THE EFFECT OF BIRCH PROPORTION ON THE GROWTH OF SPRUCE AND BIRCH IN A MIXED STAND

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Abstract. Diameter growth patterns of spruce and birch in mixed stands are discussed. The influence of birch is determined as the percentage of birch in the stand basal area. A higher share of birch in the stand reduces growth of spruce and birch itself. However, birch grows faster and thus compensates for the growth reduction of spruce. The level of birch admixture in middle-aged and mature stands reflects the silvicultural treatments during the stand history. The effect of birch admixture can be controlled by thinnings of young stands. The right proportion of birch enables one to achieve the best growth conditions and higher productivity of the stand.

Key words: mixed stand, diameter growth, spruce, birch proportion.

INTRODUCTION

The management of mixed forests as an alternative to pure stands has become an increasingly debatable subject among forest ecologists. The discussion about the productivity of mixed and pure stands has a long history in forestry (Assman, 1970). Another aspect of mixed stands is the diversity of the ecosystems and the resistance to pests and abiotic damages. Mixed stands are believed to be more stable compared to pure ones (Assman, 1970).

It is not easy to understand how the system involving interactions between different individual organisms and species operates. The reductionist approach was applied as a tool to compose a formal system of dynamic phenomena in order to get an elaborate picture of the productivity of the tree stand.

The causes for a higher productivity in a mixed stand can be of different nature. If the species have great differences in productivity, then the fastest growing species increases the productivity of the mixed stand and the

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maximum production would be achieved with pure stands of this most productive species. However, the interactions of species may affect the growth of trees and so the productivity increase is not linear.

A mixed stand can be regarded as a community consisting of populations of several species (Jõgiste, 1994). The population attributes can be used in modelling the growth of the mixed species stand. Tree species have different requirements for ecological conditions. The resources can be utilized more efficiently by communities consisting of species occupying different ecological niches.

Individual-based tree models have been very important both in ecological dynamics (succession) and growth–yield studies (Urban & Shugart, 1992). The growth of an individual tree is affected by many factors. To cope with the complexity of the system of biotic and abiotic factors the modelling approach is taken into use. The tree–environment relations are stressed in traditional growth–yield models, while the species-specific attributes have been more important in the development of gap models of forest succession (Liu & Ashton, 1995).

Rather a great share of Estonian forest stands are mixtures of tree species. The present work is focused on the growth of Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) in a mixed stand. An attempt was made to describe the growth relations of the two species in a forest stand. Some conclusions can be drawn about the effect of biotic factors on the basis of this study.

METHODS

The present study is based on tree ring measurements. The trees for ring measurements were cored on 10 temporary sample plots.

The material was collected in the Järvselja Experimental Forest and in the Käru Forest District, Estonia, in 1992–94. Mixed stands of spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) were observed. Ten circular sample plots each 0.1 ha in area were measured in spruce–birch stands of different composition and age. The stands were chosen from the database of the Forest Survey according to the following criteria: main species – *Picea abies*; percentage of the principal component – 60–80; forest site type – *Oxalis*, *Aegopodium*; age of the stand – 40–100 years. The real situation was compared with data in the database. Some of the plots were rejected and additional plots were selected in the field.

The sample plots were established in forests belonging to *Oxalis*, *Myrtillus–Oxalis*, and *Aegopodium–Oxalis* site types (Lõhmus, 1984). The site productivity is quite high in these forest site types. Pseudopodzolic and podzolic soils were represented in the sample plots. Most soils in the sample plots had signs of moderate gleyzation. Stands consistent with the criteria mentioned were examined in field and decisions were made on the sample plot location.

The field layer is composed of plant species specific to the *Oxalis* site type: *Oxalis acetosella* L., *Maianthemum bifolium* (L.) F.W. Schm., *Vaccinium myrtillus* L., *Dryopteris expansa* (C. Presl) Fraser-Jenkins et Jermy, and *Rubus saxatilis* L. A big proportion of *Calamagrostis arundinacea* (L.) Roth is evident in older stands due to the occurrence of gaps and better light conditions. *Aegopodium podagraria* L., *Asperula odorata* L., and *Mercurialis perennis* L. were found in plots with more fertile soils.

The following data were recorded for each tree in the sample plot with a diameter at breast height (dbh) bigger than 6 cm: 1) species, 2) dbh at accuracy 0.5 cm, 3) crown class as dominant or suppressed. The stem number was recorded in each plot. The crown class was assessed visually and trees lower than 80% of the stand mean were considered as suppressed. Trees were divided into 4 cm dbh classes and a subsample of trees (20%) from each class was selected. Subsample trees were cored and the height was recorded for each tree in a subsample. The radial growth and age at breast height were measured on increment cores.

All tree rings were measured on the increment core until the pith. Years and ring widths to the pith were estimated for cores without the pith, using ring densities from similar complete cores (Aplet et al., 1988). The growth data were arranged into a database. The diameter growth was calculated for 5-year periods starting from the centre of the tree stem. Each 5-year periodic growth was related to the diameter (under bark) prior to this period. Altogether 1492 growth periods for spruce (128 cores) and 595 for birch (50 cores) were used in analysis. The mean 5-year periodic diameter growth of the trees was calculated.

Diameter growth equations were calculated for spruce and birch using multivariate regression analysis. Age, diameter at the beginning of the 5-year growth period, and birch percentage in the stand basal area were used as independent variables. In the case of thinnings the cut portion was added to the stand in calculating the proportion of the birch basal area. However, the birch competition must be treated with caution because the present situation in the stand is used and the real birch percentage in the past is not known (Mielikäinen, 1985).

It must be stressed that the age and diameter are variables of individual trees while the birch percentage is a stand level attribute. The stands sampled were even-aged, consequently the spruce and birch are approximately of the same age.

RESULTS AND DISCUSSION

The individual tree approach in the studies of forest stand development has yielded good results in explaining the processes. The population dynamics principles in these models involve the competition as a factor affecting the growth of an individual tree.

The growth rate of an individual can be described as a function of population size distribution which is affected by intraspecific competition (Weiner & Thomas, 1986). On the other hand, the relations between

populations of different species have been suggested as variables to predict the growth of individuals.

In the present study sampling was carried out asymmetrically – the stands with spruce dominance were selected. So, the relations of spruce and birch can be treated as competition only with reservation. Competition is interpretable as an interaction between two individuals, populations, or species. Both partners are adversely affected in the course of this inter-action. Lotka–Volterra model (Kimmins, 1987) is an example describing the nature of competition as an interaction where the growth of one side is restricted by the other. The models describing the competition effect in such a way stay purely phenomenological. The resource limiting the growth determines the competition in the coexistence of competing partners and models explaining the mechanism of plant interactions can be based on this fact (Tilman, 1990). At the same time a number of environmental resources can be utilized simultaneously by several species.

It is possible to predict the further growth of individuals and populations knowing the size relations of the competing sides caused by competition. The effect of competition on growth can be obtained on the basis of the competition indices that indicate the position of the subject tree via the size of its neighbours and the distance to the neighbouring trees (Munro, 1974; Weiner & Thomas, 1986; Туллус, 1992) or the stand attributes (e.g. stand basal area, ratio of subject tree diameter to stand diameter). Teck and Hilt (1991), for instance, used the stand level variable BAL – basal area larger than that of the subject tree. The same variable was applied by Quicke and co-authors (1994). The birch percentage used as a competition variable in the present study is a stand level attribute.

The potential tree growth functions are used in several studies to describe the individual tree growth (Amateis et al., 1989; Teck & Hilt, 1991). Then the modifier function is needed to introduce the effect of competition to the stand growth model (Biging & Dobbertin, 1995). In this case the modifier introduces both the environmental and competition effects. Competition can also be incorporated into a single model of individual tree growth (Wykoff, 1990; Quicke et al., 1994). In the present study the single tree model has been used as well.

Table 1 gives the main attributes of the stands sampled. Some variables of the two observed species in mixed stands are given in Table 2. The fitting of regression models to growth data gave the following results:

$$\ln[\hat{i}(d5+)]_{\text{SPRUCE}} = 1.273 - 0.033\,\text{AGE} + 0.130\ln(D) - 0.009\,B \qquad (1)$$

and

$$\ln[\hat{i}(d5+)]_{\text{BIRCH}} = 0.942 - 0.024\,\text{AGE} + 0.207\ln(D) - 0.003\,B, \qquad (2)$$

where $i(d5+)$ = 5-year periodic diameter increment (the circumflex denotes that this is an estimated quantity), AGE = tree age at the beginning of the increment period, D = tree diameter at the beginning of the increment period, B = birch percentage in the stand basal area. The R^2 values were 0.47 for spruce and 0.41 for birch.

General characteristics of mixed spruce–birch stands of the Järvselja Experimental Forest and Käru Forest District. G = basal area at breast height; N = number of trees per hectare; M = standing volume; B = birch percentage of the stand basal area; H_{dom} = dominant height (height of first layer)

Plot No.	G, m² ha⁻¹	N, ha⁻¹	M, m³ ha⁻¹	B	H_{dom}, m
1	38.0	1080	450	40	25.5
11	38.0	640	509	21	29.7
12	38.9	680	497	26	29.0
13	43.6	710	587	6	30.1
15	35.1	850	417	45	27.1
16	38.6	1660	463	67	31.9
17	39.0	1770	429	28	25.7
18	39.2	1750	440	31	26.2
19	38.3	960	496	28	28.7
20	23.8	670	299	37	27.3

Characteristics of spruce and birch populations in sample plots of the Järvselja Experimental Forest and Käru Forest District. T = mean age of trees; D = mean diameter at breast height

Plot No.	Spruce				Birch	
	I layer		II layer			
	T, years	D, cm	T, years	D, cm	T, years	D, cm
1	48	23.3	46	14.2	48	24.7
11	72	30.0	71	17.7	75	30.2
12	88	30.9	78	17.7	79	28.6
13	82	31.0	68	19.8	79	29.0
15	66	24.9	65	16.3	65	26.1
16	61	24.7	51	13.3	58	23.3
17	43	22.1	41	11.8	46	19.3
18	47	20.8	46	12.7	48	20.4
19	55	24.8	50	14.8	56	28.9
20	52	22.4	51	16.1	57	23.6

The interactions among variables according to the fitted models (Eqs. (1) and (2)) are shown in Fig. 1. Birch demonstrates faster growth than spruce. The effect of birch is shown in Figs. 2 and 3. The tree age is kept constant at 60 years in Fig. 2. The birch percentage has greater effect on the spruce growth than on its own growth. The birch diameter growth is highly dependent on the tree diameter at the age of 60 years (Fig. 2).

Figure 3 shows the birch population effect on the growth of both species when the diameter of a tree is kept constant (20 cm). The adverse effect of birch is obvious in the case of very young trees. The spruce growth is influenced to an especially high degree in young stands, which is well known from silvicultural practice. It can be concluded that from the practical point of view the stand age is a very important factor in planning the management of mixed stands.

The estimation obtained is somewhat biased because the log-log dependence between the diameter and diameter growth is not linear as assumed with a regression model (the natural logarithm is used in case of both variables). As a result, the growth rates in older stands are under-estimated. But the correlation between these two variables is high and the main assumption yields a realistic estimation of birch effect.

The results of the present study are constrained to a narrow range of site conditions. Extrapolations outside the range of site conditions determined in this study are not justified.

The birch percentage in a mixed stand is also a measure of thinnings during the stand history. The structure of intermediate age mixed forests is determined by silvicultural treatments in the stand youth (Muiste, 1980; Jõgiste, 1995). It has been a long practice to cut all the birches in young stands giving so an advantage to spruce. The result is the predominance of pure spruce stands.

Palik and Pregitzer (1993) have pointed out that the growth patterns of different species are not merely inherited growth rates but are the consequence of initial conditions of stand development. The suppressed tree layer may fail to develop if individuals of certain tree species are competitively uninhibited. Usually the initial conditions are changed with silvicultural treatments. Thus, the silvicultural treatments can be seen as one of the reasons for variation in growth patterns described in this work. Too big share of birch in a stand reflects the stand history with modest thinnings. The result of that is a reduced growth rate of trees, particularly of spruce (Fig. 3).

It is known from previous studies that birch acts as a heavy competitor (Mielikäinen, 1985). However, the optimum proportion of birch in stand composition has been found in order to obtain the maximum productivity in managed forests (Mielikäinen, 1985; Valsta, 1993). That means that the increasing birch percentage promotes the spruce diameter growth up to a certain proportion. The optimum cannot be described by linear models of this study. The main conclusion is the negative effect of birch on the diameter growth of both species as a general trend.
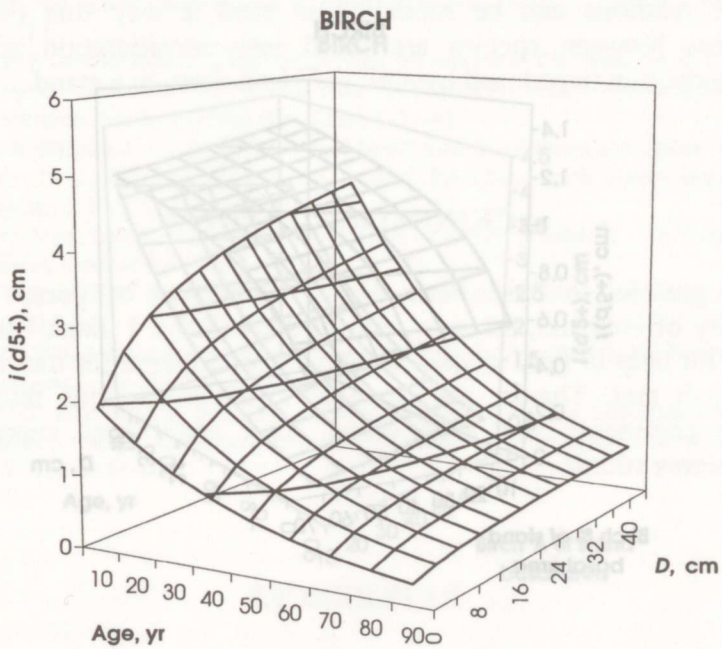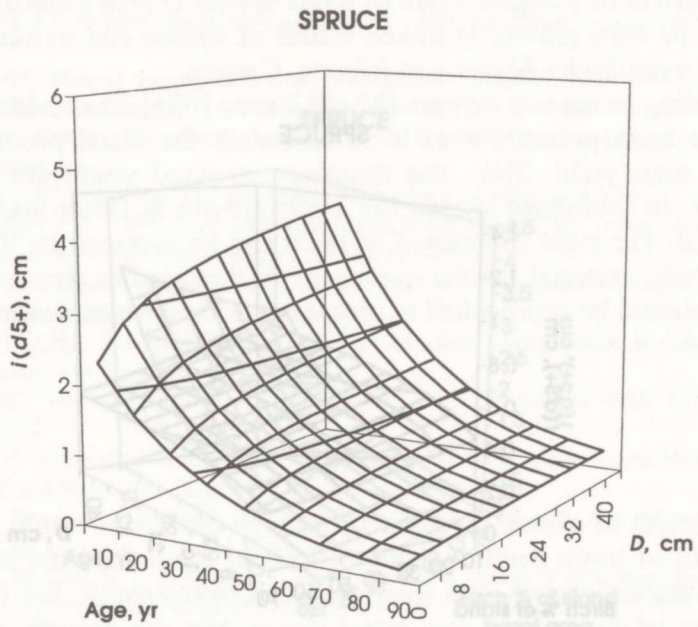
Fig. 1. The individual tree diameter (D) growth of spruce and birch predicted by tree age and diameter according to the applied regression model. The third independent variable, birch percentage, is kept constant at 10%. i(d5+) = 5-year periodic diameter increment.
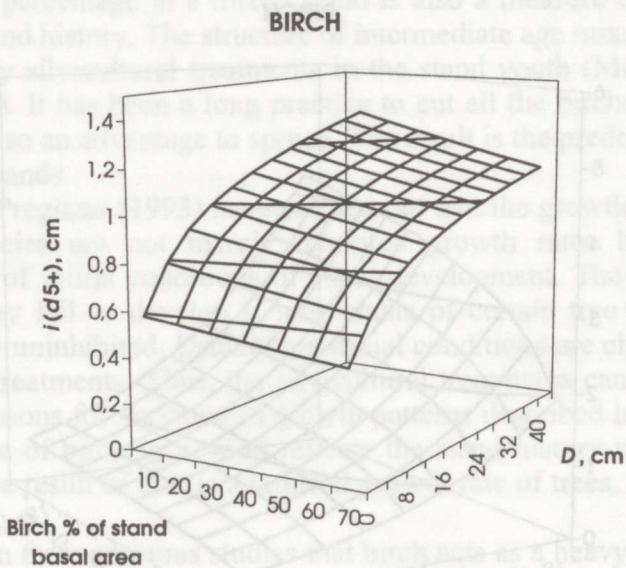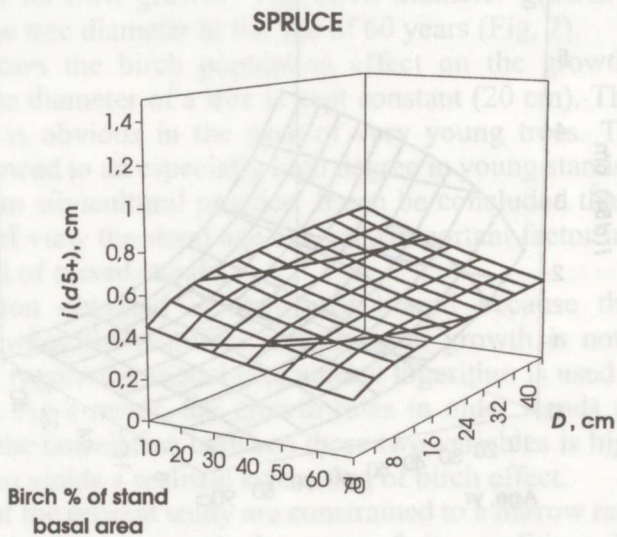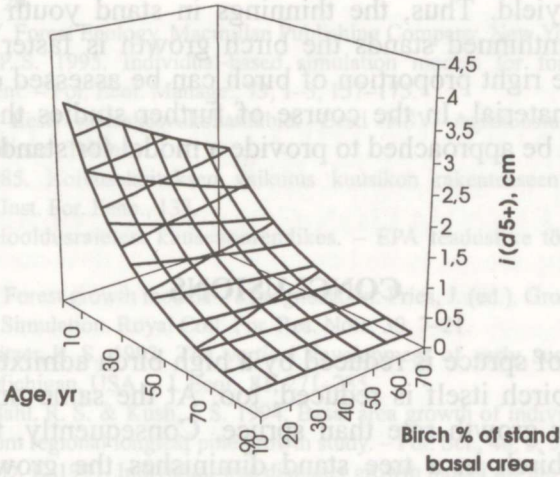
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Fig. 2. The individual tree diameter (*D*) growth of spruce and birch predicted by tree diameter and birch proportion according to the applied regression model. Tree age is kept constant at 60 years. *i*(d5+) = 5-year periodic diameter increment.
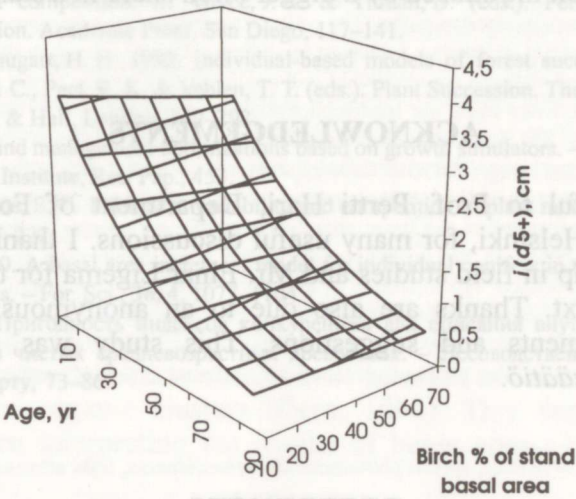
Fig. 3. The individual tree diameter (*D*) growth of spruce and birch affected by birch proportion and tree age according to the applied regression model. Tree diameter is kept constant at 20 cm. $i(d5+)$ = 5-year periodic diameter increment.

However, research by Huang and Titus (1995) shows a general negative effect of a higher share of white spruce (*Picea glauca* (Moench) Voss) on its own growth in mixed stands of spruce and trembling aspen (*Populus tremuloides* Michx.) in Alberta, Canada.

According to several authors (Mielikäinen, 1985; Tham, 1989; Valsta, 1993) the right proportion of birch increases the stand productivity in terms of total yield. Thus, the thinnings in stand youth are especially important. In unthinned stands the birch growth is faster and spruce is suppressed. The right proportion of birch can be assessed on the basis of greater study material. In the course of further studies the optimization problem should be approached to provide a model for stand management.

CONCLUSIONS

The growth of spruce is reduced by a high birch admixture; moreover, the growth of birch itself is reduced, too. At the same time birch has a higher diameter growth rate than spruce. Consequently, the rise of the percentage of birch in a tree stand diminishes the growth due to the adverse influence of birch but the growth loss is compensated for by the bigger diameter growth of birch.

These relations can be modelled in such a way that the growth differences between species are taken into consideration adding the growth reduction introduced by a bigger birch share in a stand.

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REFERENCES

Amateis, R. L., Burkhart, H. E. & Walsh, T. A. 1989. Diameter increment and survival equations for loblolly pine trees growing in thinned and unthinned plantations on cutover, site-prepared lands. – South. J. Appl. For., **13**, 4, 170–174.

Aplet, G. H., Laven, R. D. & Smith, F. W. 1988. Patterns of community dynamics in Colorado Engelman spruce–subalpine fir forests. – Ecology, **69**, 2, 312–319.

Assman, E. 1970. The Principles of Forest Yield Study. Pergamon Press, Oxford.

Biging, G. S. & Dobbertin, M. 1995. Evaluation of competition indices in individual tree growth models. – For. Sci., **41**, 2, 360–377.

Huang, S. & Titus, S. J. 1995. An individual tree diameter increment model for white spruce in Alberta. – Can. J. For. Res., **25**, 9, 1455–1465.

Jõgiste, K. 1994. Kuuse–kase segapuistute struktuurist. – Metsanduslikud Uurimused XXVI, Tartu, 4–15.

Jõgiste, K. 1995. Natural regeneration and development of spruce–birch mixed stands. In: Korpilahti, E., Salonen, T. & Oja, S. (eds.). Caring for the Forests: Research in Changing World. IUFRO XX World Congress, 6–12 August 1995, Tampere, Finland. Poster Abstracts, 29.

Kimmins, J. P. 1987. Forest Ecology. Macmillan Publishing Company, New York.

Liu, J. & Ashton, P. S. 1995. Individual-based simulation models for forest succession and management. – For. Ecol. Manage., **73**, 1–3, 157–175.

Lõhmus, E. 1984. Eesti metsakasvukohatüübid. Eesti NSV Agrotööstuskoondise Info- ja Juurutusvalitsus, Tallinn.

Mielikäinen, K. 1985. Koivusekoituksen vaikutus kuusikon rakenteeseen ja kehitykseen. – Commun. Inst. For. Fenn., 133.

Muiste, L. 1980. Hooldusraietest kuusenoorendikes. – EPA teaduslike tööde kogumik, 128, 108–120.

Munro, D. D. 1974. Forest growth models – a prognosis. In: Fries, J. (ed.). Growth Models for Tree and Stand Simulation. Royal Coll. For. Res. Note, 30, 7–21.

Palik, B. J. & Pregitzer, K. S. 1993. The vertical development of early successional forests in northern Michigan, USA. – J. Ecol., **81**, 271–285.

Quicke, H. E., Meldahl, R. S. & Kush, J. S. 1994. Basal area growth of individual trees: A model derived from regional longleaf pine growth study. – For. Sci., **40**, 3, 528–542.

Teck, R. M. & Hilt, D. E. 1991. Individual-tree diameter growth model for the Northeastern United States. – USDA For. Serv. Res. Pap., NE-649.

Tham, Å. 1989. Prediction of individual tree growth in managed stands of mixed *Picea abies* (L.) Karst. and *Betula pendula* Roth & *Betula pubescens* (Ehrh.). – Scand. J. For. Res., **4**, 491–512.

Tilman, D. 1990. Mechanisms of plant competition for nutrients: The elements of a predictive theory of competition. In: Grace, J. R. & Tilman, D. (eds.). Perspectives on Plant Competition. Academic Press, San Diego, 117–141.

Urban, D. L. & Shugart, H. H. 1992. Individual-based models of forest succession. In: Glenn-Lewin, D. C., Peet, R. K. & Veblen, T. T. (eds.). Plant Succession. Theory and Prediction. Chapman & Hall, London, 249–292.

Valsta, L. 1993. Stand management optimizations based on growth simulators. – The Finnish Forest Research Institute, Res. Pap., 453.

Weiner, J. & Thomas, S. C. 1986. Size variability and competition in plant monocultures. – Oikos, **47**, 2, 211–222.

Wykoff, W. R. 1990. A basal area increment model for individual conifers in the Northern Rocky Mountains. – For. Sci., **36**, 4, 1077–1104.

Туллус X. 1992. Пригодность индексов конкуренции для описания внутривидовой конкуренции в чистых средневозрастных древостоях. – Лесоводственные исследования **XXV**. Тарту, 73–86.