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Competition indices and the prediction of radial growth in Scots pine

Timo Pukkala & Taneli Kolström

TIIVISTELMÄ: KILPAILUTEKIJÄT JA MÄNNYN SÄDEKASVUN ENNUSTAMINEN

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The effect of competition on the radial growth of Scots pine was studied in three naturally regenerated stands located in North Karelia, Finland. The competition situation of an individual tree was described with various competition indices which depended on the sizes and distances from the neighbouring trees. One competition index explained about 50 % of the variation in 5-year radial growth in one stand. If all stands were combined, one index explained 43.5 %, two indices 48.9 % and three indices 51.2 % of the variation. In one stand, the best competition indices accounted for about 20 % of that variation which could not be explained by tree diameter. If all three stands were combined, the best index explained 11 % of the residual variation. About 40 % of the variation in 5-year radial growth could not be explained by the diameter and competition indices.

Kilpailun vaikutusta männyn sädekasvuun tutkittiin kolmessa Pohjois-Karjalassa sijaitsevassa, luontaisesti syntyneessä männikössä. Puun kilpailutilannetta kuvattiin muuttujilla, jotka riippuivat naapuripuiden koosta ja etäisyydestä (kilpailutekijät). Yksittäisessä metsikössä parhaat kilpailutekijät selittivät n. 50 % viiden vuoden sädekasvun vaihtelusta. Kun kaikki metsiköt yhdistettiin, yksi tekijä selitti 43,5 %, kaksi tekijää 48,9 % ja kolme tekijää 51,2 % sädekasvun vaihtelusta. Parhaat kilpailutekijät selittivät yhdessä metsikössä n. 20 % läpimittaluokan sisäisestä sädekasvun vaihtelusta. Kun kaikki kolme metsikköä yhdistettiin, paras kilpailutekijä selitti 11 % läpimittaluokan sisäisestä vaihtelusta. N. 40 %:a sädekasvun vaihtelusta ei voitu selittää puun läpimitan tai kilpailutekijöiden avulla.

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Authors' address: University of Joensuu, Faculty of Forestry, P. O. Box 111, SF-80101 Joensuu, Finland.

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1. Introduction

The benefit of silvicultural treatment depends on its effects on the future development of the stand. One way to evaluate different treatments is to simulate the future development of a tree stand.

In the simulation model the stand can be described with the help of stand characteristics or by individual trees. In the latter case one diameter class may be represented by one or several trees. If there are several trees in one class, the stand is mostly illustrated as a forest stand plot. In this case the spatiality could be taken into account (distance-dependent tree-model; see Heqyi 1974, Ek and Monserud 1974, Monserud 1975).

In an empirical simulation model the growth of tree dimensions is usually calculated by empirical growth equations which are either standwise (e.g. Vuokila and Väliaho 1980) or tree models (e.g. Nyyssönen and Mielikäinen 1978). In Finland spatial data has not been used for growth prediction (except in some models for restricted purposes, see e.g. Mielikäinen 1980) which means that the growth estimate has been the same for all trees having certain diameter and height.

In a real stand growth varies considerably inside a diameter class. If this variation is not taken into account, the simulated development of the stand may differ remarkably from the real one. For example, the differentiation of trees into diameter or height classes may be slower in simulation than in reality. In this case the results obtained by a simulation model are biased. Also the deductions made from such simulations may be erroneous.

One reason for differentiated growth rate inside a diameter class is the variation in competition caused by other trees. This variation could best be predicted if the locations of all trees of the plot were known. If the coordinates of trees are known, the silvicultural treatments and the birth, growth and mortality processes could be simulated more accurately than if coordinates are unknown. In addition, the use of simulation in spatial problems becomes possible. For example, the effects of systematic thinnings, harvest strips or spatial distribution of trees on growth could be examined (Eriksson 1977, Bucht 1981).

The spatial data can be used (1) for predicting tree growth in absolute terms or in relation to average or potential growth (Lin 1974, Eriksson 1977), or (2) for predicting the deviation of growth of an individual tree from the average growth of trees with the same diameter. Models of the former kind can be used with standwise growth models for distributing the total growth between individual trees or in those simulation models in which the growth estimate is based on potential growth which is corrected to a lower level according to the competition (Ek and Monserud 1974, Lin 1974). Models predicting the deviation from the average growth of the diameter class can be used for correcting the estimate of non-spatial tree model.

The effect of other trees on the radial growth of an individual tree is usually assessed by competition indices (CI) (e.g. Gerrard 1969, Ek and Monserud 1974, Lin 1974, Eriksson 1976). The competition index can be defined as follows (Mäkelä and Hari 1986)

$$CI = \frac{i_r}{i_{r,\ EXP}} \qquad (1)$$

where i_r is the actual and $i_{r,\ EXP}$ the expected radial growth of a tree. The expexted growth can be the average growth of all trees, the potential growth (growth without competition) or the average growth of the diameter class, depending on the use of the competition model.

In investigations carried out in other countries the competition indices have accounted for a significant amount of variation beyond that associated with the size of the tree (e.g. Adlar 1974, Beck 1974, Hegyi 1974, Braathe 1980). Thus it seems reasonable to examine possibilities of using competition indices also under Finnish conditions. The purpose of this work is (1) to calculate the amount of variation in radial growth, (2) to study how the competition index should be calculated and (3) to find out the manner in which growth is affected by the competition indices in Scots pine stand in Finland.

When studying the latter problems, it is assumed that the competition between two trees depends on their distance and sizes: the greater the neighbour and the smaller the distance, the more competition the neighbour causes. Consequently, the competition situation of one tree is described with variables which depend on the sizes and distances of the neighbouring trees (Bella 1971, Lin 1974, Monserud 1975).

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2. Material and methods

2.1 Study material

The effect of competition on radial growth was studied in three naturally regenerated Scots pine stands located in North Karelia, Finland (63° 40'N, 31° 5'E, Table 1). Two of the stands were in the phase of first commercial thinning (stands 1 and 3). In stand 2 a very light thinning was done 6 years ago. The spatial distribution of trees is most uneven in stand 2 (Fig. 1). Also the size of trees varies most in stand 2 (Fig. 1).

In all stands a sample plot was measured (Table 1). Every tree was characterised by the following measurements:

- X- and Y-coordinates (dm)
- diameter at beast height (mm)
- height (dm)

The height of the crown base (dm) and width of the crown (dm) were measured from 30 . . . 50 sample trees. For other trees the crown characteristics were calculated by equations (1) and (2) which are based on sample trees of this study and sample trees of three other plots measured in pine forests.

Height of crown base

$$h_c = -1.186 - 0.2128d + 0.8031h \qquad (2)$$

t-value: 6.2 10.1 25.4

where h_c = height of crown base (m)
d = diameter at breast height (cm)
h = height (m)

Crown width

$$d_c = 0.5182 + 0.5182d \qquad (3)$$

t-value: 9.0 31.8

where d_c = crown width (m)
d = diameter at breast height (cm)

The main statistical characteristics of the Equations (2) and (3) are:

	Equation 2	Equation 3
Number of observations	278	278
Degree of determination	0.78	0.79
F-value	503.7	1009.9
Degrees of freedom	2, 275	1, 276
Standard error of est.	0.94	0.39

Table 1. Main characteristics of the study stands.

	Stand 1	Stand 2	Stand 3
Total volume, m^3/ha	84.3	145.4	114.4
Basal area, m^2/ha	18.6	19.5	23.1
Number of trees/ha	2933.3	1224.5	3808.3
Mean diameter, cm	10.4	18.8	10.0
Mean height, m	8.2	15.2	9.2
Area of the plot, ha	0.1444	0.1849	0.1520
Number of trees			
– on the plot	392	215	585
– inside isolation strip	264	150	350

On all plots a strip of 4 m was left as a buffer zone. Radial core was bored at breast height from all trees inside the buffer strip. The radial growths during the last 1, 2, 5 and 10 years (1/100 mm) were measured at the core with the help of the measuring microscope.

For statistical analysis the radial growth was converted to (1) proportion of average growth of all trees of the plot and (2) proportion of normal growth. The normal growth is defined as the average growth of trees having the same diameter. It corresponds to an unbiased growth estimate obtained by a nonspatial model.

The normal growth was estimated by equation

$$i_d = ad \qquad (4)$$

where i_d = normal growth (1/100 mm),
a = parameter and
d = diameter (cm).

This function proved to be the best one for explaining the dependence of radial growth on diameter. The function was constructed separately for 1, 2, 5 and 10 years' growth and also separately for every plot (Table 2).

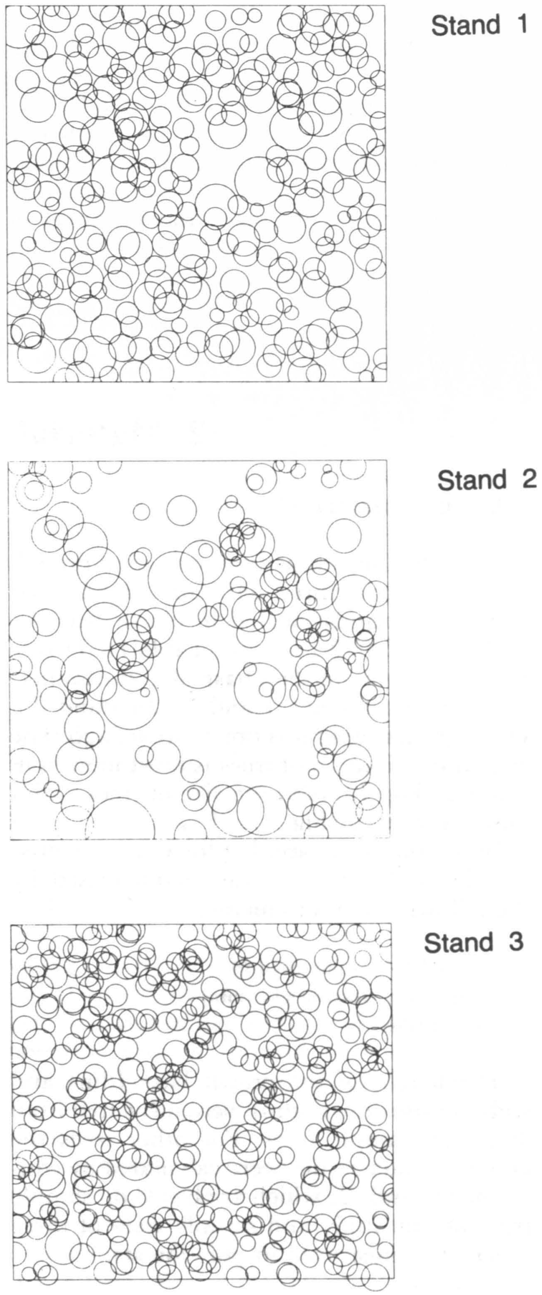

Fig. 1. Maps showing the horizontal crown projections on the study plots. Only the area inside isolation strip is shown. The diameter of the circle equals the maximum diameter of the crown.

2.2 Competition indices

The competition situation of a tree was described with 12 different competition indices (Table 3). Some indices were obtained from other studies and some proposed by the authors. Nine of the indices are sums of the angles from a tree to its neighbours (see. Fig. 2, Table 3). The angle sums were calculated by using 2, 4, 5, 6 and 8 m as the maximum distance of the neighbour, which was included in the sum (radius of the competition circle). The other conditions are presented in Table 3. If the maximun distance was greater than the distance of the tree from the nearest edge of the plot, the tree was omitted in further analysis.

The calculations were also made by assuming that the competition distance depends on the diameters of both competitive trees; the

Table 2. Equations used for calculating the normal radial growth of certain diameter. The function is always G=ad (G=growth, 1/100 mm, a=coefficient, d=diameter, cm). t = t-value of the regression coefficient, F = F-value of the equation, R^2 = degree of determination (%), N number of observations, S_e = standard error of the estimate (1/100 mm).

Growth	Coeff.	t	F	(d.f.)	R^2 (%)	N	S_e
Stand 1							
1 year	10.18	47.5	8380	(1,251)	39	252	30
2 years	21.39	51.2	37007	(1,251)	44	252	60
5 years	62.75	58.9	318430	(1,251)	48	252	152
10 years	150.1	64.6	1020055	(1,251)	42	252	331
Stand 2							
1 year	4.89	29.2	4805	(1,135)	52	136	28
2 years	11.32	32.2	25772	(1,135)	57	136	57
5 years	41.06	37.4	339335	(1,135)	67	136	181
10 years	69.70	41.8	9775835	(1,135)	70	136	275
Stand 3							
1 year	9.08	46.0	6475	(1,338)	40	339	32
2 years	19.09	48.8	28559	(1,338)	44	339	64
5 years	53.38	58.1	223075	(1,338)	48	339	150
10 years	137.1	73.0	1256780	(1,338)	47	339	306

Table 3. Competition indices used for predicting the radial growth of tree j. All trees which fulfil the conditions stated after equation are included in the sum if they are nearer than the maximum competition distance used in computations. n = number of trees of the plot, c = weight variable which depends on the compass direction of the competitor, d = diameter, h = height, h_c = height of crown base, D_{ij} = distance between trees i and j. The angles and areas of the equations are explained in Fig. 2.

Index	Form	Conditions	Fig.
1	$CI_{1(j)} = \sum_{i=1}^{n} \alpha_i$	$i \neq j$	2a
2	$CI_{2(j)} = \sum_{i=1}^{n} \alpha_i$	$i \neq j,\ d_i > d_j$	2a
3	$CI_{3(j)} = \sum_{i=1}^{n} \beta_i$	$i \neq j,\ h_i > h_j/2$	2b
4	$CI_{4(j)} = \sum_{i=1}^{n} \beta_i$	$i \neq j,\ h_i > h_{c(j)} + 0.5(h_j - h_{c(j)})$	2c
5	$CI_{5(j)} = \sum_{i=1}^{n} \beta_i$	$i \neq j,\ h_i > h_j$	2d
6	$CI_{6(j)} = \sum_{i=1}^{n} c\beta_i$	$i \neq j,\ h_i > h_j$	2d
7	$CI_{7(j)} = \sum_{i=1}^{n} \alpha_i$	$i \neq j,\ h_i > h_j$	2d
8	$CI_{8(j)} = \sum_{i=1}^{n} \alpha_i \beta_i$	$i \neq j,\ d_i > d_j,\ h_i > h_j/2$	2a, 2b
9	$CI_{9(j)} = \sum_{i=1}^{n} \alpha_i \beta_i$	$i \neq j,\ h_i > h_j$	2a, 2d
10	$CI_{00(j)} = \sum_{i=1}^{n} a_i/A_j$	$i \neq j$	2f
11	$CI_{11(j)} = \sum_{i=1}^{n} (d_i/d_j)/D_{ij}$	$i \neq j$	–
12	$CI_{12(j)} = \sum_{i=1}^{n} (h_i/h_j)/D_{ij}$	$i \neq j$	–

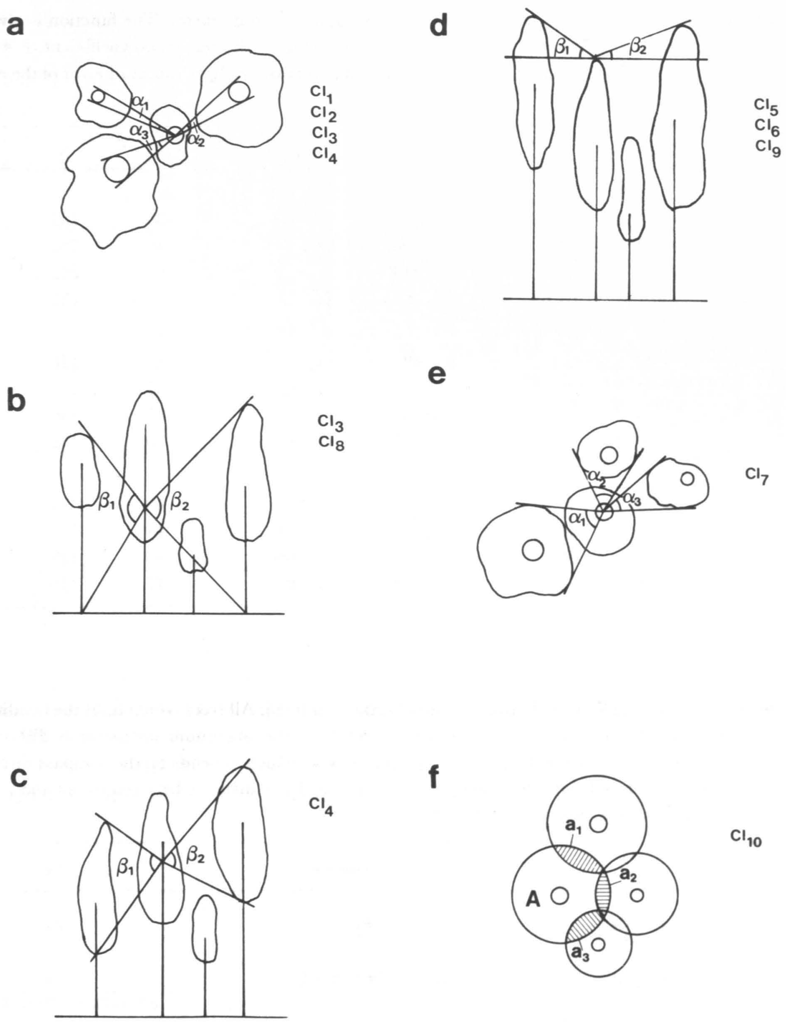

Fig. 2. Principles used in the calculation of competition indices. The indices beside the drawings show the indices for which the angles or areas are used.

distance from three i to tree j (dm) was tested against equations

$$A = (5+10d_j) + (5+10d_i) \quad (5)$$
$$B = (10+5d_j) + (10+5d_i) \quad (6)$$

where d_j and d_i are diameters (cm) of trees j and i, respectively. If the distance was less than A – or, in other computations, les than B – the tree was included in the angle sums.

CI_1 and CI_2 were calculated horizontally at the height of 1.3 m. They express the sum of angles from the tree to both sides of the stem of the neighbours (Table 3, Fig 2a). CI_3 is the sum of vertical angles from the midpoint of the stem to the base and top of the neigbouring stems (Fig. 2b). CI_4 is constructed by calculating the sum of vertical angles from the centre of the crown to the lower and upper crown limit of its neighbours (Fig. 2c).

CI_5 consists of vertical angles between the horizontal plane and the line from the top of a tree to the top of its neighbours (Fig. 2d). Now only angles to trees higher than the tree for which the index was calculated were included in the sum. CI_6 index is almost the

same as CI_5. The difference is that the angles were multiplied by a weight variable. The weight depended on the direction of the neighbour from the tree concerned. The weight of north was 0.5 and that of south 1.5. Between these extremes the weight depended according to sine function on the direction of the neighbour (weights of east and west were 1).

CI_7 is the sum of the maximum horizontal angles from the centre of the stem to both sides of the neighbouring crown (Fig. 2e). CI_8 is the sum of products of angles calculated for indices 2 and 3, and CI_9 the sum of products of angles calculated for indices 1 and 5. Both consist of products of one vertical and one horizontal angle (Table 3, Fig. 2).

CI_{10} differs remarkably from all the other indices (Fig. 2f). It is the sum of overlapping growth areas which the tree has with its neighbours divided by the growth area which the tree was expected to need (Isomäki and Niemistö 1983). It takes into account the fact that small trees need less growing space than large ones and that also their zone of influence is smaller. The radius of the needed growth area (r, dm) was calculated by the following equations: (1) r=20d, (2) r=40d, (3) r=50d, (4) r=60d and (5) r=80d (d=diameter, cm).

CI_{11} and CI_{12} (see Table 3) are proposed by Heqyi (1974) and Braathe (1974). They are sums of the ratios of diameters (CI_{11}) or heights (CI_{12}) calculated by using the inverse of distance between trees as a weight variable. Also CI_{11} and CI_{12} were calculated by using 2, 4, 5, 6 and 8 m as a maximum competition distance.

When taking into account the different ways of defining the competition distance, the competition situation of each tree was described by 82 different variables.

3. Results

The variation in radial growth is very great in all stands: the standard deviation of growth is 32 . . . 63 % of the average growth (Table 4). One year's growth varies most and ten years growth least. When the growth is expressed as the proportion of normal growth – i.e. as the proportion of average growth of the same diameter – the standard deviation is 28 . . . 45 %. This means that in about 33 % of trees the growth differs more than 28 . . . 45 %, and in 5 % of trees more than 56 . . . 90 % from the normal growth, depending on the stand and time period concerned (Table 4). The diameter explains 39 . . . 70 % of the variation of the radial growth (Table 2). The rest of the variation is between trees of the same size.

The correlations between the best competition indices and radial growth are −0.4 . . . −0.77 (Fig. 3). The correlation depends on the maximum interaction distance. Generally the correlation is the better the greater the maximum distance. However, after 4 . . . 5 m the increase rate of the absolute

Table 4. Total variation in radial growth (upper part) and variation inside one diameter class (lower part).

Growth as proportion (%) of average growth	Standard deviation of growth Stand 1	Stand 2	Stand 3
of all trees			
in 1 year	44.5	63.1	54.7
in 2 years	43.2	60.8	53.8
in 5 years	38.7	60.7	46.5
in 10 years	32.9	57.1	35.5
of trees of same diameter			
in 1 year	39.1	45.7	43.5
in 2 years	36.8	46.1	40.5
in 5 years	33.7	39.2	43.1
in 10 years	31.9	34.0	28.5

value of the coefficient is slow. It appears that in young pine stands, when predicting the radial growth of a tree with the help of sizes and distances from its neighbours, it is sufficient to take into account only trees nearer

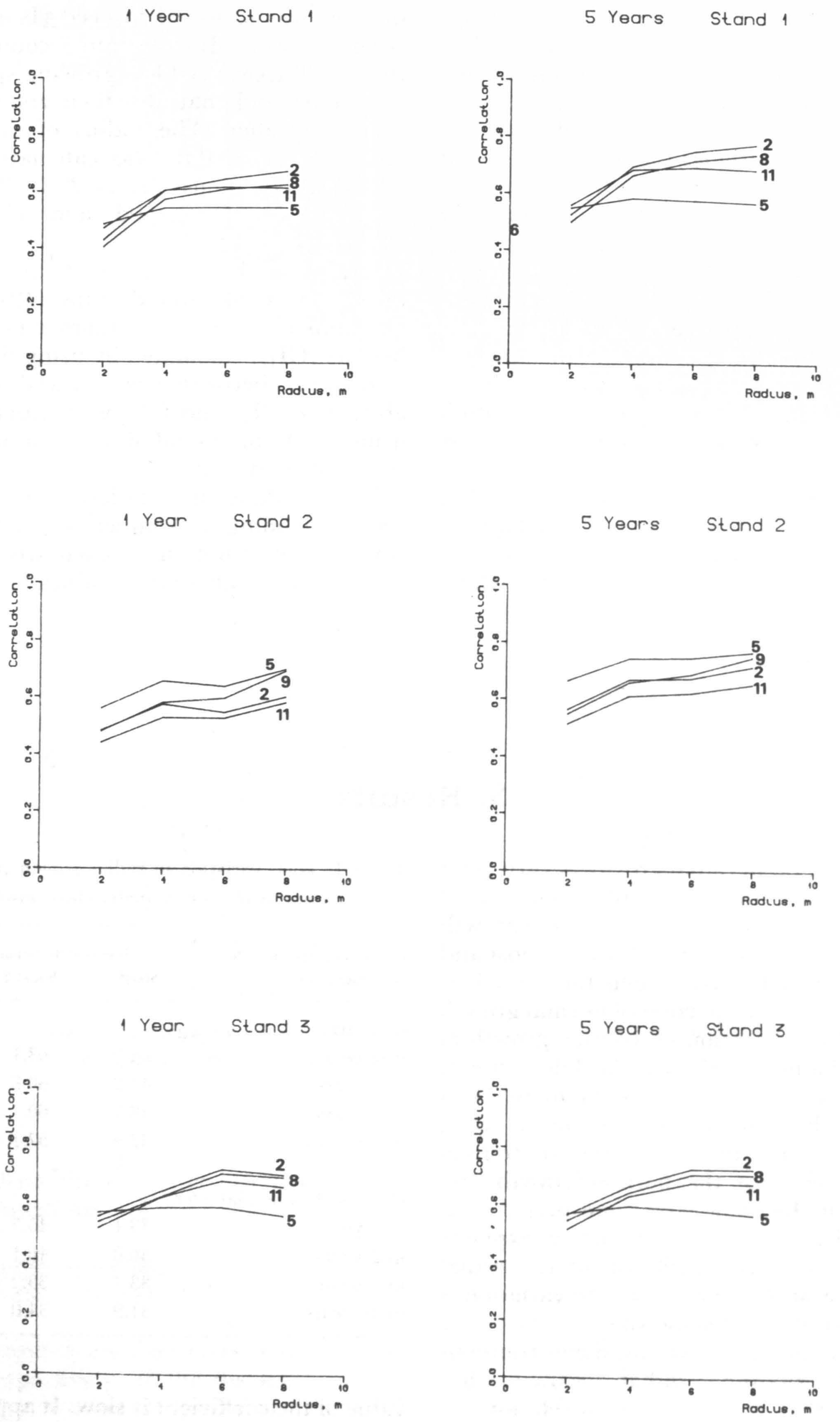

Fig. 3. Dependence of correlation between the competition index and radial growth on the maximum competition distance. Growth is expressed as proportion of average growth of the plot. In each diagram four best indices are shown.

than five metres (see Eriksson 1976, Bucht 1981). The small significance of remote trees is partly explained by the fact that the contribution of a tree to the competition index decreases when the distance increases.

In stands 1 and 3 the four best competition indices are the same, i.e. indices 2, 5, 8 and 11 (Fig. 3). In stand 2 CI_8 is replaced by CI_9 (Fig. 3). In individual stands the linear relationship between CI_2 or CI_5 and 5-year growth explain over 50 % of the variation in growth if the best maximum competition distance is used. CI_2 is the sum of horizontal angles to the stems of those neighbours which have greater diameter than the tree. CI_5 is the sum of angles between the horizontal plane and the line from the top of the tree to the top of its neighbours.

If all stands are combined, CI_2 correlates best with radial growth, if the maximum competition distance is 5 m (Fig. 4). Next comes CI_8, then CI_6, CI_5 and CI_9 (Table 5).

In the studied stands the crown characteristics do not increase the possibilites of explaining the variation in radial growth. Thus only diameter and height are to be known besides the coordinates in distance-dependent tree-growth simulation models made for young pine stand.

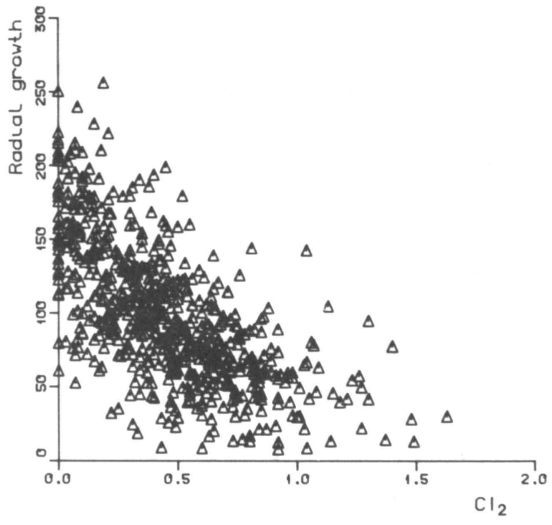

Fig. 4. Dependence of 5-year radial growth on CI_2 in whole study material. The maximum competition distance is 5 m.

Table 5. Correlations between radial growth and fixed-radius competition indices in the whole study material. The radius of the interaction circle is 5 m, except for index CI_{10} where the radius of the growth area is 50d dm (d=diameter, cm).

Competition index	Growth in 1 year	Growth in 5 years
1	–.202	–.223
2	–.610	–.660
3	–.126	–.138
4	–.125	–.123
5	–.579	–.610
6	–.577	–.624
7	–.130	–.148
8	–.584	–.633
9	–.570	–.608
10	–.254	–.303
11	–.544	–.585
12	–.414	–.444

The best equations for predicting the radial growth in the 5-year period are:

One predictor

$$G_5 = 146.0 - 103.4\,CI_2 \tag{7}$$

t-value: 57.8 22.1

Two predictors

$$G_5 = 145.3 - 68.72\,CI_2 - 2.934\,CI_6 \tag{8}$$

t-value: 60.5 11.3 8.3

Three predictors

$$G_5 = 126.2 + 35.65\,CI_1 - 91.85\,CI_2 - 2.479\,CI_6 \tag{9}$$

t-value: 30.0 5.5 12.6 7.0

where G_5 is the 5-year radial growth as a proportion (%) of the average growth of all the trees of the stand. The unit of CI_1, CI_2 and CI_6 is radian. Equation (7) explains 43.5 %, Equation (8) 48.9 % and Equation (9) 51.2 % of the variation in growth. The F-values and residual variations (S_e) of Equations (7) . . . (9) are as follows:

Equation	F-value	(d.f)	S_e
7	490.0	(1,634)	35.2
8	305.3	(2,633)	33.5
9	223.0	(3,632)	32.7

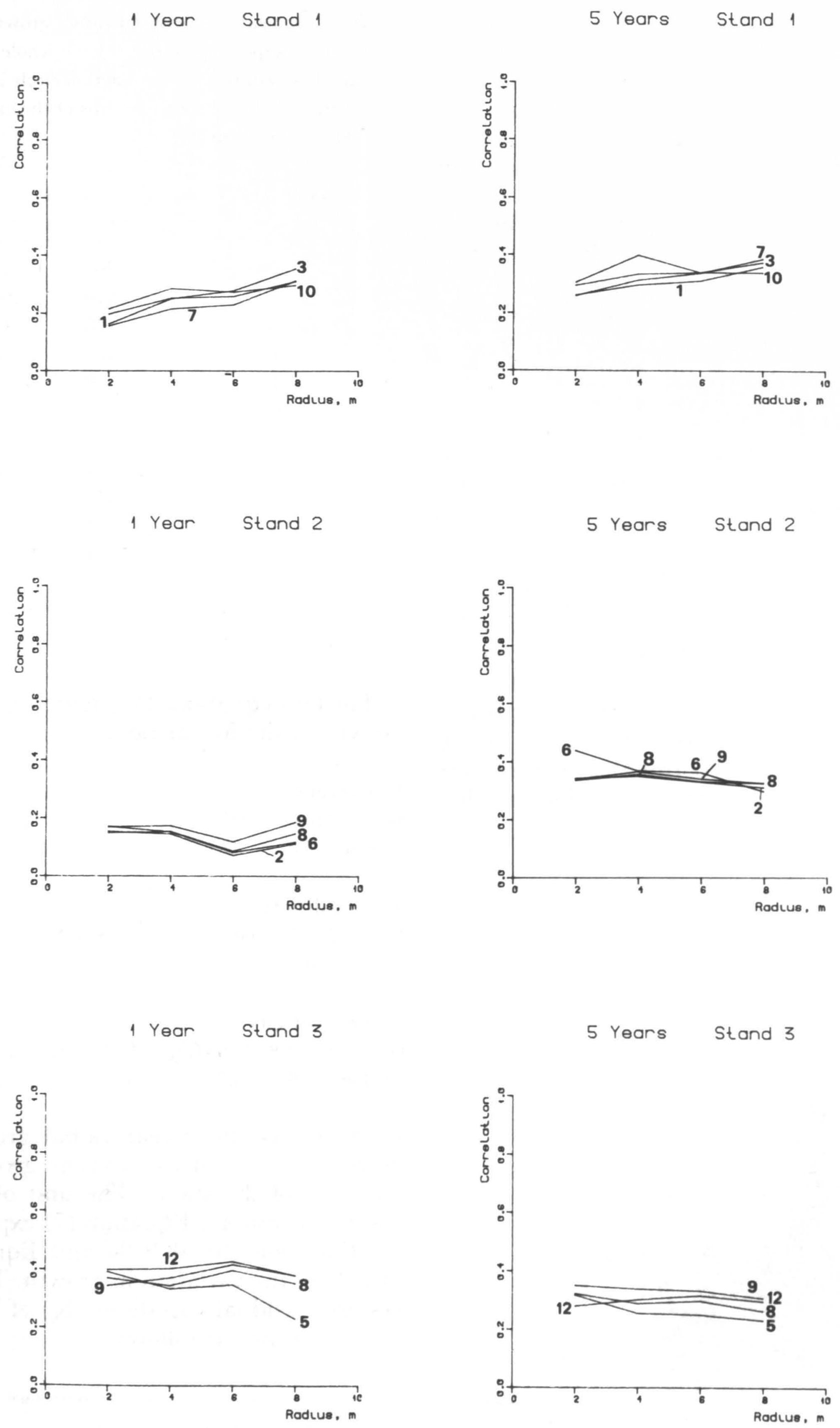

Fig. 5. Dependence of correlation between the competition index and radial growth on the maximum competition distance. Growth is expressed as proportion of normal growth. In each diagram four best indices are shown.

If growth is expressed as a proportion of normal growth (or as proportion of the estimate of a distance-independent tree-growth model) the correlations between competition indices and growth are rather low (Fig. 5). The best indices vary from stand to stand. The linear relationship between growth and the best competition indices with fixed maximum competition distance explains only 5 . . . 20 % of one or five-year growth. There appears to be no clear optimum radius of the competition zone (Fig. 5).

The correlations are little better if the competition indices are calculated so that the maximum interaction distance depends on the diameter of both interacting trees (Tables 6 and 7). Also now the best competition indices vary from stand to stand. With one

Table 6. Correlation coefficients between competition indices and radial growth. The maximum distance of the interaction is calculated by Equation 5. Only coefficients less than –0.25 are included.

Competition index	Radial growth in proportion to average growth of trees of same diameter					
	Stand 1		Stand 2		Stand 3	
years:	1	5	1	5	1	5
	correlation coeffient					
1	–.271	–.387	.	–.264	–.293	–.285
2	.	.	.	–.358	–.366	–.320
3	–.261	–.375	.	.	.	.
4	.	–.360	.	.	.	.
5	.	.	.	–.422	–.386	–.320
6	.	.	.	–.409	–.372	–.316
7	–.257	–.382	.	.	.	.
8	.	.	.	–.354	–.367	–.324
9	.	.	.	–.384	–.411	–.358
11	.	.	.	–.287	–.375	–.306
12	.	.	.	.	–.351	–.296

Table 7. Correlation coefficients between competition indices and radial growth. The maximum distance of the interaction is calculated by Equation 6. Only coefficients less than –0.25 are included.

Competition index	Radial growth in proportion to average growth of trees of same diameter					
	Stand 1		Stand 2		Stand 3	
years:	1	5	1	5	1	5
	correlation coeffient					
1	.	–.333	.	–.294	–.304	–.285
2	.	.	.	–.368	–.356	–.302
3	.	–.311	.	–.289	.	.
4	.	–.276	.	.	.	.
5	.	.	.	–.424	–.369	–.295
6	.	.	.	–.424	–.355	–.291
7	.	–.311	.	–.253	.	.
8	.	.	.	–.364	–.358	–.309
9	.	.	.	–.381	–.405	–.348
11	.	.	.	–.275	–.361	–.284
12	.	.	.	.	–.348	–.281

index it is possible to explain about 20 % of the variation which cannot be explained with the diameter.

For explaining the deviation of the 5-year growth from the normal growth in the whole study material the following equation was constructed. Only the diameter, height and coordinates must be known when using the equations.

$$G_5 = 838.2/(7.783 + CI_6) \quad (10)$$
t-value: 9.5 27.0

The unit of G_5 is % (% of normal growth) and that of CI_6 radian. The F-value of Equation (10) is 91.0 (1, 726), degree of determination 11.0 % and the residual variation (S_e) 35.5.

All the competition indices correlate negatively with the diameter. The average correlation coefficient between diameter and competition indices is −0.49 in stand 1, −0.53 in stand 2 and −0.47 in stand 3, when 5 m is used as the maximum competition distance. The correlations are still better for those four indices which are the best for predicting the deviation of growth from the total mean, the average correlation coefficient being −0.80 in stand 1, −0.70 in stand 2 and −0.76 in stand 3. The diameter can be regarded as a characteristic describing the past competition of the tree (Perry 1985). It seems now that it also reflects the variation in present competition rather well.

4. Discussion

The competition indices used in this study explain about 50 % of the total variation of the radial growth in a Scots pine stand of medium age. They account for 10 . . . 20 % of the variation which cannot be explained without spatial data. This means that the error variation in predicting radial growth could be decreased only by 20 % with the help of spatial data and the indices. The results indicate that in the study material the variation in stand density causes less variation in competition than the variation in tree size. This is probably the situation in most unthinned stands, because the size variation is partly a consequence of variation in competition (Perry 1985). If the aggregation pattern of trees were created by thinning, the competition indices would probably explain a greater proportion of the growth variation inside one diameter class. This depends, of course, on the manner in which the size distribution and spatial distribution of trees are affected by the thinning.

In Adlard's (1974) study the tree basal area explained 14 . . . 95 % of the variation of the volume growth in *Pinus patula* stands and 52 . . . 91 % in *Cupressus* stands. The competition indices explained 0 . . . 43 % of the rest of the variation. The differences between stands were considerable. In Beck's (1974) study the tree and stand characteristics explained 36.2 % of the variation of 5-year diameter growth in *Liriodendron tulipifera* stand. The various competition indices he used accounted for additional amounts of variation ranging from 3.4 to 14.3 %, the best index being that developed by Gerrard (1969). In *Pinus banksiana* stands, Heqyi (1974) obtained correlations from −0.270 to −0.385 between competition index (CI_{11} of this study) and 5-year diameter growth. In Braathe's (1980) study, the competition indices (CI_{12} of this study and its modifications) explained 30 . . . 45 % of the variation in height growth. In this study about the same amount or little more variation as above could be explained by the competition indices.

In pine stands studied in this work about 40 % of the variation could not be explained by the diameter or competition indices. Part of this variation is due to competition which is not associated with the chosen indices. This part could be decreased by using indices which put more emphasis on the distribution of the direction of the competitors, for example, on one-sided competition (Eriksson 1976, Rudra 1980, Perry 1985).

Probably most of the residual variation arises from the spatial variation in the site characteristics and a small part is caused by genetic differences between trees (Arney 1974, Perry 1985). The variability of site factors makes the investigation of competition difficult in unthinned natural stands because of the correlations between site characteristics, diameter and competition indices. This difficulty could be avoided by creating the competition variation artificially and independently of site variation.

The amount of variation in growth due to site characteristics could be evaluated by fitting a trend surface on that part of variation which could not be explained by the diameter and competition indices. The effects of the site variability could be taken into account in simulations by correcting the growth estimate by a factor which has the same spatial properties as the spatial variation in soil fertility.

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