Note: plots with zero volume are not included; decimal degree of cover. UF = unfertilised, F = fertilised*

| **Function No. and independent variable** | **Pine stand** | | **Spruce stand** | | **Mixed stand** | |
|---|---|---|---|---|---|---|
| | **β** | **p-value** | **β** | **p-value** | **β** | **p-value** |
| **Function** | **f1** | | **f2** | | **f3** | |
| Constant | 4.241 | 0.000*** | 1.403 | 0.000*** | 3.684 | 0.000*** |
| UF lush *D. flexuosa* 1988 | 0.685 | 0.540 | 5.822 | 0.000*** | 2.970 | 0.004** |
| F lush *D. flexuosa* 1988 | −0.292 | 0.759 | 7.453 | 0.000*** | 1.113 | 0.263 |
| $R^2$ / Standard deviation | 0.11 / 1.105 | | 0.32 / 1.392 | | 0.17 / 1.153 | |
| **Function** | **f4** | | **f5** | | **f6** | |
| Constant | 3.339 | 0.000*** | 6.171 | 0.088 | 3.195 | 0.000*** |
| ln [No. trees/plot] | 1.122 | 0.000*** | 1.495 | 0.000*** | 1.111 | 0.000*** |
| Spruce proportion | −2.102 | 0.000*** | −6.602 | 0.067 | −1.880 | 0.000*** |
| UF lush *D. flexuosa* 1988 | 0.746 | 0.269 | 4.509 | 0.000*** | 3.131 | 0.000*** |
| F lush *D. flexuosa* 1988 | 0.600 | 0.295 | 6.210 | 0.000*** | 2.872 | 0.000*** |
| $R^2$ / Standard deviation | 0.68 / 0.656 | | 0.63 / 1.034 | | 0.51 / 0.889 | |
| **Function** | **f7** | | **f8** | | **f9** | |
| Constant | 4.227 | 0.000*** | 2.946 | 0.000*** | 4.610 | 0.000*** |
| UF Crowberry 1995 | −0.031 | 0.985 | −7.661 | 0.002** | −5.004 | 0.000***(a) |
| F Crowberry 1995 | 0.740 | 0.653 | −8.728 | 0.003** | −11.243 | 0.000*** |
| $R^2$ / Standard deviation | 0.10 / 1.107 | | 0.17 / 1.542 | | 0.36 / 1.016 | |
| **Function** | **f10** | | **f11** | | **f12** | |
| Constant | 3.506 | 0.000*** | 4.602 | 0.259 | 4.285 | 0.000*** |
| ln [No. trees/plot] | 1.096 | 0.000*** | 1.682 | 0.000*** | 1.011 | 0.000*** |
| Spruce proportion | −2.128 | 0.000*** | −4.182 | 0.299 | −1.682 | 0.000*** |
| UF Crowberry 1995 | −0.523 | 0.601 | −5.908 | 0.002** | −6.144 | 0.000***(b) |
| F Crowberry 1995 | −0.326 | 0.740 | −4.035 | 0.079 | −10.313 | 0.000*** |
| $R^2$ / Standard deviation | 0.68 / 0.661 | | 0.52 / 1.171 | | 0.64 / 0.757 | |
| **Function** | **f13** | | **f14** | | **f15** | |
| Constant | 4.721 | 0.000*** | 4.502 | 0.000*** | 4.952 | 0.000*** |
| UF Bilberry 1988 | −1.405 | 0.116 | −5.400 | 0.000*** | −2.121 | 0.011** |
| F Bilberry 1988 | −1.018 | 0.248 | −5.400 | 0.000*** | −2.742 | 0.001*** |
| $R^2$ / Standard deviation | 0.12 / 1.094 | | 0.22 / 1.496 | | 0.20 / 1.134 | |
| **Function** | **f16** | | **f17** | | **f18** | |
| Constant | 3.678 | 0.000*** | 5.687 | 0.144 | 4.723 | 0.000*** |
| ln [No. trees/plot] | 1.080 | 0.000*** | 1.673 | 0.000*** | 1.129 | 0.000*** |
| Spruce proportion | −2.115 | 0.000*** | −3.892 | 0.307 | −1.744 | 0.000*** |
| UF Bilberry 1988 | −0.699 | 0.193 | −4.601 | 0.000*** | −3.100 | 0.000*** |
| F Bilberry 1988 | −0.359 | 0.503 | −3.864 | 0.000*** | −2.984 | 0.000*** |
| $R^2$ / Standard deviation | 0.69 / 0.654 | | 0.57 / 1.111 | | 0.53 / 0.873 | |
| No. observations | 108 | | 117 | | 117 | |

Note: (a) p-value = 0.000*** for the difference between $\beta_{unfertilised\ crowberry95}$ and $\beta_{fertilised\ crowberry95}$
(b) p-value = 0.002** for the difference between $\beta_{unfertilised\ crowberry95}$ and $\beta_{fertilised\ crowberry95}$

*Table 19b. Functions with ln [stand volume per plot (dm³ o.b.)] as dependent variable. Note: plots with zero volume are not included; decimal degree of cover*

| Function No. and independent variable | Pine stand | | Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| **Function** | **f1** | | **f2** | |
| Constant | 3.2826 | 0.000*** | 2.6389 | 0.000*** |
| ln [No. trees/plot] | 1.1087 | 0.000*** | 1.5292 | 0.000*** |
| Spruce proportion | −2.1078 | 0.000*** | −1.9938 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.9917 | 0.211 | 2.3630 | 0.002** |
| Fertilised lush *D. flexuosa*88 | 0.2064 | 0.774 | 3.0174 | 0.000*** |
| Unfertilised Crowberry95 | 1.356 | 0.300 | −2.753 | 0.024* |
| Fertilised Crowberry95 | −0.369 | 0.763 | −4.680 | 0.002** |
| Unfertilised Bilberry88 | −0.4657 | 0.535 | −0.4352 | 0.577 |
| Fertilised Bilberry88 | 0.4760 | 0.514 | −0.0007 | 0.999 |
| (Logging residues)$^2$ | 1.343 | 0.222 | 4.368 | 0.001*** |
| Spruce stand | - | - | −0.3742 | 0.000*** |
| $R^2$ | 0.68 | | 0.73 | |
| Standard deviation | 0.657 | | 0.908 | |
| **Function** | **f3** | | **f4** | |
| Constant | 3.2673 | 0.000*** | 2.5582 | 0.000*** |
| ln [No. trees/plot] | 1.1331 | 0.000*** | 1.5206 | 0.000*** |
| Spruce proportion | −2.0689 | 0.000*** | −2.0068 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.7523 | 0.319 | 2.3835 | 0.000*** |
| Fertilised lush *D. flexuosa*88 | 0.4732 | 0.457 | 3.2429 | 0.000*** |
| Unfertilised Crowberry95 | 0.220 | 0.846 | −3.329 | 0.001*** |
| Fertilised Crowberry95 | 0.517 | 0.642 | −4.087 | 0.002** |
| (Logging residues)$^2$ | 1.2175 | 0.219 | 4.523 | 0.000*** |
| Spruce stand | - | - | −0.3765 | 0.000*** |
| $R^2$ | 0.68 | | 0.73 | |
| Standard deviation | 0.661 | | 0.905 | |
| No. observations | 108 | | 234 | |

*Table 19c. Functions with ln [stand volume per plot (dm³ o.b.)] as dependent variable. Note: plots with zero volume are not included; decimal degree of cover*

| Function No. and independent variable | Pine stand | | Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | **β or α** | **p-value** | **β or α** | **p-value** |
| **Function** | **f1** | | **f2** | |
| Constant | 2.6903 | 0.000*** | 0.9989 | 0.000*** |
| ln [No. trees/plot] | 1.1015 | 0.000*** | 1.5143 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.489 | 0.154 | 2.0202 | 0.002** |
| Fertilised lush *D. flexuosa*88 | 0.4316 | 0.625 | 2.9936 | 0.000*** |
| Unfertilised Crowberry95 | 1.780 | 0.254 | −3.229 | 0.004** |
| Fertilised Crowberry95 | 1.739 | 0.259 | −4.566 | 0.001*** |
| (Logging residues)$^2$ | 2.359 | 0.085 | 4.370 | 0.000*** |
| Spruce stand | - | - | −0.7553 | 0.000*** |
| $R^2$ | 0.38 | | 0.69 | |
| Standard deviation | 0.919 | | 0.984 | |
| **Function** | **f3** | | **f4** | |
| Constant | 4.1283 | 0.000*** | 3.1977 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.029 | 0.414 | 2.9037 | 0.001*** |
| Fertilised lush *D. flexuosa*88 | −0.406 | 0.701 | 2.9177 | 0.002** |
| Unfertilised Crowberry95 | 0.025 | 0.989 | −4.061 | 0.005** [(a)] |
| Fertilised Crowberry95 | 1.512 | 0.417 | −7.242 | 0.000*** |
| (Logging residues)$^2$ | 1.238 | 0.450 | 0.260 | 0.860 |
| Spruce stand | - | - | −0.8308 | 0.000*** |
| $R^2$ | 0.09 | | 0.48 | |
| Standard deviation | 1.114 | | 1.270 | |
| **Function** | **f5** | | **f6** | |
| Constant | 3.2758 | 0.000*** | 1.6815 | 0.000*** |
| ln [No. trees/plot] | 1.0928 | 0.000*** | 1.6676 | 0.000*** |
| Spruce proportion | −2.0665 | 0.000*** | −1.7536 | 0.000*** |
| No. stumps | 0.0864 | 0.214 | 0.2542 | 0.000*** |
| Logging residues | 0.8893 | 0.075 | 3.9695 | 0.000*** |
| Fertiliser | 0.0876 | 0.497 | 0.2173 | 0.106 |
| Spruce stand | - | - | −0.4479 | 0.000*** |
| $R^2$ | 0.69 | | 0.68 | |
| Standard deviation | 0.649 | | 0.995 | |
| No. observations | 108 | | 234 | |

Note: [(a)] p-value = 0.037* for the difference between $\beta_{\text{unfertilised crowberry95}}$ and $\beta_{\text{fertilised crowberry95}}$

*Table 19d. Functions with ln [stand volume per plot (dm³ o.b.)] as dependent variable. Note: plots with zero volume are not included; decimal degree of cover*

| Function No. and independent variable | Pine stand | | Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | β or α | p-value | β or α | p- value |
| **Function** | f1 | | f2 | |
| Constant | 3.6827 | 0.000*** | 2.5373 | 0.000*** |
| ln [No. trees/plot] | 1.0907 | 0.000*** | 1.5021 | 0.000*** |
| Spruce proportion | −2.1245 | 0.000*** | −2.0542 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.7211 | 0.381 | 2.3511 | 0.001*** |
| Fertilised lush *D. flexuosa*88 | −0.0254 | 0.971 | 3.1350 | 0.000*** |
| Unfertilised Crowberry07 | −0.3339 | 0.635 | −1.5699 | 0.017* |
| Fertilised Crowberry 07 | −0.3087 | 0.681 | −1.3027 | 0.030* |
| Unfertilised Bilberry07 | −1.2157 | 0.176 | 0.7997 | 0.341 |
| Fertilised Bilberry 07 | −0.4158 | 0.629 | 0.5177 | 0.440 |
| (Logging residues)$^2$ | 0.834 | 0.421 | 4.355 | 0.000*** |
| Spruce stand | - | - | −0.3503 | 0.000*** |
| $R^2$ | 0.68 | | 0.73 | |
| Standard deviation | 0.659 | | 0.912 | |
| **Function** | f3 | | f4 | |
| Constant | 3.3035 | 0.000*** | 2.7700 | 0.000*** |
| ln [No. trees/plot] | 1.1266 | 0.000*** | 1.4918 | 0.000*** |
| Spruce proportion | −2.1035 | 0.000*** | −2.0278 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.8364 | 0.282 | 2.3327 | 0.000*** |
| Fertilised lush *D. flexuosa*88 | 0.3324 | 0.606 | 3.0616 | 0.000*** |
| Unfertilised Crowberry07 | −0.1109 | 0.848 | −1.7095 | 0.002** |
| Fertilised Crowberry 07 | 0.2824 | 0.648 | −1.5869 | 0.003** |
| (Logging residues)$^2$ | 1.1430 | 0.252 | 4.025 | 0.001*** |
| Spruce stand | - | - | −0.3569 | 0.000*** |
| $R^2$ | 0.68 | | 0.73 | |
| Standard deviation | 0.659 | | 0.909 | |
| No. observations | 108 | | 234 | |

*Table 19e. Functions with ln [stand volume per plot (dm³ o.b.)] as dependent variable. Note: plots with zero volume are not included; decimal degree of cover*

| Function No. and independent variable | Pine stand | | Spruce stand & Mixed stand | |
|---|---|---|---|---|
| | β or α | p-value | β or α | p- value |
| **Function** | f1 | | f2 | |
| Constant | 2.6241 | 0.000*** | 1.1817 | 0.000*** |
| ln[No. trees/plot] | 1.1173 | 0.000*** | 1.4860 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 1.428 | 0.187 | 1.9803 | 0.004** |
| Fertilised lush *D. flexuosa*88 | 0.4688 | 0.602 | 2.8355 | 0.000*** |
| Unfertilised Crowberry07 | 0.9600 | 0.226 | −1.6393 | 0.007** |
| Fertilised Crowberry07 | 0.7243 | 0.400 | −1.6979 | 0.003** |
| (Logging residues)$^2$ | 2.386 | 0.085 | 3.883 | 0.002** |
| Spruce stand | - | - | −0.7405 | 0.000*** |
| $R^2$ | 0.38 | | 0.68 | |
| Standard deviation | 0.920 | | 0.990 | |
| **Function** | f3 | | f4 | |
| Constant | 4.2414 | 0.000*** | 3.6104 | 0.000*** |
| Unfertilised lush *D. flexuosa*88 | 0.613 | 0.638 | 2.4725 | 0.004** |
| Fertilised lush *D. flexuosa*88 | −0.531 | 0.623 | 2.4971 | 0.010** |
| Unfertilised Crowberry 07 | −0.0815 | 0.931 | −2.6582 | 0.001*** |
| Fertilised Crowberry 07 | 0.078 | 0.940 | −3.2555 | 0.000*** |
| (Logging residues)$^2$ | 1.131 | 0.495 | −0.772 | 0.610 |
| Spruce stand | - | - | −0.7950 | 0.000*** |
| $R^2$ | 0.08 | | 0.49 | |
| Standard deviation | 1.119 | | 1.257 | |
| No. observations | 108 | | 234 | |

*Table 19f. Estimate of the effect on total volume yield to year 2006 in the Spruce stand and the Mixed stand, of indicator species, fertilisation and logging residues*

| **Variable properties** | **Cover, %** | **Effect (%) on stand volume** |
|---|---|---|
| **Function: Table 19b:f4 including ln[No. trees/plot] and Spruce proportion** | | |
| Unfertilised lush *D. flexuosa* 1988 | 12 | + 0.33 |
| Fertilised lush *D. flexuosa* 1988 | | + 0.48 |
| Unfertilised Crowberry 1995 | 10 | − 0.28 |
| Fertilised Crowberry 1995 | | − 0.34 |
| Logging residues | 25 | + 0.33 |
| **Function: Table 19c:f4 without ln[No. trees/plot] and Spruce proportion** | | |
| Unfertilised lush *D. flexuosa* 1988 | 12 | + 0.42 |
| Fertilised lush *D. flexuosa* 1988 | | + 0.42 |
| Unfertilised Crowberry 1995 | 10 | − 0.33 |
| Fertilised Crowberry 1995 | | − 0.52 |
| Logging residues | 25 | + 0.02 |
| **Function: Table 19d:f4 including ln[No. trees/plot] and Spruce proportion** | | |
| Unfertilised lush *D. flexuosa* 1988 | 12 | + 0.32 |
| Fertilised lush *D. flexuosa* 1988 | | + 0.44 |
| Unfertilised Crowberry 2007 | 29 | − 0.39 |
| Fertilised Crowberry 2007 | | − 0.37 |
| Logging residues | 25 | + 0.29 |
| **Function: Table 19e:f4 without ln[No. trees/plot] and Spruce proportion** | | |
| Unfertilised lush *D. flexuosa* 1988 | 12 | + 0.35 |
| Fertilised lush *D. flexuosa* 1988 | | + 0.35 |
| Unfertilised Crowberry 2007 | 29 | − 0.54 |
| Fertilised Crowberry 2007 | | − 0.61 |
| Logging residues | 25 | − 0.05 |