th, N.J. 1993. Estimating leaf area index and light extinction coefficients in stands of Douglas-fir (Pseudotsuga menziesii). Canadian Journal of Forest Research 23: 317-321.
t, P.W. & K.F. Wells 1992. Method of application of a model to predict the light environment of individual tree crowns and its use in a eucalypt forest. Ecological Modelling 60: 199-231.

4.5 Structural diversity as a result of silvicultural operations

H. Pretzsch

Abstract
The aim of the study is to quantify the effect of silvicultural treatment on the spatial structure of forest stands. One method relies on indices that are capable of reliably quantifying horizontal tree distribution patterns, vertical stand profile and segregation of species. A second means of modelling the spatial stand dynamics is the single-tree simulator SILVA 2. Combining SILVA 2 with a program module for structural analysis, creates a flexible tool which can be used to examine the influence of different regeneration techniques, thinning regimes and site conditions, on growth, yield and spatial stand structure. By a series of simulation runs, the influence of the initial structure, thinning method and thinning degree on the spatial structure of mixed stands of spruce and beech is examined. The results underline the fact that light and moderate thinning from the top offer an effective possibility to improve the stand structure and support its diversity. The spatial stand structure as a result of thinning from below tends to be more homogeneous. The desired integration of structural diagnosis into prognosis models that hitherto have been aligned exlusively to growth and yield, offers the possibility of considering, quantifying and optimizing production and stability aspects of silvicultural treatment.

Key words: diversity, structural parameters, growth simulation, stand treatment, structure scenarios

Introduction

In commercial forests spatial stand structure is considered an important factor in determining habitat and species diversity. Quantitative studies on this subject show that increasing heterogeneity of horizontal and vertical stand structure is concomitant, as a rule, with a greater number of species and with a higher ecological stability (Altenkirch 1982; Ammer et al. 1995; Blab 1986; Ellenberg et al. 1985; Haber 1982). Silvicultural operations can modify the stand structure and therefore have an important potential in securing stand diversity and ecological stability.

The objective of the present investigation is to elaborate methodological principles for a systematic analysis of relationships between stand treatment and spatial stand structure. The first step is to use indices which give a quantitative idea of horizontal tree distribution patterns, vertical species profile and intermingling intensity of tree species all of which serve as valuable indicators of habitat and species diversity. The second important contribution comes from the stand growth simulator SILVA 2, which is capable of reproducing spatial stand dynamics for a wide range of site conditions, initial stand structures and treatment variants (Pretzsch 1992). For the purpose of this investigation SILVA 2 was extended to include a program routine for structural analysis and structure diagnosis. A research instrument had thus been developed with which the influence of silvicultural operations on spatial stand structure may be analysed by simulation. In a series of test runs with SILVA 2 the longterm effect of light, moderate and heavy thinning from below and selective thinning, as well as the effect of different mixture types on the spatial stand structure were investigated.

Material and methods

Material

The data for the study comes from 82 long term experimental plots in mixed stands of spruce and beech in Bavaria (Table 4.5.1). The single tree simulator SILVA 2 was calibrated and validated with the growth and yield data from this network of survey plots. The oldest plots are under survey since 1928, the youngest were established in 1995. The plots cover a broad range of ages, proportions and structures of mixtures, thinning regimes and site conditions. The model functions are fitted with the whole data set of the network. However the following simulation runs represent the stand structure dynamic on a recently established age series near Freising, on fresh sandy loams, in the Upper Bavarian tertiary montane area (growth district 12.8 'Oberbayerisches Tertiärhügelland'). The spruce has a productivity index of 40 according to the spruce yield tables of Assmann and Franz (1963), while that for beech is class I, according to the beech-yield table by Schober (1975). These imply excellent growth conditions for both tree species. On the modelled test plots of 0.25 hectares, the beech is 10 years older than the spruce. At the start of the prognosis runs (age of spruce and beech 30 and 40 years respectively), the stem number is 2,196 trees per ha, with a basal area of 45.2 square meters per ha. Spruce and beech occupy equal proportions of the basal area.

Methods

To determine and identify spatial stand structures use may be made of a repertoire of reliable quadrat count and distance methods. (Pielou 1975, 1977; Ripley 1977, 1981; Upton & Fingleton 1985, 1989). The indices R by Clark and Evans (1954) and S by Pielou (1977) were used to identify the horizontal tree distribution pattern and the intermingling of species respectively and thus quantify different aspects of spatial heterogeneity. Index A, for the vertical species profile, developed in analogy to the Shannon index (1948), served to quantify the spatial distribution of tree species.

Aggregation index R by Clark and Evans

The aggregation index by Clark and Evans (1954) describes the horizontal tree distribution pattern by relating the observed average distance of a tree to its nearest neighbour to the average distance to be expected when trees are randomly distributed

Table 4.5.1
Data base of the study are 15 long-term experimental plots in mixed stands of spruce and beech in Bavaria.

SPECIES	LOCATION	NUMBER OF PLOTS	TOTAL AREA (ha)	BEGIN SURVEY	SURVEY PERIODS	STEM CHART	CROWN DIMENSION	YOUNG GROWTH INVENTORY
sp/be	Zwiesel	8	1.86	1954	6	x	x	
sp/be	Zwiesel	10	3.00	1985	2	x	x	
sp/be	Mitterteich	3	0.76	1928				
sp/be	Freising	6	3.0	1994	1	x	x	x
sp/be	Schongau	8	4.0	1995	1	x	x	x
sp/be	Bodenmais	5	2.5	1995	1	x	x	x
sp/fir/be	Kreuth	22	3.60	1973	2	x	x	x
sp/fir/be	Zwiesel	4	1.93	1987	1	x	x	x
sp/fir/be	Garmisch	5	1.59	1954	5	x	x	
sp/fir/be	Freyung	3	1.50	1980	3	x	x	x
sp/fir/be	Bodenmais	2	1.00	1981	3	x	x	x
sp/fir/be	Ruhpolding	1	0.31	1953	8	x	x	x
sp/fir/be	Ruhpolding	1	0.30	1963	5			
sp/fir/be	Marquartstein	2	0.81	1953	5	x	x	
sp/fir/be	Wolfegg	1	0.31	1952	6	x	x	x

$$R = \frac{\overline{r}_{observed}}{\overline{r}_{expected}} \cdot \qquad (1)$$

R is obtained by calculating the distances $r_{i,i=1....N}$ to the nearest neighbour for eac of N trees on a test plot of size F, and then proceeding to calculate the averag distance

$$\overline{r}_{observed} = \frac{\sum_{i=1}^{N} r_i}{N} \qquad (2)$$

This observed distance to the nearest neighbour is related to the expected averag distance for random tree distribution

$$\overline{r}_{expected} = \frac{1}{2\sqrt{\frac{N}{F}}} \qquad (3)$$

where

r_i = distances of i = 1....N trees to their nearest neighbours on the test plot,
N = total number of trees on the test plot, and
F = area of test plot in square meter.

Theoretically, R lies between 0 (greatest clustering) and 2.1491 (regular hexagon pattern). Aggregation values below 1.0 show a tendency towards cluster formatic

Use of aggregation index R for characterizing the horizontal distribution of trees

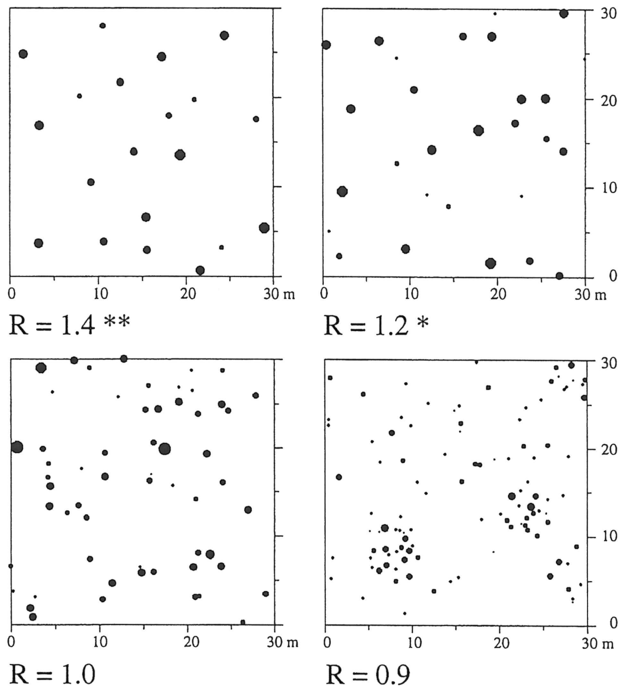

Figure 4.5.1
Identification of four horizontal tree distribution patterns by the aggregation index of Clark and Evans (1954). The symbol size is proportional to the stem diameter at a height of 1.30 metres. R-values of more than 1.0 indicate a trend to regular distribution, values below 1.0 indicate a trend to clustered distribution. Random distribution is indicated by values of R = 1.0.

while those around 1.0 are indicative of random distribution and those above 1.0 reveal a tendency towards regular distribution. Thus, the aggregation index R measures the extent to which the observed spatial pattern diverges from a random or Poisson distribution. It can be used for the overall stand, as well as for individual tree species in the stand (Fig. 4.5.1).

The calculation of the aggregation index R for the tree distribution patterns shown in Figure 4.5.1 gives values for R which lie between 1.48** and 1.2* (* and ** designate clustering with an error probability of 5 and 1% respectively), revealing rather more regular distribution patterns than are usually found in age-class forests thinned from below. R = 1.0 (Fig. 4.5.1, lower left hand side) is indicative of a random distribution typical of selection forest stands and virgin forests, while an aggregation index of R = 0.9 (Fig. 4.5.1, lower right hand side) shows a tendency towards clustering.

Index A for characterizing the vertical distribution of species

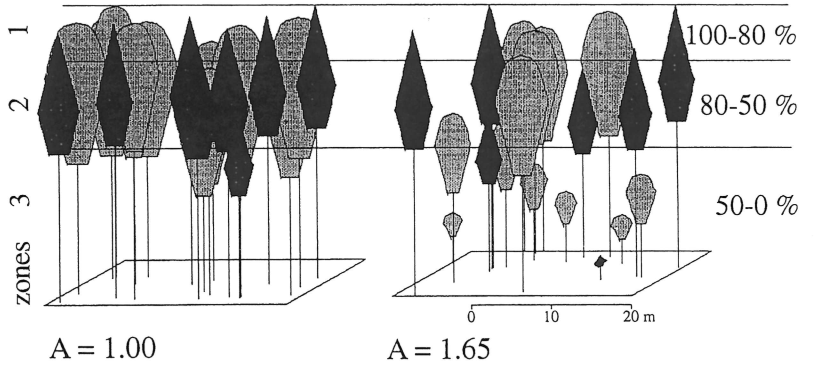

Figure 4.5.2
For the diagnosis of the species profile index A, the stand is subdivided into three height zones. The zones 1 to 3 represent 100-80 %, 80-50 % and 50-0 % of the maximum height of the stand. For the computation of index A, the proportions of the different species are counted out separately according to the different height zones.

Index A for the vertical species profile

The index A for the species profile is based on the index H by Shannon and Weaver, which was originally developed in the context of information theory and later applied to the description of species diversity in biological systems (Shannon 1948).

$$H = -\sum_{i=1}^{S} p_i * \ln p_i \qquad (4)$$

where

S = number of species occurring in the stand
p_i = portion of species in relation to total population $p_i = \frac{n_i}{N}$
n_i = frequency of species i
N = total number of individuals.

Index H for species diversity is derived from the product of species proportion p_i and logarithmic species proportion ln p_i for the sum of a total of S species occurring in the stand. By introducing the logarithmically transformed species proportion as multiplying factor, the index is disproportionately raised by rare species, while dominant species lead to a disproportionately low increase. The index A for the vertical species profile developed in the course of this study considers species proportions separately for three height zones ranging from 0 to 50%, 50 to 80% and 80 to 100% of maximum stand height (Fig. 4.5.2).

$$A = -\sum_{i=1}^{S} \sum_{j=1}^{Z} p_{ij} * \ln p_{ij} \qquad (5)$$

where

S = number of species in the stand
Z = number of height zones (three in this case)
p_{ij} = species proportions in the zones $p_{ij} = \frac{n_{i,j}}{N}$
n_{ij} = frequency of species i in zone j
N = total number of individuals

Index A summarizes and quantifies species diversity and distribution of species in the stand. While the index is lowest for one-storied pure stands, it rises for pure stands with two or more layers. A mixture of several species effectively raises the index and peak values are reached in mixed stands with heterogeneous structures (Fig. 4.5.3). Every deviation from the one-storied pure stand is reflected in a distinct rise in the species profile index A.

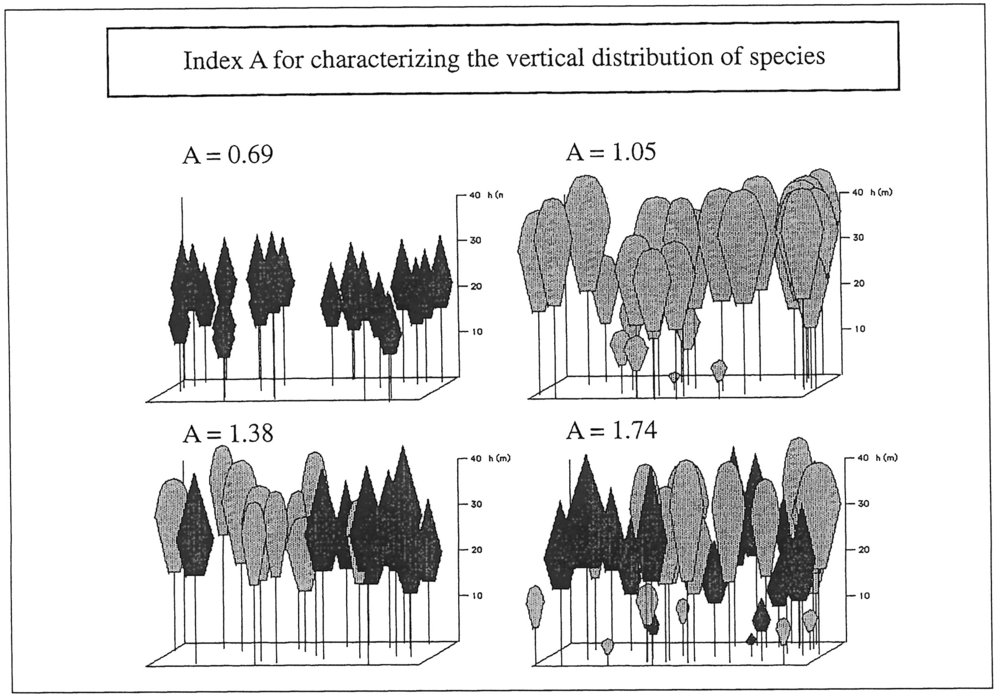

Figure 4.5.3
Species profile index A for mono- and multi-layered pure and mixed stands of spruce and beech.

Segregation index by Pielou for the intermingling of species

The segregation index S, by Pielou (1977), determines the intermingling of two tree species according to the nearest neighbour method. For its calculation, a search run serves to determine the species of the nearest neighbour for each of N trees in the test plot, using the number of trees of species 1 and 2 (m, n), the number of trees with neighbours of their own species (a, d) and the number of trees with neighbours of the other species (c, b). The segregation index is thus derived from

$$S = 1 - \frac{\textit{observed number of mixed pairs}}{\textit{expected number of mixed pairs}} \qquad (6)$$

and will lie between -1.0 and + 1.0. From the basic values in the 2 x 2 table (Table 4.5.2) it is calculated as follows:

$$S = 1 - \frac{N*(b+c)}{(v*n+w*m)} \qquad (7)$$

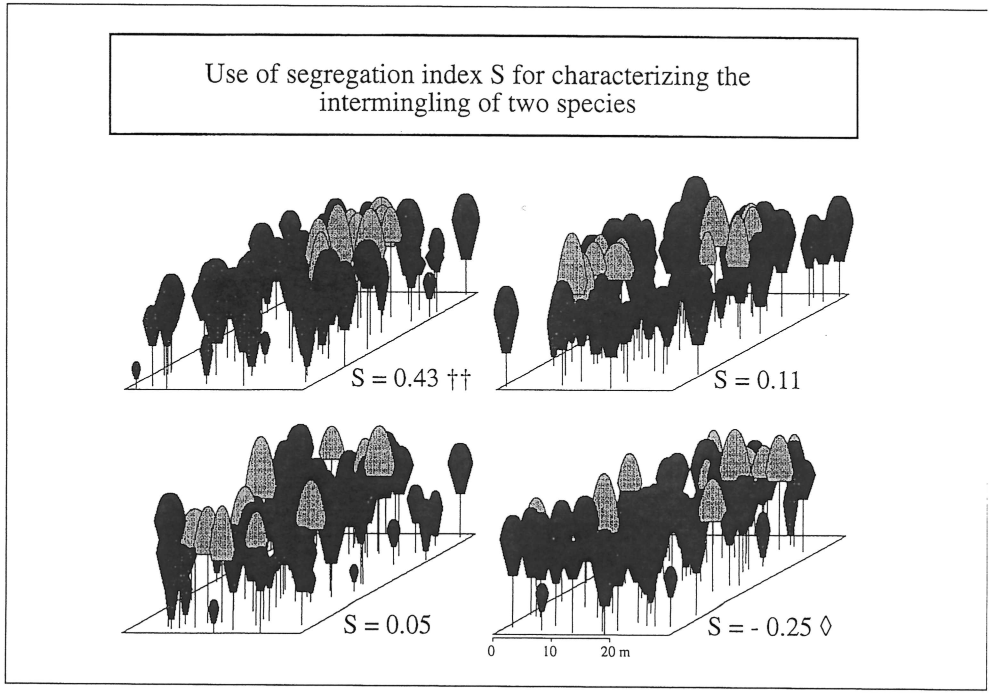

Figure 4.5.4
Identification of the mixture type of beech (dark grey) and larch (light grey) by the segregation index of Pielou (1977). S-values of more than 0 indicate a trend to segregation, values below 0 indicate a trend to association. Independent distribution of species is indicated by values near 0.

If the observed number of mixed pairs is higher than the expected one, this will lead to $S < 0$, indicating a close coupling or association of species. Conversely, if the observed number of mixed pairs is less than expected, then $S > 0$ and is evidence of segregation, i.e. the spatial separation of species. Where $S = 0$, i.e. the number of observed and expected mixed pairs is equal, then species are distributed independently of each other.

Table 4.5.2
Four-field table with the basic variables for the computation of the segregation index S according to formula (7). Explanation of the variables in the text.

	NEAREST NEIGHBOUR		
	TREE SPECIES 1	TREE SPECIES 2	TOTAL
Base tree species 1	a	b	m
Base tree species 2	c	d	n
Total	v	w	N

The mixed stands of beech and larch from the Solling in lower Saxony in Figure 4.5.4 reveal a wide range of intermingling intensities. While small cluster and group mixtures (Fig. 4.5.4) have segregation indices of S = 0.43x and S = 0.11 respectively, big clusters and single tree mixtures tend to lower them to S =-.25xx. Where x indicates significant segregation with 1% error probability, xx indicates significant association with 5% error probability. High segregation indices are indicative of pronounced intra-species competition, whereas low values imply species association and the dominance of competitive conditions between species.

Stand growth simulator SILVA 2 with program routine for structure diagnosis

The position-dependent individual tree model SILVA 2 sub-divides forest stands into a mosaic of individual trees and reproduces their interactions as a space-time system. It can therefore be used for pure and mixed stands of all age combinations. Primarily it is designed to assist in the decision making processes in forest management. Based on scenario calculations SILVA 2 is able to predict the effects of site conditions, silvicultural treatment and stand structure on stand development, and therefore also serves as a research instrument. To explain the incorporation of a program routine which permits structural analyses, a representation of the essential elements of SILVA 2 is provided in Figure 4.5.5. The model is described in greater detail by Pretzsch (1992), Pretzsch and Kahn (1996) and Kahn (1995).

The first element of the model reflects the relationship between site conditions and growth potential and aims at adapting the increment functions in the model to actual, observed site conditions. With the aid of nine site factors reflecting nutritional, as well as water and temperature conditions, the parameters of the growth functions are determined in a two-stage process (Kahn 1994). The stand structure generator STRUGEN facilitates the large-scale use of position-dependent individual tree growth models. The generator converts verbal characterizations

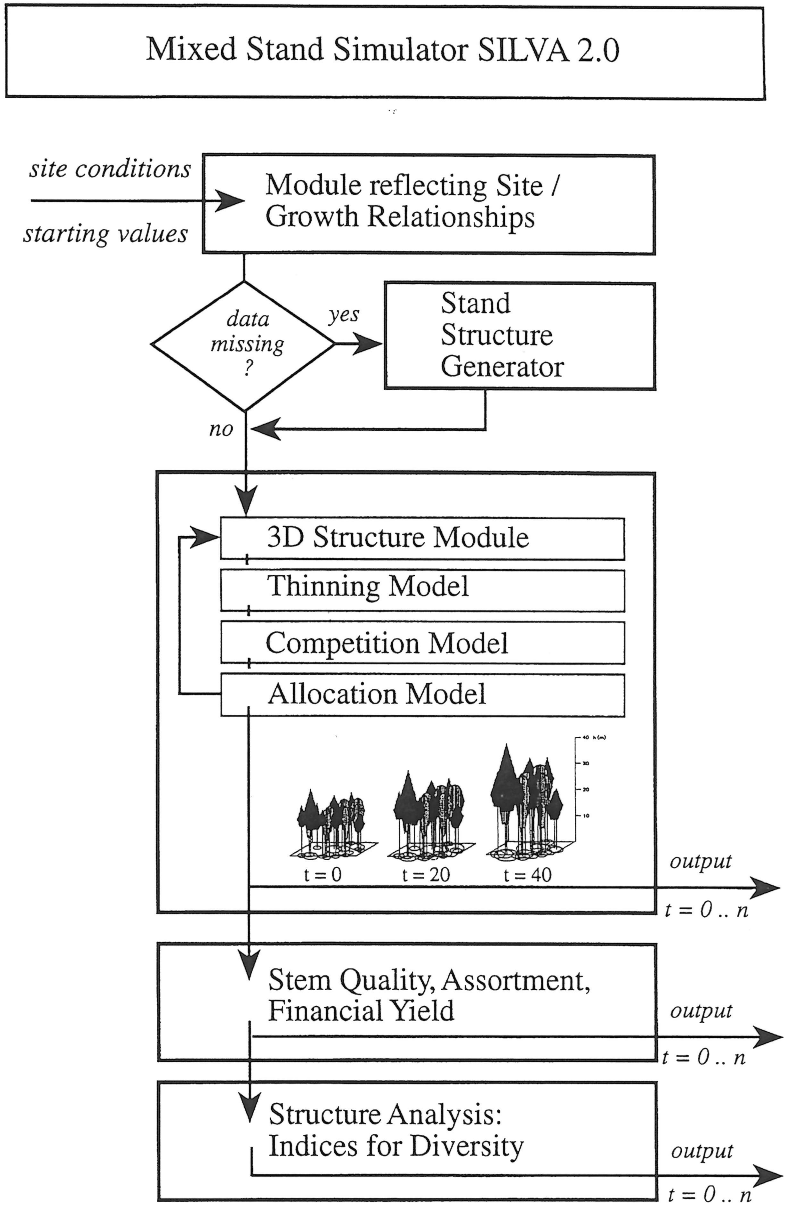

Figure 4.5.5
Scheme of the stand growth model SILVA 2 with the program module for structural analysis.

commonly used in forestry practice (e.g. mixture in small clusters, single tree mixture, row mixture), into a concrete initial stand structure, with which the growth model can subsequently commence its forecasting run (Pretzsch 1993). The three-dimensional structure model uses tree attributes such as stem position, tree height, diameter, crown length, crown diameter and species-related crown form models to construct a three-dimensional stand structure model. The generated three-dimensional model of the observed stand forms the basis for the derivation of structural indices R, A and S. The thinning model is also single-tree based and can model a wide spectrum of treatment programs (Kahn 1995). The core of the thinning model is a fuzzy logic controller. In the simulation studies described below the thinning model simulates various thinning methods (thinning from below and selective thinning) and thinning intensities (light, moderate and heavy). The competition model employs the light-cone method (Pretzsch & Kahn 1996) and calculates a competition index for every tree on the basis of the three-dimensional stand model. The allocation model controls the development of the individual stand elements; DBH, tree height, crown diameter, height of crown base, crown shape and survival status at five year intervals, in relation to site conditions, interspecific and intraspecific competition. Finally, classical yield information for the prognosis period, at both stand and single tree level, are compiled in listings and graphs. Additional information on stem quality, assortment yield and finances completes the growth and yield characterisation. At every stage of the simulation run a program routine for structural analysis calculates a vector of structural indices which serve as indicators for habitat and species diversity. Based on the three-dimensional structural model the indices described above can be calculated, i.e. the horizontal tree distribution pattern index R, the vertical species profile index A and the intermingling index S, which form a link with the ecological assessment of forest stands.

The algorithmic sequence for predicting forest development consists is as follows: the first step is the input of data describing the initial structure and site conditions of the monitored stand. Secondly, the parameters of the growth functions are adapted to actual site conditions. Once the starting values for the prognostic run are complete, monitoring can begin. If there are no initial values, e.g. stem positions are unknown, the missing data can be realistically complemented with the help of the stand structure generator. Once the spatial model has been constructed (step 4) the silvicultural treatment program is specified in the fifth step. Step 6 calculates the competition index for each tree which is used, in step 7, to control individual tree development. Steps 4 to 7 are repeated until the entire prognosis period has been run through in five-year cycles.

Results

The use of structural analysis in conjunction with a stand growth simulator is explained now on the basis of a series of simulation test runs. Specific examples will serve to demonstrate the effects of different stand establishment structures (single or group mixtures), different thinning methods (thinning from below and selective thinning) and different thinning intensities (light, moderate and heavy) on the spatial stand.

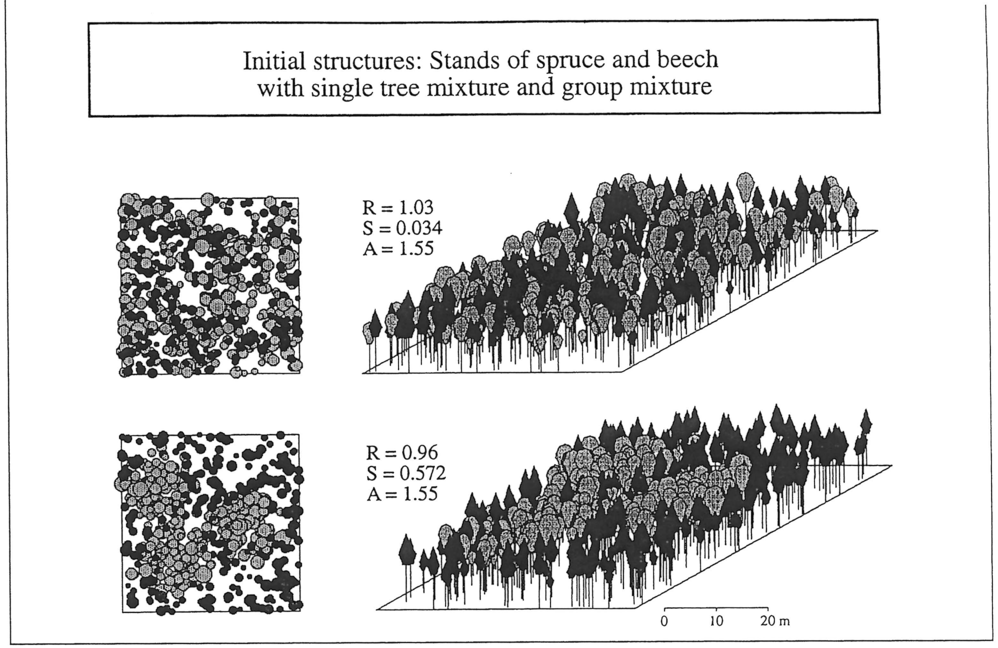

Figure 4.5.6
Initial structures for the simulation study are spruce-beech mixed stands with single-stem mixture of beech (above) and group mixture of beech (below). Indices for single tree mixture: R=1.03, RFI=1.01, RBU=0.99, S=0.034, A=1.55 and for group mixture: R=0.96, RFI=0.93, RBU=0.68**, S=0.572, A=1.55.

The input comprises two different variants of mixture structure (Fig. 4.5.6). The first is a single tree mixture with a random horizontal distribution pattern for the total stand, as well as for spruce and beech separately (R = 1.03, Rspruce = 1.01, Rbeech = 0.99). In this case the segregation index (Pielou 1977) shows an independent distribution of the two species (S=0.034). The second variant comprises a group mixture of beech with spruce as the initial structure. In this case the horizontal distribution pattern of beech shows significant clustering (Rbeech = 0.68**) and the segregation index (Pielou 1977) reveals a highly significant segregation of spruce and beech (S = 0.572). Both stands have similar vertical species profiles; A = 1.55 is indicative of great structural diversity in species representation. The thinning regimes simulated in the 100 year prognosis period, are characterized in Figure 4.5.7 in terms of the corresponding number of stems and the basal area development of the remaining stand. Thinning from above was carried out in the form of stepwise selective thinning according to the 'Schweizer Auslesedurchforstung' technique. When considering two basic structures (single tree and group mixtures), two thinning methods (thinning from below and from above) and three thinning intensities (light, moderate, heavy), the result is twelve developments whose spatial structural diversity is discussed below.

Studied thinning regimes: Thinning from below and selective thinning (slight, moderate, heavy)

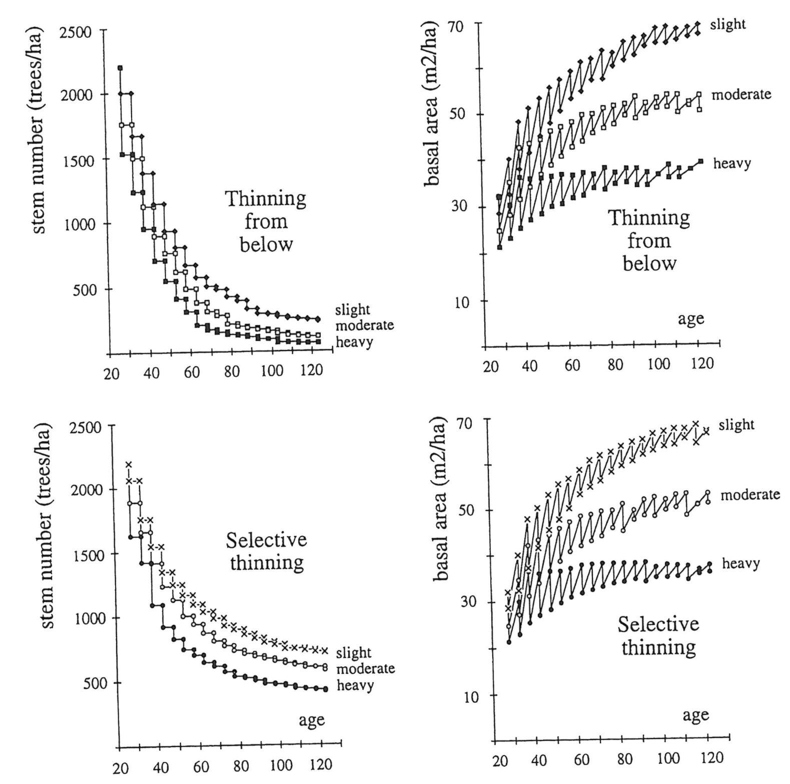

Figure 4.5.7
Stem number and basal area curves per hectare (left and right respectively) of the six basic treatment scenarios. Slight, moderate and strong thinning from below (above) and slight, moderate and strong selective thinning from above (below).

The horizontal tree distribution pattern

The more or less random horizontal tree distribution pattern of the total stand at the beginning of the prognosis period is converted into a rather more regular pattern as a result of thinnings from below, especially where these thinnings were intense (Fig. 4.5.8). This tendency for regular distribution patterns to be caused by thinning from below, can be attributed to the systematic removal of understory and intermediate trees, which inevitably leads to qualitatively satisfactory, dominant trees remaining in the stand, at rather more regular intervals. Thus resulting in stands with a homogeneous spatial structure. Stand structures of this type are increasingly replaced by more intensely structured stands which are mainly thinned from above. Selective thinning as observed in this study, especially in its light and moderate variants, causes random to clustered tree distribution patterns, since vigorous trees occasionally are left to grow in groups, while understory and intermediate trees are maintained. This leads to tree distribution patterns, where parts with denser stocking exist next to those with lesser density. Thinning from below and slight to moderate selective thinning achieves a greater heterogeneity than heavy thinnings. This is due to the fact that heavy thinning from above supports the encroachment of understory and intermediate trees into the dominant stand class and heavy thinning from below removes all trees of the lower social classes. Both methods strengthen tendencies towards regular tree distribution patterns.

A look at the species-related tree distribution patterns of spruce reveals that spruce tends to maintain its initial distribution pattern. This is again an example of the effect, obvious in the overall stand, that slight and moderate thinning from below leads to rather greater spatial homogeneity. In comparison, selective thinning is seen to be the cause for rather greater spatial heterogeneity in stand structure. Beech tends to occur in clusters, independent of whether it initially grew in group mixtures or single tree mixtures. This is less pronounced when treatment consists of thinning

Effect of initial structure, thinning method and thinning intensity on the horizontal tree distribution

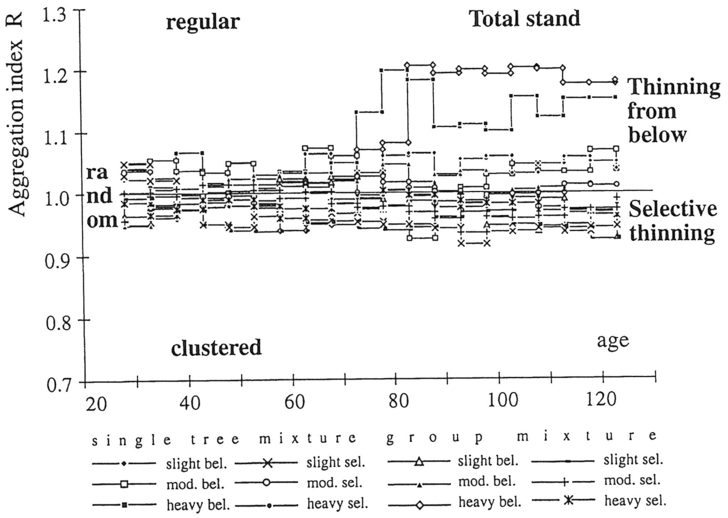

Figure 4.5.8
Development of the aggregation index R for the whole stand (spruce and beech together) during the prognosis period of one hundred years. Thinnings from below support regular distribution, thinnings from the top produce random or clustered stem distribution patterns.

Effect of inital structure, thinning method and thinning intensity on the vertical species distribution A

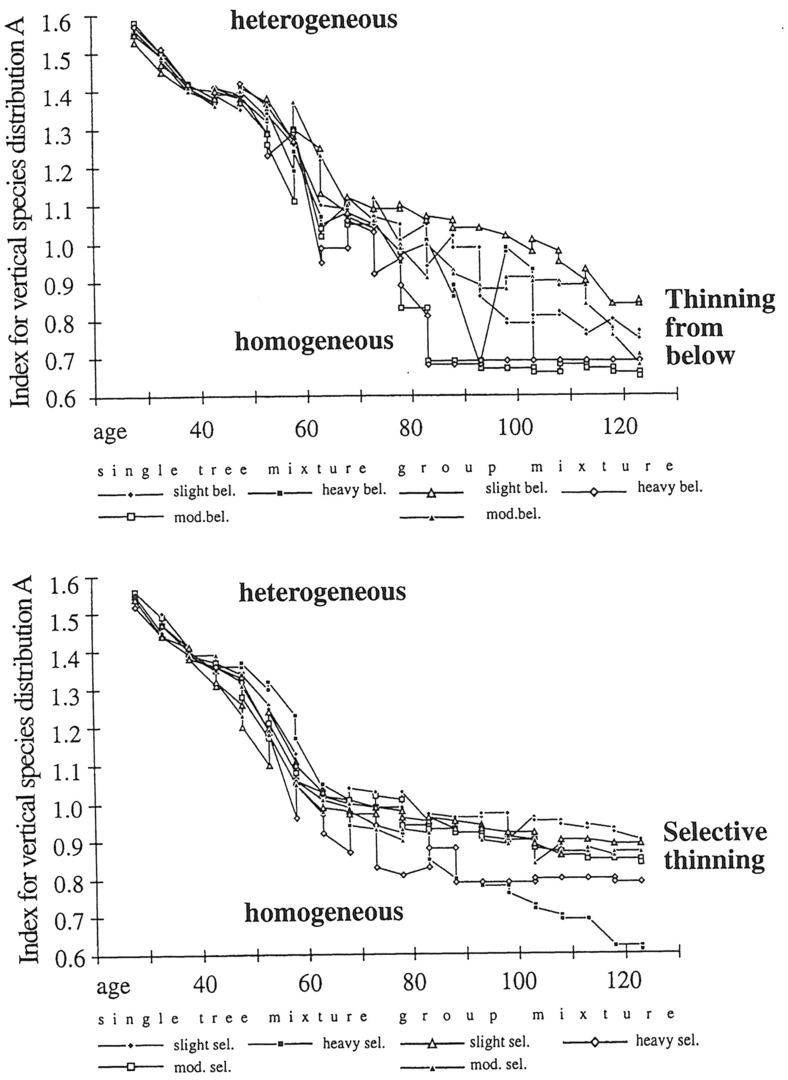

Figure 4.5.9
Effect of thinning from below (above) and selective thinning from the top (below) on the vertical species profile in mixed stands of spruce and beech.

from below rather than selective thinning. In single tree mixtures and large and small cluster mixtures thinning from above very often causes cores with intraspecific competition to remain. Since beech is inferior to spruce on the observed site its initial distribution pattern is to a very large extent overridden by both thinning method and thinning intensity.

The vertical species profile

With progressive ageing and differentiation, all simulated stands suffer a loss in vertical structure. The particularly severe competition for light in these phases leads to the decline of structure-contributing and poorly supplied stand elements at lower height levels. This is evidenced by the severe reduction in index A in pole crops and young timber observed for all thinning programs of this study (Fig. 4.5.9). Only when a new stand generation grows in a subsequent regeneration phase does index A seem to recover. While the species profile shows an almost linear decrease on account of thinning from below, during the course of the forecasting period (Fig. 4.5.9), selective thinning, especially if light to moderate, maintains greater spatial heterogeneity until final felling (Fig. 4.5.9, below). With both, thinning from below and above, light to moderate thinning favours greater structural diversity than does heavy thinning. The higher species profile index A in stands thinned from above is attributable to understory and intermediate stands which can be maintained over the entire production period through light and moderate thinning of the uppermost layer. There is no statistically significant effect of initial stand structure (i.e. single tree mixtures, or large and small cluster mixtures) on the vertical species profile A. Any differences in species profile between single tree and group mixtures, which existed at the start of the prognosis period, are being counteracted by both thinning method and intensity.

The intermingling of species

Similar results are obtained overall, when analyzing the segregation index S under varying thinning regimes and intensities (Fig. 4.5.10). Differences initially evident in intermingling intensity, such as pronounced intermingling for single tree and small cluster mixtures and poor intermingling for large cluster mixtures, are increasingly negated by the thinning methods during the course of the 100 year forecasting period. Independent of initial stand structure, thinning from above leads to a rather more segregated occurrence of species, i. e. to cores with stronger intraspecies competition. By contrast, thinning from below leads to stand homogenization. The more intense removal of weak trees causes stand parts with intraspecies competition to be increasingly replaced by trees whose neighbours belong to the other species. Similar interspecies neighbour relationships on a large scale contrast with heterogeneous stand structures when thinning is done selectively. As with the species profile, index A, the segregation index shows a particular reactivity, especially in the pole crop and young timber, to subsequent competitive processes and the thinning regimes employed. Stands of medium and higher ages display only slight shifts in species intermingling. This quantitatively supports the well-known silvicultural rule that growth regulation in forest mixtures is only effective in young stands.

Effect of initial structure and thinning regime on the intermingling intensity of spruce and beech

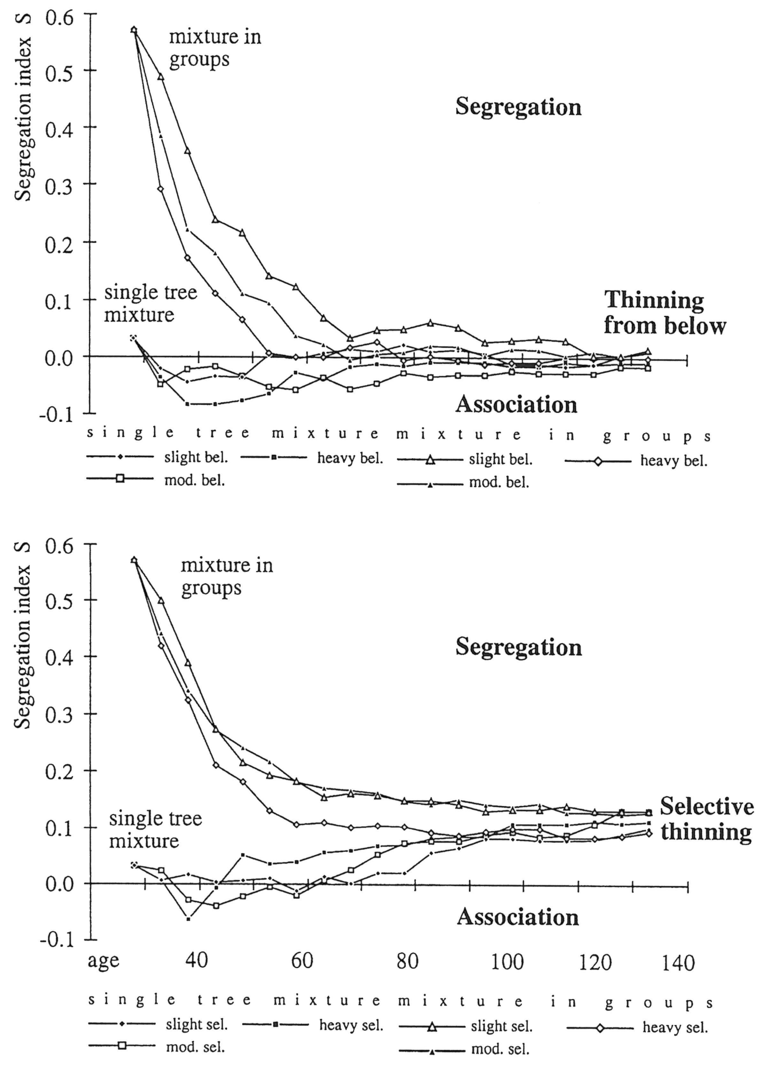

Figure 4.5.10
Effect of initial structure (single tree mixture and group mixture) and thinning regimes (thinning from below and selective thinning) on the segregation of spruce and beech during the prognosis run of one hundred years.

Discussion

The use of a program routine for structural analysis in conjunction with the stand simulator SILVA 2 led to the development of a feasible model with which the effects of different stand structures, thinning regimes and intensities on the structural diversity of mixed spruce-beech stands can be studied. While the simulation results serve as examples, however, the small number of samples as yet permits no generalization of the results described. The indices R, A and S, used to quantify horizontal distribution patterns, vertical species profile and intermingling of species respectively, each highlight merely selected aspects of spatial stand structure. The implementation of further indices would lead to an even more accurate description of structural stand formation. In particular, an even better characterization of species intermingling, contact frequencies and border lines between species mixtures would be desirable, as this kind of information controls, inter alia, faunistic diversity.

First predictive runs give quantitative evidence that stand establishment and stand treatment methods provide effective means of improving stand structure and diversity. The comparison between thinning from above and below emphasizes the potential of modern treatment programs to improve stand structure. A vector of structural parameters gives a quantitative idea as to what extent silvicultural measures, such as mixture regulation, removal and thinning, can be used as effective control instruments in securing structural diversity and ecological stability.

Individual tree models, provided they are based on sound parameterisation, offer the best possible link with the analysis of stand structure, by reproducing stand dynamics as a time-space system. In combination with the spatial model, any amount of structural information is available for every phase of the simulation run. Thus, for a wide range of forest structures, treatment regimes and site conditions (apart from basic natural production indices e.g. development of stem numbers. basal area, stock, increment) structural parameters are obtainable which can be used as indicators for habitat or species diversity. In this manner production and stability aspects can be coordinated and optimized in the model.

Due to the lack of methodological principles, model validation has to date mainly relied on classical yield data and thus, the validity of the simulated spatia structure remains untested. However, the closeness with which the modelled spatia structure is compatible with reality, particularly in distance-dependent individua tree models, is of central significance to its predictive accuracy. As a by-product o this study, the usefulness of structural parameters R, A and S was recognized in th validation of distance- dependent individual tree models. A comparison of modelled spatial structures, with those diagosed on test plots, is possible, based on the use o these indices. Such comparisons permit conclusions to be drawn as to how realistic the structural components of the growth model actually are. The structural indices primarily introduced to assist in structural diagnosis, thus, also show new, efficien alternatives to improve model parameterisation and validation.

References

Altenkirch, W. 1982. Ökologische Vielfalt - ein Mittel natürlichen Waldschutzes? Der Forst- und Holzwirt 37, 8: 211-217.

Ammer, U., R. Detsch & U. Schulz 1995. Konzepte der Landnutzung. Forstwissenschaftliches Centralblatt 114: 107-125.

Assmann, E. & F. Franz 1963. Vorläufige Fichten-Ertragstafel für Bayern. Institut für Ertragskunde der Forstlichen Forschungsanstalt München. 104 p.

Blab, J. 1986. Grundlagen des Biotopschutzes für Tiere. Ein Leitfaden zum praktischen Schutz der Lebensräume unserer Tiere. Kilda, Bonn. 257 p.

Clark, P. J. & F.C. Evans 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology 35, 4: 445-453.

Ellenberg, H., M. von Einem, H. Hudeczek, H.-J. Lade, H.U. Schumacher, M. Schweinhuber & H. Wittekindt 1985. Über Vögel in Wäldern und die Vogelwelt des Sachsenwaldes. Hamburger Avifaunistische Beiträge 20: 1-50.

Haber, W. 1982. Was erwarten Naturschutz und Landschaftspflege von der Waldwirtschaft? Schriftenreihe des Deutschen Rates für Landespflege 40: 962-965.

Kahn, M. 1994. Modellierung der Höhenentwicklung ausgewählter Baumarten in Abhängigkeit vom Standort. Forstliche Forschungsberichte München 141: 221 p.

Kahn, M. 1995. Die Fuzzy Logik basierte Modellierung von Durchforstungseingriffen. Allgemeine Forst- und Jagdzeitung 166, 9/10: 169-176.

Pielou, E. C. 1975. Ecological diversity. Wiley, New York.

Pielou, E. C. 1977. Mathematical ecology. Wiley, New York. 385 p.

Pretzsch, H. 1992. Konzeption und Konstruktion von Wuchsmodellen für Rein- und Mischbestände. Forstliche Forschungsberichte München 115. 358 p.

Pretzsch, H. 1993. Analyse und Reproduktion räumlicher Bestandesstrukturen. Versuche mit dem Strukturgenerator STRUGEN. Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächsischen Forstlichen Versuchsanstalt, Band 114. Sauerländer, Frankfurt am Main. 87 p.

Pretzsch, H. & M. Kahn 1996. Modelling growth of Bavarian mixed stands in a changing environment. In: E. Korpilahti, H. Mikkelä & T. Salonen (eds.), Caring for the forest: research in a changing world. 20th World Congress of IUFRO, Tampere, Finland, 6-12 August 1995; Congress Report, Volume II: 234-248.

Ripley, B. D. 1977. Modelling spatial patterns. J. Roy. Stat. Soc., Series B, vol. 39, 2: 172-212.

Ripley, B. D. 1981. Spatial statistics. Wiley, New York.

Schober, R. 1975. Ertragstafeln wichtiger Baumarten. Sauerländer, Frankfurt am Main. 154 p.

Shannon, C. E. 1948. The mathematical theory of communication. In: C. E. Shannon & W. Weaver (eds.), The mathematical theory of communication. University of Illinois Press, Urbana; 3-91.

Upton, G. J. G. & B. Fingleton 1985. Spatial data analysis by example. Volume I: Point pattern and quantitative data. Wiley, New York. 410 p.

Upton, G. J. G. & B. Fingleton 1989. Spatial data analysis by example. Volume II: Categorical and directional data. Wiley, New York. 416 p.

4.6 Mixed-species forests in Portugal: perspectives for the development of management-oriented growth models

M. Tomé, J. Sales Luís, M. Loreto Monteiro & Â.C. Oliveira

Abstract

The aim of this paper is to analyse the importance of mixed-species forests in Portuguese forestry and to relate state-of-the-art research to the management of mixed-species forests, namely in the area of growth and yield modelling. A brief characterisation of the forest cover in Portugal is given. Special emphasis is placed on the importance of mixed-species forests, in order to stress the differences between land use and forest types in Portugal and in Central and Northern Europe. Different mixed-species stand types, requiring different silvicultural treatments and management, are identified and briefly characterised. The present and future research strategies for the development of growth and yield models, or which to base sound management decisions, are also described.

Key words: mixed-species stands, modelling approaches, data gathering, designed experiments, Portugal

Introduction

The forest area in Portugal almost doubled in the last century as a consequence o successive afforestation programs that occurred from the 1930's onwards. Most o the areas regenerated under these afforestation programs are pure monocultures o maritime pine or eucalyptus plantations, although small patches of hardwoods o mixed-species stands have sometimes been regenerated on the better sites. The silviculture of mixed-species stands has therefore not been a tradition in Portugal. In fact, most of the forest areas are owned by private landowners or by loca communities (78% and 12% of total forested area respectively) that do not tend thei stands properly, even if they own pure stands or plantations. Exceptions to thi situation are the pure eucalyptus stands owned or rented by the pulp companies o some state-owned pure maritime pine stands (approximately 6% and 3% of tota forest area respectively) that have had management plans devised and implemented. In the last decades, however, as in other European countries, the paradigm of usin mixed-species stands instead of monocultures of coniferous or eucalyptus plantation is gaining importance in Portugal. Coordinated research is beginning and it aims t define management models for these forests, which can guarantee successfu management both from ecological and economic points of view. The aim of thi paper is to analyse the importance of mixed-species forests in Portuguese forestr and to relate state-of-the-art research to the management of mixed-species forests specifically in the area of growth and yield modelling.

MISSION

Believing that the ecological value of an area is influenced by agriculture, urbanisation, recreation, infrastructure, traffic and other human activities, and that both ecological value and sustainability are enhanced if these activities take account of ecological principles, the DLO Institute for Forestry and Nature Research (IBN-DLO) aims to provide the scientific basis for public debate on how best to achieve nature conservation. By helping to solve problems arising from the conservation, restoration and development of nature in this way, IBN-DLO aims to contribute constructively to a high quality environment in The Netherlands and abroad.

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Management of mixed-species forest: silviculture and economics

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Preface

In June 1993, foresters and researchers interested in the management of mixed-species forests and small-scale forestry met in Besançon in France, for the International ProSilva Congress. During the meeting, it became apparent that the level of expertise on the management of mixed forests in Europe was varying significantly, with some countries demonstrating already a long history of research, while others were only beginning to address this topic. It thus seemed appropriate to form a group of scientists, from both advanced and less advanced countries in this respect, to discuss the current state of the art, exchange experiences, identify gaps and define research priorities for the near future.

To reach these objectives, the concerted action 'Management of Mixed-species Forests: Silviculture and Economics' was proposed to and eventually funded by the European Commission's AIR specified RTD programme (AIR CT94 2149). Since its start in December 1994, the concerted action provided the means for the organisation of three workshops, where 22 researchers from 13 EU countries presented their work, reflected on ideas and identified research priorities for the future. A number of selected invited speakers have contributed significantly to the success of the project by sharing their experience and thought with the participants of this action.

The present volume summarises all contributions made throughout the action's lifetime and is meant to provide useful 'food for thought' to the European forestry community concerning the prospects and orientations of the silviculture, economics, and ultimately, the multifunctional management aspects of mixed-species forests in Europe.

I want to thank all participants and invited speakers for their enthusiasm in the meetings and their contributions towards the realisation of this volume. Especially, I want to thank Dr.Ir. H.H. Bartelink (Forestry Section of the Wageningen Agricultural University) for his great efforts to edit and compile this book, and Jack Gardiner and Sara Wall (Department of Crop Science, Horticulture and Rural Development, University College Dublin) for the technical and linguistic editing. Dr. A. Arabatzis has been our counterpart with DG XII, the European Commission's Directorate for Science, Research and Development. Finally I want to thank Drs. T.A.W. van Rossum and M. Pijfers who took care of the final book production.

I hope this book shows many persons the way to mixed forests. In most European countries, there is a desire for further expansion of the area of mixed forest with a multifunctional goal. This book shows that management of mixed forest is a challenging task, and that sound research is needed to provide guidelines for a sustainable silviculture.

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