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International Union of Forestry Research Organisations
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MODELLING GROWTH OF BAVARIAN MIXED STANDS OF FAGUS SILVATICA AND PICEA ABIES ON THE DATA BASE OF LONG-TERM SAMPLE PLOTS

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ABSTRACT

Based on the data obtained by long-term observation of pure and mixed forest stands of spruce and beech in Bavaria, a single-stem growth simulator for pure and mixed stands of spruce *(Picea abies L.- Karst.)* and beech *(Fagus sylvatica L.)* has been developed. The 3-dimensional growth constellation of single trees is recorded via the lateral restriction of the crown ε and the amount of shade ω caused by neighbouring trees. The model does not only take into consideration the well-known fact that each species reacts differently to a certain amount of shade, for example that beech is more tolerant to shade than spruce. But it also considers the fact that the amount of shadow cast by neighbouring trees depends on their species, for example that beech is more light permissive than spruce. The model depicts the development of the stand structure by elevation drawings, crown maps and horizontal cuts through the crown space. It generates information on the development of every single stem on a plot and summarizes the area-related stand values in classical yield tables.

KEYWORDS: Single-tree simulator, 3-dimensional approach, Bavarian mixed stands, *Picea abies L.-Karst.*, *Fagus sylvatica L.*, yield tables for mixed stands.

STRUCTURAL ANALYSIS OF THE CROWN SPACE

The spatial structure of a stand, its horizontal and vertical composition, have a strong influence on the further development of stand growth (PETRI, 1966). Considering the importance of spatial pattern in mixed stands we choose a space-time model approach for simulating the growth of pure and mixed stands of spruce and beech in Bavaria. A single tree growth simulator was developed that describes the competitive situation of trees by their 3-dimensional growth constellation. The fundamental element of the simulator is a program routine that models the 3-dimensional stand structure. The spatial structure of the stand is modelled, based on the stem coordinates, the crown radii, the tree's height and crown length and generalized crown forms of each species *(Fig. 1)*. The 3-dimensional extension of the crown is determined by the input data height, basis of the crown and crown radius according to the crown form models by the Swiss BADOUX and BURGER. Afterwards three factors can be registered for all points in the crown space according to the dot-count principle: By which trees is the point hit? By which species is it hit? How often is the point hit by a crown? In this way we can get far-reaching information about the stand structure, for example about how the crown space is utilized by trees and the presence of various species in different heights.

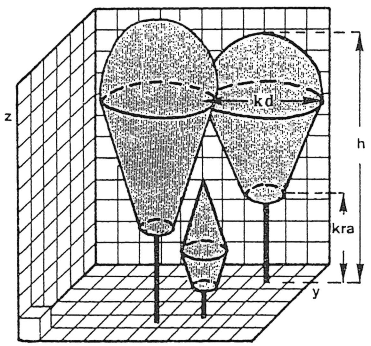


Fig. 1 The 3-dimensional stand structure is reproduced mathematically and shown graphically

h:	tree height	kra:	height of basis of the crown
kd:	mean crown diameter	x, y:	coordinates of the position of the tree

Moreover, information about the competitive situation of single trees in the stand can be obtained with the dot-count principle. Most of all, two structural parameters have proven to be essential for single-tree growth determination: The lateral restriction of the crown and the amount of shade caused by neighbours (PRETZSCH, 1992).

SPATIAL ANALYSIS OF THE GROWTH CONSTELLATION OF SINGLE TREES

Lateral Restriction of the Crown ε

The lateral restriction of the crown ε is determined according to the following steps *(Fig. 2)*: 1. The potential crown diameter kd_{pot}, that could be expected for tree A under optimum conditions for crown growth is determined. 2. The overlapping zone with the central tree A is calculated for all neighbours of the same crown layer. The above mentioned dot count-principle

is the underlying principle for determining the overlapping zones at the border between light-foliaged and shade-crown section of the tree in question. These overlapping zones are set into relation to the overall area at the potential crown diameter; this results in a relative measure for the lateral restriction of the crown. By a repetition of the calculation for the structure of the stand after a thinning process, ε_{before} and ε_{after} can be found out and the lateral liberation created by the thinning can be calculated: $\Delta\varepsilon = \varepsilon_{before} - \varepsilon_{after}$.

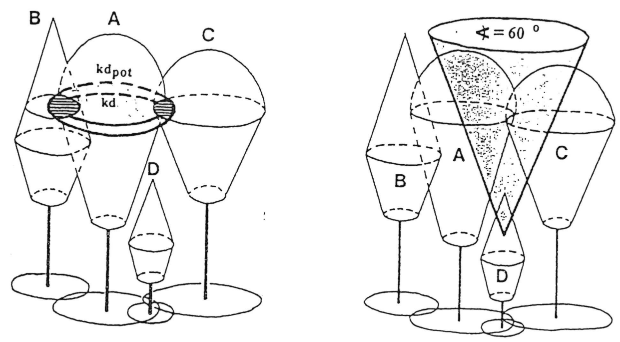


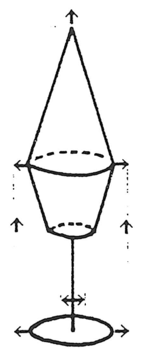
Fig. 2 Determination of the lateral crown restriction ε *(left)* and the amount of shade ω *(right)* of single trees.
left determination of the lateral crown restriction ε of tree A
right determination of the amount of shade ω of tree D according to the cone-of-light principle

Determining the Amount of Shade on Crown ω

In order to find out a tree's amount of shade, we construct a light cone with an opening angle of 60 degrees at 70 % of the tree's height, following SLOBODA and PFREUNDT (1989). The more the neighbouring trees intrude into the central tree's light cone, the worse its supply of light and its growth constellation will get *(Fig. 2)*. The shelter situation within the light cone is registered by the value of ω. The calculation of ω comprises the following steps: 1. The central tree's light cone and the competitors intruding in it are determined. 2. A number of points within the light cone are analyzed whether they are hit by a crown. If this is the case, the spatial point will leave its mark on the index of the amount of shade ω. The calculated index of the amount of shade ω is a relative measure for the amount of shadow cast on a tree by its neighbours. It must be stressed that not only the overall amount of shade ω will be found out, but also the amount from each species. The result of an analysis of a tree's amount of shade in a mixed stand of spruce and beech could be for example: ω=3, consisting of $\omega_{SP}=1$ and $\omega_{BE}=2$; this means that the tree concerned is provided with more shadow by neighbouring beeches than by spruces. The analysis of the amount of shade is carried out for the structural situation before and after thinning measures.

Lateral Restriction of the Crown ε and Amount of Shade ω as the Regulatory Items of the Model

The structural parameters ε and ω are the central regulators of the simulation model. The first step of a simulation run is to read a list of trees with their dimensions and coordinates given in the beginning. During the second step, the 3-dimensional structure of the stand before a thinning is reproduced numerically and depicted by a graph. After the thinning has been specified in step 3, in step 4 the stand structure after thinning is reproduced numerically and depicted by a graph. Step 5 determines the structural parameters ε and ω of each tree and their changes (Δε and Δω) caused by the thinning. These results - the structural parameters ε, ω, Δε and Δω - are used in step 6 to predict the height and crown diameter growth, the change of the basis of the crown, the basal area increment and the mortality in the five year growing period to follow. The updated actual dimensions of the individual trees at the end of the first simulation cycle of five years represent the initial values for the second simulation cycle. Steps 2 to 6 are repeated again and again until the whole prognostic period has been passed through in steps of five years each (see MITCHELL, 1975 and MONSERUD, 1975).



$\hat{zh} = f(zh_{pot}, B, \varepsilon, \omega_{SP}, \omega_{BE}, \Delta\varepsilon, \Delta\omega)$

$\hat{T} = j(\varepsilon, \omega, M, V, g_a, \hat{zg})$

$\hat{zkd} = g(zkd_{pot}, \varepsilon, \omega_{SP}, \omega_{BE}, \Delta\varepsilon, \Delta\omega)$

$\hat{\Delta B} = i(h, \omega_{SP}, \omega_{BE})$

$\hat{zd} = h_1(\hat{zg}) = h_2(g_a, M, V, \omega_{SP}, \omega_{BE}, \Delta\omega)$

Fig. 3 Model approaches for the changes in dimension of single stems - preliminary results:

predicted dimensions:		variables of influence:	
$\hat{zh}$:	height growth	ω_{SP}, ω_{BE}:	amount of shade by spruce and beech
$\hat{zkd}$:	increment of crown diameter	ε:	lateral crown restriction
$\Delta\hat{B}$:	change of live crown ratio	Δω, Δε:	changes in ω, ε by thinning
$\hat{zd}$:	diameter increment	zh_{pot}:	potential height growth
$\hat{zg}$:	basal area increment	zkd_{pot}:	potential increment of crown diameter
$\hat{T}$:	mortality	h:	tree height
		M:	crown surface area
		V:	crown volume
		g_a:	initial basal area

CONSTRUCTION OF THE MODEL

A growth model of this structure has been realized for mixed stands of spruce and beech. 22 experimental plots in pure and mixed stands with spruces and beeches in the Bavarian Forest provided the data base. The tree growth - estimated in step 6 of the simulation loop - is discribed by the model approaches presented in *Figure 3.* Suitable model functions for increment estimation were developed and fitted to the data by non-linear regression analysis and logistic regression calculation.

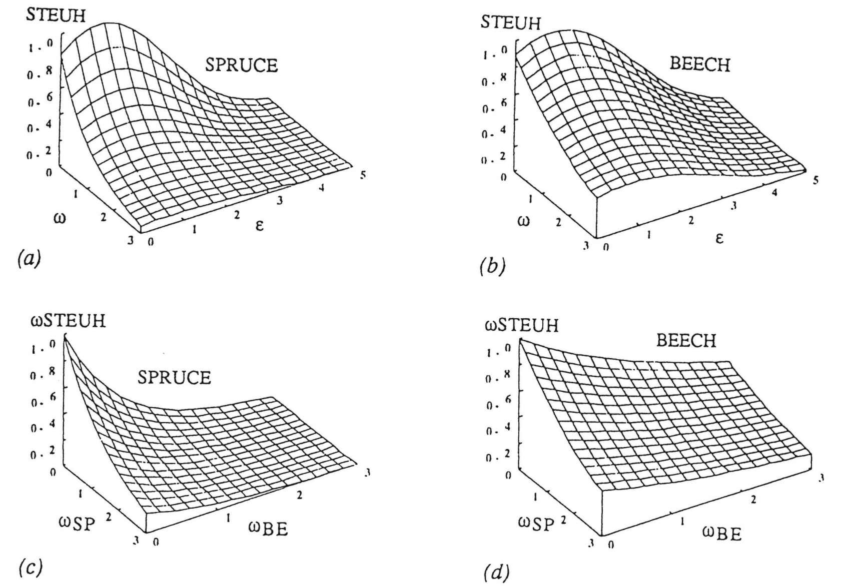


Fig. 4 Influence of the structure parameters ε and ω on the height growth - preliminary results:
a and b effect of the combination of ε and ω on the height growth of spruce *(a)* and beech *(b)*
c and d effect of the amount of shade (specific to different species) of spruce and beech on the height growth of spruce *(c)* and beech *(d)*

Height Growth Model

The height growth model shows the way the parameters ε and ω regulate the growth. A tree's current increase in height $\hat{zh}$ is assessed from its potential increase in height zh_{pot}, which could be expected under optimum conditions. If the tree does not have optimum conditions, which is expressed by the measures B, ε, Δε and ω and Δω his increment decreases. In the following we will only discuss the effects that ε and ω exert on height growth.

The description of the growth constellation of a tree by the two factors ε and ω aims at the separation of horizontal and vertical competition and the quantification of their specific effects on growth *(Fig. 4, a and b)*. The upper graphs show the combined effect of the lateral restriction ε and the amount of shade ω on the factor STEUH for spruces and beeches (STEUH = 1.0 means potential height growth). There is an optimum relation between the degree of the lateral restriction ε and the height growth of spruces and beeches: A maximum height growth is reached at a medium lateral competitive situation ε. With rising amount of shade ω, the height growth diminishes exponentially. The fact that the beech is a shade tolerant tree is expressed by the considerably lesser slope of its curve compared with that of spruce.

The shade cast on a tree by neighbouring spruces ω_{SP} and beeches ω_{BE} has a different effect in the height growth model. *Figure 4 (c and d)* shows how a spruce reduces its potential height growth when its surroundings consist of spruces ($\omega_{SP} > 0$, $\omega_{BE} = 0$) or beeches exclusively ($\omega_{BE} > 0$, $\omega_{SP} = 0$). In these cases, the values of the height reduction factor ωSTEUH are shown on the basic lines of the regression surface which are parellel to the x- and y-axis and represent the situation of a pure stand. Besides, the effect on height growth (ωSTEUH) can be seen for any admixture of beeches and spruces ($\omega_{SP} > 0$ and $\omega_{BE} > 0$). So the model does not only take into consideration the well-known fact that each species reacts differently to a certain amount of shade, for example that beech is more tolerant to shade than spruce. But it also considers the fact that the amount of shadow cast by neighbouring trees depends on their species, for example that beech is more light permissive than spruce.

BEHAVIOUR OF THE MODEL

By compilation of the sub-models for height and crown-diameter growth, for the displacement of the basis of the crown, the diameter increment and mortality, we create a growth simulator for mixed stands of spruce and beech. The following simulation test run gives an impression of the growth dynamics of sub-montane stands of spruce and beech in eastern Bavaria. Here spruce trees have optimum growth conditions and are superior to beech trees in their growth. As the initial situation of the simulation run *(t = 0)* we have chosen the stand structure of an area of 0.10 hectares which lies in a mixed stand of spruce and beech in the forest district of Zwiesel.

Development of Height and Diameter Growth of Single Stems

At the beginning of the simulation run over 60 years the spruce in the stand was about 60 years old and had a mixture proportion of about 70 per cent, whereas the beech was 80 years old and occupied about 30 per cent of the basal area. Within that stand, beech trees are - despite their advanced age - clearly inferior to spruce as far as height growth is concerned. The height growth and diameter development shows that spruces cover the upper part of the height and

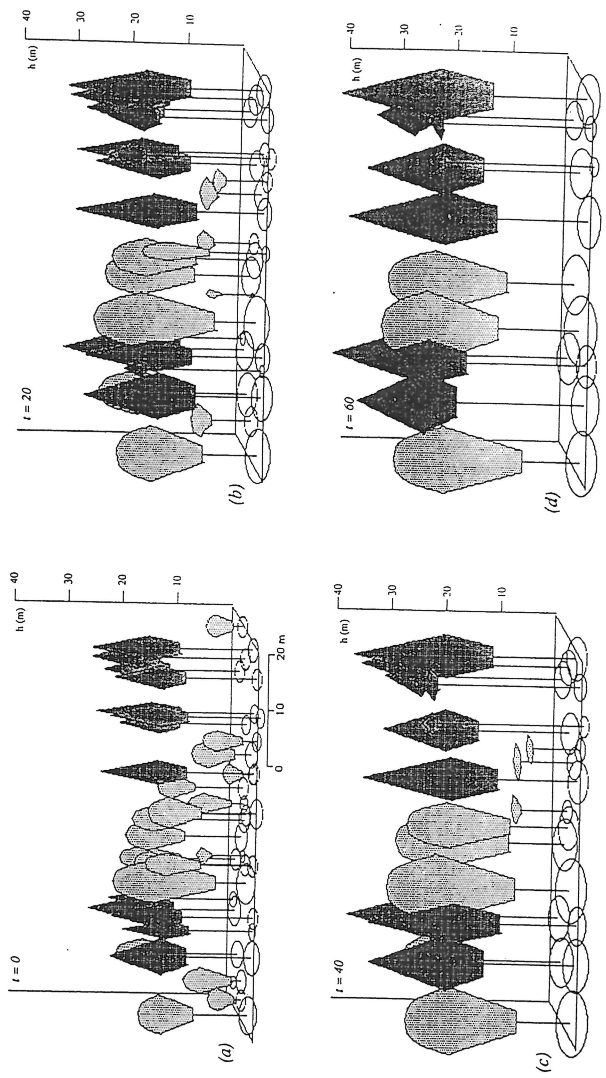


Fig. 5 Dynamics of a stand on a five-metre strip within the experimental plot of the spruce-beech stand (according to the results obtained by a simulation run over 60 years). We see the structure of the stand in the beginning *(t=0)* and after 20, 40 and 60 years *(t = 20, t = 40 and t = 60)*.

diameter spectrum - on the whole unhindered by the beeches. Non-parallel curves can be observed especially in the middle and lower part of the curve spectrum, because in this sector the self-thinning processes are very effective. The diameter and height distributions can be shown for any point of time during the simulation run.

Time Series of Elevation Drawings of the Stand Structure and its Development

The actual stand structure can be plotted for every phase of the simulation run. *Figure 5* shows the stand structure on a five metre strip within the experimental plot at the beginning of the simulation run (spruce 60 years old, beech 80 years old) and the simulated stand structure at the end of 20, 40 and 60 years *($t = 20$, $t = 40$ and $t = 60$)*. We see that without any active thinning, beeches are crowded out more and more by spruce trees and, as a consequence, die - unless they are liberated or grow in groups.

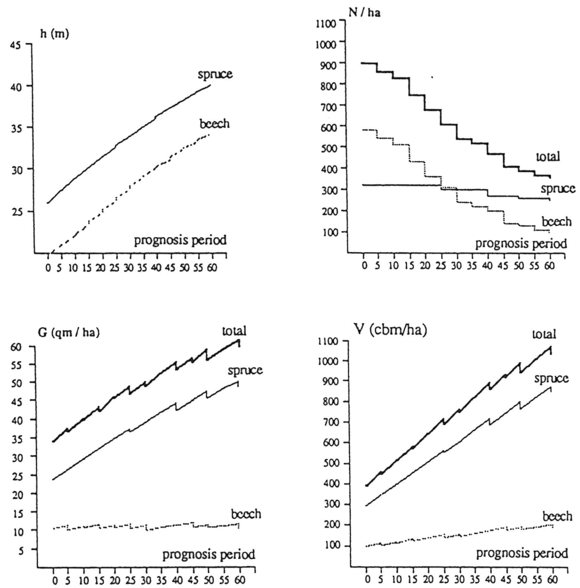


Fig. 6 Developement of the most important values of the remaining stand (per ha) on the experimental area of the mixed stand for spruce and beech according to the results obtained by a 60-years simulation run *(from $t=0$ to $t=60$)*.
above height of the average tree (h_m in metres) and number of stems (N/ha)
below basal area (G in square metres/ha) and volume ($V_{>7cm}$ in cbm/ha) of the remaining stand

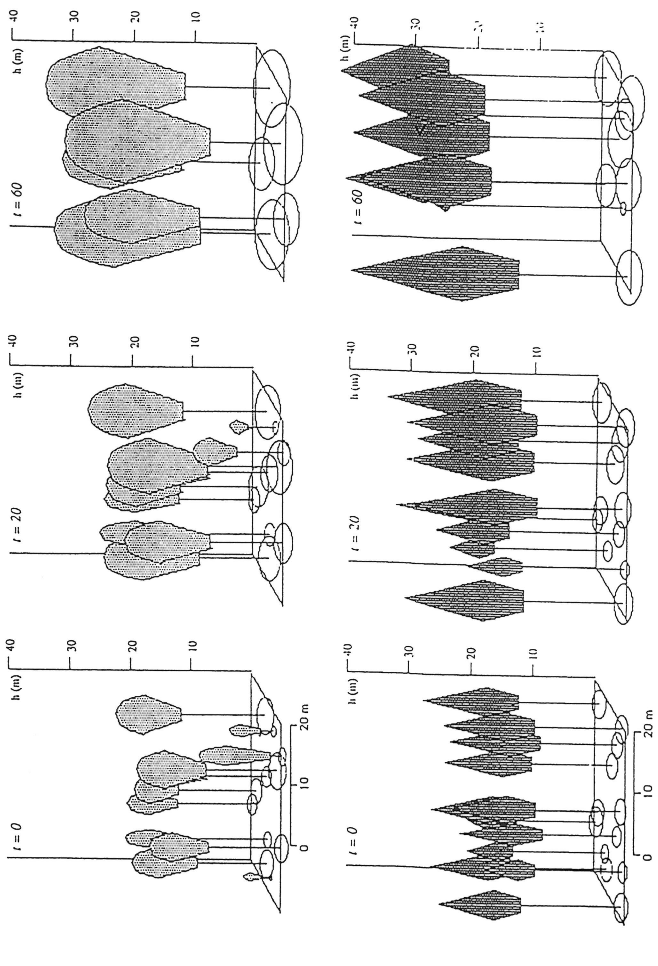


Fig. 7 Developement of a pure stand of spruce *(above)* and beech *(below)* as results of a simulation run of 60 years. We see the structure of the stand in the beginning *($t = 0$)* and in the phases $t = 20$ and $t = 60$ on a sector within the experimental plot which is five metres wide and 30 metres long.

Yield Elements of the Stand

By summarizing the changes of all single stems on a plot we are provided with the classical stand data. *Figure 6* shows the simulated average height, number of stems, basal area and volume per hectare in the predictive period of 60 years for the presented mixed stand without any active thinning *(spruce : solid line, beech : dotted line).* The development of the average height underlines the superiority of spruce. Without any thinning, the number of beech stems declines continually. The values for basal area and volume correspond well with the data of neighbouring experimental plots which are untreated or only slightly treated. The results of the simulation run are finally united in tables corresponding to the classical construction of yield tables. They contain the yield components of the stand in five-year intervals for spruce and beech separately. These tables represent the lowest level of the broad range of information made possible by the single stem simulator. Apart from the development of mixed stands of spruce and beech with different admixtures and thinning concepts, the development of pure stands of spruce and beech can also be reproduced by the simulator. The development of spruce and beech in pure stands are covered by our model as the border situation of mixed stands (FRANZ, 1987). *Figure 7* shows details from a simulation run for a pure spruce stand *(above)* and a pure beech stand *(below)* at the beginning of the simulation run, at 20 and at 60 years .

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August, 1992

International Union of Forestry Research Organizations
IUFRO Centennial Meeting, Berlin, August 31-September 5, 1992
Session S4.01-03: Long term sampling with emphasis on mixed stands

GROWTH OF SOME PREDOMINANT TREES OF DIFFERENT SPECIES IN A MIXED STAND OF SOUTHERN BAVARIA*

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SUMMARY

Concepts for silvicultural treatment of stands suppose some knowledge about the proportion of growing of the concerning species. This growing is predesigned by site conditions and actually influenced by stand density, tending interventions and thinnings. Until today long term observations of mixed stand trials are mostly missing. Therefore stem analysis is necessary for to try retrospective conclusions about the development of the stand.

When choosing stem analysis trees for this purpose in a mixed stand it is important to catch the typical growth of the different species at this particular site as well as at the typical structure and composition of the mixture.

With stem analysis trees of oak (*quercus robur L.*), beech (*fagus sylvatica L.*), hornbeam (*carpinuns betulus L.*), birch (*betula pendula* Roth), norway spruce (*picea abies L.*), scots pine (*pinuns sylvestris L.*) and larch (*larix decidua Mill.*) from a 130 year old mixed stand near Munich, these problems are discussed and some results are presented.

Keywords: Mixed stand, stem analysis, comparison of species.

PROBLEM

Besides the social competition within one species in a pure stand we have to consider in a mixed stand also the various species competitions. These may be for the first the mostly unequal growing rhythm and productivity of the species and for the second the advantage or handicap of being older or younger than the surrounding trees - besides all man made cleaning and thinning effects.

* This study contributes to the cooperation project "Lissabon/München", which is supported by the Alexander v. Humboldt Foundation within the "Forschungskooperation Europa"

Research on Growth and Yield with Emphasis on Mixed Stands

Proceedings / Berichte / Competes rendus / Actas

from Sessions of S4.01
"Mensuration, Growth and Yield"

IUFRO Centennial Meeting
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Vorwort

Zur Hundertjahrfeier des Internationalen Verbandes Forstlicher Forschungsanstalten (IUFRO) in Berlin/Eberswalde vom 31. August bis 4. September 1992 organisierte die Fachgruppe S4.01 "Holzmessung, Zuwachs und Ertrag" vier Vortragsreihen für ihre vier aktiven Arbeitsgruppen sowie zusätzlich eine Poster-Ausstellung.

Der Berichtsband enthält die Beiträge dieser vier Vortragsreihen. Es war unser Bemühen, jeden dieser Vorträge zur Hundertjahrfeier in voller Länge wiederzugeben. Zusätzlich wurden einige Beiträge mit aufgenommen, die wegen Problemen bei der Postzustellung nicht rechtzeitig eingetroffen waren und daher während des Kongreß nicht hatten vorgetragen werden können.

Die Autoren lieferten druckfertige Textvorlagen und sind allein und ausschließlich für deren Inhalt verantwortlich. Es wurden vom Herausgeber lediglich einige unbedeutende Änderungen in der Formatierung vorgenommen. Die einzelnen Beiträge sind in der Reihenfolge ihrer Vortragstermine geordnet. Die zusätzlich vorgelegten Texte erscheinen jeweils am Ende der Arbeitsgruppen-Beiträge.

IUFRO kann keinerlei Unterstützung zur Herausgabe von derartigen Sonderberichten leisten. Daher danken wir ganz besonders der Hanskarl Goettling Stiftung, Freising/München, die in großzügiger Weise die Herausgabe dieses Berichtsbandes unterstützte. Hanskarl Goettling war der erste Leiter der Bayerischen Forstlichen Versuchs- und Forschungsanstalt nach deren Trennung von der Forstwissenschaftlichen Fakultät der Universität München im Jahr 1979. Die Stiftung fördert Forschung und Wissenschaft in den Bereichen, die zu den Aufgaben und Zielen der Bayerischen Forstlichen Versuchs- und Forschungsanstalt gehören, welche unmittelbare Nachfolgerin der früheren Bayerischen Forstlichen Forschungsanstalt ist. Diese war eines der Gründungsmitglieder des Internationalen Verbandes Forstlicher Forschungsanstalten (IUFRO) in Jahr 1892.

Daneben möchten wir dem Leiter von S4.01 und ganz besonders seinem Stellvertreter, Herrn Dr. Klaus Johann, Wien, und den *chairmen* und *co-chairmen* der Arbeitsgruppen für die Vorbereitung und Organisation des Treffens in Berlin danken.

Teja Preuhsler München/Freising, November 1992

Dieser Berichtsband "Research on Growth and Yield with Emphasis on Mixed Stands - IUFRO Centennial 1992 - Sessions of S4.01" ist erhältlich bei der Bayerischen Forstlichen Versuchs- und Forschungsanstalt, Hohenbachernstraße 20, D-8052 Freising, gegen Erstattung der Versandtkosten von DM 12.-
Die meisten *abstracts* für den gesamten Kongreß sind in den *CENTENNIAL PROCEEDINGS* enthalten, die über das IUFRO-Sekretariat, Seckendorf Gudent-Weg 8, A - 1131 Wien, Österreich, zu einem Preis von DM 25.- und zusätzlich DM 12.- für den Versandt bezogen werden können.

Preface

At the IUFRO Centennial Meeting in Berlin/Eberswalde, Germany, held from August 31 to September 4, 1992 the Subject Group S4.01 "Mensuration, Growth and Yield" organized four sessions for the four active working parties and additional one poster session.

Papers from the four working party sessions constitute this volume. We have attempted to make full versions of each paper presented at the Centennial Meeting in Berlin/Eberswalde. As during the meeting some more papers appeared without notification in time, because of mailing problems, these are also included.

The authors submitted the camera-ready copy of their manuscripts and they are solely responsible for the contents. No attempt was made to obtain review or to edit the material submitted, besides some format changings. The papers are presented by their terms within each session. The additional papers follow at the end of the sessions.

No financial provisions are made for the publications of special proceedings volumes from IUFRO. Thus we are most grateful to the Hanskarl Goettling Stiftung, Freising/Munich, Germany, who generously supported the printing of this proceedings. Hanskarl Goettling was the first Director of the Bavarian Forestry Experiment and Research Station after separation from the Forest Faculty of the University of Munich in 1979. The foundation supports research and science according to the objectives and aims of the Bavarian Forestry Experiment and Research Station, which is directly in tradition to the former Bavarian Forest Experiment Station as one of the founding members of IUFRO in 1892.

Finally we thank the leader of S4.01 and especially the deputy leader, Dr. Klaus Johann, as well as the chairmen and co-chairmen of the working parties for all foreground and background organizings of the meeting in Berlin.

Teja Preuhsler München/Freising, November 1992

Further volumes of this publication "Research on Growth and Yield with Emphasis on Mixed Stands - IUFRO Centennial 1992 - Sessions of S4.01" are available at the Bayerische Forstliche Versuchs- und Forschungsanstalt, Hohenbachernstraße 20, D-8052 Freising, Germany, by payment of the mailing costs of 12.- Deutsche Mark.
Abstracts of most papers of all the meeting are printed in the CENTENNIAL PROCEEDINGS, which can be obtained from the IUFRO-Sekretariat, Seckendorf Gudent-Weg 8, A - 1131 Wien, Austria, for a cost of 25.- Deutsche Mark, additional 12.- Deutsche Mark for mailing.

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<u>Schlußfolgerungen aus langfristigen Mischbestandsversuchen in Südwestdeutschland</u>

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Vor rd. 120 Jahren wurden im damaligen Großherzogtum Baden bzw. im Königreich Württemberg forstliche Versuchsinstitutionen begründet. Sie dienten über viele Jahrzehnte ausschließlich der waldbaulich-waldwachstumskundlichen Forschung. Später kamen weitere Gebiete dazu, wie z. B. Boden und Standort, Forstschutz, Forstbenutzung u.s.w.. Im Zusammenhang mit den waldbaulich-waldwachstumskundlichen Fragen wurde ein Netz langfristiger Versuchsflächen in Rein- und Mischbeständen angelegt, um baum- und flächenbezogene Wachstumsgänge in Abhängigkeit von Standort und Behandlung zu ermitteln. Dieses Versuchsnetz wurde nach Bedarf erweitert. Es umfaßte um 1960 rd. 3500 Felder; gegenwärtig sind es nach mehreren Bereinigungen noch rd. 1300.

Dank dieser langfristig ausgerichteten Tätigkeit vieler Forschergenerationen[1)] verfügen wir heute über dendrometrische Meßreihen für die wichtigsten Baumarten in reinen und gemischten Beständen. Sie umfassen in nicht wenigen Fällen ein Jahrhundert. Bei der Fichte reichen sie z. T. über zwei Bestandesgenerationen. Damit haben wir weltweit einzigartige Daten zur Beurteilung langfristiger Wachstumsgänge und - last not least - der evtl. Veränderung von Standorten (KENK et al. 1991).

Die ersten Veröffentlichungen zu Mischbeständen aus Fichte und Buche stammen von LOREY 1896 und 1902 aus Württemberg. Es folgten in Baden SIEFERT 1905, später HAUSRATH 1926, 1938, dann wieder DIETERICH 1928 und ZIMMERLE 1937 aus Württemberg u.s.w.. Freilich gibt es aus dieser Zeit und bis heute deutlich mehr Publikationen zu reinen bzw. (waldbaulich-ökonomisch wie ökologisch überwiegend)

[1)] Zu den "Klassikern" der ersten 80 Jahre zählen z. B. BAUR, BÜHLER, LOREY, NÖRDLINGER, SCHUBERG, EBERHARD, HAUSRATH, SIEFERT, DIETERICH, ZIMMERLE, MITSCHERLICH.