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FROM YIELD TABLES TO SIMULATION MODELS FOR PURE AND MIXED STANDS

OD RASTOVÝCH TABULIEK K SIMULAČNÝM MODELOM ROVNORODÝCH A ZMIEŠANÝCH PORASTOV

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ABSTRACT: The objective of the article is a short and instructive introduction to model approaches for pure and mixed forest stands from yield tables to eco-physiological process models. For a deeper understanding of the introduced model types the literature list offers the most important references. A model's objective and the existing knowledge of the observed system determine how complex the model approach has to be. Single tree models, eco-physiological based gap models and hybrid models are of particular interest for forest management as they are suitable for pure and mixed stands and a broad range of climatic zones. Version 2.2 of the SILVA model, developed for pure and mixed stands, belongs to the promising category of hybrid models and is used to explain the functional principles underlying this model approach. The SILVA stand simulator provides quantitative growth and yield information as a decision support for forest management.

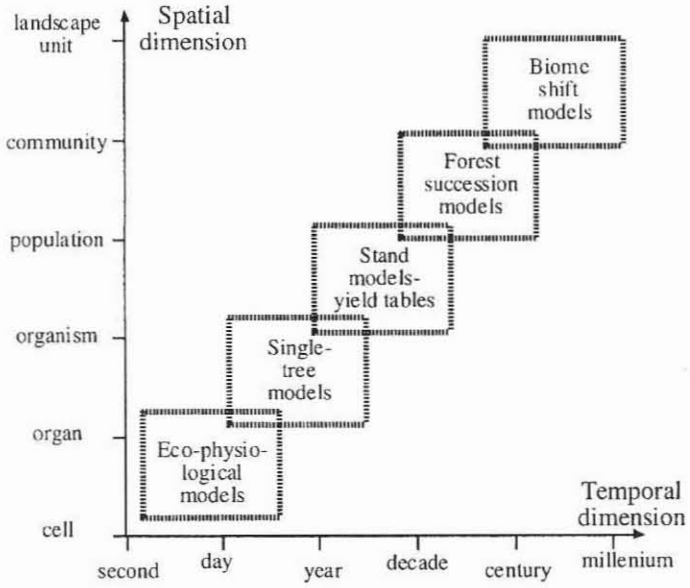
yield table; mixed stands; single tree simulator; structure generator; decision support

ABSTRAKT: Cieľom príspevku je krátky prehľad princípov modelovania rastu rovnorodých a zmiešaných porastov, a to od rastových tabuliek až po ekofyziologické procesné modely. Pre hlbšie pochopenie uvedených druhov modelov sú v príspevku uvádzané aj najvýznamnejšie citácie. V závislosti od cieľa modelovania a existujúcej úrovne poznania skúmaného systému je stanovený stupeň komplexnosti úrovne modelovania. Jednotlivo-stromové modely, na ekofyziologických základoch postavené „gap“-modely a tzv. hybridné modely sú pre lesné hospodárstvo zvlášť zaujímavé, pretože sú vhodné nielen pre rovnorodé, ale aj pre zmiešané a nerovnoveké porasty, a to v širokom spektre klimatických podmienok. Rastový simulátor SILVA 2.2 patrí do skupiny perspektívnych hybridných modelov a je v tejto práci použitý na objasnenie funkčných princípov tejto kategórie rastových modelov. Jednotlivo-stromový simulátor SILVA poskytuje užívateľovi kvantitatívne rastovo-produkčné informácie, podporujúce rozhodovací proces v riadení lesného hospodárstva.

rastové tabuľky; zmiešané porasty; jednotlivo-stromový simulátor; generátor štruktúry porastu; podpora rozhodovania

INTRODUCTION

Forest growth models consolidate the knowledge of single processes of forest growth to the notion of a comprehensive system. Forest ecosystems may be modeled with varying degrees of temporal and spatial resolution. The time scale may range from seconds to millenia while the spatial scale may encompass anything from cells and mineral surfaces to continents (Fig. 1). The slow processes on a large spatial scale fix the boundary to quicker processes on smaller scales. The other way round, the quick and spatially bounded processes determine the processes on higher levels. Model approaches that take into consideration these feedback loops between the different system levels can deliver an important contribution to system understanding as well as to management decision support. The model's objective and the existing knowledge of the observed system determine how complex the model approach will need to be. At the present state of system knowledge single tree and stand models, which model the processes on a temporal scale from year to century and on a spatial scale from tree to stand level fullfill the demands of forest management in the best way. They model the stand dynamic on the basis of the classical growth and yield variables like diameter, height, crown length etc. Process models have a higher spatial and temporal resolution and come to the classical variables by up-scaling. But the behaviour of the whole system can be more than the sum of the underlying processes. Forest sucession and biome shift models become an important tool for global change research in forest ecosystems.



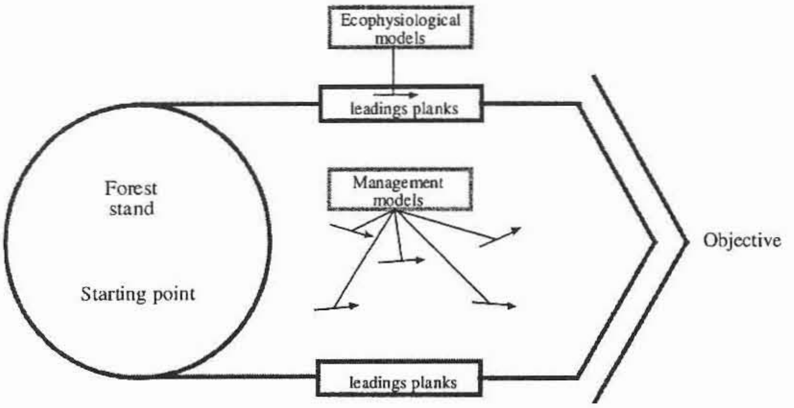
1. Spatial and temporal dimensions of process in forest ecosystems and models with increasing aggregation from eco-physiological models to biome shift models

The history of forest growth models is not simply characterized by the development of continuously improved models replacing the former, inferior ones. Instead, different model types with diverse objectives and conceptions were developed simultaneously. Objectives and structure of a model reflect the state of the art of the respective research area at its time and document the contemporary approach to forest growth prediction. The history of growth modeling also documents the extended knowledge in the science of forest growth. Beginning with yield tables for large regions as a basis for taxation and planning – such as the tables by Schwappach (1893) and Wiedemann (1932, 1939a,b, 1942) – model development led to regional yield tables and site-specific yield tables and culminates in the construction of growth simulators for the evaluation of stand development under different management schemes. Vanclay (1994) strives for an overview of growth and yield management models and their application to mixed tropical forests. The 1980s brought a new trend towards development of eco-physiological models which give insight into the complex causal relationships in forest growth and predict growth processes under various ecological conditions. The emphasis in model research shifts towards eco-physiological models and away from models which aim only at providing growth and yield information for forest management. These models strive to simulate forest growth on the basis of fundamental eco-physiological processes. The scientific value of eco-physiological models cannot be overrated; however, they will not be applied in forest management for the next few years as they are not yet sufficiently validated in many ways. Also, input and output variables do not yet meet the demand of forest management practice.

A major change has taken place in model conception, i.e. the understanding of forest growth on which the model is based: the tables by Weise (1880), Schwappach and Wiedemann still result from a purely descriptive analysis of sample area data in form of total and mean values about the observed processes of stand development. These descriptions were later combined with theoretical model concepts which also considered natural growth relationships and causal relations as far as they were known at the time. Yield tables for mixed stands of pine and beech created by Bonnemann (1939) for example characterise growth of beech in the middle and lower storey by mean values. The FOREST-model by Ek and Monserud (1974) controls increment behaviour of lower-storey trees by geometrical competition indices, and the eco-physiological growth models by Bossel (1994), Mäkelä, Hari (1986) and Mohren (1987) derive increment behaviour of lower-storey trees from light availability and performance in terms of photosynthesis.

The change of model objectives and conceptions is closely related to a change of quality in the information generated. Pure management models aim at reliable prediction of forest yield values applicable to planning and controlling in forest management, e.g. height and diameter increment and associated economic value of the assortment. Eco-physiologically models aim at biomass development, nutrient input and loss etc. Variables relevant to forest management are ancillary information in those models. For future planning in modern forestry, models meeting the information demands of ecology as well as of economy will gain in importance.

On the way from a starting point of a forest stand to an objective stage eco-physiological models and management models can give a specific decision support (Fig. 2). Ecological and socio-economic frame conditions define the leading planks and thus the corridor for management decisions. Eco-physiological models can support the ecological elements of the leading planks, e.g. the effect of site conditions, species mixture and thinning variants on critical loads, water quality or



2. Stand management models and eco-physiological models for decision support in forest ecosystem management

acidification. Stand treatments of interest can be judged in this way as ecologically acceptable or unacceptable. Management models help to optimize the path from starting point to the objective stand through the given corridor, they support e. g. the decision between different thinning and pruning strategies.

With the shift from tree and stand management models with low resolution to more complex eco-physiological models, different source data are needed for model construction and for the determination of model parameters: standard data sets derived from research sample plots (diameter, height etc.) were used for the development of stand growth models for applied forestry. For the construction of single-tree oriented models, additional data is required (crown dimension, tree position etc.). The transition to eco-physiological models requires an additional data base which can only be provided by broadened experiment concepts and co-operation with neighbouring disciplines.

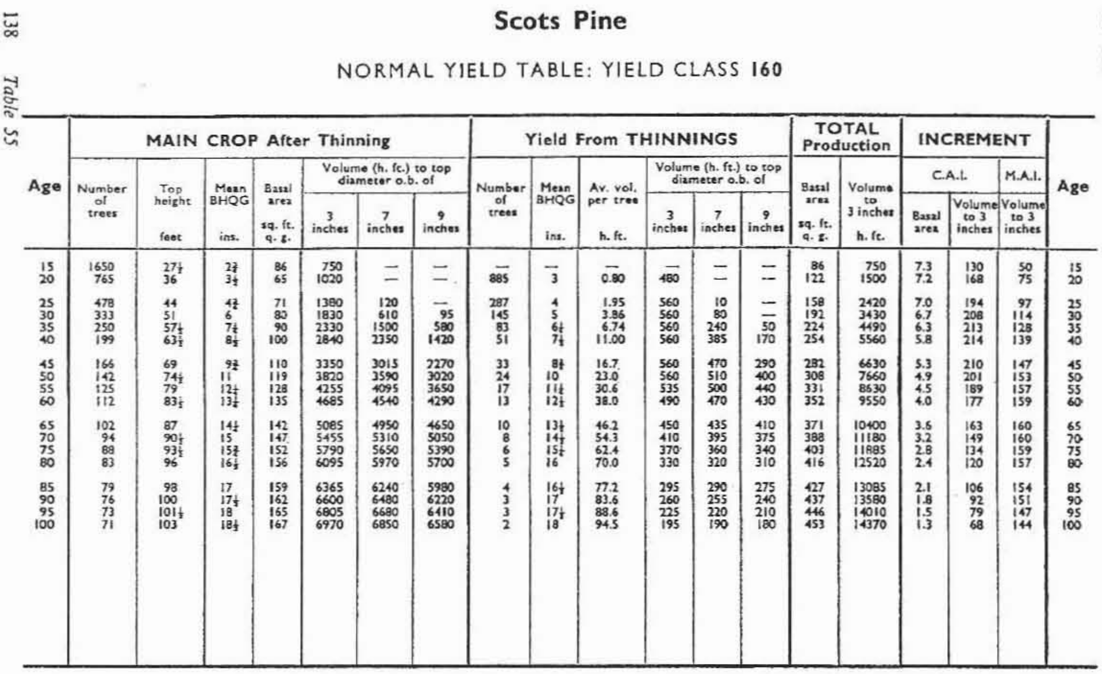
Models are always an abstraction of reality. They are greatly influenced by the model developer's knowledge and his perception of nature. This applies to the construction of yield tables as well as to building eco-physiological models.

STAND GROWTH MODELS BASED ON MEAN STAND VARIABLES

With a history of over 250 years yield tables for pure stands may be considered the oldest models in forestry science and forest management. They are representations of stand growth within defined rotation periods and are based on a series of measurements of diameter, height, biomass etc. reaching far back into the past. From the late 18th to the middle of the 19th century German scientists such as Paulsen (1795), von Cotta (1821), Hartig R. (1868), Hartig Th. (1847), Hartig G. L. (1795), Heyer (1852), Hundeshagen (1825) and Judeich (1871) created the first generation of yield tables based on a limited data set. These original yield tables soon revealed great gaps in scientific knowledge. A series of longterm data collection campaigns on experimental areas was therefore started. That was the birth period of a unique network of long term experimental plots in Europe which has been under survey and permanently has grown until present.

The second generation of yield tables, tackled towards the end of the 19th century and continued into the 1950s, follows uniform construction principles proposed by the Association of Forestry Research Stations, the predecessor organization of IUFRO, in 1874 and 1888 and has a solid empirical data basis. The list of protagonists involved in this work includes names such as Weise (1880), von Guttenberg (1915), Zimmerle (1952), Vanselow (1951), Krenn (1946), Grundner (1913) and, in particular, Schwappach (1893), Wiedemann (1932) and Schober (1967), who designed yield tables that were conceptually related and are still being used to today. A brilliant example of their work are the yield tables for European beech. In the 1930s and 1940s first models of mixed stands were constructed under the direction of Wiedemann. Data material from some 200 experimental areas established by the Prussian Research Station led to the widely used yield tables for even-aged mixed stands of pine and beech (Bonnemann, 1939), spruce and beech (Wiedemann, 1942), pine and spruce (Christmann, 1939), and oak and beech (Wiedemann, 1939a). World War II prevented Wiedemann from bringing the development of yield tables for uneven-aged pure and mixed stands to an end, but his studies initiated systematic research on mixed stands. Yield tables for mixed stands of this generation were never consistently used in forestry practice as they were restricted to specific site conditions, intermingling patterns and age structures.

Yield tables developed by Gehrhardt (1909, 1923) affected a transition from purely empirical models to models based on theoretical principles and biometric formulas and led to the third generation of yield tables. The core of these models designed by, inter alia, Assmann, Franz (1963), Hamilton, Christie (1973, 1974), Vuokila (1966), Schmidt (1971), Lembcke et al. (1975) is a flexible system of functional equations. These functional equations are based as far as possible on natural growth relationships and are generally parameterized by means of statistical



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Scots Pine

SP 160

NORMAL YIELD TABLE: YIELD CLASS 160

Age	MAIN CROP After Thinning							Yield From THINNINGS						TOTAL Production		INCREMENT			Age
	Number of trees	Top height feet	Mean BHQG ins.	Basal area sq. ft. q. g.	Volume (h. fc.) to top diameter o.b. of			Number of trees	Mean BHQG ins.	Av. vol. per tree h. ft.	Volume (h. ft.) to top diameter o.b. of			Basal area sq. ft. q. g.	Volume to 3 inches h. fc.	C.A.I.		M.A.I.	
					3 inches	7 inches	9 inches				3 inches	7 inches	9 inches			Basal area	Volume to 3 inches	Volume to 3 inches	
15	1650	27½	2¾	86	750	—	—	—	—	—	—	—	—	86	750	7.3	130	50	15
20	765	36	3½	65	1020	—	—	885	3	0.80	480	—	—	122	1500	7.2	168	75	20
25	478	44	4¾	71	1380	120	—	287	4	1.95	560	10	—	158	2420	7.0	194	97	25
30	333	51	6	80	1830	610	95	145	5	3.86	560	80	—	192	3430	6.7	208	114	30
35	250	57½	7¼	90	2330	1500	580	83	6¼	6.74	560	240	50	224	4490	6.3	213	128	35
40	199	63½	8½	100	2840	2350	1420	51	7½	11.00	560	385	170	254	5560	5.8	214	139	40
45	166	69	9¾	110	3350	3015	2270	33	8¾	16.7	560	470	290	282	6630	5.3	210	147	45
50	142	74½	11	119	3820	3590	3020	24	10	23.0	560	510	400	308	7660	4.9	201	153	50
55	125	79	12¼	128	4255	4095	3650	17	11¼	30.6	535	500	440	331	8630	4.5	189	157	55
60	112	83½	13¼	135	4685	4540	4290	13	12½	38.0	490	470	430	352	9550	4.0	177	159	60
65	102	87	14¼	142	5085	4950	4650	10	13½	46.2	450	435	410	371	10400	3.6	163	160	65
70	94	90½	15	147	5455	5310	5050	8	14½	54.3	410	395	375	388	11180	3.2	149	160	70
75	88	93½	15¾	152	5790	5650	5390	6	15¼	62.4	370	360	340	403	11885	2.8	134	159	75
80	83	96	16½	156	6095	5970	5700	5	16	70.0	330	320	310	416	12520	2.4	120	157	80
85	79	98	17	159	6365	6240	5980	4	16½	77.2	295	290	275	427	13085	2.1	106	154	85
90	76	100	17½	162	6600	6480	6220	3	17	83.6	260	255	240	437	13580	1.8	92	151	90
95	73	101½	18	165	6805	6680	6410	3	17½	88.6	225	220	210	446	14010	1.5	79	147	95
100	71	103	18½	167	6970	6850	6580	2	18	94.5	195	190	180	453	14370	1.3	68	144	100

3. Normal yield table of Scots pine from Bradley et al. (1966) in extracts. Normal yield tables model the development of fully-stocked stands on the basis of mean stand variables e.g. number of trees per acre, mean diameter at breast height or basal area per acre

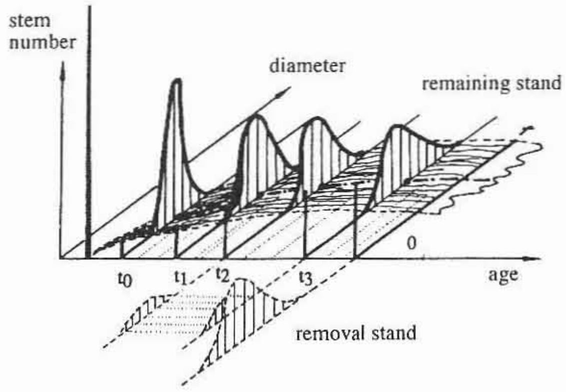
methods. The biometric models are usually transferred into computer programmes and predict expected stand development for different spectra of yield and site classes. A wealth of data was available for the construction of these models and they were processed by modern statistical methods.

Since the 1960s the fourth generation of yield table models has been created, i.e. the stand growth simulators by Franz (1968), Hoyer (1975), Hradetzky (1972), Bruce et al. (1977), Curtis et al. (1981, 1982) and Wenk (1994) which simulate expected stand development under given growth conditions for different stem numbers at stand establishment and for different tending regimes. Expected stand development under given growth conditions is simulated by means of computer programs and controlled by systems of suitable functions forming the core of the growth simulator. All information available on forest growth is synthesised into a complex biometric model which simulates stand development for a wide range of possible management alternatives and summarizes the results in tabular form similar to yield tables. Thus created yield tables reflect the stand dynamic for a wide range of imaginable management scenarios. While table and model were identical for yield tables of earlier generations, simulator-created yield tables now describe just one of many potentially computable stand development courses.

Despite a number of drawbacks yield tables still form the back-bone of sustainable forest management planning. When computing capacities and available data for model construction increased and with the rising demand for information in forestry, mean value and sum-oriented growth models and yield tables were increasingly replaced by stand-oriented growth models predicting stem number frequencies and by single-tree growth models. Prodan (1965, p. 605) commented on the significance of yield tables in the context of silviculture and forest sciences as follows: „Undoubtedly, yield tables are still the most colossal positive advance achieved in forest science research. The realization that yield tables may no longer be used in the future except for more or less comparative purposes in no way detracts from this achievement."

STAND-ORIENTED MANAGEMENT MODELS PREDICTING STEM NUMBER FREQUENCY

With the transition towards new intensive treatment concepts, the demand for information in forestry has changed in emphasis from mean stand values towards single-tree dimensions of selected parts of a stand. This changed demand for information resulted in the 1960s in the creation of the first growth models enabling prediction of mean stand values as well as frequencies of single-tree dimensions. Until then, a stand served as the usual information unit on which all predictions were based; these predictions were now strengthened by statements about stem number frequencies in diameter classes (Fig. 4) which are for example needed for precise prediction of assortment yield and value of a stand. Depending on their concept and construction, stand-oriented growth models predicting stem number frequency are classified into differential equation models, distribution prediction models and stochastic evolution models.



4. Principle of management models predicting the shift of the diameter or height distribution along the x-axis (according to Sloboda, 1976)

Many natural processes in various disciplines of the natural sciences can be described by differential equations. An example is differential equations formulating changes of yield descriptors for diameter classes of a stand – i.e. change of stem number, basal area and growing stock – depending on current yield state values. Stand development of the yield descriptors then results from numerical solution of the differential equation systems. In the 1960s and 1970s, Buckman (1962), Clutter (1963), Leary (1970), Moser (1972, 1974) and Pienaar, Turnbull (1973) developed stand-oriented growth models based on differential equation systems.

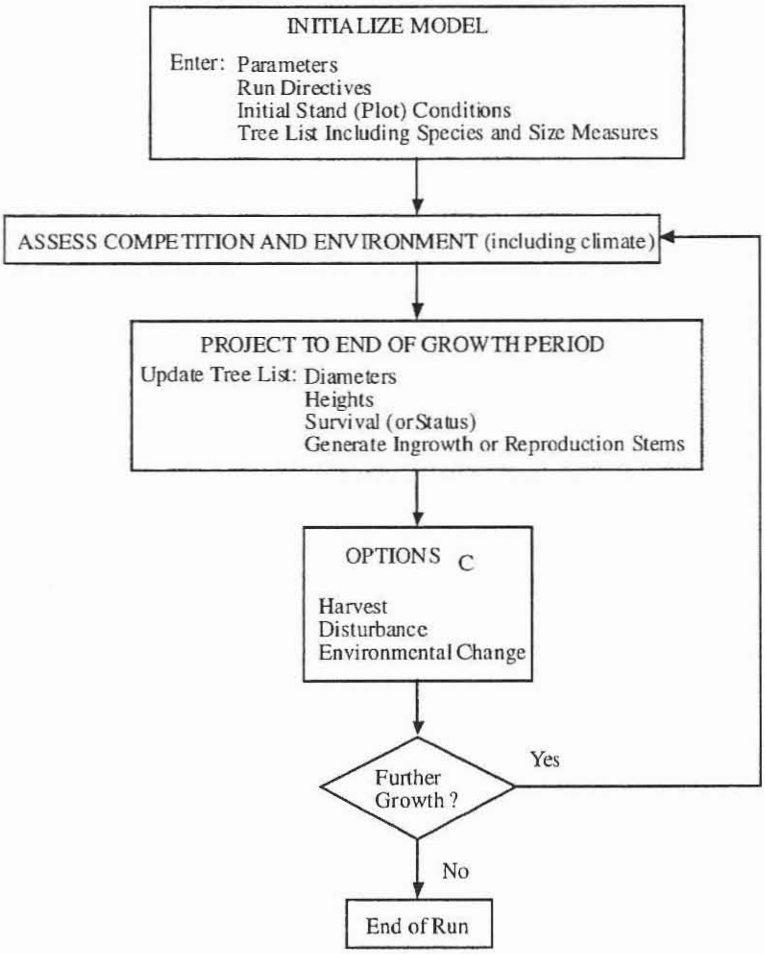
In the mid 1960s, Clutter, Bennett (1965) came to a completely new approach to stand development modeling. They characterized the condition of a tree population by its diameter and height distribution and described stand development by extrapolation of these frequency distributions. The precision of such models is decisively determined by the flexibility of the distribution type on which it is based. The suitability of different distribution types – e.g. BETA-, GAMMA-, LOGNORMAL-, WEIBULL- or JOHNSON-distribution – has to be assessed individually. In these models otherwise than in those reviewed earlier, stand development is not controlled by the age function of the individual yield descriptors, but by the parameters of the underlying frequency distribution. Models of this type were initially constructed by Clutter and Bennett for North American spruce stands and further developed by McGee, Della-Bianca (1967), Burkhart, Strub (1974), Bailey (1973) and by Feduccia et al. (1979).

The term „evolution models" for stochastic growth models is derived from the fact that in these models stand development evolves from an initial frequency distribution, e.g. from a diameter distribution known from forest inventory. Thus, these models – similar to distribution prediction models – predict frequencies of single-stem dimensions (Fig. 4). The mechanism accounting for the extrapolation, however, is based on a Markov-process, giving the transition probability for the shift between the diameter classes. Stochastic growth models were introduced to forestry science with the pioneering investigations by Suzuki (1971, 1983), and they continue to be linked to the name of Suzuki until today. His growth models, e. g. for Japanese *Chamaecyparis* pure stands, have been consistently developed by Sloboda (1976) and his team since the mid 1970s; they are mainly interested in adapting the models, which are oriented at Japanese conditions, to the issues of German forestry and in model validation based on permanent test plot data. Stand-oriented growth models based on stochastic processes have been developed by Bruner, Moser (1973) and Stephens, Waggoner (1970) also for mixed stands.

SINGLE-TREE ORIENTED MANAGEMENT MODELS

Single-tree models take the stand as a mosaic of single trees and model individual growth and interactions with or without consideration of tree position. This has paved the way for the design of models of pure and mixed stands of all age structures and intermingling patterns. An equation system which controls growth behaviour of single trees depending on their constellation within the stand is the central module of all single-tree models. Position-independent or position-dependent competition indices are used to quantify the spatial growth constellation of each tree and to predict its increment of height, diameter etc. in the following period. Compared to stand-oriented growth models based on mean stand descriptors and those predicting stem number frequencies, single-tree models work on higher resolution. The information unit in single-tree models is the individual tree. However, results of lower resolution models, e.g. mean tree development or diameter frequency distributions, can also be derived from single-tree model results by integration. Information about stand growth then results from summarising and aggregating changes. All single-tree models that are transferred into computer programs are simulating, i.e. reproducing by computer, stand dynamics based on single-tree development for a given growth period. Recent single-tree models are programmed in order to enable the user to interactively influence a simulation run. They allow to follow stand development step by step during the simulation at the computer and to specify e.g. thinning or influences of disturbance factors at any time during the simulation processes, thus influencing or diverting the current course of stand development.

After parameters for the control of the single-tree model have been set, tree characteristics at the beginning of the prediction phase for the test area to be investigated are fed into the computer as initial values for the simulation (Fig. 5). This tree list can contain data on tree species, stem dimensions, crown morphology, stem position and other data about the stand individuals. These data usually originate from single-tree based inventories of indicator plots. Starting with these initial



5. Flow chart of single tree models (according to Ek, Dudek, 1980)

values, a change (e.g. mortality or development of diameter, height or crowns) for all stand members depending on individual growth conditions is predicted using an appropriate control function; this is done for the first growth period of e.g. five years. Once the tree list has been processed, a change of growth conditions – for example due to thinning or disturbing influences – can be specified prior to continuing to the next increment period. This will now influence single tree growth in the following period. The refined state values of all trees resulting at the end of the first growth period represent also the initial values for the second growth period. These values are repeatedly extrapolated in every simulation cycle and interim results are given. The simulation continues until the envisaged prediction period has been worked off step by step. In most models, time steps are five years, sometimes only one or two years. By removing single trees during a simulation run, the growth constellation and growth behaviour of the remaining individuals change in the next growth period. Growth reaction of the stand is thus explained by the reactions of all single trees to this intervention. By relating stand development back to growth behaviour of single trees and by modeling single-tree dynamics depending on growth constellation within the stand, single-tree models, after being initialized accordingly, enable to evaluate a wide range of treatment programs.

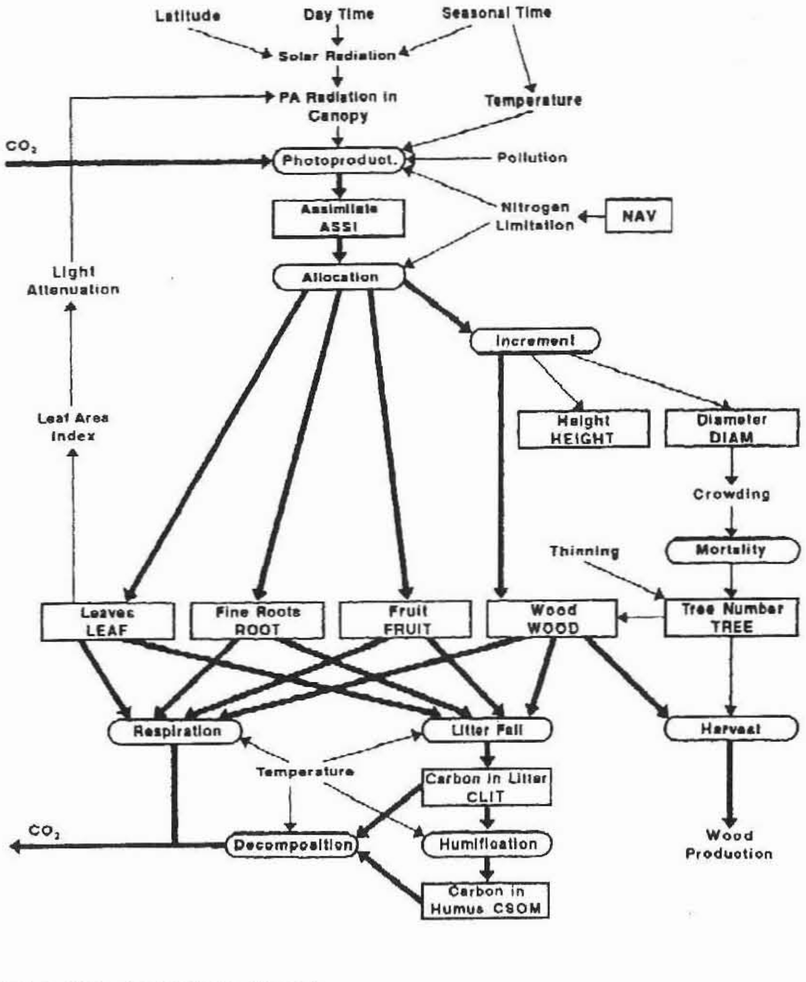
The first single-tree model was developed for pure douglas fir stands by Newnham (1964). It was followed by the development of models for pure stands by Arney (1972), Bella (1970), Mitchell (1969, 1975) and others. In the mid 1970s, Ek and Monserud applied the construction principles for single-tree oriented growth models for pure stands to uneven-aged pure and mixed stands (Ek, Monserud, 1974; Monserud, 1975). We can distinguish distance-dependent and distance-independent single-tree models; the former being able to refer to data about stem position and stem distance for the control of single-tree growth. The worldwide bibliography of single-tree growth models compiled by Ek, Dudek (1980) lists more than 40 different single-tree models which group into about 20 distance-dependent and distance-independent models each. Single-tree models developed since the 1980s – among others by van Deusen, Biging (1985), Hasenauer (1994), Nagel (1996), Pretzsch (1992, 1998, 1999), Sterba et al. (1995), Wensel, Koehler (1985) and Wykoff et al. (1982) – refer to the methodological bases of their predecessors in many parts; however, owing to the rapidly improving user interfaces of modern computers they are far more user-friendly than older single-tree models.

ECO-PHYSIOLOGICAL GROWTH MODELS

All models mentioned above rely on growth and yield data from long-term observation plots and hence have the advantage of being empirically verifiable. However, there is a drawback to historically deduced data inasmuch as growth conditions undergo changes and reaction patterns from the past cannot – without further ado – be projected into the future. In the 1970s model research was pointed in a new direction with the creation of high-resolution, so called eco-physiological process models which account for metabolism, organ formation, assimilation and respiration as well as biochemical and soil chemistry reactions. Pioneers of the eco-physiological process model concept for forest stands are Bossel (1994), Mäkelä, Hari (1986) and Mohren (1987). The term process model is slightly misleading in the sense that of course all forest growth models describe processes. Merely the temporal and spatial scale of modeled processes becomes more detailed in the transition from yield table models via single-tree management models and succession models to growth models based on eco-physiological data (Fig. 1).

The development of modern process models begins with a system analysis and the selection of characteristic system components. Results of this description can be transferred into a system diagram (Fig. 6). The system description breaks the system down into system components which are characteristic of all biological systems. By system parameters we understand parameters remaining constant during the lifetime of the system. Exogenous parameters are variables which control the system but cannot be influenced by the system, e.g. stress by air pollutants. State variables are the actual output value of the model; their current values reflect the system's state. Important state variables in stand models are accumulated carbon quantities in needles, branches, stem and roots. The initial values of the state variables give the starting values of a system and thus decisively influence its further development. In a growth model for example, stem number and initial stand structure have to be specified as initial values. The change rate of the state variables controls the change, i.e. input and output of state variables. Examples are mortality rates or respiration rates which control the change of the carbon quantities accumulated in the different compartments. Intermediary variables change simultaneously with the state variables and feed back into the system. The system components are indicated in the system diagram with differing graphical symbols and their interrelations are identified by lines and arrows.

The model thus outlined is transferred into a mathematical model and subsequently into a computer program. For this purpose, the system components and links are described by mathematical or logical relation-



6. Carbon flow (heavy arrows) in the TREEDYN3 forest simulation model with the most important state variables, processes and flows, indicated by boxes, ovals and arrows resp. (according to Bossel, 1994)

ships. Once the complete model is constructed, the causal relations implemented are parameterized. The system behaviour can be simulated by the developed computer programs. All information known about the system is therefore consolidated in the system components and the system structure. The process of system analysis and model development concludes with the validation of the final model. For validation, i.e. for testing if the causal relations assumed in the model realistically reflect the growth of stands or single trees, empirical yield data can be used among other data. If necessary, individual model assumptions are corrected or model parts revised.

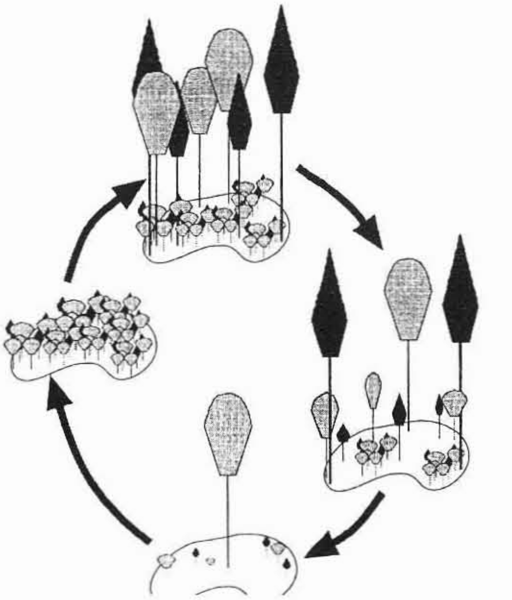
A vastly improved understanding of eco-physiological processes in forest eco-systems paved the way towards this model approach and it was the actual modeling of these processes which provided an idea of the functioning of the overall system. Another impetus to process model development was the need to understand and predict the reactions of forest eco-systems to an increasing number of adverse effects such as industrial immissions, rise in atmospheric CO_2 and climate change. In the context of environmental instability high-resolution and detailed process models are certainly the ideal approach towards understanding and predicting forest eco-system behaviour. However, there are definite constraints in developing and applying process models due to considerable gaps in the knowledge of sub-processes in assimilation organs and in the soil. Also, the up-scaling of sub-processes to the behaviour of the overall system is still largely unresolved. Moreover, the introduction of process models still requires intensive research and extremely high-powered computers that are only rarely available in practice. To date process models are, therefore, primarily research instruments rather than forest management planning tools.

GAP MODELS AND BIOME SHIFT MODELS

In view of modern theoretical ecology, a spatially extensive system is composed of mosaic-like sub-units and can be studied by analysing these sub-units. Watt (1947), Bormann, Likens (1979) and others transferred this view of extensive ecosystems to the study and model representation of growth dynamics of pure and mixed stands. This laid the foundations for the concept of gap models suitable to predict succession. According to this conception, a forest stand is an aggregation of gaps. The size of these gaps corresponds to the extent of a potential crown area of a dominant tree or tree group (areas of 0.04 to 0.08 ha). The actual information unit is the tree group in the gap; stand development results as the sum of the total spectrum of contributing gaps. Gap models imply that forest development in a gap occurs in a fixed cycle: a gap results from exploitation or death of a dominant tree. Thus, growth conditions of so far under-storey trees and natural regeneration improve. Growing trees successively close the gap and a new upper storey develops. The cycle is repeated with further losses of dominant trees (Fig. 7). Growth models with this approach were predominantly used for investigations of competition and succession in semi-natural stands.

Gap models such as designed by Shugart (1984), Pastor, Post (1985), Aber, Melillo (1982), Leemans, Prentice (1989) are primarily aimed at mixed stands. While in the models described above increment-determining factors have effects on stands or individuals respectively, gap models describe tree growth depending on growth conditions in the individual gap. Gap models simulate growth dynamics for single trees or tree classes in a gap; it is therefore possible to generate information about the development of diameter, height and volume of single trees as well as stands. However, regarding input and output variables they are less fixed on information available from or required by forestry practice; rather, they aim at predicting long-term succession in natural forest stands and the effects of altered growth conditions. However the FORMIX2 model (Bossel, Krieger, 1994) for virgin and managed Malaysian lowland dipterocarp forests is an example for an eco-physiologically based gap model with output variables, useful as a decision support in forest management.

Biome shift models developed by researchers such as Box, Meentemeyer (1991) and Prentice et al. (1992) establish statistic relationships between regional climate and vegetation type. Based on relevant climatic conditions the nature of potential biomes, i.e. communities, may be predicted on a regional and even global scale. Of all the models under discussion these are the ones that provide the highest aggregation of data on vegetation development and forest growth. They have



7. Gap models imply that stand dynamic occurs in a characteristic cycle: A gap results from exploitation or death of a dominant tree. Growth conditions in the gap improve. Young trees close the gap and form a new upper layer (according to Shugart, 1984)

therefore gained increasing importance in global change research.

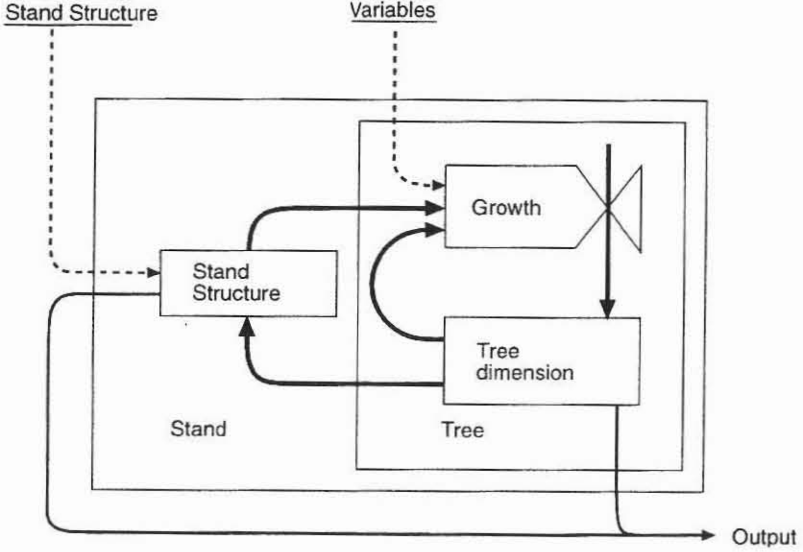
HYBRID MODELS FOR FOREST MANAGEMENT

The transfer of specific components of eco-physiological models – based on the solid process knowledge – into stand or single-tree management models – based on long-term experimental plots and increment series – leads to what Kimmins called hybrid growth models. Models of this type were constructed, inter alia, by Botkin et al. (1972) and Kimmins (1993). Their objective is to make the best possible use of newly acquired knowledge of eco-physiological processes combined with historical increment observations to assist in forest planning and management. On account of the implemented relationship between site conditions and species specific growth they can be used for pure and mixed stands. In the past 100 years mixed stands have gradually become the focus of forest research, in particular on account of studies by Gayer (1886), Wiedemann (1939b) and Assmann (1961), but until today growth models for mixed stands are missing as a quantitative planning tool. In Europe none of the above model concepts is of any practical relevance as tools to be used in the management of mixed stands.

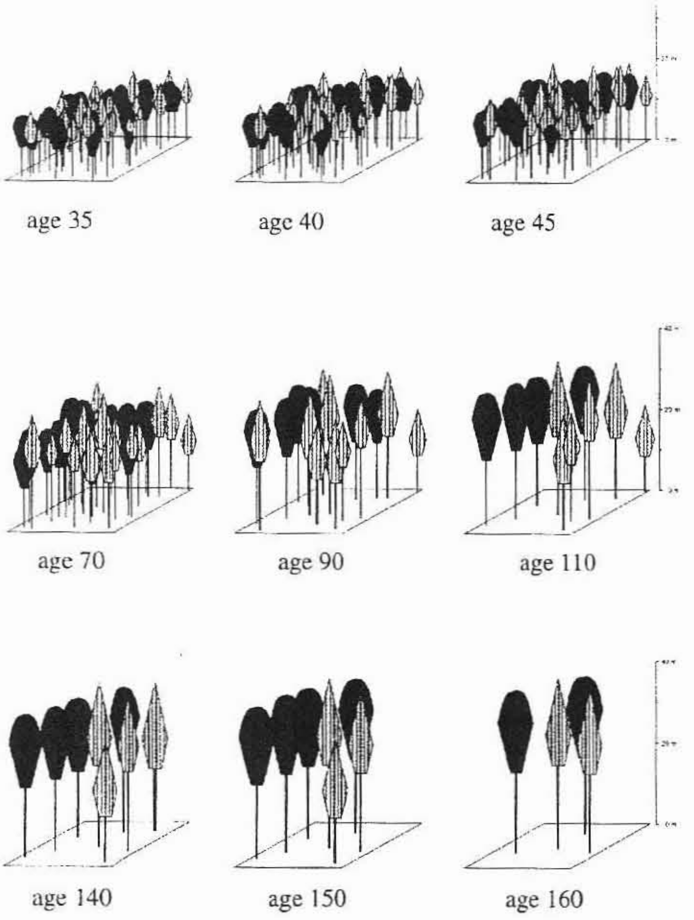
Only very recently have models created by Kolström (1993), Nagel (1996), Pretzsch (1992), Pukkala (1987) and Sterba et al. (1995) found use in forestry practice for planning work in pure and mixed stands. These are more or less site-sensitive single tree models constructed from a broad basis of eco-physiological and growth and yield data. Version 2.2 of the SILVA model, developed in Germany for pure and mixed stands, belongs to this category of hybrid models (Pretzsch, 1992; Pretzsch, Kahn, 1996; Kahn, Pretzsch, 1997) and may be used as an example to explain the functional principles underlying this model approach. In this book the SILVA stand simulator is used by Kahn and Biber. The introduced methods of data collection on experimental plots, modeling and scenario analysis in teak, dry dipterocarp and mixed dipterocarp stands based on SILVA 2.2, were developed at the Chair of Forest Yield Science, University of Munich.

MANAGEMENT MODEL SILVA 2.2 FOR PURE AND MIXED STANDS

SILVA reflects the spatial and dynamic character of mixed stand systems inasmuch as it models spatial stand structures at 5 year intervals. This allows to record the individual growth constellation of every tree and the control of tree increment in relation to growth constellation and the original dimensions of the tree (Fig. 8). The external variables determining tree increment and stand structure are treatment, risk and site factors. The model simulates the effects that tending, thinning, regeneration and natural hazards such as storms have on the stand dynamic. The feedback loop stand structure → tree growth → state of tree → stand structure forms the backbone of the model. The step by step modeling of the growth of all individual trees via differential equation systems informs about the development of assortment yield and financial yield, stand structure, stability and diversity of the stand by means of the data, required in yield calculations, on height, dhb, number of stems etc. Input and output data used in the model correspond to the data available from or required in forestry practice. Only site variables available on a large scale are considered. With models of this type a weighting between yield-related, socio-economic and ecological effects and the timber production and financial yield in pure and mixed stands becomes possible.



8. Simplified system diagram of the growth model SILVA 2.2 with the levels stand and tree, the external variables interference in stand structure and site conditions and the feedback loop stand structure → growth → tree dimension → stand structure



age 35 age 40 age 45

age 70 age 90 age 110

age 140 age 150 age 160

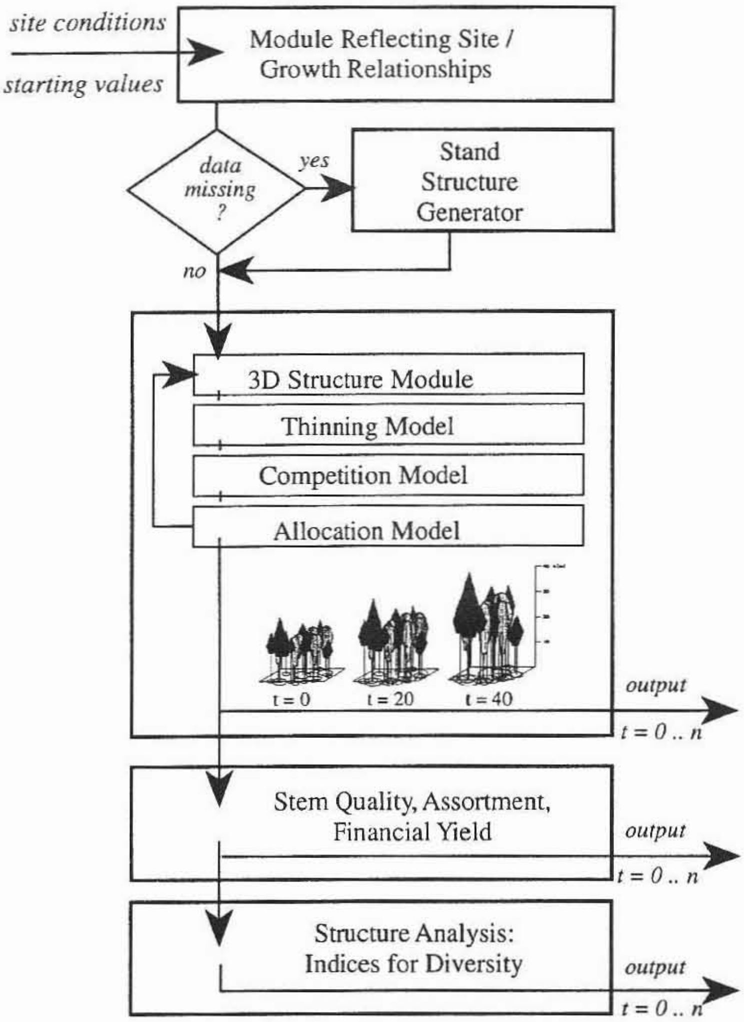
9. SILVA 2.2 breaks down forest stands into a mosaic of individual trees and reproduces their interactions as a space-time system. Excerpt of a simulation run for a mixed stand with two species (slight thinning from below)

Parametrization relies on yield and site characteristics of pure and mixed stands that have been under observation for up to hundred years.

The position-dependent individual tree model SILVA 2.2 breaks down forest stands into a mosaic of individual trees and reproduces their interactions as a space-time system (Fig. 9). It can therefore be used for pure and mixed stands of all age combinations. Primarily it is designed to assist in the decision making processes in forest management. Based on scenario calculations SILVA 2.2 is able to predict the effects of site conditions, silvicultural treatment and stand structure on stand development, and therefore also serves as a research instrument.

The first model element reflects the relationship between site conditions and growth potential and aims at adapting the increment functions in the model to actual, observed site conditions (Fig. 10). With the aid of nine site factors reflecting nutritional, water and temperature conditions the parameters of the growth functions are determined in a two-stage process (Kahn, 1994). The stand structure generator STRUGEN facilitates the large-scale use of position-dependent individual tree growth models. The generator converts verbal characterizations as commonly used in forestry practice (e.g. mixture in small clusters, single tree mixture, row mixture) into a concrete initial stand structure with which the growth model can subsequently commence its forecasting run (Pretzsch, 1997). The three-dimensional structure model uses tree attributes such as stem position, tree height, diameter, crown length, crown diameter and species-related crown form models to construct a three-dimensional stand structure. The thinning model is also an individual tree based one and can model a wide spectrum of treatment programs (Kahn, 1995). The core of the thinning model is a fuzzy logic controller. In the simulation studies described below the thinning model simulates various thinning methods (thinning from below and selective thinning) and thinning intensities (slight, moderate and heavy). The competition model employs the light-cone method (Pretzsch, 1992) and calculates a competition index for every tree on the basis of the three-dimensional stand model. The allocation model controls the development of individual stand elements. Tree diameter at height 1.30 m, tree height, crown diameter, height of crown base, crown shape and survival status are controlled, at five year intervals, in relation to site conditions, interspecific and intraspecific competition. Finally classical yield information on the stand and single tree level for the prognosis period are compiled in listings and graphs. Additional information on stem quality, assortment and financial yield complete the growth and yield characteristics.

At every stage of the simulation run a program routine for structural analysis calculates a vector of structural indices which serve as indicators for habitat and



10. Essential elements of the SILVA 2.2 simulator for pure and mixed stands

species diversity and form a link to the ecological assessment of forest stands.

The algorithmic sequence for predicting forest development comprises the following steps (Fig. 10): the first step is the input of data on the initial structure and site conditions of the monitored stand. Secondly, the parameters of the growth functions are adapted to actual site conditions. Once the starting values for the prognostic run are complete, monitoring can begin. If there are no initial values, e.g. stem positions are unknown, the missing data can be realistically complemented with the help of the stand structure generator. Once the spatial model has been constructed (step 4), the silvicultural treatment program is specified in the fifth step. The competition index calculated for each tree in step 6 is used in step 7 to control individual tree development. Steps 4 to 7 are repeated until the entire prognostication period has been run through in 5-year steps.

To date, model research has had little success in substituting yield tables for pure stands by an improved information system for pure and mixed stands. This can in no way be attributed to a deficit in methodological principles, data or technical equipment. The causes rather lie in the fact that new models are not properly adapted to practical requirements. The recent introduction of the growth model SILVA 2.2 in practical usage, instruction and research furnishes a distinct profile of practical demands to be considered in management models that will be used in decision-making processes at stand and forest enterprise levels. 1. The natural management of forests is currently making great headway. In the long run only those growth models will therefore find approval that are capable of simulating the growth of pure and mixed stands of all age compositions and structural patterns. 2. Models need to be operable at stand and forest enterprise levels and able to simulate growth behaviour under different thinning regimes and different processes of artificial and natural regeneration. 3. Flexibility of the model is essential so as to permit simulation of growth reactions to site alterations and interference factors on a large regional scale. 4. Apart from tree and stand characteristics such as volume production, assortment yield, wood quality and financial yield it should also include structural parameters determining the recreational and protective functions of forests as well as indicators showing the impact of hazards or ecological instability. 5. Forestry practice is interested, first and foremost, in calculating scenarios at stand and forest enterprise levels. This can only be achieved if input and output data of the model consider what information is available and what data are needed in forestry practice. Furthermore, achieving this goal also depends on whether the model forms part of a comprehensive forestry information system and, finally, whether hardware specifications are acceptable in practice.

For decades forestry practice has been hoping for improved growth models to assist with planning, operations and control in forest management. The general acceptance of new models by practitioners calls for a close cooperation between forest science and forest practice, from the design and development of the model to its actual introduction in forest management.

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OD RASTOVÝCH TABULIEK K SIMULAČNÝM MODELOM ROVNORODÝCH A ZMIEŠANÝCH PORASTOV

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Modelovanie lesných ekosystémov je možné na rozdielnych časových a priestorových úrovniach. V závislosti od cieľa modelovania môže siahať časová škála od niekoľkých sekúnd až po tisícročia a priestorová škála od bunkovej veľkosti až po kontinenty. Cieľ modelovania a úroveň poznatkov o modelovanom systéme určuje nutný, resp. možný stupeň komplexnosti úrovne modelovania.

S viac ako 250-ročnou históriou sú rastové tabuľky pre rovnoveké porasty najstaršími modelmi v lesníckej vede a praxi. Tieto zachytávajú rast lesných porastov za obdobie dlhšie ako ich rubná doba a opierajú sa o dlhodobé sledovania na výskumných plochách. Od konca 18. až do polovice 19. storočia vypracovali o.i. Paulsen (1795), von Cotta (1821), R. Hartig (1868), Th. Hartig (1847), G. L. Hartig (1795), Heyer (1852), Hundeshagen (1825) a Judeich (1871) na pomerne malej empirickej základni prvú generáciu rastových tabuliek, ktorá je ešte poznačená zbieraním skúseností. Tieto prvé tabuľky ale zodpovedali na široké spektrum vedeckých problémov a odštartovali etapu intenzívneho zakladania trvalých výskumných plôch.

Druhú generáciu rastových tabuliek je možné datovať od konca 19. do polovice 20. storočia a charakterizovať orientáciou na jednotné princípy konštrukcie, ktoré v roku 1874 a 1888 odporučil Zväz nemeckých lesníckych výskumných organizácií. Zároveň je možné povedať, že tieto tabuľky už boli postavené na solídnej empirickej úrovni. K protagonistom tejto generácie rastových tabuliek patria Weise (1880), von Guttenberg (1915), Zimmerle (1952), Vanselow (1951), Krenn (1946), Grundner (1913), ale predovšetkým Schwappach (1893), Wiedemann (1932) a Schober (1967), ktorých tabuľky na seba koncepčne nadväzujú a používajú sa aj v súčasnosti (napr. hore citované tabuľky pre drevinu buk). V tridsiatych a štyridsiatych rokoch vznikli pod vedením Wiedemanna prvé rastové tabuľky pre zmiešané porasty. Na základe empirického materiálu z viac ako 200 výskumných plôch Pruského výskumného ústavu boli konštruované známe rastové tabuľky pre rovnoveké, ale aj zmiešané porasty borovice a buka (Bonnemann, 1939), smreka a buka (Wiedemann, 1942) a duba a buka (Wiedemann, 1939a). Ďalšie výskumné aktivity v tejto oblasti bol však Wiedemann kvôli druhej svetovej vojne nútený prerušiť. Tieto práce už ale predstavujú začiatok systematického výskumu v zmiešaných porastoch. Rastové tabuľky zmiešaných porastov tejto generácie však pre obmedzenie platnosti len na definované stanovištia, typ a charakter zmiešania nenašli v lesníckej praxi žiadne uplatnenie.

Rastové tabuľky od Gerhardta (1909, 1923) z dvadsiatych rokov 20. storočia uvádzajú tretiu generáciu rastových tabuliek, ktorých modely nemajú len empirický charakter, ale sú aj teoreticky odôvodnené a biometricky formulované. Jadrom týchto modelov – napr. Assmann, Franz (1963), Hamilton, Christie (1973, 1974), Vuokila (1966), Schmidt (1971), Lembcke et al. (1975) – je flexibilný systém rovníc, ktorý (pokiaľ je možné) sa opiera o osvedčené rastové zákonitosti a funguje aj ako počítačový program.

Vznikom porastových simulátorov – Franz (1968), Hoyer (1975), Hradetzky (1972), Bruce et al. (1977), Curtis et al. (1981, 1982) a Wenk (1994) – na konci šesťdesiatych rokov možno datovať začiatok štvrtej generácie rastových modelov. Tie umožňujú pre zvolené rastové podmienky, východiskový počet stromov v poraste a pestovný režim prognózovať vývoj lesných porastov.

Aj napriek všetkým nedostatkom predstavujú rastové tabuľky až dodnes základ na princípoch vytrvalosti založeného plánovania v lesníctve. K postaveniu rastových tabuliek v kontexte Náuky o raste lesa a lesníctva Prodan (1965, s. 605) poznamenáva: „Je nepochybné, že konštrukcia rastových tabuliek bola doposiaľ najvýraznejším a najpozitívnejším výkonom lesníckej vedy. Táto skutočnosť neznižuje ani poznatok, že rastové tabuľky budú v budúcnosti slúžiť len na účely porovnávania."

Na konštrukciu rastových tabuliek, podnietenú predovšetkým v nemecky hovoriacich krajinách, nadväzuje od šesťdesiatych rokov modelovanie rastu lesa na princípoch prognózovania rozdelenia početností stromov alebo na základe jednotlivo-stromových modelov. Autori Moser (1972, 1974), Clutter (1963), Clutter, Bennett (1965), ale aj Sloboda (1976) a Suzuki (1971) konštruujú modely na princípoch rozdelenia početností, ktoré vývoj porastu popisujú prostredníctvom diferenciálnych rovníc alebo funkcií rozdelenia početností, resp. zohľadňujú stochastické procesy. Jednotlivo-stromové modely, ktoré zaviedli Arney (1972), Bella (1970), Ek, Monserud (1974), Mitschell (1969, 1975), Monserud (1975), Newnham (1964) a Wykoff et al. (1982), idú v časovej a priestorovej úrovni modelovania ešte o jeden krok ďalej. Tu je považovaný porast ako mozaika jednotlivých stromov, v ktorom je rast a interakcia každého jednotlivého stromu prognózovaná so zohľadnením alebo bez zohľadnenia pozície stromov v poraste. Tým sa otvára cesta pre modelovanie rovnorodých, ale aj zmiešaných porastov rôznej vekovej štruktúry a typu zmiešania.

Modely na základe rozdelenia početností stromov a jednotlivo-stromové modely boli vyvíjané prevažne v anglo-amerických krajinách, kde aj našli uplatnenie v lesníckej praxi. V strednej Európe však na uplatnenie ešte len čakajú. Všetky doteraz spomenuté generácie modelov sa opierajú o dlhodobé sledovania prírastku na výskumných plochách a empiricky sú dobre fundované. Toto možno považovať za ich prednosť. Na druhej strane je to ale aj nevýhoda, pretože pri zmene rastových podmienok nie je možné rastové reakcie z minulosti použiť na prognózovanie rastu do budúcnosti.

S vývojom na vysokej časovej a priestorovej úrovni koncipovaných – tzv. procesných – modelov, ktoré zohľadňujú podľa stupňa komplexnosti látkovú výmenu, tvorbu orgánov, asimiláciu a respiráciu, biochemické alebo pôdno-chemické reakcie, vznikol v sedemdesiatych rokoch nový smer. Podporené to bolo rastom poznania o čiastkových procesoch v lesných ekosystémoch, ktoré bolo prostredníctvom modelovania obohatené aj o predstavu správania sa celého systému. Rastom ovplyvňovania ekosystémov rušivými faktormi ako imisie, rast koncentrácie CO_2 v ovzduší, zmena klímy, ale aj rastúcim záujmom o porozumenie reakcií lesných ekosystémov s možnosťou vedieť ich aj prognózovať dostal tento smer výraznú podporu. Označenie procesné modely nie je ale pre tento druh modelov najvýstižnejšie, pretože každý rastový model popisuje procesy. Od evolučných alebo sukcesných modelov cez rastové tabuľky až po modely spočívajúce na biochemických reakciách sa mení len časová a priestorová škála modelovaných procesov. Za pionierske práce v oblasti procesného modelovania možno označiť modely, ktoré publikovali Bossel (1994), Mäkela, Hari (1986) a Mohren (1987).

Vysoko detailné procesné modely predstavujú pre pochopenie a prognózu správania sa lesných ekosystémov v meniacom sa životnom prostredí ideálnu úroveň modelovania. Vývoj, ale aj využitie týchto modelov je však úzko ohraničené, pretože existujú ešte značné nevedomosti o čiastkových procesoch v asimilačných orgánoch a pôde a taktiež nevyriešený ostáva tzv. up-scaling čiastkových procesov vo vzťahu k správaniu sa celého. Okrem toho procesné modely vyžadujú rozsiahle stanovištné a klimatické informácie pre vlastnú inicializáciu a extrémne výkonné počítače, čo ich praktické využitie v súčasnosti obmedzuje len na exemplárne prípady. Preto sú v súčasnosti procesné modely viac výskumným, ako manažérskym plánovacím nástrojom.

Prepojením špeciálnych komponentov procesných modelov s porastovými alebo jednotlivo-stromovými modelmi, ktoré spočívajú na dlhodobých sledovaniach prírastku, vznikli tzv. hybridné modely. Modely tohto typu, ktoré publikovali napr. Botkin et al. (1972) a Kimmins (1993), sú už využiteľné v lesníckej praxi, a to nielen v rovnorodých, ale aj v zmiešaných porastoch. Využívajú pritom nové poznatky o ekofyziologických procesoch a časové rady prírastkov z trvalých výskumných plôch.

Sukcesné modely, ktoré vyvíjajú predovšetkým Shugart (1984), Pastor, Post (1985), Aber, Melill (1982), ale aj Leemans, Prentice (1989), sú zamerané predovšetkým na zmiešané porasty. Podobne ako hybridné modely, aj tieto hľadajú strednú cestu, a to medzi porastovými a procesnými modelmi. Svojimi vstupnými, ale aj výstupnými charakteristikami sú však pre praktické potreby lesného hospodárstva málo prispôsobené. Viac sú zamerané na dlhodobé predpovede sukcesných procesov neobhospodarovaných porastov a na zachytenie efektu zmenených rastových podmienok. Sukcesné modely však podnietili ďalší vývoj hybridných modelov.

Biomové modely, ktoré sú spojené s menami Box, Meentemeyer (1991) a Prentice et al. (1992), sú postavené na štatistických vzťahoch medzi regionálnou klímou a vegetačnými typmi. Na základe vstupných klimatických podmienok je možné podľa týchto modelov na regionálnej až globálnej úrovni predpovedať výskyt biomov, tj. životných spoločenstiev. Z doteraz spomenutých modelov sú prognózy týchto modelov z pohľadu vývoja vegetácie a rastu lesa najvyššie agregované. Modely tohto charakteru získali na význame predovšetkým v rámci výskumu globálnych zmien.

V Európe nedosiahol ani jeden zo spomenutých nových druhov modelov praktické uplatnenie ako manažérsky nástroj pre zmiešané porasty. Zmiešané porasty sa tu však za posledných 100 rokov hlavne pričinením Gayera (1886), Wiedemanna (1939b) a Assmanna (1961) začali stále viac dostávať do stredobodu lesníckeho výskumu, ale až dodnes chýbajú pre tieto porasty plánovacie nástroje, postavené na kvantitatívnych základoch. Len v poslednom období Kolström (1993), Nagel (1996), Pretzsch (1992), Pukkala (1987), Hasenauer (1994) a Sterba et al. (1995) vyvinuli modely, ktoré už vo väčšej miere boli využité v plánovacom procese lesného hospodárstva, a to nielen v rovnorodých, ale aj v zmiešaných porastoch. Tieto modely sa vyznačujú stanovištnou citlivosťou, sú konštruované ako jednotlivo-stromové modely a opierajú sa o širokú empirickú bázu. Na príklade rastového modelu SILVA, ktorého verziu 2.2 možno zaradiť k hybridným modelom (Pretzsch, 1992; Pretzsch, Kahn, 1996; Kahn, Pretzsch, 1997), ktorý bol vyvíjaný v SRN pre rovnorodé a zmiešané porasty, bude v ďalších častiach objasnený ich funkčný princíp.

Priestorový a dynamický systémový charakter zmiešaných porastov zohľadňuje rastový model SILVA tým, že modeluje v päťročných časových intervaloch priestorovú štruktúru porastu, v ktorej je kvantifikovaná rastová konštelácia každého stromu. Prírastok stromov je potom stanovený na základe spomenutej rastovej konštelácie (konkurencie) a východiskových dimenzií (obr. 1). Ako ďalšie externé premenné, podmieňujúce rast a štruktúru porastu, vstupujú: spôsob obhospodarovania porastu, riziko a stanovištné podmienky. So všetkými dôsledkami pre dynamiku vývoja porastu je možné modelovať vplyv cielených zásahov do štruktúry porastu cez výchovné opatrenia (čistky, prebierky) a obnovné zásahy, ale aj vplyv nežiadúcich faktorov (kalamity) a prirodzenej mortality stromov. Spätná väzba medzi štruktúrou porastu – prírastkom stromov – novo dosiahnutým stavom a štruktúrou porastu tvorí kostru modelu. Systém navzájom previazaných rovníc umožňuje prognózovať nielen vývoj jednotlivých stromov a z nich odvodených dendrometrických porastových charakteristík (napr. počet stromov, zásoba, stredná hrúbka), ale aj sortimentnú štruktúru a celý rad ekonomických ukazovateľov, ako sú napr. výnosy a náklady. S prognózami charakteristík naturálnej a ekonomickej povahy sú ďalej spojené prognózy charakteristík štruktúry porastu (rôzne indexy), stability porastu a diverzity. Prognózovanie výnosových, socio-ekonomických a ekologických charakteristík modelmi tohto typu dáva potom možnosť posudzovať produkciu rovnovekých a zmiešaných porastov multikriteriálne na kvantitatívnom základe. Rastový model SILVA je orientovaný svojimi vstupnými a výstupnými charakteristikami na informačný potenciál a informačnú potrebu lesníckej praxe. Model napr. využíva len tie stanovištné charakteristiky, ktoré sú bežne zisťované v rámci celoplošného stanovištného prieskumu. Na jeho parametrizáciu boli k dispozícii produkčné a stanovištné charakteristiky veľkého počtu rovnorodých a zmiešaných porastov, z ktorých najstaršie sú sledované a merané viac ako 100 rokov.

Výskumu v oblasti modelovania rastu lesa sa v Európe zatiaľ nepodarilo nahradiť rastové tabuľky rovnorodých porastov lepším informačným systémom pre rovnorodé a zmiešané porasty. To nevyplýva z deficitu metodických základov, malého rozsahu dát pre parametrizáciu alebo špatného technického vybavenia. Dôvodom je viacmenej nedostatočné prispôsobenie na požiadavky lesníckej praxe. Skúsenosti zo zavádzania rastového modelu SILVA 2.2 do lesníckej praxe v SRN priniesli jasný profil požiadaviek praxe na manažérske modely pre podporu rozhodovania na porastovej a podnikovej úrovni. Sú to predovšetkým tieto požiadavky:

- Prírode blízke obhospodarovanie lesa sa stáva viac ako samozrejmosťou. Preto sa v dlhodobom meradle presadia len také modely, ktoré dokážu prognózovať rast rovnorodých a zmiešaných porastov rôzneho veku a štruktúry.
- Možnosť nasadenia modelov na porastovej, ale aj podnikovej úrovni pri zohľadnení rôzneho spôsobu založenia a výchovy porastov.
- Model by mal byť tak flexibilný, že dokáže reagovať na regionálnej úrovni na vyskytujúce sa rastové reakcie spôsobené zmenou stanovišťa a rušivými faktormi.
- Vedľa typických stromových a porastových charakteristík – ako je napr. stromová produkcia, sortimentná štruktúra, kvalitová štruktúra a hodnotová produkcia – by mali modely podávať informácie aj o štruktúrálnych charakteristikách kvantifikujúcich mimoprodukčné funkcie lesa a o indikátoroch ekologickej stability.
- Modely by mali umožňovať v prvom rade tzv. variantné štúdie na porastovej, ale aj podnikovej úrovni, a to s vstupnými informáciami, ktoré sú prístupné v bežnej lesníckej praxi. Výstup by mal byť prispôsobený informačným potrebám praxe. Modely by mali byť implementovateľné do lesníckych informačných systémov, pričom hardwerová náročnosť a časový aspekt simulácií by mal zodpovedať stanoveným cieľom.

Lesnícka prax čaká už desaťročia na lepšie rastové modely pre plánovanie, prevádzku a kontrolu v lesnom podniku. Širšia akceptancia nových modelov zo strany praxe predpokladá spoluprácu praxe a výskumu od tvorby koncepcií modelov cez vývoj až po ich zavádzanie.

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