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Preface

This year's 10th issue of the scientific journal *LESNICTVÍ (FORESTRY)* published by Academy of Agricultural Sciences of the Czech and Slovak Federative Republic (CSFR) is especially focused on some research results in the field of forest biometrics, forest management, and close forestry sciences. As it has become a tradition, these scientific branches have usually been dealt with every two years in the 10th issue of our journal. The birth of this tradition was provoked by Professor Ing. Václav K o r f, DrSc. (*1907, †1985), a many year's member of our editors board, an outstanding forestry specialist, a former head of the Department of Dendrometry and Forest Management at Prague Forestry Faculty and her many years' dean and vice-president of University of Agriculture in Prague. Some of our foreign readers may have been informed that Prague Forestry Faculty was abolished by bureaucratic measure in the period 1959–1964, which was closely related to the political leadership of that time.

Czech and international public felt that impropitious fact as a considerable impoverishment of Czech forestry tradition and Czech culture in general. As a student of Professor K o r f I am glad I can voice also to international community of foresters that Prague Forestry Faculty was re-established by the issue of Academic Senate of the University of Agriculture in Prague in full scope on the 1st August 1990 and its academic and research activity has started grounded on more than 70 years' tradition (founded in 1919). At the same time, the faculty's activity has been extended with the branch of applied ecology and landscape engineering.

There are many considerable changes in the life of whole society in course our countries at present. Scientific work steps out of tough uniformity of centralized planning and direct control. It is necessary to hope the development will tend toward real independent research work aimed at success of our forest sciences, competition, and establishment of scientific schools.

Basic forestry scientific branches, which forestry biometrics and management undoubtedly belong to, demand thoughtful scientific intentions for their successful development. Their implementation must have necessarily a long-term effect, as it is straightly implied both from a long-term character of forests growth process and forest ecosystems development and lasting consequences of sometime not well-thought-of anthropogenic activities impropitious to forests, demonstrated e.g. by the influence of the development of industrial society which may not be every time thoroughly induced. At the same time we have to react readily on newly emerging problems or scientific concepts in the field of sciences investigating the Earth or biosphere. That concerns above all the biospheric function of forests, which represent obviously principal regulator of a long-term sustained development in the wide sense of L o t k a ' s (1925) biological interpretation of Le Chatellier-Braun or Van't Hoff law. There are most topical question of forest ecosystems development and

development of forest production under changing growth conditions and function of forests in a substances circulation in biosphere (and/or geosphere).

Articles dealing with problems of sick forests are presented in this issue by authors K u p k a, D r a p e l a and Z a c h. H l a d í k presents his results of a many years research of Slovak mixed forests based on vast experimental material. K o u b a presents a theory of the establishing of the first age class and of other age classes with regards to a theory of normal forest defined stochastically. Ž í h l a v n í k deals with an important problem of forest stands boundary determination in applications of remote sensing. P r i e s o l gives synoptical information on results of basic research in forest biometrics and forest management. Z a t l o u k a l informs on result of Czech national inventory 1990 and gives an overview of the advance of forest managerial statistics. Topically, there is included a contribution by Z e z u l á k informing about decision support system AquaLog, tool of water science and computer technology. This article contains an interesting system approach and mathematical apparatus used in forestry in the modelling of forest stands growth.

In future, the editors board of L e s n i c t v í would like to publish more than one issue in English a year, as they have strived so far. We wish the editors would acquire also a good language consultant - speaking English as a mother tongue - and so improve the language level of articles written in English.

Jan K o u b a, Head of Department of Forest Management, Faculty of Forestry, University of Agriculture in Prague, CS-165 21 Prague

Letošní desáté číslo vědeckého časopisu *LESNICTVÍ*, vydávaného Akademií zemědělských věd České a Slovenské federativní republiky, je věnováno speciálně některým výsledkům výzkumu v oblasti lesnické biometrie a hospodářské úpravě lesů a v blízkých lesnických oborech. Jak se stalo již tradicí, je těmto oborům lesnické vědy věnováno vždy po dvou letech právě desáté číslo našeho časopisu. U zrodu této tradice stál dlouholetý člen naší redakční rady prof. ing. dr. Václav K o r f, DrSc. (*1907, †1985), vynikající český lesnický odborník, bývalý vedoucí katedry dendrometrie a hospodářské úpravy lesů na pražské lesnické fakultě a její dlouholetý děkan a prorektor Vysoké školy zemědělské v Praze. Jak možná byli někteří naši zahraniční čtenáři informováni, byla pražská lesnická fakulta v letech 1959–64 zrušena administrativním zásahem, který měl úzkou spojitost s tehdejšími politickým vedením. Česká i mezinárodní lesnická veřejnost pociťovala tuto neblahou skutečnost jako výrazné ochuzení české lesnické tradice a české kultury vůbec. Jsem rád, že jako žák profesora K o r f a mohu i mezinárodnímu společenství lesníků oznámit, že pražská lesnická fakulta byla usnesením akademického senátu Vysoké školy zemědělské v Praze dnem 1. srpna 1990 v plném rozsahu obnovena a byla započata její pedagogická a vědecká činnost v tradici původní fakulty, která je více než 70letá (založena v roce 1919). Současně byla činnost této fakulty rozšířena o obor aplikovaná ekologie a krajinné inženýrství.

Základní lesnické vědecké obory, ke kterým lesnická biometrie a hospodářská úprava lesů bezesporu patří, vyžadují pro svůj úspěšný rozvoj promyšlené vědecké záměry, jejichž realizace musí mít nutně dlouhodobější záběr, jak to i konečně přímo vyplývá z dlouhodobého charakteru procesu růstu lesů a vývoje lesních ekosystémů, ale i z dlouhodobých následků ne vždy dobře promyšlené, lesům nepříznivé lidské činnosti, jak to ukazuje mj. i vliv ne vždy zcela domyšleného vývoje industriální společnosti. Při tom je třeba i zde pohotově reagovat na nově se objevující problémy, ale i vědecké koncepcí v oblasti věd o Zemi či věd o biosféře a jejím vývoji. To se týká především biosférické funkce lesů, které představují zřejmě dosti podstatný regulátor dlouhodobě stabilního vývoje v širším smyslu *L o t k o v y* (1925) biologické interpretace zákona *Le Chatellierova–Braunova* či *Van't Hoffova*. Zde je velice aktuálním tématem otázka vývoje lesních ekosystémů a vývoje produkce lesů v měnících se růstových podmínkách a funkce lesů v koloběhu látek v biosféře (příp. i geosféře).

V tomto čísle jsou uvedeny příspěvky týkající se problémů nemocných lesů – autorů *K u p k y*, *D r a p e l y* a *Z a c h a*. Výsledky dlouholeté práce ve studiu produkce slovenských smíšených lesů na podkladě velice rozsáhlého experimentálního materiálu uvádí ve svém příspěvku *H l a d í k*. Teorii tvorby 1. věkového stupně a ostatních věkových stupňů s ohledem na teorii normálního lesa definovanou stochasticky uvádí ve své stati *K o u b a*. *Ž í h l a v n í k* se věnuje

důležitému problému stanovení hranic lesních porostů při dálkovém průzkumu Země. Přehlednou informaci o výsledcích základního výzkumu podává *P r i e s o l*. O výsledcích České národní inventarizace 1990 informuje a přehled o vývoji lesnické hospodářsko-úpravnické statistiky podává *Z a t l o u k a l*. Aktuálně je zařazen příspěvek *Z e z u l á k a*, který informuje o modelovacím systému AquaLog. Pro lesníky je zde m.j. zajímavý systémový přístup a matematický aparát, který je v lesnictví užíván při modelování růstu lesního porostu.

Redakční rada časopisu *L e s n i c t v í* by ráda v budoucnu zařadila více čísel psaných v anglickém jazyce než jedenkrát ročně, jak se o to s velkými obtížemi doposud snažila.

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STUDY OF THE STRUCTURE AND PRODUCTION OF MIXED STANDS IN THE FORESTS OF SLOVAKIA

M. Hladík

Hladík M.: (Faculty of Forestry, Zvolen): *Study of the structure and production of mixed stands in the forests of Slovakia*. *Lesnictví*, 37, 1991 (10):773-786.

Mixed stands constitute an important component of the forests of Slovakia. The most abundantly represented are the mixed stands of beech and oak (approx. 195 000 ha) and of beech with spruce and fir (approx. 400 000 ha). The type of areal mixture and the age as well as spatial structure are very variable. Therefore a combination of more variants of input data collection and processing (on the whole stand surface, on experimental plots systematically stratified over the stand surface, on permanent experimental plots, from stem analyses of various species growing in one biogroup) are proposed. The methods of evaluation of the effect of species occurrence on the development of mensurational characteristics of the species concerned as well as of the whole stand are characterized in greater detail. In mixed stands of beech and oak this effect proved to be insignificant, because these two species are very similar on a particular site in respect of growth and production. In the mixed stands of beech and spruce and/or beech and fir these relations become more complicated. Based on the analysis of the distribution of the basal area over the stand surface and on the theory of the full stocking unit, a procedure of determination of this unit for mixed stands is proposed. The unit of the full stocking would be constituted by basal area, computed using the formula: $G_j = \bar{G} + 1.28s_g$ (s_g —standard deviation of basal area) for the corresponding age, site and species combination.

mixed stands; species occurrence level; diameter-class frequency distribution; basal area; full-stocking unit

One of the main prerequisites for the elaboration of correct phytotechnical treatments in silviculture and of principles of operational planning in forest management is the knowledge of the laws of the growth, structure and production of individual trees and, especially, of their stands. That is why a wide range of specialists in our country as well as abroad have paid much attention to this problem. An extensive collection of scientific papers has been elaborated to solve the methodical problems in pure and even-aged stands, in our country especially in connection with the construction of new yield tables for main tree species of Czecho-Slovakia (H a l a j, 1968; H a l a j and Ř e h á k, 1979).

Less attention has been paid to studies of uneven-aged and mixed forests. More complex views may be found in papers by A s s m a n (1966), K e n n e l (1965), K r y s t a n o v (1979) and in Czecho-Slovakia in papers by H a l a j (1959, 1978), H l a d í k (1975, 1988), K o r p e ě (1980, 1981), P o l e n o (1979, 1981), P r u d i ě (1981, 1982) and P a u l e (1978).

Considering the extent of occurrence of mixed stands in Slovakian forests and also the increasing importance of these stands from the points of view of stability

and fulfilling all functions of forests, the problems of the growth and production laws of these began to be studied at the Department of Forest Management, Faculty of Forestry, Zvolen. Within the research the methods have been elaborated and partially verified for acquisition and processing of input information in typical mixtures of principal tree species of Slovakian forests. The aim of this paper is a brief description of these mixtures and methodical procedures used with the interpretation of partial results.

MATERIAL AND METHODS

OCCURRENCE OF MIXED STANDS IN THE FORESTS OF SLOVAKIA

Mixed stands occur in a wide spectrum of combinations of species in Slovakia. Nevertheless, the most important component of these is represented by mixtures with participation of our main tree species, particularly of beech. According to the information acquired from the data of Lesoprojekt (Forest Management Institute) and processed by us, the most frequent stand types by area are the following ones:

- 16 - oak-beechwoods approx. 118 000 ha
- 17 - beech-oakwoods approx. 77 000 ha
- 22 - spruce-fir beechwoods approx. 220 000 ha
- 23 - beech-fir-spruce forests approx. 178 000 ha
- 24 - oakwoods with admixture of conifers approx. 38 000 ha.

According to inclusion in ecological units (HS), mixed forests are most frequently represented in following ones:

- HS 25 - "oak stands on rich sites" (stand type 17 on 30 000 ha, stand type 24 on 14 000 ha)
- HS 35 - "beech stands with oak on rich sites" (stand type 16 on 65 000 ha; stand type 17 on 25 000 ha)
- HS 45 - "beech stands, rich sites of middle altitudes" (stand type 22 on 53 000 ha, 23 on 25 000 ha)
- HS 55 - "spruce stands on rich sites of higher altitudes" (stand type 22 on 45 000 ha, stand type 23 on 48 000 ha)
- HS 65 - "spruce stands system on rich sites in mountains" (stand type 22 on 12 000 ha, stand type 23 on 24 000 ha)

The kind of areal mixture may be very variable. In some cases, an individual, small-group, medium-group, large-group mixture, or even mixture of small stands of individual species can be met in one stand. According to proportion of species in the vertical direction the stands may be one-layer, but more frequently two-layer or more-layer ones, up to the stands of a genuine selection forests nature.

METHODS OF ACQUISITION OF INPUT INFORMATION

All authors dealing with the problems of research in mixed stands point out the degree of complication of the points at issue (P r u d i ě, 1981; P o l e n o, 1981; V i n š and Š i n d e l á ř, 1973).

Problems begin to arise when the comparison characteristics of production identity (similarity) of the sites have to be chosen (lesser representability of mean and/or top height), where the measurements should be performed. Further, when the acreage of experimental plots should be determined (acceptable limit of the acreage of a group of one species), they increase. Finally, the problem of determination of the stocking of these stands, which is very important in production analyses, has not been solved yet.

These problems led us to the utilization of more variants of methodical procedures of acquisition of basic input information, with respect to the nature of the object investigated and also with respect to the possibilities of mutual complementation and/or confrontation of results obtained

in individual variants. In all variants we anticipated and, to some extent, simplified used the typological units (forest type) and derived composed units for selection of comparison character of production identity of the site. We proceeded here from the conclusions of H a n ě i n s k ý (1983) and R a n d u š k a (1985). A wider scale of obtained information (heights, basal area etc.) will enable us to retrospectively analyse the suitability of use of these typological units.

VARIANTS OF METHODOLOGICAL PROCEDURES OF ACQUISITION OF INPUT DATA

Up to now, the following procedures have been applied in our work:

- a) Acquisition of data on the whole stand area (H l a d í k, 1975)
- b) Acquisition of data on temporal experimental plots systematically stratified over the whole stand surface in a set of stands belonging to a growth set (H l a d í k, 1975, 1979, 1988).
- c) Acquisition of data on permanent experimental plots (H l a d í k, 1982).
- d) Acquisition of data from stem analyses of different tree species growing in one biogroup (H l a d í k, 1978, 1988).

Variant a) was used in the acquisition of data necessary to characterize the structure and production of uneven-aged mixed stands under a selection management system. The data obtained will enable us to construct the stand models of different types of selection forest. For more detailed justification of the facts stated, it is necessary to complement this variant by data from variant c) and/or d).

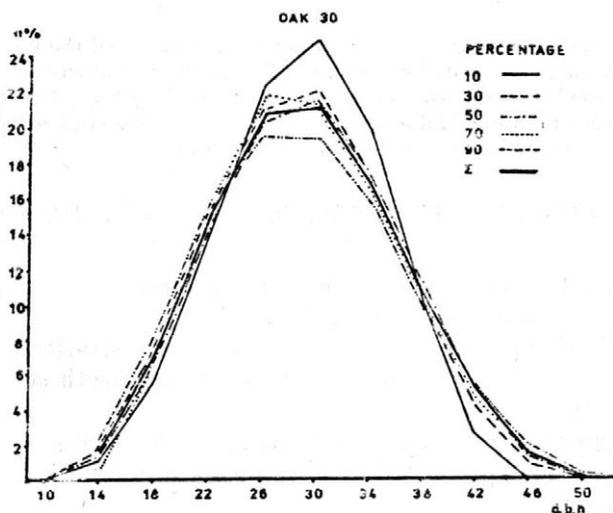
Variant b) should be used in even-aged mixed stands. It is based on the principle of a very extensive set of input information (3000–4000 experimental plots for one mixture), which will enable us to obtain more general conclusions, which may be used in forest management practice. The more detailed analysis and empirical justification of these conclusions may be performed on more complex data sets obtained in variant c) or d).

The most important task in the utilization of the variant b) is the selection of stands and classification of them into a growth set, which can also be considered as a characteristic of their yield homogeneity (H a l a j, 1968). For the stands evaluated the following characteristics were necessary:

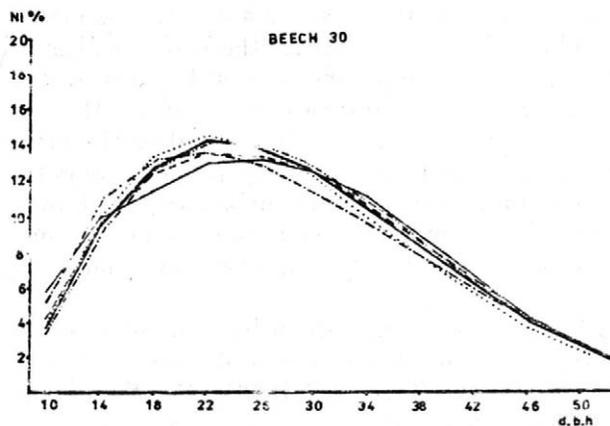
- stocking of more than 0.7
- occurrence of beech of more than 20 % (sum of occurrence of beech and oak and/or of beech and spruce and/or beech and fir at least 80 %)
- a standard quality and state of health of wood in the given region.

The basic data were obtained on temporal circle experimental plots of area of 0.02 – 0.10 ha, dependent on stand age. For all stands a standard number of 25 plots has been chosen. The plots were systematically stratified over the surface of the forest stand according to the sampling procedure of forest inventory elaborated by Š m e l k o (1968). For each experimental plot a separate record was done, with complementary measurements aimed at a more precise determination of the age of individual tree species (two cores from stem of the mean diameter of the main tree species) and of the height structure.

From data obtained in this way a database on magnetic media was established. For the computation of basic mesurational characters and statistical characteristics a set of computer programs was elaborated for the computer of the EC-series and at present for IBM-PC.



1. Curves of the diameter-class relative frequency distribution of beech and oak of a mean diameter $d_g = 30$ cm in beech-oak mixtures.



The obtained data will allow us.

- to estimate the effect of the proportion of a particular tree species on the development of mensurational characteristics,
- to derive the full-stocking unit for given mixture of tree species and the production region chosen, and/or for another unit (management class, class of forest types),
- to derive the actual values of goal characteristics (diameter, basal area, volume) of management in actual growing conditions,
- to compare mensurational characteristics of pure and mixed stands in the particular growing region.

Variante c) may be used in all stands. The classical acquisition of data was complemented by the determination of coordinates of individual trees and crown radii. The established database on the magnetic medium and the set of computer programs enable a wide scale of analyses of relations between individual tree species and mensurational traits of individual trees and their set on an arbitrarily chosen area (within the area of the permanent experimental plot).

Variant d) is used as a complement to all variants given above. The information obtained will allow us to complete the knowledge already acquired and/or to confront results of the same nature obtained by different techniques (e.g., growth curves of height from measurements on temporal plots in a growth set and from stem analyses).

RESULTS AND DISCUSSION

The data obtained in variant a) – mensurational data of 5 stands of selection forest with occurrence of 50 % fir and 50 % beech belonging to ecological unit 411 “beechwoods on rich sites” – enabled us to construct the model of a management group (70 ha) of selection forest. The data of this model were used to compare the development of the main mensurational characteristics in the cutting and selection management system (H l a d í k, 1972).

Up to now, primary attention has been paid to variant b) of acquisition of input information. In total, 2850 experimental plots in mixed beech-oak stands, 1200 plots in mixtures of beech and fir and 450 plots in mixtures of beech and spruce have been measured.

For a more detailed analysis of the effect of species occurrence on the development of mensurational traits, especially the data on the set of experimental plots in beech-oak mixture in ecological unit HS 85 “beech stands with oak on rich sites” were utilized, owing to the fact that this is the most extensive one. In the study, time-dependent as well as time-independent relationships were applied. Time-independent relationships were used especially for the evaluation of the effect of the level of occurrence on diameter-class frequency distribution and on the development of the number of trees and of the basal area for selected mean diameters d_g and for the evaluation of the height development of individual species within the diameter classes.

Time-dependent relationships were used in the analysis of the influence of the level of occurrence on the development of the number of trees, mean diameter and mean height, basal area and volume of the composite (main) forest stand, and for deriving the full-stocking unit.

All relationships were analyzed in the whole set of measured data as well as in the selected sets (e.g. the set of data from experimental plots with the basal area larger than the mean basal area of the given stand). In such a set, more immediate mutual relationships of occurring species were assumed.

As an example of the obtained outputs, an evaluation of the effects of the level of occurrence on the diameter-class frequency distributions, and a proposal for deriving the unit of full stocking will be given.

For the solution of the problem as such (i.e. the evaluation of the effect of the level of occurrence on the shape of frequency curves), we proceeded from the statement of H a l a j (1957), that the diameter-class frequency distribution does not significantly depend on the age, site quality and/or mean height of the tree species in the stand. All these partial effects may be replaced by one argument – mean diameter, (in the paper by H a l a j the diameter of the mean-volume stem d_m , in our material the diameter corresponding to the mean basal area d_g).

Within the created subsets defined by the mean diameter (interval of 4 cm)

and the level of species occurrence (interval of 20 %), the frequencies of species occurrence in individual diameter classes ($d_{1,3}$) were computed for the experimental plot. In this way we received basic information about the absolute distribution of diameter-class frequencies within the range of mean diameters $d_g = 10 - 50$ cm and levels of occurrence of 10 to 90 % (2965 experimental plot in total).

With respect to the generally known advantages of the relative frequencies for the processing of data and comparison of obtained results, these have been used also in our case. They were also utilized for the estimation of differences and/or "goodness-of-fit" of the diameter-class frequency distributions within individual levels of occurrence (10, 30, 50, 70, 90 %) when the d_g remains the same.

For the analysis as such, we proceeded from the "hypothesis testing theory". In our case we tested the hypothesis of goodness of fit of two sampling frequency distributions using the nonparametrical "goodness-of-fit" tests. The computed values of testing criteria of X^2 -test and K o l m o r o v - S m i r n o v -test are given in the computer listing together with fitted values of frequency curves.

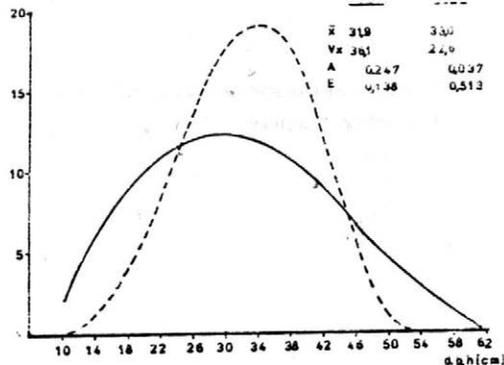
The results given in these listings indicate that in the absolute majority of cases, the differences between diameter-class frequency distribution within the same mean diameter and different levels of occurrence are only accidental, (i.e., they are equal in basic populations). Only sporadically the effects of the level of occurrence on the diameter-class frequency distribution proved to be significant, particularly when the species occurrence drops under 20 % which corresponds partially to the data by H a l a j (1957). The comparison of test results in the whole data set and in the selected one (when $G_i > G$) further indicates that these sporadic significant differences found in the whole set have not occurred in the selected set. This allows us to conclude that also in the case of low level of occurrence the effect of occurrence on the diameter-class frequency distribution of compared species is practically insignificant when the stocking is sufficient.

Based on the given statements and analyses of the comparison of graphically presented frequency distributions (Fig. 1), it may be concluded that the models of curves of diameter-class frequencies may be constructed without respect to the level of occurrence for beech and oak growing in the mixture.

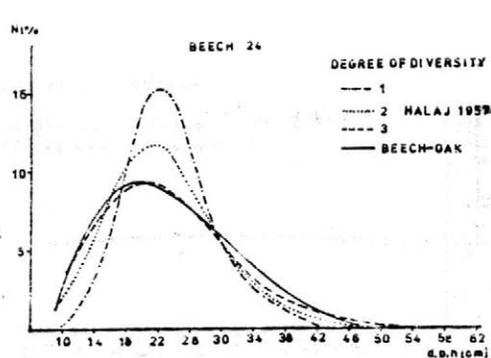
Further, the following statements may be made:

- Frequency curves of beech and oak are markedly different for the same mean diameter (the curves of beech have a larger variation range and are more skewed to the left (Fig. 2).
- Model frequency curves of beech are essentially equal to those derived by H a l a j for even-aged stands of the 3rd heterogeneity degree (Fig. 3). The frequency curves of oak lie between the 2nd and 3rd heterogeneity degrees with a larger representation in higher diameter classes.
- The effect of the occurrence level on the mean diameter of beech is statistically significant for occurrence under 10 %. For higher levels of occurrence; the diameter is influenced only accidentally.
- The level of diameter development is nearly equal in both species, only in the age of 110-130 years a prevalence of beech over oak occurs (mean diameter of beech is larger than that of oak).

To estimate the effect of the occurrence level on the diameter development level in the same age, Fig. 4 gives the course of fitted curves of mean diameter



2. Comparison of curves of the diameter-class relative frequency distribution of beech in pure stands (H A L A J, 1957) with those of mixed beech-oak stands.



3. Comparison of curves of the diameter-class relative frequency distribution of beech and oak of the same mean diameter in beech-oak mixtures.

for individual species in the mixtures analyzed. It follows from the figure that beech in mixture with oak reaches the same diameter development level, which is not affected by the occurrence level. In the mixture with spruce and fir, beech falls behind these species. Along with increasing occurrence the mean diameter of beech and fir increases, whereas that of spruce decreases.

In Fig. 5, the diameter development level of beech in all three mixtures is compared. A more significant effect of the occurrence level is to be found in the mixture of beech with spruce, especially when beech occurrence level is low and this species forms the stand filling. Therefore diameter development level of beech is lower in these stands.

Based on the comparison of fitted curves of the number of trees (Fig. 5), it can be stated that the highest number of trees occurs in mixtures of beech and oak; the lowest one in those of beech and fir. Nevertheless, the relation to their occurrence level is not very close.

The course of the fitted lines of the basal area (Fig. 5) is affected by the diameter development level as well as the occurrence level of both species. A more pronounced dependence on the occurrence of beech may be found in the mixture with spruce and fir.

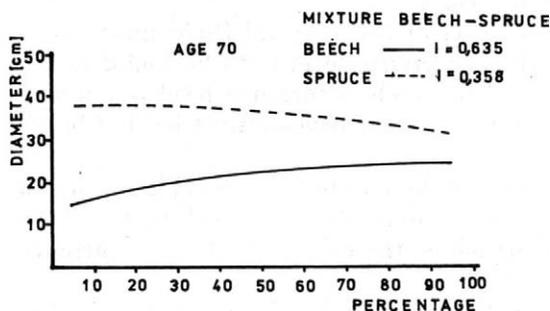
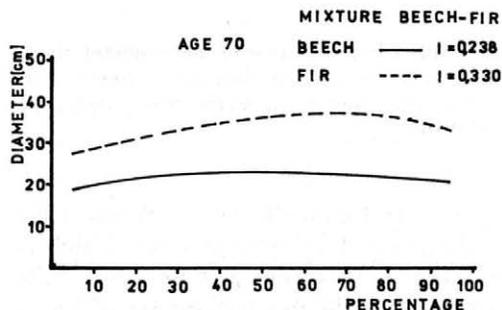
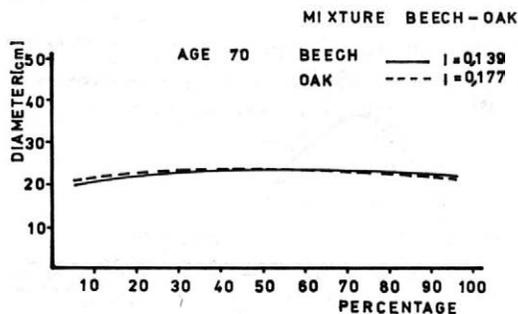
The given statements and graphs represent only a small précis of an extensive mathematical, statistical and graphical processing of a very rich database obtained in typical mixed stands described in the introductory part of this paper. A more detailed analysis and evaluation of these data exceeds the limitations of this.

PROBLEMS OF THE DETERMINATION OF THE FULL-STOCKING UNIT

It follows from the methods of yield table construction that these may be elaborated on either for mean stocking, or for the full (maximum) one.

Mean stocking occurs most frequently in practice. The tables based on this kind of stocking give a stocking of more than 1.0 for stands with maximum density.

4. Effect of the species occurrence level on this mean diameter.



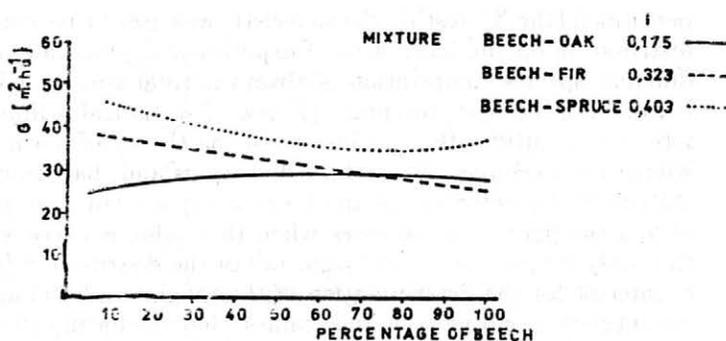
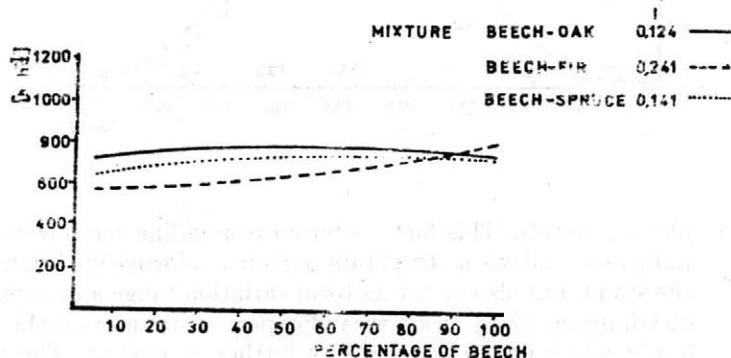
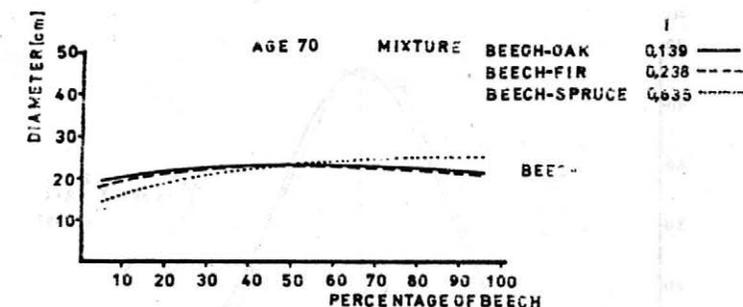
Full (maximum) stocking is the highest stocking corresponding to the basic characteristic which it is derived from. The tables elaborated for this kind of stocking give a stocking level under 1.0 for the prevalent majority of stands.

Prior to the elaboration of the methods of determination of the basal area size, which determines the full stocking unit, it is necessary to solve the problem of the kind of basal area used. In the literary sources (A s s m a n n, 1968; H a l a j, 1973), four kinds of basal area are given:

- natural (maximum) basal area
- optimum basal area
- critical basal area
- economical basal area.

In our case, in accordance with the conclusions of H a l a j (1973), the economic basal area was chosen as a basic characteristic, which is appropriate to

5. Effect of the occurrence level of beech on the mean diameter of beech, number of trees and basal area of the stand in beech-oak, beech-spruce and beech-fir mixtures.



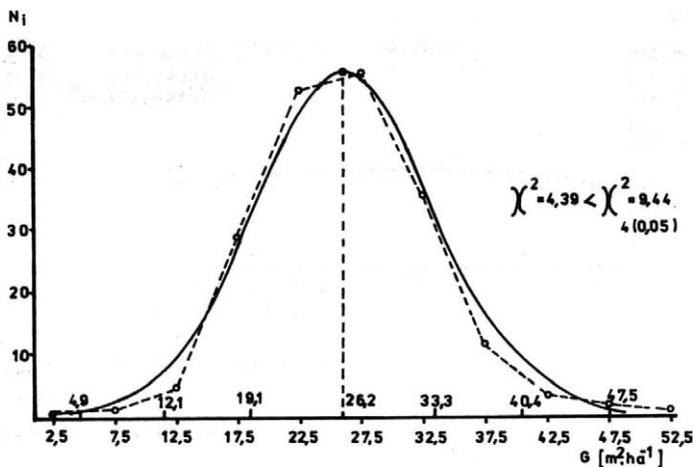
deriving the full stocking unit.

The economic basal area is that one which occurs in actual stands thinned in a usual way.

For successful definition of the full-stocking unit, an objective determination of the numeric value of the economic basal area of a stand of the given mixture in the given growing conditions under the tending procedure applied is necessary.

From practical experience as well as from theoretical analyses performed for the elaboration of the representative inventory methods, it is known that the trees in a prevalent majority of cases are distributed over the surface of a stand irregularly. It follows from the papers by Š m e l k o (1968) that this differentiation may be best recorded by stratifying experimental plots of an appropriate size, the number of which was computed in advance, based on the regular systematic sampling method.

For practical measurement, the methodology of circle experimental plots for statistical inventory (Š m e l k o, 1968) is used, with the difference of recording each



6. Comparison of the empirical basal area frequency distribution of experimental plots within the age class (age 70 years, 200 plots) with the normal one.

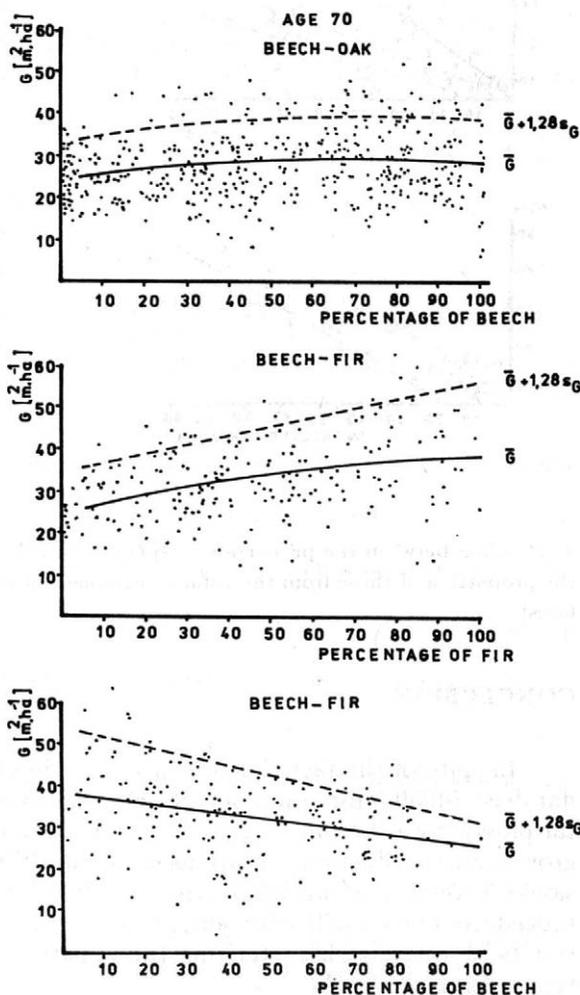
plot separately. This fact - after corresponding mensurational and statistical computations - allows us to obtain not only information about the mean basal area of the stand, but also about its total variation range and about the shape of frequency distributions of the basal area of experimental plots within the chosen classes (e.g., 3 m²), which has to be known for further evaluation. The computations and testing performed (the X²-testing characteristic was used) gave evidence that the frequency distribution on the basal area of experimental plots in stands of different age and different species composition is always normal and/or it is acceptable to suppose it to be normal from the point of view of statistical computations (Fig. 6). Therefore, we can utilize the conclusions of the theory of normal frequency distribution within the multiples of standard deviations and, based on the known (computed) statistical characteristic of the basal area, we can compute for any chosen value of $g_{1.3}$ the percentage of cases when this value is exceeded. Considering the fact that only frequencies on the right tail of the distribution (exceeding the mean) are of interest for the determination of the maximum basal area, it is possible to find out, in corresponding statistical tables, that the mean value increased by 1.28-times standard deviation is exceeded by 10 % of plots (1.5-times s_g is exceeded by 6.7 % of plots).

The value of the basal area of a stand computed in this manner may be supposed (in the sense of definitions and requirements given above), to be the full-stocking unit of the particular stand (and/or set of stands), represented by particular mensurational characteristics (i.e.: species occurrence, age, site quality, forest type, way of tending).

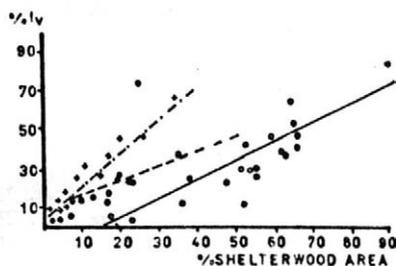
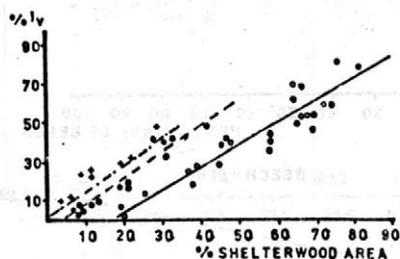
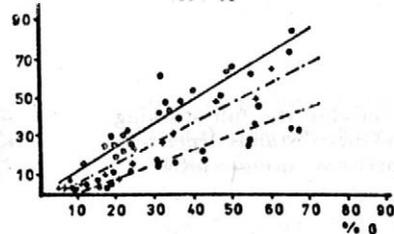
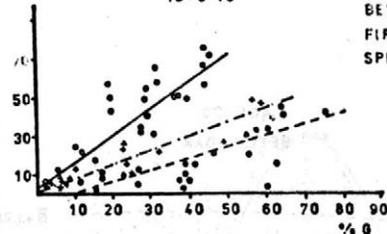
An example of deriving the full-stocking unit for the 7th age class of a mixed stand of beech and oak and/or beech and fir is given in the Fig. 7. From the course of the fitted lines it may be concluded, that in the beech-oak mixture the value of the full-stocking unit does not substantially change. On the other hand, in the mixture of beech and fir, the occurrence of beech substantially affects the size of this unit. Particular values for all three types of mixtures investigated will be published in a separate paper.

From the data obtained on permanent experimental plots, special attention

7. Deriving the full stocking unit of mixed stands dependent on species occurrence level.



has been paid to the evaluation of relations of mensurational characteristics of individual species on areal units of different sizes and also between the tree species as such. Specifically, a comparison of the proportion of individual species from the basal area (shelterwood area) and volume increment is presented here. We stated at the same time that the proportion of beech from the total volume increment as compared with the generally more productive species (spruce, fir) is significantly higher also in the case when its proportion from basal area is equal. Nevertheless, when evaluating the proportion of species from the shelterwood area and the volume increment, a reverse order of species was recorded (Fig. 8). A more detailed explanation of these relations will be performed based on the analysis of information about the proportion of tree classes of individual species.



8. Relation between the proportion of species from the total basal area (shelterwood area) and the proportion of those from the volume increment of the permanent experimental plot of mixed forest.

CONCLUSION

In spite of the fact that we succeeded in obtaining a comparatively extensive database (4950 temporal plots, 15 selection forest stands, 3 permanent experimental plots) from the most frequent mixed forests of Slovakia, the large variation of growth and production conditions does not allow us to draw generally valid conclusions. Nevertheless, we are convinced that using the combination of the methodical procedures of data collection and processing described above, it is possible to obtain results objectively characterizing the growth, structure and production of various types of mixed stands.

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Hladík, M.: (Lesnícka fakulta VŠLD, Zvolen): *Štúdium štruktúry a produkcie zmiešaných porastov lesov Slovenska*. Lesnictví, 37, 1991 (10):773-786.

Zmiešané porasty sú významnou zložkou lesov Slovenska. Najrozšírenejšie sú zmiešané porasty buka a duba (cca 195 000 ha) a buka so smrekom a jedľou (cca 400 000 ha). Plošné zmiešanie, veková štruktúra i priestorová výstavba je veľmi variabilná. Preto sa navrhuje kombinácia viacerých variant zberu a spracovania vstupných informácií (na celej výmere porastu, na skusných plochách systematicky rozmiestnených po ploche porastu, na trvalých výskumných plochách, na kmeňových analýzách stromov rôznych drevín rastúcich v biogrupe). Bližšie sa charakterizuje metodika hodnotenia stupňa zastúpenia dreviny na vývoj dendrometricko-taxačných veličín tejto dreviny a celého porastu. V zmiešaných porastoch buka a duba sa ukázal tento vplyv ako nevýznamný, nakoľko sa jedná o rastovo a produkčne podobné dreviny (na danom stanovišti).

V zmiešaných porastoch buka so smrekom a buka s jedľou sú už tieto vzťahy zložitejšie. Na základe analýzy variability rozmiestnenia kruhovej základne po ploche porastu a teórie jednotky plného zakmenenia sa navrhuje postup jej určenia pre zmiešané porasty. Jednotku plného zakmenenia by tvorila kruhová základňa, ktorá sa vypočíta zo vzťahu

$$G_j = \bar{G} + 1,28s_g$$

pre príslušný vek, stanovište a kombinácia zastúpených drevín.

zmiešané porasty; stupeň zastúpenia dreviny; rozdelenie kruhových základní; početnosť; kruhová základňa; jednotka plného zakmenenia

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A DIAMETER INCREMENT ANALYSIS OF SPRUCE IN THE BESKYDY MOUNTAINS IN THE AREA UNDER THE INFLUENCE OF AIR POLLUTANTS

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Zach J. - Drápela K.: (Faculty of Forestry, Brno): *A diameter increment analysis of spruce in the Beskydy Mountains in the area under the influence of air pollutants*. *Lesnictví*, 37, 1991 (10):787-794.

The tree-ring analyses of 10 sample plots were carried out in the Beskydy Mountains. Diameter increments of damaged and relatively healthy forest stands were compared, using Cook's linear model of components affecting the diameter increment. The autoregression in tree-ring chronologies was computed (first-order autoregression was the highest) and the differences between original chronologies and computed ones were obtained. These differences were correlated with some climatic components (April and September temperatures from both the present and prior growing seasons were the most important). Then the differences obtained by multiple regression and the original ones were compared. A distinction between the original and computed differences is clearly visible in the sample plots of damaged forest stands. It is possible to assume that some other factors (air pollutants very probably) are the cause of the great decline of diameter increments.

effects of air pollutants; diameter; increment analysis

We have analysed selected growth processes of spruce. This analysis should contribute to the solution of the problem of large-area damage of the Beskydy forest stands caused by air pollutants, their influence on all functions of forest ecosystem and development of suitable forest management measures.

The special attention was paid to the development of the diameter structure of the forest stands and diameter increment of individual trees. The tree-ring analysis was used for research of the diameter increment and its dependence on some factors. The contribution contains some main results of this research.

METHODS

Cook's linear model (C o o k, 1985) of factors influencing the width of the tree-rings was used.

$$W_t = T_t + K_t + \delta D1_t + \delta D2_t + E_t \quad (1)$$

where: W_t - measured tree ring width
 T_t - the age-related growth trend
 K_t - the climate-related growth variations
 $D1_t$ - the endogenous disturbance pulse originating from forces within the forest stand
 $D2_t$ - the exogenous disturbance pulse originating from forces outside the forest stand
 E_t - the random variation
 δ - the binary indicator (indicates the presence or absence of disturbance pulses)

STANDARDIZATION

The following three functions were used for evaluating the age-trend of all tree-ring series. The removing of age-related trend is necessary because of transferring the original tree-ring series to the stationary time series (A n d ě l, 1978; M o n s e r u d, 1986). The process of removing the age trend from tree-ring series is called standardization.

1. Exponential function

$$W = b_1 \cdot T^{b_2} \cdot e^{b_3 T} \quad (2)$$

where: $b_1 > 0, b_2 < 0, b_3$ - parameters

2. Korf's function

$$W = A \cdot \frac{k}{T^n} \cdot e^{\left[\frac{k}{(1-n) \cdot T^{n-1}}\right]} \quad (3)$$

where: $k \neq 1, n > 1, A$ - parameters

3. Function

$$W = a + \frac{b}{T} + \frac{c}{T^2} \quad (4)$$

where: $a, b > 0, c < 0$ - parameters In all equations,

W - computed tree-ring width

T - time (age)

Correlation and regression analyses were carried out with tree-ring indices I

$$I = \frac{W}{\mathcal{W}} \quad (5)$$

where: W - measured tree-ring

\mathcal{W} - computed (standardized) tree-ring

In the case of autocorrelation in the series of tree-ring indices it is possible to write

$$I'_{j+1} = A(I_j) \quad (6)$$

$$I_{j+1} - A(I_j) = \Delta I_{j+1} \quad (7)$$

where: I_j, I_{j+1} - indices of j and $j + 1$ year

$A(I_j)$ - autoregression function

I'_{j+1} - computed index

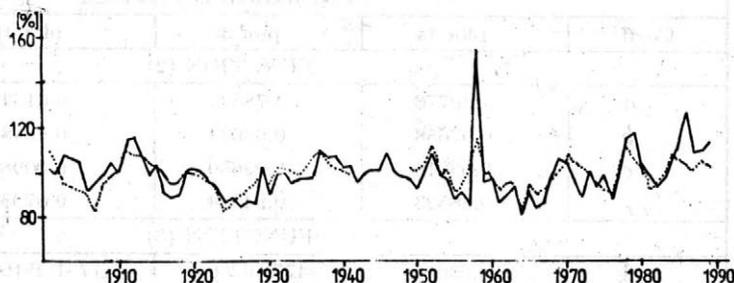
REGRESSION WITH CLIMATE

Correlation between the difference of indices ΔI and the components of the climate can be described by equation

$$\Delta I_{j+1} = R(K_{j+1}^i) \quad (8)$$

where: K_{j+1}^i - is a vector of climatic components influencing the width of the tree-ring.

1. Comparison of original and modelled tree-ring indices. (Plot 35)



EMPIRICAL DATA

This research was carried out in the forest stands of forest enterprise Ostravice in the Moravskoslezské Beskydy. Its northern part is formed by the mountains of Lysá hora (1325 m), Kněhyně (1257 m) and Smrk (1282 m). The relief is very ragged with deep and narrow valleys (usually N-S orientation). All this area is under a strong influence of air pollutants.

Our sample plots are in the area of Kněhyně and Smrk. A random selection of individual trees was carried out and then the increment cores were bored in bhd (1.3 m). Both the tree-ring series of individual trees and average tree-ring series of sample plots were analysed. The average tree-ring series are the averages from all well-dated tree-ring series of each sample plot. The climatic data are from the meteorological station Lysá hora (the nearest station).

Ten sample plots were analysed (including 4 "healthy" and 6 "damaged"). All these plots have comparable growth conditions.

Tab. I contains basic growth data of sample plots.

RESULTS

Measured tree-rings widths were standardized using functions (2), (3), (4).

I. Basic data on sample plots

Forest stand	Forest type	Site index	Level ab. sea [m]	Exp.	Slope [%]	Zone of damage	Deg dec.	N. pl.
UNDAMAGED PLOTS								
422 A3	5S1	1	620-720	NE	10-35	D	0	14
116 B2	5S1	1	620-720	W	30	D	0	33
430 E2	5S1	1	560-670	E,NE	30	D	0	18
546 A5	5S1	2	740-860	NE	25-40	D	0	35
DAMAGED PLOTS								
547 A3	6S1	3	1030-1120	E,SE	25-35	B	2	24
403 A3	6S1	2	870-920	NW	25	C	1	11
401 B3	6S1	3	880-1070	SE	10-70	B	1	39
560 B4	6S1	3	910-1030	S,SE	25	B	2	28
555 A7	6S9	2	1060-1170	NE	30	B	2	29

II. Coefficients and correlation index of functions used for standardization

UNDAMAGED PLOTS					
Coeff	plot 14	plot 33	plot 18	plot 35	
FUNCTION (2)					
<i>a</i>	6.30776	4.78631	6.61321	8.98334	
<i>b</i>	0.07658	-0.63034	-0.19484	0.26055	
<i>c</i>	-0.03618	-0.02659	-0.00988	-0.01506	
<i>I_{y,x}</i>	0.88523	0.94524	0.87338	0.93849	
FUNCTION (3)					
<i>A</i>	906.93020	477.86266	1731.25100	459.91960	
<i>n</i>	1.33237	1.34677	1.24985	1.42385	
<i>k</i>	1.97958	1.98192	1.61911	2.36956	
<i>I_{y,x}</i>	0.88223	0.95778	0.97421	0.95226	
FUNCTION (4)					
<i>a</i>	2.69441	1.30541	1.37024	0.93646	
<i>b</i>	18.18696	15.09351	19.15680	33.01397	
<i>c</i>	-15.42400	-12.60000	-15.38730	-30.01397	
<i>I_{y,x}</i>	0.74007	0.86030	0.89210	0.91256	
DAMAGED PLOTS					
Coeff	plot 24	plot 11	plot 39	plot 28	plot 29
FUNCTION (2)					
<i>a</i>	5.37529	3.83697	5.19185	7.09911	5.44763
<i>b</i>	0.26431	0.55058	-0.26831	-0.07558	0.06950
<i>c</i>	-0.07141	-0.09071	-0.03358	-0.02378	-0.02008
<i>I_{y,x}</i>	0.98628	0.89077	0.96877	0.96679	0.85055
FUNCTION (3)					
<i>A</i>	269.23220	939.57280	320.04856	572.04656	401.32580
<i>n</i>	1.51785	1.34426	1.41893	1.36025	1.46962
<i>k</i>	2.73315	2.21437	2.21636	2.14027	2.99105
<i>I_{y,x}</i>	0.96381	0.68286	0.98039	0.99310	0.98069
FUNCTION (4)					
<i>a</i>	1.45883	3.65825	1.10441	1.60435	1.01064
<i>b</i>	24.21230	10.41157	17.71739	22.38788	26.25006
<i>c</i>	-15.42400	-10.65910	-14.30101	-16.48196	-25.69129
<i>I_{y,x}</i>	0.87096	0.52915	0.84925	0.86267	0.82397

The best-fitted function was chosen, using the correlation index.

Tab. II contains these indices and regression coefficients for all used functions and all sample plots. According to the indices, Korf's function is the best (see Tab. III - the numbers of best-fitted functions for the sample plots).

According to autoregression analysis both the individual tree-ring series and the average ones, first-order autocorrelation is the highest (see Tab. IV a - autoregression coefficients for the sample plots).

On the basis of equations (9) and (10) "expected" tree-ring indices (W_j) were

III. Best-fitted functions for an individual tree-ring series

Area no.	FUNCTION (2)		FUNCTION (3)		FUNCTION (4)	
	number	[%]	number	[%]	number	[%]
UNDAMAGED PLOTS						
14	29	61.7	15	31.9	3	6.4
33	20	40.9	23	46.9	6	12.2
18	5	12.2	26	63.4	10	24.4
35	6	19.3	15	48.4	10	32.3
DAMAGED PLOTS						
24	20	54.1	11	29.7	6	16.2
11	29	61.7	15	31.9	3	6.4
39	8	20.5	25	64.1	6	15.4
28	2	4.9	28	68.3	11	26.8
29	2	7.4	10	37.0	15	55.6

Iva. Statistically significant autocorrelation coefficients of tree-ring series

UNDAMAGED PLOTS			DAMAGED PLOTS		
N.pl.	autoc.I.o.	autoc.II.o	N.pl.	autoc.I.o.	autoc.II.o
14	0.35094	0.48026	24	0.65827	0.43703
33	0.33302		11		
18	0.68602		39	0.61591	0.40852
35	0.28301		28	0.60206	0.43703
			29	0.50808	0.34727

IVb. First-order autoregression coefficients and coefficients of determination (R^2) for average tree-ring series

N.plot	Abs. coeff.	Coeff. b	R	R^2 [%]
UNDAMAGED PLOTS				
14	61.45630	0.37205	0.39665	15.73
33	60.97500	0.37960	0.37122	13.78
18	31.31110	0.68062	0.39665	15.73
35	70.70825	0.28936	0.28623	8.19
DAMAGED PLOTS				
24	20.11700	0.78395	0.74158	54.99
11				
39	34.21198	0.64553	0.67777	45.94
28	34.72820	0.63977	0.65398	42.77
29	48.65260	0.50835	0.51948	26.99

computed. Then the differences between measured and expected tree-ring widths were computed. These differences represent climatic, endogenous, exogenous and random pulses influencing the diameter increment.

These differences were correlated with the components of climate (especially with the temperatures). Stepwise regression was carried out and the set of predictors (Fritts, 1976) was chosen.

V. Coefficients of multiple regression between components of climate and tree-ring series

UNDAMAGED PLOTS					
Coef.	plot 14	plot 33	plot 18	plot 35	
t_4	-0.62350	-2.01818	-0.35095	-0.06114	
t_9	-1.28555	0.82503	0.43129	1.28999	
tp_4	-0.01119	-0.62083	-0.55133	-0.00869	
tp_9	0.11961	0.00139	0.19988	0.46768	
tp_{12}	-0.01235	-0.00927	-0.36470	-0.01931	
at_6	-0.00635	0.00928	0.00984	0.00749	
CONST	5.85431	5.61252	-3.45466	-5.17358	

DAMAGED PLOTS					
Coef.	plot 24	plot 11	plot 39	plot 28	plot 29
t_4	-0.41903	1.11241	-0.69630	0.30103	-0.06358
t_9	0.01694	0.53725	0.02480	0.72453	0.76723
tp_4	-0.58240	-1.13403	-0.48460	-0.83619	-0.32653
tp_9	0.05832	0.71541	0.96463	0.27039	0.83555
tp_{12}	-0.63198	-0.08548	-0.59152	-0.08981	-0.08555
at_6	0.00579	0.04223	0.00928	0.02341	0.00062
CONST	0.85314	91.70490	-2.31622	-13.62570	-3.15942

Legend: CONST - absolute coefficient
 t_4 - April temperature
 t_9 - September temperature
 tp_4 - April temperature in the season prior to growth
 tp_9 - September temperature in the season prior to growth
 tp_{12} - December temperature in the season prior to growth
 at_6 - sum of active temperatures up to June

The best fitted climatic components are April and September temperatures both of growing season and the season prior to growing season and the sum of active temperatures up to June (the sum of temperatures $> 10^\circ\text{C}$).

Then we have used the multiple regression to estimate "expected" differences of tree-ring indices, including the influence of main climatic components.

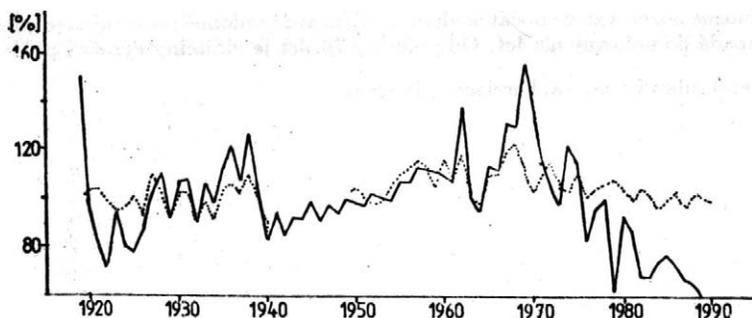
Tab. V contains all coefficients computed by multiple regression for all plots.

Figs. 1 and 2 show the comparison of originally computed differences (the differences between original tree-ring indices and indices computed by autocorrelation equations) and differences obtained by multiple regression.

This comparison shows some interesting details:

1) In the case of undamaged plots (Fig. 1) there is clearly visible very good coincidence between originally computed differences and differences obtained by multiple regression. It could be explained by the fact that almost all variations of tree-ring indices are caused by the influence of climatic components. We had no climatic data for the years of 1949-1955.

2) In the case of the damaged plots (Fig. 2) a distinctive disagreement between differences are visible. The main disagreement begins in the mid-sixties. For instance, in the case of sample plot 28, approximately up to 1975 originally computed differences exceed differences computed by multiple regression in a positive



sense. Then the original differences are distinctively higher in a negative sense. We explained these disagreements by the influence of the exogenous factors, especially by air pollutants.

3) We assume that the beginning of the influence of air pollutants is approximately in the year of 1975 because a rapid increasing of diameter increment is a typical factor the first years of the influence of air pollutants. Ten years later, a distinct depression of diameter increment is the direct consequence of long-term influence of air pollutants.

The result mentioned in this paper are only the first steps on the way to a fully objective methods for evaluating the influence of air pollutants on the forest ecosystems. This problem needs large-scale research on an international scale.

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Zach J. - Drápela K.: (Lesnická fakulta, Brno): Analýza tloušťkového přírůstku v porostech Beskyd pod vlivem imisí. Lesnictví, 37, 1991 (10):787-794.

Cílem práce bylo ověření nových metodických postupů posouzení průběhu tloušťkového přírůstku v imisně zatížených porostech. Jako modelový příklad byly použity zkušné plochy v Beskydech (LZ Ostravice). Bylo analyzováno 10 zkušných ploch v porostech ležících v různých stupních poškození a pásmech ohrožení. K separaci jednotlivých hlavních vlivů působících na tloušťkový přírůst byl užit Cookův lineární model. Na základě výpočtu standardizačních funkcí byly vytvořeny stacionární časové řady letokruhových indexů. V nich byl zkoumán vliv autokorelace 1. a 2. řádu. Pomocí vícenásobné lineární regrese byl stanoven model působení klimatických činitelů na tloušťkový přírůst. Pomocí krokové regrese byla stanovena sada prediktorů (teploty v dubnu a v září roku růstu a v roce předcházejícím růstu). Na základě modelu byl vypočítán modelový průběh tloušťkového přírůstku (se započítáním vlivu věku, autokorelace a klimatu) a srovnán se skutečným průběhem. Srovnáním modelového a skutečného průběhu letokruhových indexů se dospělo k těmto závěrům: 1. V případě nepoškozených ploch nejsou viditelné podstatné rozdíly mezi modelovými a skutečnými letokruhovými indexy. Může to být vysvětleno tím, že hlavním faktorem působícím na tloušťkový přírůst je klima. 2. U poškozených ploch je možné pozorovat významné rozdíly v průběhu tloušťkového přírůstku mezi modelovými a skutečnými indexy. Dále je

možné pozorovat, že počátek vlivu imisí (pravděpodobně projevující se mírným zvýšením přírůstu) spadá do poloviny 60. let. Od poloviny 70. let je viditelný výrazný pokles přírůstu.

letokruhovová analýza; korelace; vliv imisí



The results presented in this paper are only the first steps on the way to a fully objective method for evaluating the influence of air pollutants on the forest ecosystem. This problem needs large-scale research on an international scale.

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HEIGHT GROWTH CHANGES IN SPRUCE STANDS IN THE CZECH REPUBLIC

I. Kupka

Kupka, I.: (Forest and Game Management Research Institute, Jiloviště - Strnady): *Height growth changes in spruce stands in the Czech Republic*. *Lesnictví*, 37, 1991 (10):795-805.

Anthropogenic immissions change the ecology of forests. The Forest and Game Management Research Institute has 72 permanent research plots where data have been recorded for more than a 30 year period. Statistical tests show that there are significant declines in the height growth of trees and stands of spruce. Older trees have larger changes than younger ones. Stands had a more visible growth changes in the 1980's than earlier. On the other hand there were some positive growth changes in the 1960's. The statistical significance of only height growth changes can be proved in these plots. Other stand characteristics are much more influenced by thinning regimes.

anthropogenic immissions; spruce stands; growth changes; Czechoslovakia

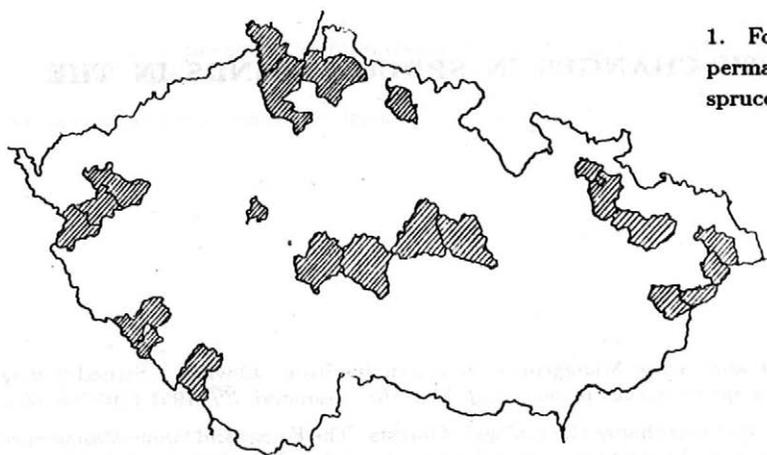
INTRODUCTION

Anthropogenic immissions are probably the most important agents of change in Czech forests. Studies by many authors (K a u p p i et al., 1984; A l c a m o et al., 1985; I n n e s et al., 1986; N i l s s o n et al., 1987; R o b e r t s et al., 1985 etc.) have shown that the changes are the results of synergenic influences such as (besides the above-mentioned immissions) dryness and temperature fluctuation in very short time periods. It has been shown by many authors (R e h f u e s s, 1987; B a d o t, 1991 etc.) that young needles in polluted areas have the same physiological characteristics as older needles in clear areas. The result of this process is that these 'physiologically old' needles fall. This clearing of crowns may be the cause of possible growth changes many authors have found (T e s a ř, 1960; M a n d e l a et al., 1986; M a t e r n a, 1986; K u u s e l a, 1987; D o n g e t K r a m e r, 1987 etc.).

It is well known and proven by many measurements, especially in diameter increments, that the increment fluctuates from year to year. On the other hand, a periodic increment of a 5-year period can be thought of as a characteristic of sufficient stability. From this point of view it can be used for assessment whether there are evident growth changes in spruce as our most important species and whether these changes are evident at a usual statistical level of importance.

Research on growth, as mentioned above, found that growth changes are highly dependent on the damage level of trees (needle loss). These results can be found in studies of J o n s s o n e t S v e m s s o n, 1982; K r a m e r, 1986; K o u b a, 1987;

1. Forest area covered by permanent research plots in spruce stands



O v a s k a i n e n, 1987 etc. However, we are interested in finding if there are evident changes on trees which do not have visible damage i.e. trees without any needle losses. It is important for us to test this hypothesis because there are also many stands which are judged as stands with the first signs of damage (classified as O/I by the Institute for Forest Management Plans; the area of these stands with classification O/I is 656300 ha - i.e. 27.2 % of the entire forested area of the Republic). These stands are also composed of trees without any damage (damaged stands are always of very heterogenic composition). For these reasons it is very important to know any growth changes on these apparently non-damaged trees.

Besides the results which show the growth diminishing in stands under the influence of immissions, there are also some stands showing higher increments in some periods (P r e t z s c h, 1988). An interesting explanation of this phenomenon can be found in G ä r t n e r and H r a d e t z k y, 1988, who showed that damaged stands can have different growth dynamics. One also has to take into consideration the possible fertilization effect of lighter immissions, especially on the poor sites.

The main goal of this study is searching for the evident growth change in the spruce stands which are without any visible damage in the Czech Republic in the period from 1960 (when immissions ceased to be only a local problem of the Ore mountains) until now.

DATA AND METHOD

We have collected and compiled data from permanent research plots of our Institute's spruce stands (see picture Fig.1). All plot trees are numbered and have signs where two diameters were measured. The measurements at the plots are done at regular 5 year intervals. Heights are measured on random samples of trees which are spread over the whole plot. They are measured by a Blume-Leiss hypsometer so that there are at least 3 measurements of height in every 1 cm diameter class. The basic stand characteristics are calculated from these data, especially the dominant height h_{100} (the average height of the 100 thickest trees per ha), average stand height h_g (mean height calculated from stand basal area), average stand diameter d_g (calculated from stand basal area), stand basal area G and stand growing stock V . Basic information about the data can be found in Tab. I. The data do not include the measurements from damaged stand:

I. Number of measurements used for statistically tested increments

Dominant height [m]	Period [year]							
	1961-70		1971-80		1981-90		Total	
	dom.	av.	dom.	av.	dom.	av.	dom.	av.
15.1-17	6	4	4	3	-	-	10	7
17.1-19	6	5	3	2	-	-	9	7
19.1-21	10	6	2	2	8	6	20	14
21.1-23	6	3	6	3	5	4	17	10
23.1-25	3	2	5	3	1	-	9	5
25.1-27	-	-	7	5	4	3	11	8
27.1-29	-	-	3	2	6	4	9	6
Total	31	20	30	20	24	17	85	57

dom. - number of measurements used for testing of dominant height increment

av. - number of measurements used for testing of stand average height increment

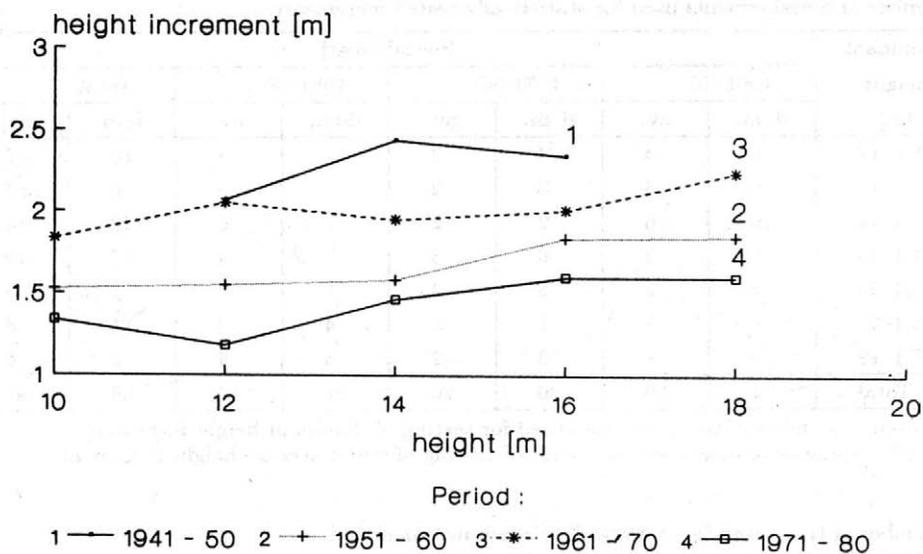
II. Number of trees used for statistically tested increments

Tree height [m]	Tree age [years]									Total
	41-50			51-60			61-70			
	period			period			period			
	1951-60	61-70	71-80	1951-60	61-70	71-80	1951-60	61-70	71-80	
13.1-15	28	7	28	-	-	-	-	-	-	63
15.1-17	41	26	9	-	-	-	-	-	-	76
17.1-19	31	21	2	10	35	9	-	13	4	125
19.1-21	15	21	1	6	28	7	-	35	21	134
21.1-23	-	-	-	8	10	5	-	22	9	54
23.1-25	-	-	-	-	-	-	-	9	8	17
Total	115	75	40	24	73	21	-	79	42	469

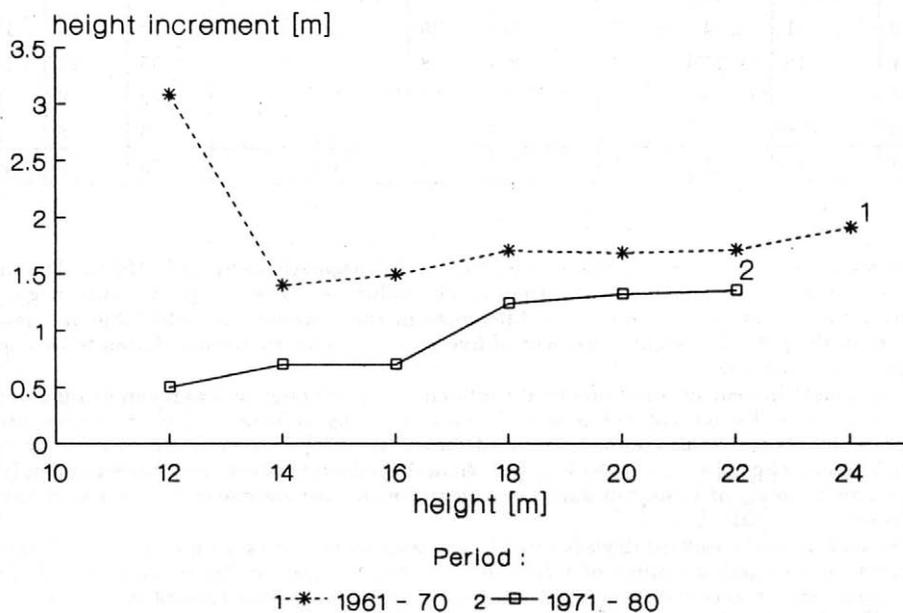
and from stands with a site index lower than 3 (from Schwappach yield table 1902). The main part of these plots has a site index better than 2. The influence of the site index can be neglected from this point of view if we realize that differences in the Schwappach yield table are smaller than 0.3 m in the periodic height increment of five years: we formed groups of stands for 2 m of dominant height intervals.

Stand height increment is not practically influenced by thinning, and so it can be regarded as the most important characteristic of growth changes caused by influences other than silviculture. The hypothesis was tested also on non-damaged sample trees felled in areas which are very close to research plots. The trees were 31 to 70 years old and height increments were measured on lying stems with an accuracy of 1 cm. Similar classes were used for the sample trees as for stand plots, as can be seen from Tab. II.

The average and standard deviations of height increments for every group were calculated. The increments for similar groups of trees with the same dominant height and age but from different time periods were then tested by Student's *t*-test at the usual level of importance. The test includes, of course, the testing of the significance of differences of variance (Eckhlagger et al., 1980). The graphs for sample trees were drawn additionally for the sample trees (see Fig. 2,3). The number of trees used for the graphs is higher than is written in Tab. II. Some of these trees cannot be used for the *t*-test because there were not enough trees in comparable groups. But these graphs are so illustrative that we also used them in our study.



2. Sample trees of age 41-50 (spruce)



3. Sample trees of age 61-70

III. Dominant height increments of spruce stands in different periods

Dominant height	Period								
	1961-70		1971-80			1981-90			
	1		2			3			
	i_{hd}	s	i_{hd}	s	1-2	i_{hd}	s	2-3	1-3
15.1-17	1.8	0.3	2.3	0.3	0	-	-	-	-
17.1-19	2.1	0.4	2.6	1.6	-	-	-	-	-
19.1-21	2.4	0.5	1.4	0.4	0	1.6	0.2	-	xx
21.1-23	1.8	0.3	2.3	0.6	-	1.5	0.3	x	-
23.1-25	1.6	0.5	1.9	0.2	-	1.3	-	-	-
25.1-27	-	-	2.7	0.5	-	1.9	0.5	0	-
27.1-29	-	-	2.1	0.4	-	1.3	0.3	0	-

Notes: level of statistical significance

- no significance

0 - low significance (= 0.1)

x - significance (= 0.05)

xx - high significance (= 0.01)

i_{hd} - dom. height increment

s - standard deviation

1-2- t - test

IV. Stand mean height increments of spruce stands in different time periods

Dominant height	Period								
	1961-70		1971-80			1981-90			
	1		2			3			
	i_h	s	i_h	s	1-2	i_h	s	2-3	1-3
15.1-17	1.8	0.1	2.2	0.3	-	-	-	-	-
17.1-19	1.8	0.4	1.7	0.9	-	-	-	-	-
19.1-21	2.7	1.1	2.0	0.4	-	1.9	0.5	-	-
21.1-23	2.2	0.4	2.8	0.5	-	2.4	0.7	-	-
23.1-25	2.0	1.1	2.4	0.3	-	-	-	-	-
25.1-27	-	-	3.0	0.8	-	1.6	0.0	x	-
27.1-29	-	-	3.0	0.0	-	1.4	0.2	xx	-

Notes: level of statistical significance

- no significance

0 - low significance (= 0.1)

x - significance (= 0.05)

xx - high significance (= 0.01)

i_h - stand mean height increment

s - standard deviation

1-2- t - test

RESULTS AND DISCUSSION

DATA FROM PERMANENT RESEARCH PLOTS - DOMINANT HEIGHT

The most important and the most evident changes of growth dynamics is the dominant height. The data also include measurements from control plots, i. e. data from plots where no silviculture regime is exercised. It can be supposed that dominant height is not influenced by thinning. The results including Student's *t*-test are printed in Tab. III. It follows from the results there are no statistically significant differences between dominant height increment in the 1960's and 1970's, except for two groups where increment changes are significant at the level of 0.1. The first of these groups in the 1970's (15.1 - 17 m dominant height) has a higher increment, while the other group (19.1 - 21 m dominant height) has a lower increment. An extensively different situation can be seen in the 1980's. All stands as the range of 19.1 to 29 m dominant height have diminishing growth at a different level of significance with one exception (for 19.1 - 21 m), which had changed 10 years earlier. If we compare the increment from the 1980's to the 1960's, the changes are at a very significant level (0.01).

DATA FROM PERMANENT RESEARCH PLOTS - STAND HEIGHT

Data from control plots excluded before statistical tests were performed on this data set. The results, including Student's *t*-test, are gathered in Tab. IV. The results seem to be very similar to those in Tab. III, although there are not such evident changes as a dominant height. There are no changes in the 1970's. There are evident changes in the 1980's for plots with dominant heights ranging from 25.1 to 29 m than for older stands. These stands are close to the physiological limit of their growth possibilities, which is probably the reason why they react more markedly than younger ones.

DATA FROM PERMANENT RESEARCH PLOTS - OTHER STAND CHARACTERISTICS

The other stand characteristics are influenced by silvicultural regimes. This is probably the main reason why it is not possible to prove that any significant growth changes in stand basal area and stand growing stock were influenced by growing periods in our data. There are some growth changes in the data but it was proved that this was because of thinning regimes rather than ecological changes.

DATA ON SAMPLE TREES HEIGHT

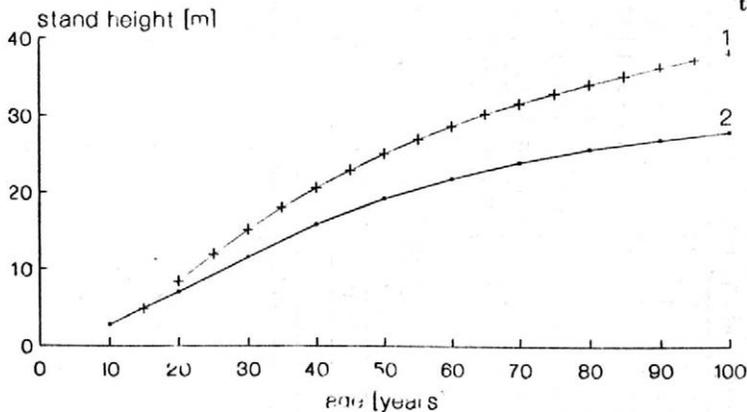
The measurements were grouped into 10 year classes from the point of view of age and class. The result can be found in Tab. V. Unfortunately, data are missing

V. Tree height increments of sample spruce trees in different time periods

Tree height [m]	Tree age (year)																										
	41-50									51-60									61-70								
	period									period									period								
	1951-60			1961-70			1971-80			1951-60			1961-70			1971-80			1951-60		1961-70		1971-80				
	1		2		3					1		2		3					1		2		3				
<i>inc</i>	<i>s</i>	<i>inc</i>	<i>s</i>	<i>a</i>	<i>inc</i>	<i>s</i>	<i>b</i>	<i>c</i>	<i>inc</i>	<i>s</i>	<i>inc</i>	<i>s</i>	<i>a</i>	<i>inc</i>	<i>s</i>	<i>b</i>	<i>c</i>	<i>inc</i>	<i>s</i>	<i>inc</i>	<i>s</i>	<i>inc</i>	<i>s</i>	<i>inc</i>	<i>s</i>	<i>b</i>	
13.1-15	1.55	0.48	2.05	0.25	xx	1.18	0.40	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15.1-17	1.58	0.50	1.95	0.70	x	1.46	0.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17.1-19	1.84	0.45	2.01	0.69	-	1.60	0.14	-	-	1.41	0.26	1.74	0.44	xx	1.57	0.37	-	-	-	-	1.49	0.27	0.70	0.10	xx	-	-
19.1-21	1.85	0.49	2.24	0.54	x	1.60	-	-	-	1.88	0.37	1.79	0.41	-	1.66	0.32	-	-	-	-	1.70	0.60	1.24	0.28	xx	-	-
21.1-23	-	-	-	-	-	-	-	-	-	2.31	0.25	1.58	0.19	xx	1.66	0.31	-	xx	-	-	1.68	0.27	1.32	0.38	x	-	-
23.1-25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.71	0.38	1.35	0.23	x	-	-

Notes: - level of statistical significance

inc - average height increment*s* - standard deviation*a - t* - test between columns 1-2*b* - test between columns 2-3*c* - test between columns 1-3



Data from yield tables of :

1 —+— Halaj 1987 2 —•— Institute for Forest management plans

concerning the 1970's for younger trees so that we can only say, there is no evident diminishing in the height increment between the 1950's and 1960's although small changes can be observed. The most significant and most evident height increment changes can be found in the group of older trees (61 - 71 years old). The decline of about 0.5 m in height increment for a 5-year interval is proved at statistically significant levels. On the other hand, for the two younger groups (41 - 50, 51 - 60 years old), the decrease in the 1970's is so small that it can hardly be demonstrated (with the exception of trees with a height of 12.1 to 14 m). In comparison with this, it is interesting to note that in the 1960's there were statistically proved growth increases in four groups (compared to the 1950's). Unfortunately, there are no measurements from the 1980's to compare previous data with the present ones.

This growth diminishing at older stands which we have proved with our data is one of the reasons why the Institute for Forest Management Plans arrived at the finding that the height growth curves from measurements in the last ten years are lower than before (see Fig. 4).

CONCLUSIONS

The statistical *t*-tests on data on dominant and stand heights of spruce have produced interesting results on growth changes which are now discussed very frequently among Czech foresters. The five-year periodic current increment of height could be thought of as one of the best indicators of these changes. Unfortunately, our data does not cover the whole period which we are interested in. Of importance is the fact that sample trees are missing for the 1980's. On the other hand the results are very interesting and soundly proved by statistical tests. The results are as follows:

- both data (for stands and sample trees) show that older trees have a greater diminishing of current increment than younger trees. We have to keep in mind that we compare similar trees which are of the same age and dominant height, so the increment is not influenced by tree age,

- stand diminishing increment is more distinct in the 1980's than in the 1970's or even earlier,
- diminishing increments of sample trees can be proved only with older trees in the 1970's (data from the 1980's are missing in our data set),
- increasing increments can be found in many cases from the 1960's (in comparison with the 1950's),
- the increment changes cannot be proved for tree and stand characteristics other than for dominant and stand height; the main reason is very large influence of silvicultural regimes.

Permanent research plots of the Institute for Forest and Game Management unfortunately do not cover all site types of forests in the Czech Republic. On the other hand, the data set is probably a unique set for a longer period, with its accuracy and extent. The data gives us a lot of interesting information about the growth of spruce stands in our region. It covers the period in which the environmental changes take place. The results show that these changes also bring changes in height increment in our spruce stands.

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Antropogenní imise jsou zřejmě nejdůležitější příčinou růstových změn, které lze v našich lesích pozorovat v posledním období. Podle šetření mnoha autorů (např. Kauppi et al., 1984; Alcamo et al., 1985; Innes et al., 1986; Nilsson et al., 1987; Roberts et al., 1985 aj.) dochází k těmto růstovým změnám vlivem synergického působení nejrůznějších stresových faktorů, z nichž nejdůležitější, vedle už zmíněných imisí, jsou sucho a velké teplotní výkyvy během krátkých časových úseků. Řada prací ukázala (např. Rehfuess, 1987; Badot, 1991), že v oblastech zatížených vyššími koncentracemi antropogenních imisí má jehličí mladších ročníků stejné fyziologické charakteristiky jako starší jehličí v čistých oblastech. Výsledkem je předčasný opad těchto 'fyziologicky starých' ročníků jehličí. Toto řídnutí koruny - buď stejnoměrně v celém profilu nebo některých jejích částí - znamená mimo jiné i růstové změny, jak zjistila celá řada autorů (např. Tesař, 1960; Mandela et al., 1986; Materna, 1986; Kousela, 1987; Donga Kramer, 1987). Mnohá produkční šetření zjistila, že přírůstkové změny jsou přímo úměrné poškození stromů a porostů (Jonsson a Svemsson, 1982; Kramer, 1986; Koubal, 1987; Ovaska inén, 1987 aj.). Jsou však i práce, které konstatují, že se přírůst nezměnil, ačkoliv došlo k prokazatelné ztrátě jehličí (Schmid a Has, 1990). Účelem tohoto příspěvku je zjistit, zda lze přírůstkové změny prokázat i u stromů, které ještě nejeví vnější známky poškození, tj. u stromů, u nichž zatím nedošlo ke ztrátě jehličí. Za nejdůležitější a nejprůkaznější změnu v dynamice růstu porostů je nutno považovat horní výšku, která je definována jako průměrná výška sta nejlustších stromů na 1 ha. Vzhledem k omezenému počtu měření, která jsou k dispozici, byly použity i údaje z kontrolních ploch, tj. ploch, kde se neprovádějí žádné úmyslné výchovné zásahy, pouze se odstraňují odumřelé stromy. Vzhledem k definici horní výšky lze odůvodněně předpokládat, že tato veličina není ovlivňována charakterem výchovy, která se na ploše provádí. Údaje včetně hodnot Studentova *t*-testu uvádí tab. III. Z ní je patrné, že není statisticky významný rozdíl mezi přírůstkem horní výšky v 60. a 70. letech, s výjimkou 2 skupin stromů, jejichž změna přírůstu je skutečně významná na hladině 0,1. Výrazně jiná je situace při posuzování změn v přírůstu horní výšky v 80. letech. U všech porostů v rozpětí od 19,1 do 29 m je zaznamenán statisticky významný pokles pětiletého běžného periodického přírůstu na různých hladinách významnosti s výjimkou porostů s výškou 19,1 - 21 m, kde byl tento pokles už v 70. letech průkazný (na hladině významnosti 0,1). To je zřejmě důvod, proč v 80. letech k dalšímu statisticky významnému poklesu přírůstu nedošlo. Srovnáme-li však tento přírůst v 80. letech k 60. letům, je pokles statisticky vysoce významný na hladině významnosti 0,01. Data, týkající se střední výšky hlavního porostu včetně Studentova *t*-testu, jsou uvedena v tab. IV. Výsledky jsou podobné, i když ne tak průkazné jako u přírůstu horní výšky. V 70. letech nedošlo k žádným statisticky průkazným změnám v přírůstu. V 80. letech je tento pokles významný a vysoce významný u porostů s horní výškou 25,1 - 29 m, tj. u porostů starších. Tyto porosty, blížící se ke konci svých růstových možností, reagují zřejmě výrazněji na zhoršené ekologické podmínky snížením přírůstu, oproti porostům mladším. Výsledky výškového přírůstu jednotlivých stromů jsou přehledně uvedeny v tab. V. U nejmladší skupiny 31 - 40letých stromů bohužel chybí údaje ze 70. let doby, takže lze jen konstatovat, že zde není statisticky průkazného rozdílu mezi 50. a 60. lety, i když mírný pokles je patrný na první pohled. Nejvýraznější pokles statisticky významný a vysoce významný je u nejstarší skupiny zornků ve věku 61 - 70 let. Protože je zde dostatečný počet měření, lze považovat snížení výškového přírůstu v průměru o 0,5 m za dostatečně průkazné. Naproti tomu u dalších dvou věkových stupňů smrku (41 - 50, 51 - 60) je pokles přírůstu v 70. letech tak nevýrazný, že ho nebylo možno statisticky prokázat (kromě skupiny stromů s výškou 12,1 - 14 m). Naopak zajímavé je zjištění, že v 60. letech ve většině případů došlo k statisticky významnému zvýšení přírůstu (ve 4 skupinách, tj. u 129 stromů)

v 60. letech ve srovnání s přírůstem v 50. letech. Tento pokles výškového přírůstu u starších porostů v posledním období, který jsme prokázali u všech dostupných dat, může být jednou z příčin, které vedly ÚHÚL ke zjištění, že výškové křivky vytvořené z databáze HÚL jsou zejména ve druhé polovině obmýti (tj. přibližně u porostů starších 50 let) podstatně plošší, než uvádějí běžně používané růstové tabulky (viz obr. 3). Pravděpodobným důvodem může být právě statisticky průkazný pokles výškového přírůstu, který se na trvalých výzkumných plochách VÚLHM podařilo ve většině výsledků prokázat.

anthropogenic immissions; spruce stands; growth changes; Czechoslovakia

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SCIENTIFIC JOURNALS

of the Czechoslovak Academy of Agriculture present primary scientific studies on solved research projects from all fields of agriculture and forestry. There are also published scientific treatises, studies, and reviews of foreign literature dealing with scientific problems. Papers from different research workplaces concerning the same problem are edited in monothematic issues. The articles are written in Czech or Slovak with summaries in English.

In 1992 are published the following journals:

Rostlinná výroba (Plant Production)	12 issues a year
Živočišná výroba (Animal Production)	12 issues a year
Veterinární medicína (Veterinary Medicine)	12 issues a year
Zemědělská technika (Agricultural Engineering)	12 issues a year
Zemědělská ekonomika (Agricultural Economy)	12 issues a year
Lesnictví (Forestry)	12 issues a year
Sborník ÚVTIZ (Proceedings of the Institute of Scientific and Technical Information for Agriculture)	
Genetika a šlechtění (Genetics and Plant Breeding)	4 issues a year
Ochrana rostlin (Plant Protection)	4 issues a year
Meliorace (Soil Improvement)	2 issues a year
Sociologie zemědělství (Sociology of Agriculture)	2 issues a year
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The scientific journal "Scientia agriculturae bohemoslovaca" serves to readers abroad. The scientific articles and studies which represent the Czechoslovak contribution to the world knowledge of agricultural sciences are published here. The articles are written in English. (The journal is issued quarterly.)

Věstník Československé akademie zemědělské ("Bulletin of the Czechoslovak Academy of Agriculture") is a periodical of the Czechoslovak Academy of Agriculture and research institutes. It provides information on problems relating to the agricultural science and research discussed on plenary sessions, on sessions of the presidium, departments and commissions of the Czechoslovak Academy of Agriculture, on conferences and symposia. It publishes proceedings from international congresses and reports from study journeys from abroad. In numerous columns it issues the materials about plans and results of activities in particular institutes and workplaces. "Věstník ÚSAZ" is published monthly.

DERIVATION OF THE FIRST AND FOLLOWING AGE STAGES SURFACE RATES IN STOCHASTICALLY DEFINED NORMAL FOREST

J. Kouba

Kouba, J.: (Faculty of Forestry, University of Agriculture, Prague): *Derivation of the First and Following Age Stages Surface Rates in Stochastically Defined Normal Forest*. *Lesnictví*, 37, 1991 (10):807-818.

The article deals with deducing of the calculations of the transition probabilities of the first and following age stages based on thorough analysis of the process of their establishing and consideration of the process of their registration when carrying out the forest management issues. Based on the theory of Markov processes and chains respectively (systems of linear differential equations the general procedure of expressing and calculating of these probabilities is derived - see (6) - (24). Such a procedure facilitates precision of the parameters of homogeneous and regular matrix of transition probabilities, which express the effect of calamities (a natural risk) in the stochastically defined theory of a normal forest (see K o u b a, 1969, 1973, etc.). The stationary distribution of age stages and probabilities of their damage (destroy) form the basis for the optimum control of the conversion process toward a normal forest (K o u b a, 1988, 1989). The derived procedure is at the same time a theoretical basis for the analysis of the processes of age stages establishing, which enables the precisising of our estimates of those probabilities and eliminate possible logical mistakes.

normal forest; age stages distribution; first age stage; Markov chains; system of linear differential equations

The subject of my article is to express mathematically the establishing of the first age stage and starting stages and, finally, to draw a general expression of the age stages development. The results subjected were extended further on the theoretical basis of the forest management and forest production science, what is the normal forest theory based on a system of age classes (stages). I worked out bases of a new normal forest theory in my previous works (K o u b a, 1969, 1973, 1977, 1983), where I considered random, non-mature age cuts - calamities, which are of random character, and expressed them applying the random processes theory, in particular regular and homogeneous Märkov chains. In further works, I dealt with the theory of estimate and expression of above mentioned calamity cuts which represent a natural risk in the forest management, and I stemmed from basic functions of the renewal theory (K o u b a, 1988, 1989; K o u b a and K a š p a r o v á, 1989). In other works, I drew up the use of the quasi-homogeneous Markov chains to express the scenarios of the damaged forests development (K o u b a, 1985, 1987) and finally also the expression of the forest production development based on national forest inventory data including damaged forest production estimates. The last work in that field (K o u b a, 1988, 1989) dealt, in the same time, with the theory of the optimum control of conversion process of a real forest toward a stochastically

defined one (K o u b a, 1969, etc.).

The development of an age stages distribution can be calculated with the following matrix equation:

$$\mathbf{p}^{(t)} = \mathbf{p}^{(0)}\mathbf{P}^t \quad (1)$$

where $\mathbf{p}^{(t)}$ stands for the probability vector of single age stages, $\mathbf{p}^{(0)}$ is the initial vector, and \mathbf{P} is the matrix of transition probabilities of the regular homogeneous Markov chain. The matrix \mathbf{P} is given by its elements:

$$\mathbf{P} = (p_{i,1}; p_{i,i+1}) \quad \text{for } i = 1, 2, \dots, n-1 \quad (2)$$

which fulfil the relation:

$$p_{i,1} = 1 - p_{i,i+1} \quad (3)$$

In the last row there is either $p_{n,1} = 1$ or $p_{n,1} = 1 - p_{n,n}$.

$$\lim_{t \rightarrow \infty} \mathbf{p}^{(0)}\mathbf{P}^t = \mathbf{a} \quad (4)$$

\mathbf{a} is a vector of a stationary distribution of age stages calculated from the relation:

$$\mathbf{a} = \mathbf{a}\mathbf{P} \quad (5)$$

under the condition $\sum a_i = 1$. Age stages are thus states of the above mentioned Markov chain with the time span $r = 10$ years, the same time span has to be considered for single calculation steps $t = 1, 2, \dots$. The transition probabilities correspond with this time span r and express the transitions of the process after elapsing the period of r years. (More details see K o u b a, 1969, 1973, 1977, etc.)

The theory of Markov chains (stemming from the theory of renewal) was applied in Japan by S u z u k i (1959, 1981) who used the stochastic distribution of final mature cuts as a basis. K i r á l y, 1986 in Hungary worked out the control of conversion process toward a normal forest using the quadratic programming. The application of simulation methods in this field was treated by J ö b s t l in Austria (1973, 1978, 1989). The results of my work were widely mentioned in Germany, Austria, Poland, Hungary and Lithuania (D e l t u v a s, 1986; D i t t r i c h, 1985; G e r o l d, 1976; J ö b s t l, 1990; K i r á l y, 1986; K l o c e k, 1986; K u r t h, 1975; O e s t e n, 1990; M ö h r i n g, 1984; P o z n a n s k i, 1985) and in Czechoslovakia (P o l e n o, 1978; Č í ž e k, 1987; P r i e s o l, 1986).

I realized the importance of the estimate of transition probabilities for the first age stage at the very beginning of treating the above mentioned problems. The data from the forest practice (e.g. R a c h m a n, 1977) show that, as a result of reforestation failures, the clear-cut area resulting from final mature cut is usually reforested twice or even more times, in average.

The first estimate of calamities or destruction probability according to age stages considering my proposed normal forest theory was performed by P o l e n o, 1978. I considered his estimates of the first age stage destruction to be too high. The first mathematical expression of the first age stage destruction was carried out by my student Z e m a n following my request in 1980. I stated a general solution of the task to express the probability of the first age stage destruction

on the analysis of the process of its establishing and also establishing of other age stages in 1983 (K o u b a, 1983, 1986). I stemmed from the description of that process by linear differential equations with constant coefficients. Since then I have been trying to give more precise estimates of corresponding transition probabilities which characterize that process and extend further on the analysis of the whole process of description and registration forest stands distribution into age stages during that time, and it has turned out that sometime it is not possible to consider the complete process of age stages development as a simple system characterized basically by a simple expression on decreasing probabilities of survival in relation to the age and various both harmful and natural factors, which evoke this process characteristic for all life.

THE ESTABLISHMENT PROCESS OF THE FIRST AGE STAGE AND FURTHER AGE STAGES

The establishment process of the first age stage and further age stages is given above all by an intrinsic establishment of certain forest stands or their parts of one age and in the same time by procedure of their registration. These two principal procedures are closely related and sometime hardly distinguishable. In the same time, the basic relation above all between the first and other age stages can change in time.

The first age stage has got a very important meaning in the whole system of age stages, its proper size is the most significant precondition to a future age structure and consequently to the reach of the objective of the forest management. The process of its establishment starts with the establishment of a clear-cut area, proceeds through reforestation toward a stabilized culture (at the age of 5 years in our regions) and finishes in the process of culture closing. In some cases, the process of closing (arising of new culture) may exceed the time span (1-10 years).

A. The process of the first age stage establishing is preconditioned by:

- 1) The time period in which the clear-cut area must be reforested for the first time since the time it was felled (it is approximately the second year in our regions). It was formerly called as an after-cut resting time and justified by the necessity to prevent from the insect damage (mostly *Hylobius abietis*) in new plantations.
- 2) The success of reforestation and the process of culture growth but also its damaging and consequent improvement - generally by establishment of a new culture as a basis of future forest stand until it is fully stabilized (mostly up to the age of 5 years, in our conditions).
- 3) The success of the culture closing process and establishment of a new stand. This process is based on the stand plot, wood species composition, and considerably on the original plants' size and their spacing.

Usually other factors or processes are involved during establishing the first age stage:

- 4) The natural regeneration - in the plot of an establishing culture there may exist a rudiment of a natural regeneration which may be not been considered and yet the area is reforested. The natural regeneration can considerably cut the need of improvement or it can even eliminate it.

- 5) In the course of the culture up-growing or closing the theoretical spacing declines and consequently some small-sized parts which haven't succeeded in being reforested are not necessarily improved again since a certain time, as they "vanish" in the course of culture closing. A certain part of a clear-cut area cease (it is registered no more) even because we are satisfied with a lower spacing in a certain part of reforested stands.
- 6) Sometime a certain part can be joined with a neighbouring stand of different age or to a neighbouring forest stand part.
- 7) The registered clear-cut area scheduled to reforestation which originates e.g. after the drop in the spacing in the whole area after being thinned with a snow-break, may be written-off in a consequence of the rise of a natural stand stocking to a such level when the additional under-level afforestation is not worth, regarding the age and density.

B. Other age stages may change their portion mostly by changes connected with the taxation practice and regulations of the registration of stands or their parts also from the point of age.

- 1) By reducing the stand (or its part) area to such a size when it cannot be registered separately - either because of regulations or practically - and is joined with a neighbouring part and subsequently its age stage classification changes.
- 2) Re-including the clear-cut area into an age stage corresponding with the proper stand after the density rises.

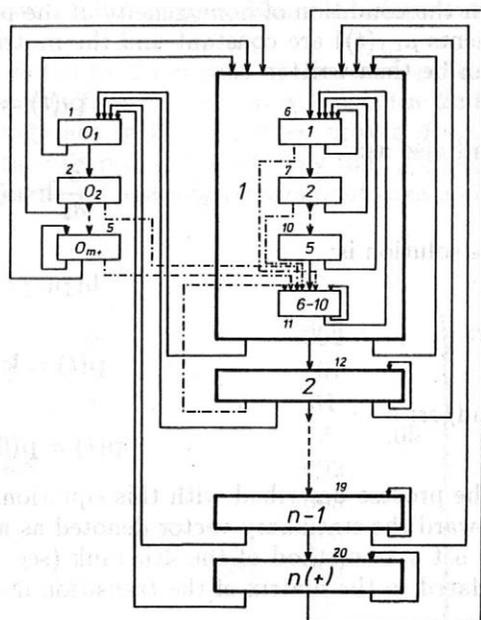
C. Generally, the area of all age stages can change:

- 1) By the change of taxation regulations (e.g. the size of elementary filed part - of a stand or its part, the procedure of average age calculation in that part and determining the age of the stand in general.
- 2) By changes in forest surveying in general, as it concerns merely the national forest inventories. In Czechoslovakia, such a change was caused e.g. by the fact that Inventory of Forests in CSSR in 1950 only recorded the forest stands larger than 10 ha and starting from the Inventory of Forests in CSSR 1970 all forests have been recorded.

THE EXPRESSING OF THE PROCESS OF ESTABLISHING THE FIRST AGE STAGE BASED ON THE THEORY OF RANDOM PROCESSES

The basic idea of the process of establishing the first age stage is apparent in the Fig. 1. There the blocks hatched in full line and marked with greater Arabic numbers represent age stages. The blocks marked O_1, \dots, O_{m+} represent the clear cut area aged 1, 2, ..., $m+$ years, where $m+$ means that this state includes clear-cut areas aged m years or older. In the first age stage there are cultures aged 1, 2, ..., 5 years, denoted by smaller Arabic numbers, and finally in the last small block there are the cultures aged 6-10 years together. The smallest Arabic numbers 1, 2, ..., 20 denote the numbers of statuses in the matrix of transition probabilities. Single blocks are connected with relations showing the direction of areal portions transitions, as it has been explained formerly. In the figure mentioned, the clear-cut area and 1st age stage only are being dealt in detail respecting the time. Other age stages are presented in whole, that is with the time span $r = 10$ years. Because in

1. Scheme of the establishment process of the first age stage with connection of further age stages (more details in text).



the 1st age stage and clear-cut area the specification is performed in single years it is necessary to express the whole process by the intensities of a probability transition related to a unit of time, i.e. 1 year. Under such conditions it is necessary to presume the existence of the limits as they follow:

$$\lim_{\substack{t \rightarrow 0 \\ i \neq j}} \frac{p_{i,j}(t, t + \Delta t)}{t} = \mu_{i,j}(t) \geq 0 \quad (6)$$

where: $\mu_{i,j}(t)$ are the intensities of the probability of the process (areal portions) transition from the state i to the state j , while $i \neq j$

$$\lim_{t \rightarrow 0} \frac{1 - p_{i,i}(t, t + \Delta t)}{\Delta t} = \mu_{i,i}(t) \geq 0 \quad (7)$$

where: $\mu_{i,i}(t)$ are the intensities of the output from state i , at the same time:

$$\mu_{i,i}(t) = \sum_{i \neq j} \mu_{i,j}(t) \quad (8)$$

These intensities from the matrix of linear differential equations

$$dp_i(t) = \sum_{j=1}^n p_j(t) \mu_{j,i}(t) \quad (9)$$

On the condition of homogeneity of the process the coefficients of that system (elements $\mu_{i,j}(t)$) are constant and the matrix $\mathbf{A}(t)$ can be denoted \mathbf{A} . The equation can be then written as:

$$\mathbf{p}'(t) = \mathbf{p}(t)\mathbf{A} \quad (10)$$

and also as:

$$\frac{d}{dt} \ln \mathbf{p}(t) = \mathbf{A} \quad (11)$$

Its solution is:

$$\ln \mathbf{p}(t) = \mathbf{A}t + c \quad (12)$$

or:

$$\mathbf{p}(t) = \mathbf{k} \exp(\mathbf{A}t) \quad (13)$$

and/or:

$$\mathbf{p}(t) = \mathbf{p}(0) \exp(\mathbf{A}t) \quad (14)$$

The process described with this equation converges despite the initial vector $\mathbf{p}(0)$ toward the stationary vector denoted as \mathbf{a} . The solution is achieved by Runge-Kutta method of the 4th rank (see Ralston, 1973). The matrix \mathbf{A} is related to the matrix of the transition matrix of the Markov chain as follows:

$$\mathbf{P}(t, t + \Delta t) = \mathbf{I} + \mathbf{A}(t)\Delta t \quad (15)$$

Considering $\Delta t = 1$ year and both matrixes $\mathbf{P}(t)$ and $\mathbf{A}(t)$ as constant in time we can write:

$$\mathbf{P} = \mathbf{I} + \mathbf{A} \quad (16)$$

$$\mathbf{A} = \mathbf{P} - \mathbf{I} \quad (17)$$

Based on the matrix \mathbf{P} we can from the relation (5) and on the condition $\sum a_i = 1$ calculate the stationary vector \mathbf{a} .

The system of equations for this task (after transposition) is following:

$$(\mathbf{P}^T - \mathbf{I})\mathbf{a}^T = \mathbf{A}^T\mathbf{a}^T = 0 \quad (18)$$

$$\sum a_j = 1$$

and because one of the equations is in consequence of condition $\sum a_j = 1$ a linear combination of the others, one equation can be omitted. We used to omit usually the 1st equation (for a_1) and substitute it with equation $a_1 + a_2 + \dots + a_n = 1$. The solution was obtained by a standard procedure within a STATGRAPHICS 4.2 programme in the Institute of Applied Ecology of our university. As the transition probabilities are considered with a different age span r (here 1, 5, or 10 years) to express the effect of the process of establishing the 1st age stage on the transition probability from the 1st age stage to the 2nd (generally all following age stages may be considered) it is only possible to use respective matrix for calculating the stationary vector and deriving the investigated transition probabilities. The formerly mentioned matrix \mathbf{P} (see Koubá, 1973) is not possible to introduce into (1) and

I. Non negative elements of the enlarged matrix \mathbf{P} sensu Fig.1.

Index i, j	$p_{i,j}$						
12,1	.0031	12,6	.0003	12,12	.9	11,12	.195
13,1	.0015	13,6	.0002	13,13	.9	12,13	.0961
14,1	.0013	14,6	.0002	14,14	.9	13,14	.0983
15,1	.0014	15,6	.0001	15,15	.9	14,15	.0985
16,1	.0016	16,6	.0002	16,16	.9	15,16	.0985
17,1	.0027	17,6	.0003	17,17	.9	16,17	.0982
18,1	.0071	18,6	.0008	18,18	.9	17,18	.0970
19,1	.0216	19,6	.0024	19,19	.9	18,19	.0921
20,1	.0900	20,6	.0100	20,20	.9	19,20	.0760

The total ratio of the 1st age stage and the clear-cut are must be:

$$a_1 = 1 - a_2 \quad (19)$$

where: a_2 - a share of the 2nd age stage - is in that stationary vector the element a_{12} .

Then the probability of transition of the 1st age stage into the second one expressed:

$$p_{1,2} = \frac{a_1}{a_2} \quad (20)$$

and the probability of sustaining of the process in the 1st age stage is:

$$p_{1,1} = 1 - p_{1,2} \quad (21)$$

In our example it is:

$$p_1 = 1 - 0.461652 = 0.538348$$

$$p_{1,2} = \frac{0.461652}{0.538348} = 0.85753$$

$$p_{1,1} = 0.14247$$

The matrix presented can only be applied to calculate the transition probability according to (19) - (21) and it only expresses the ratio of the 1st and 2nd age stage.

If a real stationary distribution of single age stages of the clear-cut area and other age stages are intended to be calculated the matrix \mathbf{P} is to be extended. The elements which are to be inserted are listed in Tab.I, the other elements are zero. The stationary vector is presented in Tab.II together with the total share of the clear-cut area, the first age stage, and the share of the 1st age stage and clear-cut area together, and also the share of other age stages. If the elements $p_{1,1}$ and $p_{1,2}$ according to (3) are considered the matrix \mathbf{P} according to (2), which will be used to express the development of the age structure according to the theory of a normal

where: \mathbf{I} is the unitary matrix, \mathbf{E} is the matrix the all elements of which are equal to 1, $\mathbf{Z} = (\mathbf{I} - (\mathbf{P} - \mathbf{A}))^{-1}$, \mathbf{Z}_{dg} is derived from the matrix \mathbf{Z} where all non-diagonal elements were replaced by zeros, \mathbf{D} is the diagonal with the elements $d_{i,i} = 1/a_{i,i}$.

The most important elements are the diagonal $m_{i,i}$ multiplied by the span of the stages r ($r = 1$ for the stages 1 - 10, $r = 5$ for the stage 11, $r=10$ for the stages 12-20). These modified elements $m_{i,i}$ are listed in Tab.II and characterize the investigated process in more time detail. (Theory see e.g. K e m e n y and S n e l l, 1960). The diagonal elements of the matrix \mathbf{M} comply with the relation:

$$m_{i,i} = 1/a_i \quad (23)$$

THE EXPRESSION OF THE EFFECT OF OTHER AGE STAGES

Generally, the possibility of all possible transitions can be considered. Such changes of age stages distribution may be caused by changes in taxation regulations and/or changes in surveying. Such changes are of an unrepeated character and are hardly exceptable. Thus the can hardly be subjected to expression by theory of stationary processes.

The changes evoked by the conditions sub. A.7. can be expressed with the means of the probability of transition from the 1st age stage back into age stages which are usually damaged by snow. These probabilities can be added into the matrixes \mathbf{P} or \mathbf{A} , respectively. Then, the probabilities $P_{i,i+1}$ can be calculated from the formula:

$$p_{i,i+1} = \frac{a_{i+1}}{a_i}, i = 1, 2, \dots, n - 1. \quad (24)$$

and the element p_{ii} from the relation (3). Based on probabilities p_{i1} and $p_{i,i+1}$ the matrix \mathbf{P} of a regular Markov chain can be composed and applied in all formulas of the stochastically based theory of normal forest (see K o u b a, 1975, 1977, etc.).

CONCLUSION

A general expression of the process of establishing the 1st and other age stages with regard to the calculation of transition probabilities has its significance for better parameterization of the stochastically defined model of normal forest.

The stationary distribution of age stages and probabilities of their damage (destroy) form the basis for the optimum control of the conversion process toward a normal forest (K o u b a, 1988, 1989). The derived procedure is at the same time a theoretical basis for the analysis of the processes of age stages establishing, which enables the precisising of our estimates of those probabilities and eliminate possible logical mistakes.

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Kouba J.: (Ústav aplikované ekologie a ekotechniky VŠZ, Kostelec nad Černými lesy): *Odvození zastoupení prvního a dalších věkových stupňů ve stochasticky definovaném normálním lese*. Lesnictví, 37, 1991 (10):807-818.

V práci je provedeno obecné odvození výpočtu pravděpodobností přechodu prvního a dalších věkových stupňů na základě pravděpodobnostního rozboru procesu jejich tvorby a úvahy procesu jejich registrace při provádění prací hospodářské úpravy lesů. Na základě teorie Markovových procesů a řetězů (příp. soustav lineárních diferenciálních rovnic) je odvozen obecný postup vyjádření a výpočtu těchto pravděpodobností. Tento postup umožňuje zpřesnit parametry regulární a homogenní matice pravděpodobností přechodu, které vyjadřují vliv kalamit (přírozeného rizika) v autorem dříve navržené stochasticky definované teorii normálního lesa. Stationární zastoupení věkových stupňů a pravděpodobnosti jejich poškození (zničení) jsou základem pro optimální řízení procesu konverze k takto definovanému normálnímu lesu (K o u b a, 1988, 1989). Odvozený postup je současně teoretickým základem pro rozbor procesů tvorby věkových stupňů. Umožňuje zpřesnit naše odhady těchto pravděpodobností a odstranit možné logické chyby.

normální les; zastoupení věkových stupňů; první věkový stupeň; Markovovy řetězce; soustava lineárních diferenciálních rovnic

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UTILIZATION OF PHOTOINTERPRETATION IN THE DETERMINATION OF FOREST STAND BOUNDARIES

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Žíhľavník Š.: (Faculty of Forestry, Zvolen): *Utilization of photointerpretation in the determination of forest stand boundaries*. *Lesnictví*, 37, 1991 (10):819-829.

By using a convenient combination of classical interpretation signs (topographical elements, tone of grey, texture, shade, shape of subjects) with special forest signs (structure and growth stage of stands) it is possible to increase substantially the rate of identification of forest stand boundaries in photointerpretation on a photogrammetric model. On a photogrammetric model from a pair of black-white air survey photographs on Topocart D, at setting the stereoscopic sign to the breaking points of stand boundaries, a mean coordinate of separate measurements $m_{xy} = \pm 0.34\text{m}$ has been obtained. This accuracy complies with detailed forest survey including the determination of surfaces from model coordinates. In the case of unidentifiable boundaries on the model it is necessary to take a terrestrial bearing, to carry out graphical mapping to the scale of the photograph and to place it on the plotted photograph. In this way it is possible to obtain photogrammetric plotting of the whole area of interest. The given results widen the knowledge in the sphere of photointerpretation and its utilization results in the rationalization of forest survey.

photointerpretation; photometric model; forest stand; boundaries

PROBLEM AND OBJECTIVE

The determination of forest stand boundaries is the subject of forest survey which is carried out at present both terrestrially and photogrammetrically. A specific feature of forest survey is that in spite of using the results of public mapping these are insufficient for the image of a vast, varied and variable forest detail which must be understood as a set of biological, technical and economic factors of the management of forests. In the selection of mapping methods the characteristics of the forest environment are taken into consideration, having specific requirements for forest survey.

It can be noted that in the contemporary forestry practice great attention is being paid to the problem of processing primary information up to the actual preparation of the basic forest map and other special-purpose ones. This is connected with the extraordinary development of instruments for cartographical work, including computers. Thus, we see of a gradual transition from analog to analytical evaluation of the basic forest map, from a classical to the digital one. This is connected with the necessity of introducing forest survey in a built-up automated information system of forest management information system. The graphical record of information represented by the present forest map will gradually fail to comply with

the future necessities of the continuous flow of information in forest management.

The obtaining of initial information represents one of the most serious problems of forest survey. Current practice is generally well prepared for terrestrial surveying (electronic telemeter, diagram tachometer). It must be noted that field measurements are carried out mostly in mountainous forest terrains representing a great part of forests in Slovakia. These measurements are very exacting and they decrease the economy of cartographic work. Therefore, there is an effort to limit them only to the most necessary works (determination of the necessary number of pass points, additional measuring of the forest detail which cannot be determined from the air survey photograph, etc.). From this point of view photogrammetry is of great importance, contributing to the rationalization of cartographical work.

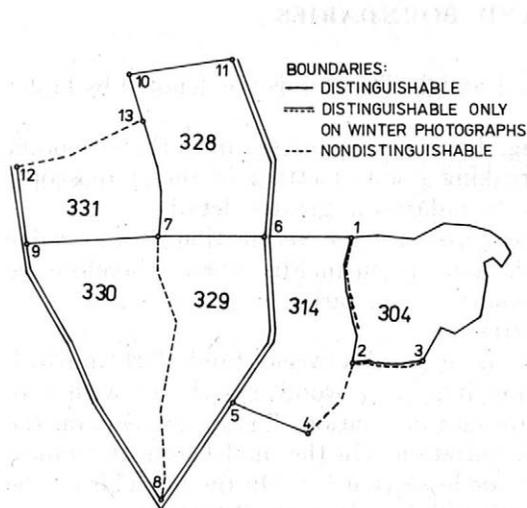
One of the most important planimetric elements in the drawing or updating of the basic forest map and other maps and in the calculation of the area is the forest stand boundary (forest subcompartment). This is the basic lowest permanent unit of the forest space which is to have uniform or at least similar production conditions and convenient shape and dimension (5 - 20 ha). If this is to be a permanent management unit, its boundaries should be represented by natural or artificial terrain elements (mountain ridges, valleys, forest roads, forest rides, etc.) combined conveniently with special forest elements (growth, production and gravitation conditions, operational goals, regeneration methods, etc.).

The determination of breaking points of the forest stand boundaries on a photogrammetric model is characterized by the fact that in their identification the topographical and special forest elements are joined. While the determination of topographical units may be referred to as professional "geodetico-photogrammetric" routine, a special interpretation is required for the determination of forest elements.

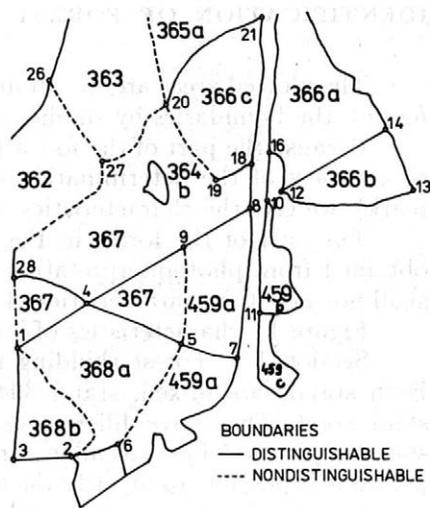
This problem has not yet been given appropriate attention in our forestry. It is interesting that the promising development of photointerpretation in Slovakia and Bohemia during the years 1940 - 1970 has come to a standstill. The works by H a l a j (1949), Č e r m á k (1961), Č i h a l (1959) and others have greatly contributed to the development of forest interpretation. They were mostly aimed at the determination of taxation quantities. Of the significant foreign contributions to the development of the forest photointerpretation during the given period it is necessary to mention B a u m a n n (1957), who synthesized separate knowledge for its utilization in some forestry disciplines (forest management, survey, protection, etc.). This knowledge is still topical as confirmed by many other authors abroad, e.g. H u s s (1984), H i l d e b r a n d t (1975, 1981) and others.

The special feature of photointerpretation is that even if the interpretation keys have been constructed as a group of different interpretation signs (shape and size of objects, tone of image, shade, texture, structure) they cannot be used as clearly and simply as the legend on the map. Different conditions of surveying, differences of the surveyed territories, various kinds of photographs and the differences in their quality, in the methods of their processing and plotting, as well as the skills of plotters must be taken into consideration in the construction and use of interpretation keys. The given facts are strongly expressed in forest photointerpretation.

Therefore, neither this paper does aim at determining the interpretation key for drawing the forest stand boundaries; rather, the aim is to give some general



1. Identification of forest stand boundaries on a photogrammetric model — summer and winter photographs



2. Identification of forest stand boundaries on a photogrammetric model — summer photographs

instruction how to proceed in this work in the case of black and white air survey photographs and their plotting on general-purpose photogrammetric devices.

This paper presents a part of the material from the research subproject of the State Plan of basic research (No. VI-6-5/02.1.2.) "Terrestrial photogrammetric methods of forest survey", finished in 1990.

EXPERIMENTAL MATERIAL

As experimental material we selected groups of stands adjacent to each other in the forest districts of Sielnica and Kováčová of the School Forest Enterprise of the University of Forestry and Wood Technology in Zvolen. These stands form two compact forest areas (Fig. 1 and 2), the structure, growth stage and terrain relief of separate stands being mostly different.

For the solution of the given problem we had used materials from terrestrial measuring, photogrammetric plotting and from the photointerpretation of the photogrammetric model. By terrestrial measuring, using the method of polygonal tracts we determined the boundaries of separate stands and the necessary points for the orientation of photographs on Topocart D. Simultaneously we carried out the description of stands on the investigated territory in accordance with the forest management plan (representation of species and their heights, stand age, stocking, exposure, inclination of the terrain, description of the growth stage and the location of individual tree species in the stand) which was further used for the identification of boundaries on the photogrammetric model. For the purpose of plotting we used black-and-white air survey photographs from the winter and summer periods to a scale of 1:10800 to 1:7800 (for territory in Fig. 2 only from summer to a scale of 1:7800) with a longitudinal overlap of the pair of plates $p = 60\%$. The plotting of photographs was carried out on a surveying apparatus Zeiss Topocart D connected with the electronic registration device Coordimeter G with a printer and a drawing table.

IDENTIFICATION OF FOREST STAND BOUNDARIES

The plotted areas are shown in Fig. 1 and 2. The stands are denoted by larger figures, the boundaries by smaller ones.

Because the part of the forest in Fig. 1 was also evaluated from the viewpoint of accuracy of the determination of breaking points (setting of the stereoscopic mark), we give the characteristics of the boundaries in greater detail.

The part of the forest in Fig. 2 was used for the verification of knowledge obtained from photointerpretation in the part given in Fig. 1 and therefore we shall not give the characteristics of its separate boundaries.

Figure 1 - characteristics of boundaries:

Section 1-2: Forest skidding road. Boundary between stands 304 and 314. Both stands are mixed, stand 304 is medium stem wood, stand 314 with thin stem wood. They have different exposure and inclination. These elements on the stereoscopic model do not allow for differentiation. On the model from the winter period it is possible to identify the forest road - section 1-2. On the model from the summer period a part of this road is unidentifiable. In point 2 there is a crossing of forest roads which can be identified on the model.

Section 2-3: Forest skidding road. Boundary between stands 304 and 305. The stand 305 is mixed. The stands have different exposure, the inclination being approximately the same. The boundary can be identified only on the model from the winter period because around the forest road there are broadleaved species and on winter photographs in leafless state they provide a better view of the inner part of the stand. In point 3 the forest road passes to a meadow.

Section 3-1: Forest margin. It is well identifiable on the model. From the planimetric viewpoint it is very complex having many curved points.

Section 2-4: Forest skidding road. Boundary between stands 314 and 305. Unexpressive on the model.

Section 4-5: Boundary along the line of steepest slope between stands 314 and 313. On the model it is identifiable because the stand 313 consists of two layers which can be distinguished. Identification is also possible due to the different age of the stand and the related different tree heights.

Section 5-6: Forest transport road. Univocally identifiable on the model.

Section 6-1: Forest margin. Well identifiable on the model.

Section 6-7: Boundary between stands 328 and 329. The stands are of different structure and growth stage. Stand 328 is mixed, small pole timber, average age 30 years. Stand 329 is mixed, small pole timber, average age 60 years. These differences are helpful in determination of the boundary on the model.

Section 7-8: Boundary between stands 329 and 330. Both stands are of approximately same structure, they have the same growth stage, different exposures (south-east, and/or south-west) and relatively large inclinations of the terrain (45 %, and/or 30 %). The boundary passes through the crest line which is very rounded, unexpressive on the model and owing to the same structure and growth stage of the stands the boundary cannot be identified.

Section 8-9: Forest transport road. Univocally identifiable on the model.

Section 9-7: Boundary between stands 330 and 331 is well identifiable. Stand 331 consists of two layers. The first one is bulky stem wood with prevail of beech

(93 %) and with the average age 95 years due to which they can be differentiated very well from stand 330 (small pole timber, mixed stand, average age 65 years).

Section 7-10: Boundary between stands 328 and 331 (also part of 332). In spite of the fact that it is the question of a rounded crest line, unexpressive on the model (continuation of section 7-8) the boundary can be well identified due to the different structure and growth stage of stands.

Section 10-11: Boundary between stands 328 and 327. Stand 327 consists of two layers. The first one is bulky stem wood with the prevail of beech (88 %) and with the average age of 105 years. Due to the different structure and growth stage of stands the boundary is well identifiable.

Section 11-6: Forest transport road. Univocally identifiable on the model.

Section 9-12: Forest transport road. Univocally identifiable on the model.

Section 12-13: Boundary between stands 331 and 332. Stand 332 consists of medium bulky stem wood, mixed, with the prevail of beech (89 %), with the average age of 95 years. Although stand 331 consists of 2 layers, the first one is similar to stand 332, the stands have the same inclination and exposure and the boundary cannot be identified on the model.

From the given characteristic it follows that when taking into consideration all the factors (visible planimetric elements, height arrangement of the terrain, structure and growth stage of the stand and further interpretation signs, such as e.g. the tone of grey, texture, etc. (it is possible to identify most of the forest stand boundaries on the photogrammetrical model. In our case, according to Fig. 1 it was possible to identify approximately 78 % of all boundaries (when using the summer and winter photographs, with the summer ones approximately 73 %), according to Fig. 2 approximately 70 % of all boundaries (here we had used only summer photographs).

Boundaries which could not be identified on the model (marked by dot line in Fig. 1 and 2) were illustrated graphically in the scale of the photograph on a translucent foil and supplemented on the photograph and thus also on the model based on terrestrial measuring (polygon or compass tension).

CHARACTERISTIC OF FOREST STAND BOUNDARIES

According to the possibility of identifying the forest stand boundaries on photogrammetric model they can be divided into 4 groups:

- 1 group: Boundaries with univocally identifiable course based on planimetric elements visible well on air survey photographs, e.g. stand margin, forest roads, streams and rides, etc.

- 2 group: Boundaries identifiable based on the differentiation of an expressive space arrangement of the terrain, e. g. sharp ridges, valleys, etc.

- 3 group: Boundaries identifiable based on the structure and growth stage of the stand (especially tree species composition, height and age articulation of the forest, stand mixture, canopy and internal structure of the stand) and further specific interpretation signs (shape, dimension, tone of the crown shade, texture, structure).

- 4 group: Unidentifiable boundaries, e. g. stands with full canopy or with the same growth stages consisting of tree species which cannot be determined exactly from air survey photographs.

Discussion on the identification of stand boundaries on a photogrammetric model

In last chapter we have divided the forest stand boundaries into 4 groups according to the possibility of their identification on a photogrammetric model from air survey photographs. Even if the course of boundaries is well identifiable problems often occur in the concrete determination of breaking points. Let us make a more detailed analysis of the problem of setting stereoscopic marks of the plotting device to individual points of the boundaries.

In the first group it is possible to set the mark to the breaking points without any problem and with certainty if the boundary is created by a road, clear ride or by any other univocal planimetric element. At the first margin when the stand boundary is theoretically represented by a connecting line of the stem centres of trees on the margin, an uncertainty takes place in the setting in dependence on tree species. Theoretically the stereoscopic mark should be set to the stem centre which may be regarded as the crown centre. The crown and its centre are well identifiable with spruce and fir which are of a pyramidal shape, fir differing from spruce by a blunter crown top. With pine the crowns are not so regular, their tops being blunter than with spruce and in some mature trees the pyramidal shape passes to a parabolical or oval one. With broadleaved species the crowns are mostly irregular and it is difficult to determine their centre. A better situation is on winter-photographs when the leaves are missing and on the stereoscopic model it is possible to distinguish the stem and to set to it the stereoscopic mark on the terrain or to shift it to the estimated centre. If the stand margin is created by crowns of the marginal trees which reach the ground and form a stand cover, if they are close to each other and if they grow together with shrubs or trees of the younger growth stage, the identification of separate trees and the setting of the mark on them are difficult and uncertain. The crown centre is estimated and a casual knowledge of the stand structure improve the setting.

In our plotting such a case occurred e.g. on section 3-1 (Fig. 1) in the direction from point 3 to point 1 about to two thirds of the section. The setting of the mark was simpler on the model from the winter period because it was mostly the question of broadleaved species and shrubs without leaves during this period.

In the second group the course of boundaries can be well determined on ridges, i.e. shapes of the terrain with a sharper marking of the crest line (the form line is very narrow, practically coinciding with the crest line), the stand boundaries being guided on it. On the crown canopy on the model it is possible to differentiate the sharp boundary line. The same is valid with deepened forms where the slopes contact in the edge and the form line is very narrow, practically coinciding with the thalway. In the case of ridges, resp. of a valley with a slightly rounded or convex top, and/or valley part, the determination of the boundary based on height differentiation of the terrain is impossible. In our case it is the question of section 7-8 (Fig. 1) or 20-28 (Fig. 2) where the ridge is relatively rounded, not clear enough on the model, thus, the boundary between stands cannot be determined.

In the third group there are wide possibilities for determining the breaking points of boundaries. The separate marks of the stand structure help the identification in different ways. The boundary between broadleaved and coniferous stands may be differentiated very well. This consists in the characteristic image of the crown arch (especially with stands with full canopy), in the characteristic drawing of the crown on separate trees distinguishable on the model, in the different tone of grey or in the shape of the shade. On winter photographs this identification is even simpler because broadleaved trees do not create an expressive crown arch, make possible a view into the stand interior, separate stems creating a characteristic structure in dependence on stocking, the tone of the image of the broadleaved stand in the photograph being lighter. In our case it is typical in section 7-10 (Fig. 1) between stands 328 and 331 because at the boundary there is a prevail of spruce in stand 328 and beech in stand 331.

The differentiation of the boundary between broadleaved stands, even if they are of another kind, is relatively complex. An easy differentiation of broadleaved species from coniferous ones is possible in the first place by a completely different crown structure because the broadleaved ones mostly do not have a continuous stem up to the top. The shapes of their crowns are more influenced by canopy losing their characteristic shape in stands. Most of the broadleaved species with a canopy are illustrated in the photographs by tone with a similar or same shape, this making their accurate differentiation on black-white panchromatic photographs practically impossible. The identification of boundaries between broadleaved stands is possible by expressive height differences or by different growth stages, such as, e. g. between stands 327 and 328 in section 10-11 (Fig. 1).

In the fourth group where the boundaries cannot be identified on the model according to any signs it is necessary to complete the model by breaking points based on terrain measuring. The setting of the stereoscopic mark on them is only the question of routine handling of the device.

JUDGEMENT OF THE ACCURACY OF IDENTIFICATION OF BOUNDARIES

The determination of forest stand boundaries on Topocart D consisted in the determination of rectangular coordinates of breaking points of a boundary on a photogrammetric space model after carrying out relative and absolute orientation of a stereoscopic pair of air survey photographs from the territory of interest. The description of the plotting photogrammetric device Topocart D and the procedure of relative and absolute orientation of photographs is given in the work of the author (Ž í h l a v n í k, 1989). Further, according to a fixed programme in the electronic recording apparatus Coordimeter G with a printer model rectangular coordinates x and y of the breaking points were recorded.

The initial values of coordinates were set to the main point of the right photograph.

Before the beginning of plotting, on the left projector on the diapositive of the air photograph, we had placed a translucent foil with geographically illustrated breaking points of the sections of unidentifiable boundaries on the model. Identification was carried out in accordance with pass points. By this way we could

determine on the model and shift from it the coordinates of all breaking points of the boundaries. This method may be considered as sufficiently accurate if we take into consideration that air photographs used in forestry for mapping purposes are in the scale 1:7000 to 1:14000, the basic forest map being made up in the scale 1:5000.

In plotting we proceeded in such a way that by means of handwheels (x, y) and a foot wheel (height setting of Topocart D) we have set the stereoscopic mark as for position and height to the breaking point of the stand boundary on the model, on the numerical keyboard of the Coordimeter we had set the serial number of the point and after visual checking of data on the display we switched on the printer and recorded the coordinates. Plotting was carried out on models from winter and summer photographs. The shifting of coordinates of each point had been carried out 5 times. Such plotting was carried out only for the territory given in Fig. 1.

For the judgement of the accuracy of the setting of the stereoscopic mark on the breaking points of stand boundaries we had chosen the following method:

- a) Calculation of the arithmetic mean of the x and y coordinates of each point from all the five measurements:

$$\bar{x} = \frac{\sum x_i}{n}, \quad \bar{y} = \frac{\sum y_i}{n} \quad (1)$$

where:

i - is the serial number of measuring ($i = 1$ to 5)

n - is the number of measurements ($n = 5$)

- b) Calculation of corrections δx_i and δy_i :

$$\delta x_i = \bar{x} - x_i, \quad \delta y_i = \bar{y} - y_i \quad (2)$$

- c) Calculation of mean errors m_x and m_y of a separate measuring:

$$m_x = \pm \sqrt{\frac{\sum \delta x_i^2}{n-1}}, \quad m_y = \pm \sqrt{\frac{\sum \delta y_i^2}{n-1}} \quad (3)$$

- d) Calculation of the mean coordinate error m_{xy} of a separate measuring:

$$m_{xy} = \pm \sqrt{0.5(m_x^2 + m_y^2)} \quad (4)$$

- e) Calculation of the mean coordinate error m'_{xy} of the arithmetic mean:

$$m'_{xy} = \pm \frac{m_{xy}}{\sqrt{n}} \quad (5)$$

The calculation did not include those points which had been determined by terrestrial measuring and supplemented in the photograph. These points are univocally identifiable and a casual error in the setting of the stereoscopic mark is not caused by the identification of the point on the model of the previously

described interpretation signs. It is only the question of the inner accuracy of the apparatus, of the fineness of the point depiction, or of the plotter's personal error.

The average values of all the measurements are:

- for photographs from the winter period: $m_{xy} = \pm 0.28$ m, $m'_{xy} = \pm 0.13$ m
- for photographs from the summer period: $m_{xy} = \pm 0.31$ m, $m'_{xy} = \pm 0.14$ m

Practically it is possible to consider the results from both pairs of plates as equivalent. The somewhat better results from the winter photographs may be explained by the fact that with broadleaved species in leafless state there is a better view of the inner part of the stand which allows better identification of e. g. the boundary passing over the forest road, broadleaved species differing from the coniferous ones, etc.

The average values are:

$$m_{xy} = \pm 0.295 \text{ m}, \quad m'_{xy} = \pm 0.135 \text{ m}$$

The results originate from five measurements in each point. It was the question of obtaining the widest possible experimental material also for further processing (transformation of model coordinates to terrain ones, calculation of areas and judgement of their accuracy. Such a number of measurements for practical purposes is not very convenient because it would prolong the plotting. To find the minimum necessary number of measurements for reaching the prescribed accuracy we had calculated the mean coordinate errors m_{xy} and m'_{xy} also for two, three and four measurements.

The average values from all the measurements are:

	2 measurements	3 measurements	4 measurements
$m_{xy} =$	0.34 m	0.32 m	0.31 m
$m'_{xy} =$	0.24 m	0.18 m	0.16 m

In accordance with the Methodic instruction. (1983) for mapping in the fifth class of accuracy within which forest survey is being carried out, the mean coordinate error for auxiliary measuring points $m_{xy} = 0.35$ m is prescribed. For the necessary planimetric points the Czechoslovak Standard 01 3410 - Large-scale maps (1978) prescribes in the 5th class of mapping accuracy the mean coordinate error $m_{xy} = \pm 0.50$ m.

If we would simultaneously consider the mean error m_{xy} , and/or m'_{xy} in the accuracy of setting the stereoscopic mark as an error of position in the determination of the breaking point it appears that for fulfilling the given criteria two measurements are sufficient which ensures the control of measurements and is adequately economical.

The sufficient accuracy of the given method of determination of the forest stand boundaries was confirmed by the calculation of the areas of plotted stands from the obtained model coordinates. The results are fully comparable with the planimetric determination of areas.

More detailed analyses of accuracy, as well as testing the normality of errors in the determination of the position of breaking points of forest boundaries (proved

agreement of selection with a normal basic population) are given in the work of the author (Ž í h l a v n í k, 1990).

EVALUATION OF RESULTS AND CONCLUSION

The aim of this paper has been pointing out of the wide possibilities of utilizing photointerpretation in the determination of forest stand boundaries on a photogrammetric model consisting of a pair of black-white air survey photographs. This is given by the possibility of convenient combination of classical interpretation signs (topographical elements, tone of grey, texture, shade, shape of subjects, etc.) with special forest ones (structure and growth stage).

The combination of winter and summer photographs is convenient for photointerpretation.

On the photogrammetric model on Topocart D, in the setting of stereoscopic mark to breaking points of stand boundaries the mean error of individual measuring $m_{xy} = \pm 0.34$ m was obtained. For reaching this accuracy it is necessary to carry out two measurings (settings of the stereoscopic mark). This accuracy conforms to the detailed forest survey and the model coordinates can be utilized also for the analytical calculation of the area of forest stands which is comparable with the planimetric determination of the area.

We recommended the following procedure in forestry practice:

- description of stands and compilation of the sketch of the course of their boundaries,
- creation of a model on a universal photogrammetric apparatus for air survey photographs and the identification of stand boundaries by photointerpretation,
- terrestrial bearing of unidentifiable boundaries, their graphical representation in the scale of the photograph and insertion into the photograph which serves for the creation of the model,
- plotting of the course of boundaries, resp. shifting of the rectangular coordinates of breaking points from the model.

The obtained results represent a contribution in the sphere of obtaining initial information for forest survey, they widen the knowledge from the sphere of forest photointerpretation and its practical utilization in forest survey means rationalization and increase of economy.

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Vhodnou kombináciou klasických interpretačných znakov (topografické prvky, tón šede, textúra, tieň, tvar predmetov) so špeciálnymi lesníckymi znakmi (štruktúra a rastová fáza porastu) možno pri fotointerpretácii na fotogrametrickom modeli podstatne zvýšiť identifikovateľnosť hraníc lesných porastov. Na fotogrametrickom modeli z dvojice čiernobielych leteckých meračských snímok na Topocarte D sa dosiahla pri nastavovaní stereoskopickej značky na lomové body hraníc porastov stredná súradnicová chyba jednotlivého merania $m_{xy} = \pm 0.34$ m. Táto presnosť vyhovuje podrobnému lesníckemu mapovaniu, vrátane určovania výmer z modelových súradníc. V prípade neidentifikovateľných hraníc na modeli je potrebné tieto terestricky zamerať, graficky zobrazíť v mierke snímky a vložiť na vyhodnocovanú snímku. Tým sa dosiahne možnosť získania fotogrametrického vyhodnotenia celého záujmového celku. Uvedené výsledky rozširujú poznatky z oblasti fotointerpretácie a ich využitie znamená racionalizáciu lesníckeho mapovania.

fotointerpretácia; fotogrametrický model; hranice lesných porastov

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TOPICAL NEWS

RECENT RESULTS OF BIOMETRICAL AND MANAGEMENT RESEARCH IN THE FORESTRY OF THE CZECH AND SLOVAK FEDERATIVE REPUBLIC

A. Priesol

Results of basic research in the field of forest species biometry and in forest management are evaluated. The data under evaluation refer to the results recently attained at universities, institutes of the Academy of Sciences and specialized research institutes in the CSFR. The evaluation covers the results of research on the growth and increment regularities within the forest stands, methods and means of determination and measurement of forestry production, growth processes and forest management in areas exposed to industrial immissions; others are associated with the modelling, regulation and forecasting of production in forest stands (and groups of forest stands), and also with the mathematic methods of forest production management.

In recent years (1986–1990), the over-all societal target set before basic forestry research has been to expand the theoretical and practical knowledge of the growth and production of forest species and forest stands for improved management and for more precise determination of forest production, including that in forest exposed to immissions. Efforts have been taken to develop a solid base for an optimization and regulation of production and rationalization of work, also using mathematical methods and computer technology.

The scientific targets included investigation of regularities of the growth and increment of forest species and forest stands, including those exposed to immissions and elaboration of the theoretical grounds for, and construction of, yield tables (by assortment and by value). Further, the objective was to examine new methods and means of determination of forest production, methods of optimization and regulation of production and possibilities of using mathematic methods of forest production management, including the management of random processes, biological information and modeling of the effect of abiotic factors on the process of growth of forest ecosystems.

The issues under study fall within five problem ranges upon which research institutions in Czechoslovakia have been working. These are: The growth and increment regularities in forest stands, Methods and means to determine forest production, Growth processes and forest management in areas exposed to immissions, Optimization of the rotation period, modelling and regulation of production in forest stands, and Mathematic methods of forest production management.

THE GROWTH AND INCREMENT REGULARITIES OF FOREST STANDS

Efforts were taken to study the problems of theoretical grounds for improving the yield tables for the main woody species in Czechoslovakia, the problems of the growth processes in unmixed beech stands, the structure, development and production in the natural forests, and the structure, development and output in the special-purpose forests.

Yield tables (by assortment and value) were derived for spruce, fir, pine, oak and beech and the process of derivation of the site quality curves for poplar I-214 was analyzed (P e t r á š and H a l a j, 1990). The assortment-type yield tables indicate, depending on site quality and age, the percent proportion of graded volumes out of the main and secondary stands and out of total production. These tables were developed from mathematic models of the new yield (1980) and graded volume tables (1988) of woody species. The tables indicate the % of the quality classes of logs: I - veneer, II - plywood, IIIA, IIIB - sawn timber, V - fibre, VI - fuelwood.

Based on age and site quality, the yield tables give the value (in Kčs) of the wood stock of "derbholz" outside bark for the main and secondary stand, and also total production. On the basis of mathematic models of graded volume yield tables and wholesale wood prices, applicable until the end of 1989, the value-based tables were worked out for the five main species. The value tables give the gross cashflow in Kčs per ha, which represents the earnings from logging (stand improvement cutting and regeneration cutting) and the net earnings, derived from the gross cashflow by deducting the prime costs of forest harvesting (felling, skidding, primary conversion and hauling of the timber).

When deriving the height curves of quality for poplar I-214, we checked the possibility of using the S l o b o d a (1971) differential first-order equation, based on the following relations:

$$\frac{dh}{dt} = h'(t, h) = \frac{b_1 \cdot h}{tb_2} \cdot \ln\left(\frac{b_3}{h}\right)$$

The empirical values were smoothed by regression according to this equation to derive the regression coefficients $b_1 - b_3$ for an integral mathematic model of the height curves of quality. According to the basic statistical characteristics of the smoothing it is clear that the height increment ($\frac{dh}{dt}$) largely depends not only on the height (h) and age (t) of stand but also on a number of other factors. Positive systematic deviations at an age of 15-20 years also occurred in the regression smoothing. For a wider use of this procedure, it is still necessary to analyze in detail, and to complement, the empirical material for a wider range of quality and age.

Within the growth processes analysis of equal-age pure beech stands, repeated measurements and tending practices were conducted in three research areas - Topolčany, Gápel and Nitrianske Rudno (H l a d í k, 1990). Detailed mathematico-graphical materials were derived from all the tending practices and biometrical measurements, and the development between the fifth and sixth thinnings was an-

alyzed. The results confirm to-date trends of development in the control, low and crown level areas of the separate permanent research sites.

Research on the structure, development and output in special-purpose forests was aimed at verifying the methods of changing a felling-system forest into a selection-system forest (R é h, 1990). Conversion by successive regeneration and tending was used for the reconstruction of the felling-system forest with a changed species composition. Another two permanent research areas, one at Matliare and the other at Sliáč, were added to the two at Kováčová. Both the statical and dynamical changes in the chief taxation quantities were analyzed within the long-term research programme in these research areas.

New information and knowledge has been gained during the research into the structure, development and output in the natural forests; the new knowledge involves findings on the growth and production capacities of wood species, on the regeneration processes, long-term dynamic changes in the stand structure and on the development regularities in the natural forests of vegetation grades 1, 2, 3 and 7 (K o r p e l, 1987-90, 1990). Analyses of the age and increment allowed to determine more precisely the length of the development cycle, the development stages and development phases. Traits of stability in the stand formations were characterized in dependence on the development phases. Quantitative criteria were identified and defined for the determination of the area range, developmental independence, and the environmental and production equality of the forest ecosystems of vegetation grades 1, 2, 3 and 7. Those parts of the ecosystems (typological units, height zones) were identified in which a good functional effectiveness is permanently maintained at a high level and in which no tending and no felling practices are needed for maintaining the protective functions.

METHODS AND MEANS OF DETERMINING FOREST PRODUCTION

Biometrical methods of forest inventory, terrestro-photogrammetrical methods of forest mapping, the use of remote sensing in surveying the state of the forest, and the methodical fundamentals of dendroclimatology were investigated during the research project.

The investigation of the biometrical methods of forest inventory involved attempts to solve the issue of applying the principle of mathematico-statistical selection with unequal probabilities and a combination of the estimation and measurement of quantities in determining the state of the forest (Š m e l k o, 1987). This is a new approach, leaving out the traditional selection of the units (trees, stands) irrespective of their dimensions and a greater probability is assigned to those units which are larger, i.e. those which are of a greater weight in the over-all result of the inventory. At the same time, the inventory is simplified and becomes more economical because the needed data are determined for each unit of the set just approximately (by estimation, or by using older data); accuracy is then given to it on the basis of a conversion coefficient ($q - x$ measured : x estimated), or on the basis of a regression equation (y corrected = f/x estimated), which are derived from the relationship between the measured data and the estimated data within a comparatively small number of units.

The combined method of inventory itself (estimation - measurement) was de-

veloped in two options: for the experimental areas and for whole stands.

The ranges for differentiation grades 1 - 2 - 3, needed for the determination of the stock according to the tentative areas variant with $a \pm 10\%$ prescribed accuracy (at $P = 0.95$) are as follows: $n_1 = 14 - 45 - 90$; $n_2 = 7 - 15 - 30$. The n_1 ranges are greater than with the traditional procedure of circular tentative areas but the total costs of the inventory process will be 18 % lower, on an average.

From the investigated options in the variant for whole stands, no substantial differences were found between the random and systematic PPP selections: it was confirmed that in the precision-giving stage it is better to use quotient q rather than simple regression between the measured and estimated data.

In addition, a trial was attempted with the application of a two - stage (PPP) selection also for the determination of the stand height curve, using the relation $h = f(d_{1,3})$ (Š m e l k o, 1990). Two different options were used - h and also d estimated, h estimated and d measured, and the curves derived in this way were compared with the accurate curve of the basic set, defined from the h , d measured on all trees in the stand. As confirmed, the corrected estimates well corresponded with the basic set, and a saving of about 30 % of the field work was achieved.

The following three problems were solved within the testing of the terrestrial-photogrammetric methods of forest mapping (Ž í h l a v n í k, 1990):

- a) Determining the position points in afforested areas, using long polygonal stretches, where it is recommended to follow the Methodical Instructions for Drawing the Large-scale Basic Map of the CSFR (1983);
- b) Using aerial winter photos for forest mapping, for which it is recommended to combine the interpretation of the winter photos with that of summer photos to expand the potential possibilities of interpretation and also to use it for other forestry disciplines;
- c) Photogrammetric identification of the boundaries of forest stands: using a photogrammetric model, constructed from the winter/summer combinations of photos on Topocarte D, a mean co-ordinate error of $m_{xy} = \pm 0.34$ m was reached with shifting the rectangular co-ordinates of the breaking points of forest stands boundaries; this level of error fully meets what is needed for detailed mapping of compact territory units in accuracy class 5. The model co-ordinates can also be used for direct analytical calculation of forest stand area. The obtained accuracy compares favourably with that achieved when polar planimeters are used for area measurement.

When identifying the boundaries of the stands and their breaking points, it is necessary, besides the traditional interpretation traits (topographic characters, grey colour tone, texture, shadow and others), to use also special forestry traits: stand structure and stand growth phase. Those boundaries which cannot be identified on the model should be measured on the ground and drawn to the same scale as the photo; the breaking points should be marked on a transparent film and put onto the photo inside the projector of the evaluating apparatus.

The research programme concerning the use of remote sensing for the determination of the state of the forests (S c h e e r, 1990) included efforts to solve three subproblems:

- a) Determining the proportions of different species by the selection method, using multispectral photos. It can be concluded from the results and experience

obtained that the multispectral photo method, combined with the selection procedures, is suitable for the identification of species and for determining the percentual proportions of the areas each of the species covers; this is so mainly in larger expanses of territory under more or less extensive conditions.

b) Determining the mean (dominant) height of the stands, using the aerial photo profiles. The aerial photo profiles were measured on the Topocarte D, using a stereoscopic model to a scale of 1:10000; the scale of transforming them into the map form was 1:2000. The mean heights of the photo profiles were systematically underrated ($\bar{x}_d = \pm 1.8$ m, 6.6 %). Besides the height profiles we also measured the heights of individual trees. The natural variability in repeated measurement was comparatively great, 0.7 – 6 %, mainly owing to the influence of the adjustment of the direction of the measuring mark.

c) Determining the forest stocks, using aerial photos in combination with estimation and measurement of the quantities. On the aerial measurement photos to a scale of 1:7000, the stock of beech forests at harvest maturity was estimated on the basis of the photo measurement of the widths of the crowns and on the basis of the derived regression between the mean crown width and the stock. The estimated photo stock and the area of the stands allowed to compile a list from which the stands were selected by the PPS and PPP selection methods. In the selected stands the stock was accurately determined for calculating the conversion coefficients to calculate the stock for the whole set of stands.

Systematic PPP selection (62 808 m³), having a mean error of $s_{\bar{x}} = \pm 6.1$ % was the closest to the accurate value of the stock for the set of stands (58 324 m³).

In the investigation of the methodical principles of dendrochronology, attention was focused on further development and use of the method of annual ring analyses in applications to different areas of natural sciences, social sciences and national economic studies.

As to the methodical point of view, optimum approaches were developed in the testing of the significance of the statistical quantity of parallelism, used in the verification of the results of measurements in annual ring analyses and in dating the annual ring series (J a č k a, 1988). The theoretical assumption of the random distribution of the value of parallelism was confirmed by the calculation of characteristics in random-selected sets which differed from each other in their extent.

Another methodical issue in evaluating the time series of annual ring widths is the evaluation of the rate of variability and the mutual relationships between the separate annual ring series and between the factors underlying the growth of the wood. To complement the hitherto practiced applications of the coefficient of correlation and the parallelism percentage, the possibilities to use spectral analysis were checked on the experimental material of the annual ring standards of spruce in the territory of Bohemia and Moravia. The proportions of the frequency components are expressed by spectral density; the so-called coherence and phase quotients are introduced for the quantification of the correlations between components with the same frequencies.

The coherence and phase quotients were used to characterize the relationships between the development of increments in the different geographical regions and between the increment of spruce trees and the changes in climatic factors.

As to the dendrochronological dating, wood samples were analyzed, coming

from different historical buildings and various excavations and finds (mainly in South Bohemia, including Tábor and České Budějovice) (V i n š, 1986).

GROWTH PROCESSES AND FOREST MANAGEMENT IN IMMISSION-EXPOSED AREAS

The issues of growth processes were studied in the forests exposed to immissions, including their management in space and time and the economic evaluation of the effect of the immissions on the business side of the management of forest establishments.

Within the investigation of the growth processes in immission-affected forests, the height and diameter development trend, and the change in quality depending on age, were derived for diameter grade 55 (P o l á k, 1990). The obtained data differ from the model of the currently used Schwappach growth tables and are in keeping with the finding that spruce stands at a higher altitude and those at sites of poorer nourishment quality are more sensitive to air pollution. During the annual ring studies, standardization functions were tested, of which the following proved to be suitable: the exponential functions, the Korf function and the rational fraction function with specific conditions. The Korf function was found to be generally applicable. It follows from the annual ring analyses that the changes in the normal development of diameter increment can be well derived from the median annual ring series, obtained as a result of determining the average annual increments. Attempts to quantitatively describe the effect of environmental conditions on these changes on the basis of the available information have still been unsuccessful.

As to the investigation of the management of immission-affected forests (S i m o n, 1990) by experimental determination in different regions of Moravia and Silesia, the diameter increment was found to be markedly reduced by exposure to the immissions; it was also observed that the state of health of the trees and stands, possibly with a forecast of future development, has to be given a sound objective evaluation. The investigation demonstrated the applicability of the method proposed by Professor W a r i n g e r of the Oregon University, who designed it originally as a method of evaluation of the vitality of trees in thinning experiments. A system of spatial management was proposed for the immission-exposed forests; the system is integrated in an ecological framework. Importance is also attached to the findings concerning the state of health of beech, including the newly developed system of evaluation (using diagnostic traits); the same applies to the new methods of the increment analyses of mountain pine stands etc.

The research concerning the economic evaluation of the effect of immissions on the output of wood mass (L u k á č, 1990) involves efforts to find solutions to the issues of the influence of immission damage to forests upon the economic results of forest establishments management. The specific problems of the economic evaluation of immission-affected forests are investigated in selected forest establishments by evaluation of the losses in quantitative and financial expression, with recommendations concerning the optimum time of abolishing the affected stands and renewing them, in dependence on the levels of damage.

The financial expression of the losses in wood output is based on the financial expression of the price of the land, on the financial expression of the price of the

wood mass, on the reduction of the increment, on forest products quality losses, and on losses caused by increased direct costs. Attention is paid to the effect of exposure to industrial exhalations on the performance of silvicultural and exploitation work. The development and analysis of changes in the parameters of production economy are evaluated within a time series by evaluating the organizational units with different levels of immission damage. Measures to be taken to reduce the losses are suggested.

OPTIMIZATION OF THE ROTATION PERIODS, MODELLING AND REGULATION OF PRODUCTION IN FOREST STANDS AND WITHIN FOREST STAND SETS

The research efforts have been focused on the problems of optimizing the harvest maturity of the stands, on the quantification of immission damage of the forests as a basis for the time regulation in forests, on the regulation of forest exploitation levels according to the basic parameters and probability calculation, and on the exploitation percent parameter.

The researchers who investigated the issues of optimizing the harvest maturity of the stands developed proprietary user programmes with a dialog-type mode of work for the formation and use of an experimental base for the optimization of the elements involved in time-based forest management. They also derived the target diameter grades and age levels for the technical harvest maturity and the ages of volume and value harvest maturity. A methodical procedure was proposed for the determination of the optimum circulation and regeneration periods on the basis of the interdependence of the categories of technical, volume and value-based maturity (Š u š k a and M a j o r o š, 1989).

The results indicate that the circulation times have to be lower (at groups of stands [gs] 35 they should be within an interval of 70 - 115 years, with an optimum of 85 - 105 years; at groups of stands [gs] 45 within an interval of 75 - 110 years, optimally between 80 and 100 years) than required by the standards (Decree No. 14).

The derived optimum regeneration periods, compared to the standard ones, are at the upper boundary of the latter (at [gs] 35 the optimum is 40 years and at [gs] it is 30 years); this requires finer methods of management.

The methods used in the investigation and the software developed on their basis and applicable to the available digital computers allow for differentiated determination of selected elements of time management from the viewpoints of production value on the basis of data contained in the data base of Lesoprojekt AIS HÚL.

The research concerning the determination and quantification of the damages causes to forests by industrial immissions allowed to verify a new method of objectifying the determination of damage grades and extents (the KHÚLaG method - 10 tree test areas) and to acquire primary data on the quantification of the effect of the damage on the diameter and volume increment of the spruce stands of the Kysuce-Orava Beskids Mts. area (P r i e s o l et al., 1990).

The results indicate that: a) the average value of the damage grade character-

izes the average grade of the state of health (damage) of the unit under study. On the basis of the derived dependence of the damage grade on the relative proportion of the number of trees at each damage grade, the stands can be included in damage zones according to an objective criterion, i.e. the damage grade; b) the effect of the damage grade and age on diameter increment was not found to be significant at all levels of both factors, nor were the factors always observed to interact. After elimination of age, statistical significance of the differences in diameter increments manifested itself at all levels. In calculation according to the age classes in comparison with the zero one (with a 100 % growth rate), the rate of growth declined to 86 % at damage grade 1, to 72 % at damage grade 2 and to 50 % at damage grade 3.

In calculation according to diameter classes, the growth rate declined to 84 % at damage grade 1, to 74 % at damage grade 2 and to 48 % at damage grade 3; c) research on the effect of climatic factors on the diameter increment of the damaged stands confirmed the conclusions arrived at by foreign authors, according to whom the variability of the diameter increment of trees significantly decreases at a higher damage grade (grades 2 and 3) at maximum and minimum levels of average rainfall and average annual temperatures, as compared with variability in healthy trees (grade 0); d) the quantitative level of output volume markedly decreases with damage grade. In comparison with the zero trees it declines by 10 % at damage grade 1, by 25 % at damage grade 2 and by 50 % at damage grade 3 in calculation according to the age classes. Decreases by 10 % at damage grade 1, by 25 % at damage grade 2 and by 51 % at damage grade 3 occur in calculation according to the diameter classes; e) theoretical fundamentals were developed for objectifying the time management of forests.

In research on the exploitation parameter according to the exploitation percentage, the exploitation percentage was derived with exploitation symmetrically distributed around circulation period - it was not just read from the exploitation percent data in the still valid Decree of Ministry of Forestry and Water Management No. 14/78 of Col., where the exploitation levels are symmetrically distributed around the centre of the last age group, being shifted towards the younger age classes and cover more age classes than the length of the rotation period suggests. This was also the reason why the scientists examined the effect of the premature felling of part of the stocks of younger age classes upon the over-all production of the management classes. As suggested by the calculations, premature felling of part of the stocks of younger stands reduces the total production volume by 3-10 percent, decreases the average age of felling the regenerated stands, and brings a contradiction between the derivation of the parameter for the management class and the method of planning and performing regeneration felling in each stand. Hence, it is recommended to redefine the exploitation percentages in the new regulations.

MATHEMATICAL METHODS OF FOREST PRODUCTION MANAGEMENT

New findings were obtained mainly on the basis of using random processes; these findings involve those in the field of bio-information issues of forest ecosystems

and those in modelling the effect of abiotic factors on the process of growth in the forest ecosystems.

Applying the random processes on the reproduction process in the forest stock, the researchers defined the theoretical principles of the method of estimating and expressing the probability of the passage of the given matrix into a homogeneous and regular Markov chain as a basis of the new theory of normal forest, which had been developed by K o u b a (1969-1981). The basic types of damages conducive to the destruction of the stands (rise of productive reduced clearcut area) are expressed on the basis of the reliability theory and Weibull's and Person's probability distribution. A significant part of the investigation deals with expressing the development of the total volume output of forests; software is also available for this purpose. Also involved in the research were the theoretical grounds of optimum management of forest output on the basis of entirely random processes (K o u b a and K a š p a r o v á, 1988).

Another range of problems studied during the research included the issues of improving the theoretical expression and estimation of random fellings, which must be followed by reforestation; the different factors associated with these issues were studied in dependence on age and on the basis of the random process theory, special theory of reliability and the Markov chain theory.

The method of expressing and estimating such fellings derives from the use of Weibull's distribution and a modification of this distribution as a uniform base for expressing all kinds of damage in dependence on the age of the forest. This provided a great improvement of accuracy. Further, the method of using linear programming was developed for optimum management of the processes of conversion of actual forest to the so-called normal forest, defined stochastically on the basis of the above-mentioned random fellings.

In addition, a comparative study was evolved, based on the inventory of forests in the countries of Central Europe, deriving mainly from the adjustment of registered stocks by means of the Korf growth function (K o u b a and K a š p a r o v á, 1989).

The important items studied in the field of bio-information within forest ecosystems include:

- Proposals to reduce redundancy, to optimize the structure of AIS HÚL data bases and to integrate the AIS HÚL subsystems. Model for determining regeneration felling.
- Verification of the possibility of using data base systems. Solution to conversions and restructuring of data bases. Design and implementation of recording and information systems.
- Proposal to introduce electronic equipments with an economical mode of work (patent pending, file entry No. 264972 of May 18, 1989, system developed by S p o d n i a k - Š u š k a - K u n d r í k).
- Conclusions concerning the structure of the parent forest and subsequent beech forest in permanent research areas.
- Development of software for the simulation of determining the level of regeneration felling, using IBM XT/AT computer type.
- Software for basic biometric analysis (for annual diameter increment, analysis of the state of health of stands damaged by immissions, approximation and

characteristic points of development curves, computer graphics software).

- Analysis of interdependence of selected growth and bioelectric quantities of beech stands (with tentative checking in other species). The results prove that a medium-impedance / potential tree of a homogeneous set of trees is equal with a medium-increment tree, but has a lower variability, which allows to reduce the number of measurements. The derived bioelectrical characteristics allow to develop a system of relative regulators in exploitation management (Š u š k a and Ž i a k o v á, 1988; Š u š k a and M a j o r o š, 1989; Š u š k a and H e r i c h, 1989).

While solving problems in the field of the simulation of the effect of abiotic factors on the process of growth of forest ecosystems, researchers studied the direction and intensity of changes in a network of research areas, established within the Tatra Mts. National Park. The effect of the action of immissions on the trees was evaluated on the basis of tree classification. This evaluation includes the assessment of tree classes, crown classes, yellowing of assimilatory organs, defoliation and its forms. It follows from the results that in general the problem of the effect of immissions on the position of trees within the stand and on the crown trees in which the trees are included can be addressed by stating that immissions act mainly on dominant and codominant trees which have larger crowns. Consideration was also given to the issue of the effect of immissions on the diameter increment of trees in monitored areas. The analysis confirmed a dependence between the diameter increment and the grade of defoliation according to tree classes. The greatest decline in increment is recorded in tree class 1, a smaller in class 2 (dominant and codominant trees). Over the past fifty years, the increment recorded in the BPP-h area (the Tatranská Lomnica transect) declined from 9.33 mm to 5.87 mm, i.e. by up to 37.1 %. Of this reduction, 32.6 % can be ascribed to the natural decline in BPP-h and 48.5 % to immissions. The rest, i. e. 18.9 %, can be considered to be due to uncontrollable factors. The rate of damage and of the continuous adverse effect of immissions on the forest ecosystems is great: immissions act continuously and directly through the assimilatory organs and indirectly through the soil and is conducive to a very significant impact on the formation of tree biomass. It can also be stated on the basis of the analyses that a significant decline in increment occurred 15 years ago and a highly significant 11 years ago (V o š k o et al., 1989).

CONCLUSION

Solutions to the problems of forest species biometrics and the theoretical fundamental of forest management make a significant contribution to the wealth of theoretical knowledge of the regularities of growth and on the performance of the main species in homogeneous as well as mixed stands as well as in spontaneously developed forests. Further improvement of the theoretical base of the growth tables allowed to compile graded volume tables and price tables.

On the basis of investigation of new methods and means of determination of forest production performance, new techniques were developed for gaining the basic forest classification information on the basis of both terrestrial and remote sensing methods.

Significant primary data were obtained to be used for the quantification of

forests and for forest management in immission-exposed areas (the Western Beskids and the Kysuce-Orava Beskids).

Improvement was achieved in the theoretical knowledge concerning time management, especially the rotation periods and regeneration periods and in the knowledge needed for optimizing and regulating production on the basis of exploitation parameters, including the use of the probability theory.

New possibilities were investigated in the area of mathematical methods of forest production management, including the random processes, biological information and modelling of the effect of abiotic factors on the process of growth of forest ecosystems.

These research results provide a significant enrichment of biometric knowledge and theoretical grounds for forest management; at the same time, they offer solutions to many practical problems of forest management today.

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CURRENT STATUS AND DEVELOPMENT OF FOREST RESOURCES IN THE CZECH REPUBLIC DERIVED FROM FOREST INVENTORIES DATA

V. Zatloukal

SUMMARY PROCESSING OF DATA ON FORESTS IN THE PAST

The effort to collect and process summarized data on forests on our territory dates back to the 19th century.

The first complex investigation, containing 23 groups of data, started in Bohemia (initiated by Dr. Karel K o ř í s t k a) in 1880 and was published in 1885 (entitled as "Contributions to Forest Statistics in Bohemia").

After the declaration of independent Czechoslovakia a statistical investigation on forests was put into execution in 1920. It was supervised by JUDr. Jan A u e r h a n and published by him in 1924 as "Contributions to the Forest Statistics in the Czechoslovak Republic".

In the period after World War II a continuous series of forest inventories started in 1950 and has been going on in ten-year intervals up to the year 1990. A bit different structure of data and the way of finding it out complicate the possibility to compare the data of forest inventory made in 1950 and especially in 1960 with the subsequent inventory data. On the contrary the structure and accuracy of 1980 forest inventory data nearly accord with those of 1990 inventory.

FOREST STAND AREA AND FOREST LAND AREA

Forest stand area and forest land area counted among important extensive data on forests. They have been followed since 1850 in spite of obstacles due to inaccuracy of the former statistics and cadastre or political (territorial) changes in the mentioned region. During the period 1850 to 1875, forest area in Bohemia decreased, in Moravia it increased. Since 1875 forest area of the territory of the Czech Republic has been increasing. The fastest increase of stand and forest area occurred to pass after World War II, owing to the decrease of agricultural land use intensity which was caused especially by the war events and consequential evacuation of the border land. It resulted in the successive afforestation of the former agricultural land. When comparing the data of 1950 forest inventory with the balanced area found out in 1930, the forest area increased by 5.0 % and stand area even by 8.6 %.

Another expressive increase of forest area came as a result of delimitation of the land fund which was finished on 31/12/1960. The primary intention proclaimed 99 thousand hectares of non-wooded land to be afforested, but owing to the intervention of political bodies the projected area was later decreased. The increase of forest area was influenced also by continuous giving precision to the land filing and

by the management of all forests in the Czech Republic up to the date 1/11/1971. The increase manifested itself in the 1970 forest inventory. During the period 1960 to 1970 forest land area increased according to the 1960 and 1970 forest inventory by 3.6 % and forest stand land by 4.2 %. After 1970 forest stand land and forest land was considerably stabilized. During the period 1970 to 1980 forest stand land increased by 0.2 % only, and during last period 1980 to 1990 it increased by 0.4 %.

The increase of forest area resulting from the afforestation of non-wooded land is being in a rising extent swallowed up by the decrease of forest area owing to its occupation for construction activities.

By the 1990 forest inventory the forest stand area amounts to 2,583 thousand hectares and forest land area is 2,637 thousand hectares. It represents an increase, compared with data found in 1920, being the first reliable data concerning the Czech Republic's territory as to the forest stand area, by 310 thousand hectares, and increase of forest land by 268 thousand hectares. Forest percentage rose during the same period from 29.9 % to 33.3 % and forest area per capita rose from 0.23 hectares to 0.25 hectares.

FOREST PROPERTY AND FOREST LAND USE

The development of forest property and forest land use had always sensitively reflected the changes in the field of politics and economy. For example in 1918, before the declaration of the Czechoslovak Republic, only 8.191 hectares of forests in Bohemia were in possession of the State Forests (it was 0.6 %), in Moravia there were only 139 hectares owned by the State and in Silesia the area of State forests did not amount to more than 18 hectares. In Moravia and Silesia most of the State forests were administered by the State Railways. The area of state forests in the Czech Lands (Bohemia, Moravia and Silesia), western part of the Czechoslovak republic, amounted to 103 thousand hectares, i. e. 4.4 %, and by 1930 it increased to 318 thousand hectares, i. e. 13.5 %. In a parallel way the area of private forests decreased. Extremely outstanding turn in forest property and forest land use came after 1945, and especially after February 1945.

A hard pressure aiming to the socialization of forests had continued up to the 1960's (the socialization of forests was finished in legislative way by governmental order No. 81/1958 of. Col., on the basis of which the forests of forest co-operative were nationalized).

The political pressure aiming to transfer the private forests to the State continued even after 1980. It resulted in nearly total liquidation of private forest property (by 1990 forest inventory there is only 1,386 hectares, i.e. 0.05 % of private forests in the Czech Republic). Considering the political and economic changes coming after November 1989, one can suppose that in the near future the conditions in forest property will return close to the situation in 1947 or 1948.

The development of forest property on the territory of the Czech Republic is referred to in Tab. IV.

FUNCTIONAL ORIENTATION OF FORESTS

The society's requirements for the role of forests has developed successively to a multifunctional conception of forest. It is manifested by intensifying transition of the area of production forests (with prevailing wood-production function) to the forests with prevailing non-production functions (at present the protection forests and special-purpose forests). While by the 1950 forest inventory the production forest area amounted to 97.2 % of forest stand area, by the 1990 inventory it decreased to 58.4 %. The complement up to 100 % represents the forests with prevailing non-production functions. The transition had been outstanding during last ten years, when the decrease of production forest area was 19.9 %, the principal reason being especially the increase of air-polluted forest area. If the damage to forests due to air-pollution calls for special management system, the forests are classified in accordance with Edict No. 13/1978 of the Czech Ministry of Forest and Water Economy into the special purpose forest category, its subcategory "e".

Since there are simultaneously the reasons to classify the forest into another special-purpose forest subcategory or protection forest category, it is the criterion of air-pollution which is superior to all, because usually air-pollution influences all activities in the forests in a most significant way. The other subcategories of special-purpose forests or protection forests are in this case declared as overlapped by the air-pollution forest subcategory. That is why the actual rate of individual categories and subcategories is not clear now. It is supposed that future forestry legislation will have solved the change conception of the functional forest orientation.

Tab. II shows the development of forest categories as recorded by 1980 and 1990 forest inventories (the categorization criterion has not been changed).

SILVICULTURAL MANAGEMENT FORM

In the forests of the Czech Republic the high forest prevails significantly and its area has continuously been increasing all over the registered period (see Tab. III). By the last (1990) forest inventory the high forest occupies 99.7 % of forest stand area. The rest, 0.3 %, is taken by coppice forest. Coppice with standards hasn't been registered by the post-war inventories. Its area is negligible and is included mostly in the high forest area. The high forest area includes also part of "quasi" high forest dated into the post-war period, when the rotation of the better quality coppice forest with the higher share of hard broad-leaf species (especially the oak) had been prolonged. Most of the bad quality coppice forests were converted after World War II by direct conversion into the high forest.

The coppice forest stays exceptionally as a target management form in the conditions in which this is necessary for fulfilling non-production functions.

SILVICULTURAL MANAGEMENT SYSTEM AND ITS FORMS

The choice of the optimum silvicultural management system and its form under actual natural and forest stand conditions is an important cardinal decision influencing outstandingly the forest condition.

I. Development of forest land area specified by the sort of property and land use on the territory of the Czech Republic during the period 1895–1990

Year	Common property						Collective property		Private property		Total forest land	
	state		municipal		church		in thousand hectares	[%]	in thousand hectares	[%]	in thousand hectares	[%]
	in thousand hectares	[%]	in thousand hectares	[%]	in thousand hectares	[%]						
1895 ¹⁾	–	0.3	–	11.2	–	6.7	–	–	–	81.8	–	100.0
1920	103	4.4	233	9.8	188	7.0	47	2.0	1,798	75.9	2,369	100.0
1930	318	13.5	263	11.2	172	7.3	49	2.1	1,552	65.9	2,354	100.0
1950	1,728	69.9	494	20.0	–	–	15	0.6	235	9.5	2,472	100.0
Sort of property and land use												
	direct		controlled						private owners		Total	
			limited		other state bodies		agricultural cooperatives					
1960	2,302	89.2	–	–	–	–	212	8.2	67	2.6	2,581 ²⁾	100.0
1970	2,310	88.8	–	–	65	2.5	197	7.6	28	1.1	2,600	100.0
1980	2,393	91.5	55	2.1	4	0.2	148	5.7	14	0.5	2,614	100.0
1990	2,468	93.6	57	2.2	1	0.05	109	4.1	1	0.05	2,637	100.0

¹⁾ Data stated in 1895 list of the Austrian Ministry of Agriculture don't include Silesia, data originated before and after the year 1918 aren't with regard to the territorial changes comparable.

²⁾ Specification by the sort of property and land use quoted by the Statistic year-book (including wind belts)

II. Development of forest categories in the course of period 1980 to 1990

Forest category	1980 forest inventory		1990 forest inventory	
	in hectares	[%]	in hectares	[%]
Production forests	2,001,129	78.22	1,507,418	58.37
Protection forests	102,061	3.97	63,608	2.46
Special-purpose forests	458,143	17.81	1,011,754	39.17
out of which forests damaged due to air-pollution (subcategory "e")	204,416	(7.95)	734,094	(28.42)
Total forest stand land	2,572,133	100.00	2,582,780	100.00

III.

Management form	Statistics of forests ¹⁾				Forest inventory									
	1875		1920		1950		1960		1970		1980		1990	
	[%]	in 1000 ha	[%]	in 1000 ha	[%]	in 1000 ha	[%]	in 1000 ha	[%]	in 1000 ha	[%]	in 1000 ha	[%]	in 1000 ha
High forest	95.4	2,148	94.5	2,355	96.8	2,383	96.8	2,498	97.3	2,542	98.8	2,576	99.7	
Coppice forest	4.6	97	4.3	78	3.2	80	3.2	69	2.7	30	1.2	7	0.3	
Coppice with standards	-	28	1.2	-	-	-	-	-	-	-	-	-	-	
Total	100.0	2,273	100.0	2,433	100.0	2,463	100.0	2,567	100.0	2,572	100.0	2,583	100.0	

¹⁾ in "Contributions to the statistics of forests in the Czechoslovak Republic", data concerning 1875 stated by Dr. Kořístka - only Bohemia without Moravia and Silesia was mentioned.

The necessity of the differentiated determination of cardinal decisions including silvicultural management system is solved by way of operational management sets. The use of them is legalized by the annex to ministerial Edict No. 13/1978 and is detailed in the "Operational management models" and "Operational forest management systems" - Plíva and Žlábk, 1989. The actual area and areal share of the individual silvicultural management systems can be derived from the area of the operational management sets referred to in 1980 and 1990 forest inventories. With respect to the alternative possibility to choose one of several available forms of silvicultural management system within one operational management set, it is requested to consider the derived data as being of no high precision.

By the 1990 forest inventory the most widespread form of silvicultural management system in the Czech Republic is the small-area form of clear-cutting system, occupying 63.5 % of total area. It prevails both in the productive forest category - 64.1 %, and in the special-purpose forest category - 66.7 %. But its percentage is negligible in protection forests, where the selective management system highly prevails - it amounts to 78.1 %. In the special-purpose forests the percentage of the selective management system (3 %) can be explained by the overlap with regard to the protection forests.

The second largest share in the forests of the Czech Republic is that of the

strip-like clear-cutting as a form of the clear-cutting system. The successive regeneration fellings alternating with the shelter-wood system represents the third most widely represented form of forest management system. The large-area form of clear-cutting system is used, besides under specified natural and forest stand conditions, mostly in the air polluted forests: this explains its higher share in the special-purpose forests.

ROTATION

Determination of the length of rotation (circulation) period represents a fundamental step aiming to solve the yield regulation. During the period from the declaration of the Czech Republic to the end of the Second World War the rotation was varying between 90 and 100 years. But by the 1950 forest inventory the rotation amounted to 101.1 years. In the course of the post-war period up to 1978 the rotation slightly lengthened. During the period 1978 to 1988 an intense rise of the rotation took place as a result of the coming in force of ministerial Edict No. 13/1978, in the annex of which the lengths of rotation period were fixed (usually with a 10-year span) according to the individual operational management sets. In the "Operational management models", 1985, rotation is stated in a more detailed form. With respect to the 10-year cycle in the renovation of the forest management plans, it took 10 years to apply the rotation stated in the Edict in all forest management plans. The analysis of rotation registered for last decade in individual years demonstrates that the length of rotation has already stabilized. The maximum length of rotation (112.6 years) was achieved in 1986.

Data on rotation concerning the period 1950 to 1990 are referred on the following scheme:

Overview of rotation by 1950 to 1990 inventories

Forest inventory	1950	1960	1970	1980	1990
Rotation	101.1	101.2	102.6	108.1	112.4

PERCENTAGE OF TREE SPECIES

The long-term mean percentage of tree species in the forests of the Czech Republic has been varying extremely slowly as a result of the long production time. A continuous decrease of percentage of conifers has occurred in the course of the past 40 years - by 5.3 % of their total area. The most outstanding decrease of percentage is shown by fir (to 46.4 % of previous value), pine (to 88.0 %) and spruce (to 94.4 %). An increase up to 200.0 % is recorded in the case of the larch and other conifers.

During the same period the percentage of oak increased up to 138.6 % and that of beech up to 122.2 %. Percentage of the other broad-leaved tree species cannot be compared individually to the 1950 inventory where only two summary groups of the other broad-leaved tree species were mentioned as hard wood and soft wood. For detailed information see Tab. IV.

Note:

- in 1960 forest inventory the data on percentage of tree species are not men-

IV. Development of tree species percentage in the forests of the Czech Republic during the period 1950 to 1990

Forest inventory	Tree species in %													
	Spruce	Fir	Pine	Larch	Other conifers	Total conifers	Oak	Beech	Birch	Other hard broad-leaved	Alder	Other soft broad-leaved	Total broad-leaved	Total
1950 ¹⁾	58.9	2.8	20.8	1.6	0.2	84.3	4.4	4.5	5.3		1.5		15.7	100.0
1970	56.0	2.1	19.2	2.3	0.6	80.2	5.5	5.1	2.6	3.5	1.4	1.7	19.8	100.0
1980	56.1	1.8	18.6	2.7	0.6	79.8	5.8	5.4	2.5	3.3	1.4	1.8	20.2	100.0
1990	55.6	1.3	18.3	3.2	0.5	78.9	6.1	5.5	2.9	3.4	1.4	1.8	21.1	100.0

¹⁾ in 1950 forest inventory the forests below 10 hectares are included, the forests without yield management are excluded

V. Actual age class area in the percentage of its normal area by 1990 forest inventory (total for the Czech Republic)

Age class ¹⁾	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
Ratio in % actual/normal area	91.30	83.57	90.79	68.68	94.33	116.68	99.81	109.71	111.05	99.95	95.08	107.21	148.17	179.90	186.48	113.43	307.81

¹⁾ Note: in czech forest management there are two levels of age classification of forest stands:

- age class (represents a period of 20 years)
- age degree (represents a period of 10 years)

in this paper the term "age class" means a period of 10 years.

VI. Development of actual clear cut area in the forests of the Czech Republic by forest inventories in 1950 to 1990

Forest inventory	1950	1960	1970	1980	1990
Clearing in % of forest stand area	1.64	0.95	1.33	0.77	1.57

tioned;

- the data are converted to the area without clear cut area;
- Douglas fir is included in silver fir, Swiss mountain pine is included in pine.

Decrease of percentage of spruce and pine is connected with the effort to get the tree species composition near to the optimum corresponding with the site and to restore and stabilize pure coniferous stands. The target percentage of tree species was determined both for the individual sites and consequently for the operational management sets with an orientation to one main commercial species (in the highest tolerable percentage) completed by other tree species ensuring non-production functions of the forest. The perishing of spruce due to the imission load participates outstandingly in its decrease. The decline of fir is connected with its long-time perishing. But for the past 5-6 years a marked regeneration of fir has been occurring to pass all over the most of area. The percentage of larch is increasing both as a result of its application as a stabilizing deep-rooting species, and of its use in the forests damaged due to air-pollution; even a more accurate assessment of admixed larch is important nowadays.

Consequently, the decreasing percentage of spruce, fir and pine is substituted by the increasing percentage of broad-leaved species, especially oak, beech and birch.

The analysis of the development of the tree species percentage detailed in the age classes extends beyond the scope of the article.

AGE STRUCTURE OF FORESTS

The age structure of forests plays a fundamental role in the determination of contemporary and future cutting limits. It represents also distinct evidence of forest activities done in the past. The age structure of forests cannot be judged in an isolated way, one must especially consider its relation to the age class/degree normality following from the rotation and the regeneration interval. The outline of ratio of the actual to normal area in age degrees is referred on the following Tab. V.

The development of actual clear cut area see in Tab VI.

The area of the 1st to 5th age degree is situated extremely below the normal (it extends in total only to 85.74 % of the normal). The corresponding stocking density is 9.27. The above mentioned age degrees originated after World War II; the area of them has been influenced to a large extent by the afforestation of the former arable land. The increase of forest stand area in the course of 1950 to 1990 forest inventories makes 150 thousand hectares and it occurred mostly just in mentioned age degrees. This area being subtracted, it is evident that only about 73 % of

VII. Development of the coniferous and broadleaved standing volume in the forests of the Czech Republic during the period 1970 to 1990

Standing volume	Conifers		Broadleaved species		Total	
	in thousands cu. m. under bark	[%]	in thousands cu. m. under bark	[%]	in thousands cu. m. under bark	[%]
1970	428,124.3	88.0	58,225.0	12.0	486,349.3	100.0
1980	468,785.9	87.5	67,060.0	12.5	535,845.9	100.0
Ratio 1980/1970	1.095		1.152		1.102	
1990	485,938.2	86.1	78,171.9	13.9	564,110.1	100.0
Ratio 1990/1980	1.037		1.166		1.053	

normal area originated by means of reforestation. The lowest normal area rate is recorded in the 4th age class. At the same time the regeneration cutting deviated from the normal only a little. There are several causes of such a very unfavourable condition. The post-war economy contributed to the sub-normal area of the 4th age class by placing the cuttings so as to limit the resulting reforestation. Later, the unsuitable application of small-area clear-cutting management system, legal at that time (alternated with successive regeneration fellings), represented a frequent cause, as well as the outstanding afforestation failure and the high share of salvage felling which evoked (compared to the regeneration cutting) a substantially lower need for afforestation.

The area of forest stands 51 to 90 years old is extremely above the normal and extends up to 109.31 % of the normal, the mean stocking density being 8.78. In comparison to the 50 - year - old stands the stocking density in the above mentioned stands is decreased by 0.49 degree. The stocking density decrease was produced consequently after the stands were afflicted by salvage fellings that followed the neglected tending of young stands in the past and enormous damage to forest stands by red deer (especially in the spruce stands).

The 91 to 120-year-old forest stands have nearly normal area - 99.67 % of the normal. Compared to 1980 inventory the area increased by more than 41 thousand hectares which represented nearly 11 %. The 11th age degree is slightly sub-normal with its area being 95.08 % of the normal and the average stocking density of 8.74.

The area of forest stands older than 120 years (the 13th to 17th-plus age classes) is extremely above the normal and covers 165.72 % of the normal area with the mean stocking density of 8.38. The area increased during the past 10 years by 10.6 %. The above-normal area of older mature stands is a result of the fact that the stands have not been cut because of the extremely high share of salvage fellings. Those stands that were not attractive from the viewpoint of the quality of wood or owing to the aggravated transport conditions have not been exploited.

The mean age of forest stands represents important data on age structure. In the course of the period of 1950 to 1990 it increased from 51 to 60 years and the increase made 2.25 years per decade. The increase of the mean age by 2 years during the last decade corresponds to the above-mentioned trend.

When comparing the double mean age representing the latent rotation, to

actual rotation, it is evident that whereas by the 1950 inventory the values of actual and latent rotations are almost in the same coincidence (101.1 compared to 102.0 years), by the 1990 inventory the latent rotation exceeds the actual one by 7.6 years (112.4 in comparison with 120.0 years). This is in correspondence with the above-mentioned condition - the shortage of young stands and the surplus of the oldest stands.

STANDING VOLUME AND INCREMENT

The amount and the structure of standing volume and increment condition (in the relation to the age structure) act as a decisive factor in the evaluation not only of the wood production potential of forest but also of the condition of forests in general.

The development of standing volume in the forests of the Czech Republic has been favourable. In the course of 1950 to 1990 forest inventories the recorded standing volume had outstandingly increased. By the 1950 forest inventory (including the forests mentioned in annex, the area of which was below 10 hectares), the standing volume amounts to 325,797 thousand cu.m. (converted to the value under bark). But the volume does not involve the forests the yield of which has not been managed (about 68 thousand hectares), i.e. the quasi protection forests and the forests established on the former arable land, the standing volume of which was extremely low.

If this fact is taken into consideration, the standing volume in all forests of the Czech Republic was about 335 million cu. m. in 1950. During the 40-year period to the 1990 forest inventory the standing volume had increased by 229 million cu. m. It represents the average annual standing volume increase of 5.7 million cu. m., i.e. 1.7 %.

The increase of standing volume has been caused by the increase of forest area, by the shift of the age degrees in direction to the higher volume of stands, by the lengthened rotation, by the conversion of the coppice forests into the high forests and by the change of the volume assessment method defined with more precision. As another cause of the increase we might define the rise of the height increment recorded on sample plots; the cause of that may have been the climatic changes, the increased carbon dioxide concentration, the rising supply of nitrogenous compounds via atmosphere into the soil and other phenomena. The scope of this article limits the detailed analysis of the increase of standing volume. As to the period from 1950 to 1990, the problem was searched in detail by P o l e n o (1950-1980).

The development of standing volume during the period 1970 to 1990 is referred to in Tab. VII, VIII.

The data shown in the table prove the retardation of standing volume increase down to about a half compared to the previous period. The outstanding retardation is evident in the case of the conifers whereas the increase of broadleaved standing volume has been continuing. The mentioned rate of rising standing volume (ratio conifers/broadleaved species) is itself one of the causes of standing volume retardation, because considered on a large average the resulting standing volume per hectare is, as to the broadleaved species lower than that of conifers. But as the decisive factors influencing the retardation of the standing volume increase are

VIII. Development of the standing volume per hectare in the forests of the Czech Republic specified by the age classes

Forest inventory	Age class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+	Total
1980	Standing volume in thousands cu. m. under bark	-	4	38	109	178	237	298	329	346	351	349	340	341	341	310	250	-	208.3
1990		-	4	46	116	191	246	393	335	357	362	357	348	335	326	335	319	279	218.4
Ratio	1990/1980	-	1.000	1.211	1.064	1.073	1.038	0.983	1.018	1.032	1.031	1.023	1.024	0.982	0.956	1.081	1.180		1.048

IX. Development of the standing volume in the Czech Republic during the period 1980 to 1990

Forest stand stage	Young stands the 1st to the 5th age class	Middle age stands the 6th to the 9th age class	Growing up and mature stands the 10th age class and older	Total
Forest inventory	in thousands cu. m. under bark			
1980	81,356.4	289,218.8	165,270.7	535,845.9
1990	71,911.8	305,543.3	186,655.0	564,110.1

X. Comparison of increments in the forests of the Czech Republic by the 1980 and 1990 inventories

Sort of increment	Mean annual increment at the age of rotation [MAIR]		Total mean increment [TMI]		Total current increment [TCI]	
	in 1000 cu. m. under bark	cu. m./ha	in 1000 cu. m. under bark	cu. m./ha	in 1000 cu. m. under bark	cu. m./ha
Forest inventory						
1980	9,512	3.70	16,003	6.22	17,120	6.66
1990	9,493	3.68	16,350	6.33	17,047	6.60

considered especially the damage to the forests due to air-pollution and the high share of the dispersed salvage fellings. Continuously rising share of the oldest forest stands which have passed the increment optimum and the standing volume per hectare of which is being decreased, act in addition to the above-mentioned factors.

With respect to the outstanding changes of the rotation, the age limitation of mature and premature standing volume has changed, too; that is why to compare them isn't sufficiently instructive. Tab. IX brings therefore information on the development of the standing volume in the groups of age classes.

The standing volume decrease of the forest stands younger than 50 years is connected with the shift of the 5th age class (registered in the 1980 inventory as above normal) into the 6th age class of the 1990 inventory.

All types of increments used in a common way in forest management practice (i. e. total current increment - TCI, total mean increment - TMI and mean annual increment at the age of rotation - MAIR) have show in the post-war period (up to the 1980 inventory) a continuous increase. The reverse occurred only in the course of the last decade when the total current increment and the mean annual increment at the age of rotation slightly decreased. When comparing the recorded increments, a small inaccuracy might arise owing to the differences in determining the increments in the past. Only for illustration are a series of available data on the MAIR since 1980 referred to (Statistics, Forest inventories).

Year	Development of mean annual increment at the age of rotation (MAIR) for the period 1880 to 1990										
	1880	1890	1900	1910	1920	1930	1950	1960	1970	1980	1990
MAIR	3.0	2.8	3.1	3.0	3.0	3.1	3.0	2.6	3.1	3.7	3.7
in cu.m./ha											

XI. Cutting volume determined in the forest management plans in the Czech Republic by the 1950 to 1990 forest inventories

Forest inventory	Regeneration	Intermediate	Total	Total cutting volume per hectare	Cutting percentage of standing volume
	cutting volume	cutting volume	cutting volume		
	in cu. m. under bark				
1950 ^{†)}	4,367,122	1,524,304	5,891,426 +(18,752)	2.63 (2.56)	1.76
1960	5,446,500	1,658,000	7,074,500	2.57	2.03
1970	7,225,760	2,560,011	9,785,771	3.81	2.01
1980	8,662,500	3,598,500	12,261,000	4.77	2.29
1990	9,457,700	2,461,700	11,919,400	4.61	2.11

^{†)} 1950 forest inventory – data concerning the forests above 10 hectares; data concerning the forests the yield of which has not been managed, is included only in total cutting volume (data in parentheses)

Hereafter only the data on increments for the period 1980 to 1990 are compared, since the calculation method has not changed (see Tab. X).

With regard to decrease of site class degree corresponding with the rising age (by the yield tables used to draw up forest management plans until 1990) and the stocking density decrease in the mature stands (especially the older ones), the mean annual increment at the age of rotation originated in mature stands is in fact lower (3.17 cu. m./ha). Similarly the total mean increment as the sum of total premature and mature volume produced is affected not only by the above mentioned reduction of the mean annual increment at the age of rotation, but also by the reduction of premature produced volume resulting from the fact that the decrease of the tending intensity in connection with the stocking density is more progressive than the decrease of stocking density.

As to the total current increment the situation is more complicated because the tabular values (owing to the influence of air-pollution, changes in the carbon dioxide concentration, increased supply of nitrogenous compounds via atmosphere to the soil and other anthropogenous influences) in many of cases do not correspond with reality.

CUTTINGS

The limitation of the cutting volume ranks among the fundamental tasks of forest management. It is the valid legislation (besides the forest condition) that influences primarily the limitation of the cutting volume. Since 1978 till nowadays the limitation of the cutting volume has been controlled by ministerial decree No. 13/1978 that states for the individual age classes, in connection to the rotation and regeneration period, the model rate of the regeneration cutting. The percentage is mathematically derived from the area. In order to provide yield regulation, the model cutting volume is calculated in all forest categories for the three next decades and is adjusted, considering the normal clear-cut area and the mean annual increment at the age of rotation. The actual regeneration cutting volume set down

XII. Share of coniferous and broad-leaved cutting volume by specified kinds of cuttings in the Czech Republic during the period 1950 to 1990

Kind of cutting	Regeneration cutting		Intermediate cutting		Total cutting	
	[%]					
Forest inventory	coniferous	broad-leaved	coniferous	broad-leaved	coniferous	broad-leaved
1950	86.1	13.9	93.4	6.6	88.0	12.0
1960	87.7	12.3	91.0	9.0	88.4	11.6
1970	86.3	13.7	89.1	10.9	87.1	12.9
1980	86.8	13.2	87.4	12.6	87.0	13.0
1990	89.2	10.8	84.4	15.6	88.2	11.8

in forest management plans is determined individually in forest stands, considering their condition, and its total for the forest category is compared with a model. The divergence beyond 5 % is authorized by the Ministry. The cutting volume in premature stands is determined in detail in forest stands, the model cutting percentage being used.

In the course of 1950 to 1970 forest inventories the cutting volume determined in the forest management plans (hereafter FMP) keeps marked ascendent trend. The annual increase of the regeneration cutting volume descended to 2.0 %, whereas the annual increase of the intermediate cutting rose to 4.1 %, so that the total cutting volume increased annually by 2.5 %. In the course of the last decade 1980 to 1990 the annual increase of the regeneration cutting volume was only 0.9 %, the intermediate cutting volume showed the average annual decrease by 3.2 %, so that the total cutting volume decreased annually by 0.3 %.

The development of cutting volume determined in the FMP is referred to in Tab. XI.

The increase of the cutting volume during the whole registered period has been caused by the increase of the standing volume and especially by the development of the age structure; we can then see the shift of the age classes rich in cutting volume whose area is above the normal, to the maturity, and the cumulation of not yet felled mature stands.

The decrease of the intermediate cutting volume determined by the forest management plans during the period 1980 is due to air-pollution, repeated affliction of prematured stands by the salvage fellings, higher tending intensity in previous period (1960 to 1970), especially in the forest stands more than 50 years old, and neglected tending of young stands (where the activity has been revived since 1980).

The fact that in mature forest stands the determined cutting volume has not often been fulfilled owing to repeated salvage fellings has resulted in the accumulation of the cutting volume, especially in the oldest age degrees. Such an accumulation, when using the cutting percentage as a yield regulation index of the regeneration cutting, causes the increase of regeneration cutting.

The decrease of the total cutting volume share per hectare has occurred in the last decade for the first time since 1950, as well as the cutting percentage that was ascending slowly until 1980.

Tab. XII refers to the development of the share of conifers and broad-leaved species on the specified kinds of cutting. In general, during the period 1950 to 1990 the share of volume of conifers in the regeneration cutting volume increased, and it decreased in the intermediate cutting volume.

Long-term overfulfilling of cutting volume determined by forest management plans and the high share of waste, originated from the felling or from unprocessed dispersed salvage fellings, afflicts the development of the cutting volume. This unregistered volume is getting lost out of the produced wood. The field investigation carried out in 1986 showed that the waste amounted 3 to 4 million cu. m. "derbholz".

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DECISION SUPPORT SYSTEM AQUALOG, TOOLS OF WATER SCIENCE AND COMPUTER TECHNOLOGY

J. ZEŽULÁK

ZEŽULÁK, J. (Water Resources Department, Faculty of Forestry, Agricultural University, Prague): *Decision support system AquaLog, tools of water science and computer technology*. *Lesnictví*, 37, 1991 (10): 859 - 866.

Traditional methods of planning, design and decision making essentially culminate into computerized forms and the new trends started processes of reformulation of water science postulates. Hydrological and biochemical processes appearing in natural basins or in technological systems are sometimes too complex to be formulated by a single set of mutually interrelated mathematical relations. For large systems, consisting of a number of mathematically incompatible processes, various decomposition techniques are then adopted as the only way of practical solution. The tools of mathematical models, originally designed just for simulation of natural hydrological processes or of man activities in the basin, are now being enhanced into compact systems that cover all phases of data processing. The purpose of the paper is to contribute such tendencies and to offer an insight into the architecture of the hydrological and biochemical modeling system AquaLog, a typical integrated software product aiming at applications in field of water management, agriculture, forestry and environmental engineering

decision support system; environmental modeling; hydrological modeling; topology of hydrological systems; wastewater treatment plants; Petri nets

A BRIEF USER-ORIENTED DESCRIPTION OF THE SYSTEM

The AquaLog provides a tool for integrated modeling of complex hydrological and water resources systems and also of activated sludge plants. It integrates various modeling techniques of catchment hydrology, river-, and reservoir hydraulics and it also simulates operation of technological units of the wastewater treatment plants. The system is suitable for design purposes as well as for use in real-time. It forms a compact framework for model identification, for the data collection and data-base maintenance, for the model operation and for presentation and dissemination of the results. A friendly form of user-machine dialogue and menu-driven control of all steps of the data processing, these are the typical features of the system. Based on advanced topological algorithms, the system can service any *tree- or looped topography* of the case system. The following system options are available:

IDENT program	:	the model creation (identification) phase
DATAr program	:	bridge between historical and operational hydrological databases
EDIT program	:	the data-collection and maintenance
SIMFOR program	:	the model operation phase
LIST program	:	the display of results in table form
AL-graph	:	the display of results in graphic form

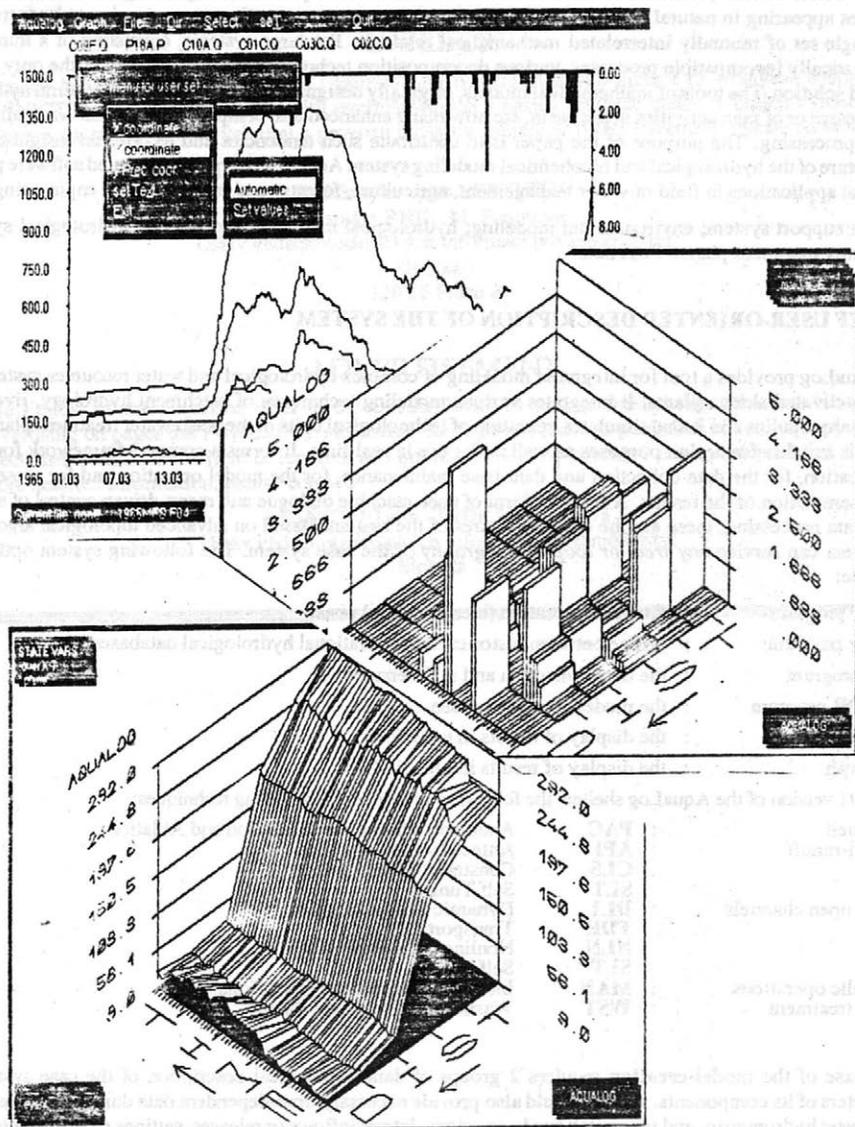
The 1991 version of the AquaLog shelters the following groups of the modeling techniques:

Snow melt	:	PAC	Anderson's Snow Accumulation and Ablation
Rainfall-runoff	:	API	Antecedent Precipitation Index
		CLS	Constraint Linear System
		SLT	Self Tuning
Rivers, open channels	:	DL1	Dynamic Looped System
		TDR	Transport Diffusion
		NLN	Nonlinear Cascade model
		SLT	Self Tuning
Hydraulic operations	:	MAN	Interactive (reservoir) Operations
Sludge treatment	:	WST	Wastewater Treatment Plants

The phase of the model-creation requires 2 groups of data: topological description of the case system and parameters of its components. A user should also provide necessary time-dependent data during the **data-collection** phase: hydrometric- and precipitation observations, lateral inflows or releases, settings of flow-control units at various control points of the model or control measurements of the biochemical process variables. During the model operation phase a user learns how a case system reacts to the initial and boundary conditions in

time-dependent input data. He can use comfortable utilities (tabular, 2D and 3D graphics, statistics) available for presentation of water stages, discharges, settings and biochemical state variables at selected computational points of the case system.

The AquaLog is widely used in Czechoslovakia, in the WMO/UNDP projects in Pakistan, Burma, Europe and elsewhere. Several large flood warning and forecasting projects, real-time monitoring systems, irrigation- and reservoir control schemes, mathematical models of fishpond systems, evaluation of catchment design characteristics, tracing the impact made by man on the natural runoff regime, simulation of the runoff from controlled or from artificial catchments (urban areas, parking places) or simulation of biochemical processes in water treatment plants, these are some of the typical application fields where the AquaLog has been used. Typical computer outputs, demonstrating the way of man-machine communication and presentation of the results are shown in Fig. 1.



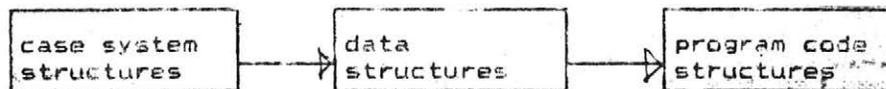
1. Samples of the AquaLog outputs

PHILOSOPHY AND THE SYSTEM DESIGN

Principles of the modern software architecture emphasize the analogy between the data structures and the structure of the code. Architecture of the AquaLog goes even beyond that point. There appear three sequences in structures (Tab. 1):

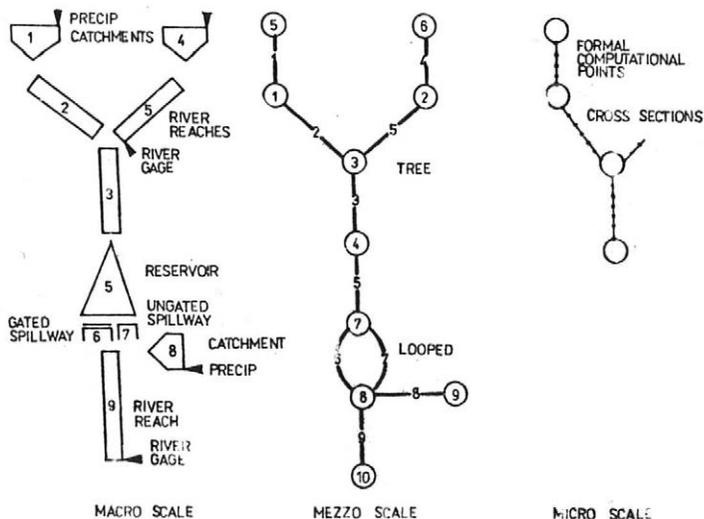
Moreover, the analogy can be observed from two different aspects of the problem computerizing: from space-

I. Analogy in system structures



and from time orientation. The topological definitions reflect topographical features of the case system; in case of natural hydrological systems this usually leads to the *tree*-systems analysis. On the other hand, one can observe the runoff formation (genetics) from purely kinematic aspect. Both aspects are imperative in the organization of the solution region over the X-T plane and consequently they are also observed in design of the database and of the programs.

Concept of decomposition of a complex hydrological and/or technological system into a number of elementary units is adopted as a dominating strategy in the AquaLog desing. Under its shell it is possible to disintegrate the case system (catchments, river systems, flow control units of hydraulic systems or technological units of the waste water treatment plants) of any configuration into a set of mutually interconnected elements that a user can consider as homogeneous and that cover processes representative for particular approach of mathematical modeling. The Fig.2 shows the extraction of the above components from the case system entity. While the *macro*-decomposition level solely admits the *tree* systems, the *mezzo*-level services both the *tree*- as well the *looped* systems. In such a manner, regions of prevailing surface runoff, open channel flow or of water accumulation processes, are



2. Three - level case system decomposition

extracted from the case system topography and solved independently.

The Fig.2 also shows an example of the 3-step decomposition. In this case the system consists of two headwater catchments (components 1 and 4), three river reaches (2, 3 and 5), one reservoir storage (4) controlled by one gated and one ungated spillway (6 and 7), one intermediate catchment (8) and the channel reach downstream of the reservoir (9). The impact of the outer inputs is communicated in form of hydrological observations (thin arrows in the scheme) at various control points of the case system. On the *mezzo*-scale the *looped* graphs are also permitted in addition to the *trees* of the *macro*-scale. They may represent elements of a complex river system (the model

DL1), the flow control units (MAN) or the biochemical processes (WST). In the particular case of the Fig.2 the graph consists of 9 edges and 10 nodes. The edges represent individual runoff components or performance of technological units. The outer nodes 5, 6 and 9 carry out the effects of time-dependent data. Mass and energy conservation are applied in the internal nodes 1, 2, 4, 7 and 8. On the *micro*-scale, individual process variables (discharges, water levels, precipitations, concentrations) are computed in discrete computational points in course of time. Two basic types of the modeling techniques appear in the AquaLog library, based either on lumped- or on distributed approach:

- 1) The lumped-modeling when, for a certain region selected from the case system, the set of equations, governing the hydrological, environmental or biochemical processes, is developed and solved numerically, complying with initial conditions given for all state variables of the process. All mathematical formulations are space independent and such region appears to the user as it was located into a single, representative point.
- 2) The distributed-modeling uses usually a system of partial differential equations to describe the process, based on initial and on boundary conditions. The state variables of the process are solved in time-spatial representation at user-selected computational points.

RELATIONS BETWEEN CASE SYSTEM COMPONENTS, TOPOLOGICAL CODING

Distributed parameter modeling of hydrological and water-related processes often requires some sort of topological coding that associates individual process components into computational entity. The coding may even be required as nonstationary. Such a facility becomes particularly useful in case of the real-time control processes, and always when there appears a need of switching the computational status of mathematical formulations or when covering gaps in the data. Introduction of the dynamic structure of computational process always substantially enhances applicability of the modeling system in real situations. In connection with the *tree*- or *looped* systems representation, the AquaLog applies two principle algorithms: generating of the dynamic *tree*-sequence for simply connected systems and application of the Petri-net algorithm for multiply connected systems.

THE DYNAMIC TREE-ALGORITHM

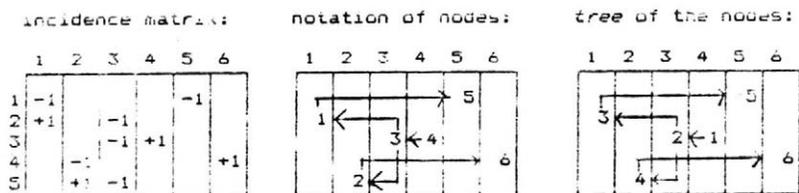
On the *macro*-decomposition level an optimum computational sequence based on selected properties of the incidence matrix of the components of the case system is generated (Zezulák, 1985). The following constraints are observed:

- (i) computational sequence will follow formal orientation of individual edges in the graph, not of the flow direction,
- (ii) a (hydrological) successor will always be resolved only on completion of its predecessors,
- (iii) computational sequence can be terminated at any exit point from the *tree* of the case system; the original graph of the *tree*-system may be upgraded into the 'forest' by considering the internal observational points as graph separators,
- (iv) computer stack memory required for the recursive evolution of the tree should be minimized.

To demonstrate the setting up of the *tree*-sequence, a simple example of the basin consisting of 2 catchments (component 1 and 4) and three river reaches (components 2, 3 and 5) is extracted from the system of the Fig.2 (upstream to the reservoir, component 4).

The incidence matrix shown in the Tab. II of the above system (components 1 through 5) becomes a framework for the *tree*-sequence construction. In fact, the *tree*-sequence represents a secondary graph overlaid over the matrix. Only two directions of the *tree*-evolution are possible, the horizontal and the vertical. The vertical arrows determine the intersection of the edges, coinciding with the starting node. The horizontal arrows relate to the nodes, adjacent to particular edge. With the exception of the first, all paths between the two nodes consist of both vectors. The target point can be reached from the starting point by vector composition of the vertical and horizontal paths. The algorithm is based on cyclically repeated search for a couple of both vector components connecting the starting points with the target points where the resulting paths on the matrix resemble a set of the knight's moves on a chessboard. The program either uses recursive calls of the procedures or the stack memory to store reentries to the starting points. In the evolution the vertical trip can be regarded as a decision on the next move. In case the node ranked $R=1$ (the outer node) have been reached, further evolution in this direction is terminated. In case of the node ranked $R=2$ the decision is trivial and the next trip is directed towards the component opposite to the entering one. If the rank $R>2$ there exist $R-1$ choices of the trip. Although such representation is rather general in choice of priorities, for reasons of clarity we restrict solely to topographical priorities in the searches:

II. Graphical construction of the *tree* - sequence



Graphical construction of the *tree*-sequence

- priority 1 : the first search from the starting point is made in the bottom-up direction,
 priority 2 : a target point with a lower serial number (a column number) has a priority compared to the node with a higher number

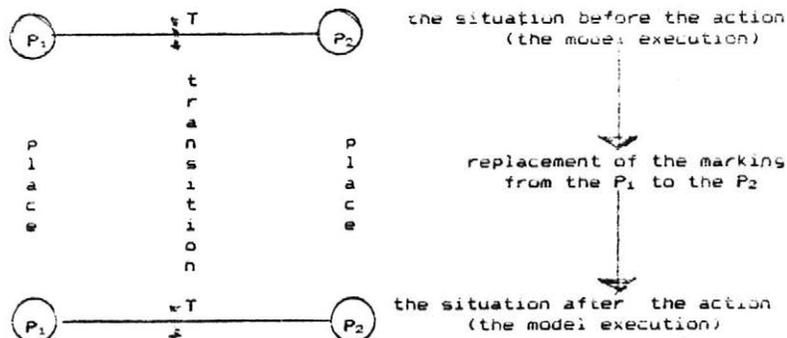
As soon as all trips emanating from the starting node have reached their targets, a new starting point is moved to the highest priority target and the procedure will be repeated. One can easily verify the following results of the above example:

the *tree* of the nodes : $T_n = 4, 3, 1, 2, 5, 6$
 the *tree* of the edges : $T_e = 3, 2, 5, 1, 4$

One can formulate either the global priorities, valid in full extent of the incidence matrix or local priorities, valid exclusively at particular nodes. The local priorities can be e.g. constructed as functions of the type of the node. In our example, however, we have used only the global priorities. Just discussed guidelines can be readily adopted for any single-root *tree*-shaped system. The *tree* algorithm serves the *macro*-decomposition in a complex model; in the hydraulic river model DL1 it is also used on *mezzo*-level to create the dynamic (piecewise) computational structure on the river subsystems having nonstationary topological configuration (either due to varying accessibility of the station data or due to switching of the hydraulic regime from sub- to supercritical and vice versa).

THE PETRI NET ALGORITHM

III. Elementary action in the Petri net



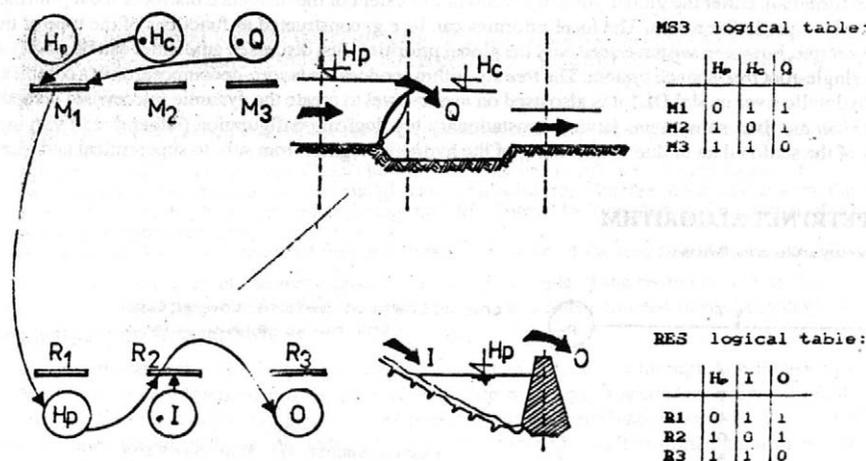
Elementary action in the Petri net

When a nonstationary topological coding appears as necessary, the AquaLog approaches such situations by introduction of pseudo-parallel data processing based on the token-ring algorithm. The computation is initiated from an arbitrary situation in mathematical determination of the problem and then it proceeds, passing a number of elementary computational actions until full determination of the problem. If an abnormal computational status appears and the system cannot automatically continue, the user-machine dialogue is initiated and the user is asked to help by keyboard entry the machine by completion the overall determination of current situation. Such asynchronous processes can be formulated by bipartite graphs called the Petri Nets, satisfying the definition

$$PN = \langle P, T, F, B, Mo \rangle$$

where **P** denotes the set of Places, **T** the set of Transitions, **F** the Forward incidence matrix, **B** the Backward incidence matrix, and **Mo** the initial Marking (Sedláček, 1979). Two categories of the nodes appear in the system graph: the **P**'s and the **T**'s. Both categories are connected by the edges; connecting of the equal-category nodes is avoided. The runtime-related marking of the **P**-node category is represented by a number of tokens, each denoting the number of remaining unresolved state variables at the particular place **P**. Realization of each transition **T** can be understood as replacement of one token from the upper place **P** towards the lower place **P**. Such transition controls an execution of the modeling technique 'installed' into the edge connecting both places, Tab. III.

The Fig.3 shows principle of synchronizing of the two interconnected modeling techniques: the gated spillway formula **MS3** (process 1) and the continuity equation of kinematic reservoir **RES** (process 2). The **MS3** formula implies 3 alternative solutions for three state variables: the pool level **H_p**, crest elevation **H_c** and discharge **Q**. Similarly, the **RES** model can be written also in three alternatives for individual state variables: pool level **H_p**, inflow **I** and outflow **O** discharges. Both logical tables in Fig.3 show formulations of all alternatives of the fully determined solutions. The overdetermined cases (three units in a line) as well as the undetermined cases (one unit in the line) are detected as abnormal computational status and they are postponed to the user decision.



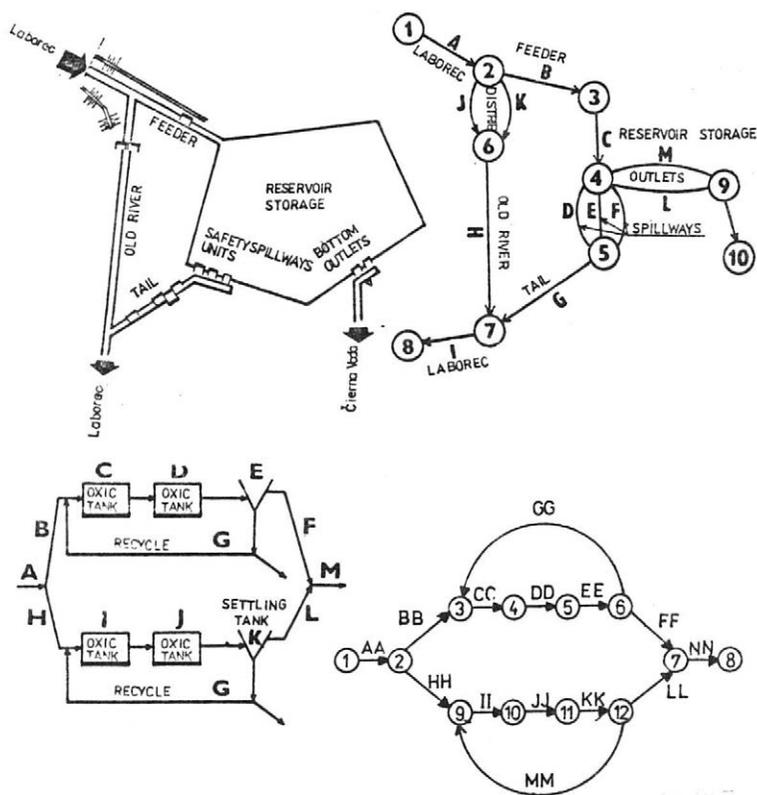
3. Synchronization of 2 interconnected modeling techniques

The Fig.3 also shows the Petri net of the interconnected modeling techniques; the places **P** represent state variables of the processes, the transitions **T** relate to individual alternatives of the equations (lines in the logical tables). It can also be seen from the graph that definition of three state variables in both systems suffices to determine the

solution. For reason of clarity, we have only depicted the interconnections related to the alternatives **M1** and **R2**. Solving the **M1**, one can compute the **Hp**. In substituting of the **Hp** into **R2** the unknown reservoir outflow **O** can be ascertained. From both logical tables the number of model alternatives needed to describe both processes can be determined by mathematical induction as

$$JJ_a = 2 \cdot JJ \cdot JJ \cdot (JJ-1) = 36$$

In this particular case the $JJ=3$ is a number of dependent variables. The (single-purpose) program code should therefore comply with 36 various alternatives to describe the model (in fact, one needs to consider only 24 realistic alternatives, as the **Hp** in the **MS3** and the **I** in the **RES** are not interconnected). Use of sequential programming methods in computerizing of even such a simple setup of 2 interconnected systems is obviously impractical and any attempt to increase a number of components would become entirely unrealistic. Therefore the AquaLog uses a pseudo-parallel processing to control the computation of the modeling techniques **MAN** and **WST**. Both techniques activate (in a random walk) the transitions **T**'s and they call for an appropriate alternative of the process equation (as e. g. in the case of **MS3** or **RES** of the above example). In such a manner the system continuously attempts to solve so far unrealized transitions. If the realization passes successfully, the Marking (the number of Tokens in the Place) is altered and the structure of the mathematical formulation correspondingly updated. For a given time-level, the computation is terminated on proviso that none of the transitions remains active, i.e. all markings at the input Places became zero valued.



4. Typical examples of the mezzo-level schematizing: by-pass reservoir and wastewater treatment plant

Two examples of the mezzo-level schematizing are given in Fig.4. The first shows the topography of the flow control units of a large by-bass reservoir Vihorlat, consisting of a feeder channel and several water transfer units (**DMY**), water distributing units (**MB3**), 4 ungated spillways (**MS3**), 4 various types of bottom outlets (**MB3**) and a unit representing the reservoir balance (**RES**). The second example shows the scheme 1. of a waste water treatment plant and its graph of two parallel cascades with sludge recycling and release, each consisting of 2 ox ic tanks and a settling tank.

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Príspevek podáva stručný popis modelovacieho systému AquaLog, vyvinutého jako programová podpora rozhodovacích procesů v oblasti hydrologie, vodního hospodářství a ekologie. Poskytuje prostředky simulační analýzy, hydrologických předpovědí v reálném čase a řízení vodohospodářských objektů. Architektura systému zdůrazňuje prvky strukturovaného programování ve dvou aspektech: ve formulaci topologie systému a v řešení fyzikálních a biochemických procesů. Dekompozice systému je chápána ve třech úrovních: makro-, mezo- a mikro. Článek uvádí základní topologické nástroje potřebné pro algoritmicizaci a řízení výpočtu systému. Tyto algoritmy jsou vyvinuty pro stromové i pro okružní grafy schematizující uvažovanou oblast. Algoritmicizace stromového grafu využívá některých vlastností incidence matice a umožňuje řešení systému s časově proměnnou strukturou. Pro řešení okružních sítí je v systému AquaLog využita metoda synchronizace výpočtových procesů prostředky Petriho sítí. Tímto způsobem může uživatel sestavit model libovolné konfigurace řešeného systému v závislosti topografii, dostupnosti hydrologických pozorování a cílové funkce řízení odtoku. V příspěvku jsou rovněž stručně uvedeny základní formulace vybraných modelovacích technik.

rozhodovací procesy; matematické modelování hydrologických a ekologických procesů; topologický popis povodí; čistírný odpadních vod; Petriho sítě

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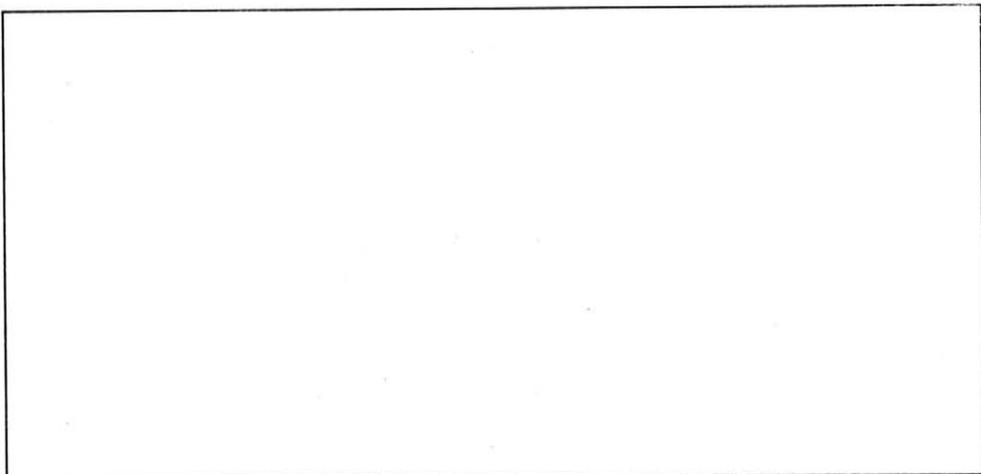
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