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LESNICTVÍ–FORESTRY

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INTRODUCTION

Dear colleagues,

These proceedings are aimed to illustrate in a way the actual situation in forest modelling in Europe and USA. Hopefully you can find new ideas and inspirations in this special issue of Lesnictví–Forestry. I am glad that the IUFRO conference of working group S4.01.04 on Growth Models could be held in Prague thanks to the support of the Ministry of Agriculture of Czech Republic, Forest and Game Management Research Institute Jíloviště-Strnady, Prague and European Forest Institute, Joensuu, Finland. The presentations of 17 participants from eight countries gave a broad overview of forest models used in different countries. The main aim of the conference was to demonstrate the practical aspect of modelling which should be applicable in forest management and forest policy. Aspects of public environmental policy were also discussed. Moreover, issues concerning IUFRO organization such as the actual and future scientific relationships in the Czech Republic and at the international level were widely discussed during the conference.

The conference focused on three main topics connected with forest models:
- model and data requirements,
- scenario models,
- forest policy issues for models.

The conclusions of the conference can be shortly described as follows:
- There is no universal model which can be used everywhere and every time. Data or information should be closely related to the complexity of the model: it is not very wise to use a very sophisticated model with poor data and vice versa. Changes in inventory technologies (see the example of Germany) create new possibilities for models. Modelers and other scientists should cooperate with people involved in inventory to find out what kind of data is needed for the good knowledge of the actual situation in forests. How this data could be collected to be accurate enough but at a reasonable cost is another important question which should be resolved quite early. Data on an ecosystem level and landscape level is becoming more and more important, showing one main direction of the actual „state-of-the art" modelling in forestry.
- A special branch of modelling is scenario modelling. Scenario models have to use not only exact data but also knowledge of actual and future problems and dangers which can have a great impact on the situation in forestry. This „softknowledge" should be used as a basis for the preparation of scenarios. Many countries (Finland is a good example) pay great attention to mapping the situation in scenario research in different specific fields to prepare complex views on a national and/or regional level. The „catalog" of the scenarios and their results should serve as decision support systems for policy making.
- It was mentioned more than once during the conference that there is a lack of connections among the different models and their results. These relationships are, however, very important for the practical use of the results of the model. The hierarchical structure of more complex models can help to resolve these problems. Models vary in complexity because of the fact – as mentioned above – that there is no universal model but models which have been constructed for different purposes. This variation can be seen in these proceedings as well.
- Another – rather general – question that was raised at the conference concerning scenario models was who should determine which approach should be used in scenario modelling and/or in forestry as the general goal? Foresters, other specialists or public opinion?

Five sessions during the conference covered the main subjects. Ms. S. Fox from the USA discussed in her paper how to make research relevant to forest policy and gave an overview of the scenario models used in USA.

Different European and American models were presented:

R. Päivinen described a strategic planning system for large forest areas in Finland. The method has been used for ten years to study the possibilities of a forest area of several hundred thousand hectares, owned by private companies. The development of stands in the model is simulated as a function of site type, tree species, age and growing stock volume per hectare. The expected drain from thinnings and clearcuttings is associated with the management rules applied in the simulation.

D. S. Solomon demonstrated the forest policy model for New England region. The current policy in

US addresses a variety of ecological and environmental concerns. To meet the needs of policy-makers, traditional tree and stand models must be based on ecological processes to project a broader consideration of resource values. The forest growth model FIBER is being extended to interrelate projection of forest succession, wildlife habitat, biodiversity, deadwood production, and economic return.

I. Kupka demonstrated a forest scenario model for Czech forests. The model takes into account the twenty most important factors influencing the future situation in Czech forests, and all their variations. These 432 variations of possible scenarios represent to a certain extent all possible future situations in Czech forestry. The most frequent situations in this spectrum have the highest probability to become reality and serve as the basis for future analyses.

Methodological aspects of models described by C. D. Bevins in his presentation *Forest Succession Modelling Using the Loki Software Architecture* arouse special interest. Architecture enables any number of concise, domain-specific simulation models (clients) to operate and communicate concurrently as an integrated, holistic ecosystem simulation. The LOKI session manager synchronizes the event-driven simulation. The model can integrate different influences (weather, forest fuel, fire, terrain etc.) with forest ecosystem growth and succession models.

A. Falcao has listed four methods as examples of possible tools for forest models: fractal and dynamic systems, cellular automata, fuzzy logic and expert systems, and neural network.

M. Gane described in his paper *Modelling Growth with TIMPLAN*, a growth model which forms a part of a much larger, comprehensive model of the forest sector, including forest resources, harvesting, wood processing and trade. The modelling system is based on the principles of „system dynamics" and uses standard components called levels, rates, auxiliaries, delays, supplementary arrays and variables.

In his paper *The MELA System as a Forestry Modelling Framework* M. Siitonen showed that MELA is a synthesis tool for solving problems of how to manage forest stands in order to achieve the overall goals at each particular decision situation.

Paper of M. Tomé and her colleagues presented by A. Falcao has referred to model for *Eucalyptus* spp. – for Central Europe quite an exotic tree with annual height increment of 2–4 metres. Their attempt to include stand responses to silvicultural treatment, soil and climatic variables in the model very interesting for all conference participants.

J. Hradetzky presented a very interesting paper describing a model based on the results of national inventory 1986–1988. The data of this survey represents the basis for the prediction of forest development taking into account all possible silvicultural measures. The limits of the model – said the author – lie in the uncertainty of the future growth trends of trees and forest stands. It is known that since 1960's growth has considerably increased in European forests. There are no reliable facts, however, indicating that the actual growth trends can also be expected in the future.

J. Hynynen expressed in his paper the view that models should be able to predict reliably the effects of various silvicultural treatments, e. g. how the growth response to thinning and fertilization can be predicted.

P. Horáček presented an empirical model as a synthesis of the changes in the average growth potential with age expressed by the age trend of tree-ring growth, and annual variations of the actual values round this trend.

R. Petráš's models are the prediction of volume, quality and value production in Slovakian forests. The paper presented „continuous mathematical models" of domestic growth tables for 13 commercially important tree species.

Unfortunately, not all presented papers can be included in these proceedings. Some authors were not able to submit their manuscripts in due time despite of my and editor's effort. The proceedings are thus incomplete, but, on the other hand, can any scientific report ever be complete?

It was a great pleasure to work together with the people in the organizing committee and I would like to express special thanks to my colleagues, who helped me a lot with the organizational work, namely to Mss. Kopřivová and Boháčová.

I would also like to thank the editorial board of Lesnictví–Forestry for giving us the opportunity to use this scientific journal for publishing the proceedings of this conference. Special thanks also go to the editor, Mgr. Chlebečková, for her patience and editorial work with the authors.

Ivo Kupka, chairman of WG S4.01.04

A STRATEGIC PLANNING SYSTEM FOR LARGE FOREST AREA

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A long-term forest management planning system, based on standwise forest inventory data and stand growth models, is presented in this paper. The development of stands is simulated as a function of site type, tree species, age and growing stock volume per hectare. The expected drain from thinnings and clearcuttings is associated with the management rules applied in the simulation. The method has been used for ten years to study the production possibilities of a forest area of several hundred thousand hectares, owned by private forest industry companies. Compared to more sophisticated methods, based on treewise growth functions and linear programming, the method is simple and does not allow for a very flexible comparison of alternative cutting strategies. However, the method is easy to use and the users are satisfied with its transparent structure.

forestry model; long-term forestry planning; forest inventory; production; Finland

INTRODUCTION

In Finland, long-term forestry planning has been conducted by utilizing three kinds of approaches:

a) The cutting budget for a desirable growing stock, based on aggregated data units
b) Simulation of stand characteristics using standwise growth models
c) Simulation of tree or tree-class growth, deriving several future developments for data units and selecting the treatment program by mathematical programming.

a) In the method published by Kuusela, Nyyssönen (1962), the forest inventory data are aggregated to 5–10 age classes, each of them having average site class and tree species distribution. For each class, the increment percentage was interpolated from the appropriate growth and yield tables. The allowable drain for an age class is derived as the difference between present volume plus the increment and the goal volume for the class. The final fellings were derived according to the rotation ages.
b) The utilization of standwise models is based on a stand or a sample plot as the data unit. The development of the growing stock is simulated using stand growth models, management regimes and predefined rotation ages. For each data unit, one standard development program is proposed. The drain is derived by adding up the removed volume from the thinnings and final cuttings within a 10-year period. The decision-maker is able to evaluate the outcomes for the following 10-year periods, and if any changes are necessary, rotation ages or thinning rules can be adjusted towards the desired goal.
c) The most advanced method in Finland is MELA (Siitonen, 1993) which employs the increment, ingrowth and mortality models based on diameter class of a certain stand type as data unit. For this approach, the growing stock has to be described in terms of diameter and height distributions. If diameter distribution is not predicted by tallied trees, it can be estimated by using models based on Weibull- or beta-functions. In the MELA, several alternative development programs are derived for each data unit. Linear programming is used to find the optimal production program for a forest area.

In this paper, a model belonging to group 2 is described in more detail. The model was created by the first author in the mid 1980's and developed further by the second author. The model is called KUHA and it has been used for strategic planning for a private forest company Tehdaspuu since the mid 1980's. Tehdaspuu company is managing 0.5 mill. ha of forest land in South-Eastern Finland.

THE DECISIONS IN A FOREST COMPANY

The task of the *long-term strategic planning* is to define the level of sustainable yield, based on the forest inventory and estimated growth rates. Long-term production possibilities have traditionally been predictable but now the possible climate change and other environmental factors may unfortunately change this situation.

In Southern Finland, private forest owners – farmers and other citizens own 77% of the forestry land while forest industry and state and others own 12% and 11%, respectively. Thus, the main source of raw timber for forest industrial companies are the private forests. The decision taken every year by the forest companies is to define the drain from their own forests during the following year. This *short-term planning problem* is solved based on

1. the long-term production possibilities of the forest,
2. liquidity of the company,
3. prospects on the timber markets in the following year.

It should be noted that the timber markets may change over the year and thus important cornerstones for the decision making are unpredictable. Due to the uncertainties in the decision-making both in the long-term and short-term tasks, the company managers feel that sophisticated optimization methods for long-term planning are not necessary.

For the planning system it would be beneficial to derive *operational plans* from the long-term planning directly. This is possible if the data unit for future predictions equals to the units to be treated in the forest. In Finnish conditions, a stand or a compartment with an average size of 2 to 5 hectares in Southern Finland, is such a unit.

To fulfil these requirements, KUHA-software was developed. It is based on growth and cutting simulations of each stand within the forest area.

FOREST INVENTORY

The forest inventory in the company has been carried out using standwise ocular assessment with the help of some measurements (basal area, height and age boring). The forest stands are delineated using false-colour aerial photographs, and each stand is visited by a surveyor. The following stand characteristics are registered:

- forest site type according to Cajander's classification,
- age and development class,
- dominant and mean height,
- basal area median diameter,
- basal area,
- growing stock volume,
- tree species proportions,
- drainage on peatlands,
- restrictions for treatments.

Before the 1980's, the standwise inventories were carried out every 10 years. Currently the stand register is updated by growth models. After each thinning, clearcutting or other treatment the stand information is remeasured and the stand delineation checked. The new stand boundaries will be put into the computerized map-drawing system used in the company. The remeasurement period of the stand information varies from 5 to 30 years. However, the stands which are growing fast will be thinned and updated by measuring more often than the slowgrowing stands.

The stand register can be checked by measuring a sample of the stands in detail using a relascope plot network (Laasasenaho, Päivinen, 1986) (Fig. 1). Ratio estimation – based on updated information and checking – makes it possible to correct any bias in the stand register and to derive the standard error for the total growing stock estimate (Fig. 2). These kinds of checkings have been carried out for the half of the company's forest area in 1980's and for a strata consisting of young stands only in 1993.

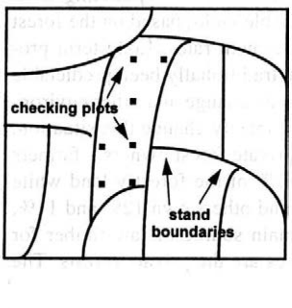
SIMULATION OF THE STAND DEVELOPMENT

The basic information for growth simulation is the updated stand data. The future scenarios are derived by utilizing the same stand growth models as in the updating. In the regression models presented by Nyyssönen, Mielikäinen (1978), growth percentage is derived as a function of

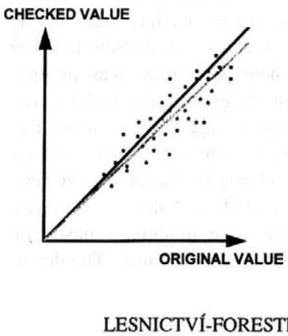
- main tree species of the stand,
- Cajander's site type class,
- growing stock volume/hectare,
- age of the stand.

The respective development of the mean height is derived by using growth and yield tables compiled by Koivisto (1959). Whenever a new volume and mean height are simulated, the new basal area is derived based on the „relascope tables" by Nyyssönen (1954) where the growing stock volume is presented as a function of mean height and basal area.

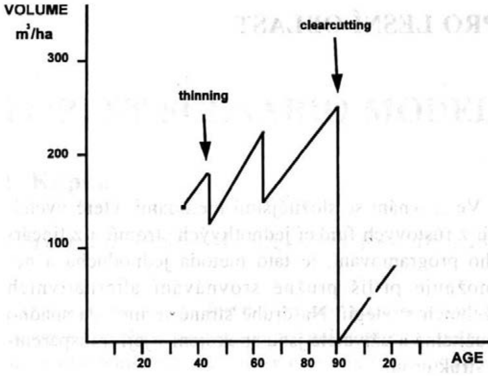
Thinning regimes in the simulation of the stand characteristics are the same as those used in the field operations. Whenever the basal area in a certain dominant height class exceeds a certain „thinning limit", approximately 30% of the volume is removed. After that, new characteristics for the thinned stand are calculated.



1. The checking plot network in a sampled stand



2. Principle for the comparison of the original and checked values. The difference between the bold and dashed lines refers to the bias in the updated data



3. Simulated „basic“ scenario for a stand with 140 m^3/ha at the 35 years of age: Thinnings at the ages of 45 and 65 years and clearcutting at the age of 90, followed by planting

THE PLANNING PROCESS

The planning is carried out by subareas in order to guarantee a geographically even distribution of cuttings because the forest property of the company is scattered on a large area in Eastern Finland. In the first phase, a basic scenario is derived by using normal thinning rules and rotation ages. Alternative management programs are derived for each subregion by varying the regeneration age. First, the stands to be regenerated within a certain 10-year period according to „basic scenario“, are arranged in a „priority order“, based on their age and growing stock volume. From this prioritized regeneration list, stands are selected in order to fulfil the alternative goals for the drain. It should be noted that thinnings are considered by the company as a „must“ and the alternatives are created by changing the regeneration ages only.

The level for the long-term drain is selected from that set of alternative programs which will sustain or increase the level of cutting possibilities and does not decrease the area of regeneration cuttings.

The result of the planning process is summarized information on the forest area, growing stock volume, increment and the drain by assortments; this all is given by age classes, site types, tree species and other interesting characteristics. All this information is presented for the following five 10–year periods.

The connection to the operative planning is clear: since the whole management plan is aggregated from stand programs each stand has a management program. However, the management program is regarded as a goal, and for the field staff certain changes – e. g. due to the cutting concentrations or unpredictable field conditions – are allowed. The annual drain may also vary around the long-term level as a consequence of short term changes in timber markets. The company may also need temporarily certain assortments more than the selected long-term program allows and, thus, change the cutting program. A new long-term planning process will be carried out in five years again.

EXPERIENCE AND CONCLUSIONS

According to the almost 10–year experience of the KUHA software, the main advantage for the company has been that the utilization of their own forest property is more efficient than before. Stand by stand calculation is very transparent and easy to check. Due to the increased confidence in the planning system the need of large safety marginals in defining the level of sustainable yield is no longer necessary.

Compared to the field-based cutting proposals, it has been learned that even for an experienced surveyor it is difficult to estimate the growing speed of young forests. Therefore, the growth simulation by computer has turned out to be more accurate especially in defining the timing of the first thinning.

The standwise scenarios have shown to be a sufficient basis for operative planning. However, in the future, more information from the stands may be needed and the measurements need to be more accurate and detailed than before. Different land-use restrictions, needs for multiple use or biodiversity protection will emphasize the need of Geographical Information Systems development in the coming years.

As seen from the forest manager's point of view, a system based on stand simulations with the possibility to adjust rotation ages, sufficiently fills the gap of uncertainty in defining the level of drain for short and long terms. The benefit of more sophisticated systems may be obscured due to the uncertainties in the growth rate, the fluctuations in timber markets and the loss of the transparency of the planning system.

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SYSTÉM STRATEGICKÉHO PLÁNOVÁNÍ PRO LESNÍ OBLAST

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V práci předkládáme systém dlouhodobého hospodářskoúpravnického plánování, který vychází z dat získaných při porostní inventarizaci lesů a z růstových modelů porostu. Simulace vývoje porostů je funkcí typu stanoviště, dřeviny, věku a objemu dřevní zásoby na hektar. Očekávané odčerpání dřevní hmoty při probírkách a mýtné těžbě souvisí s pravidly hospodaření, která se aplikují při simulacích. Tuto metodu jsme používali deset let při studiu produkčních možností lesů o rozloze několika set tisíc hektarů, kterou vlastní soukromé lesnické společnosti.

Ve srovnání se složitějšími metodami, které vycházejí z růstových funkcí jednotlivých stromů a z lineárního programování, je tato metoda jednoduchá a neumožňuje příliš pružné srovnávání alternativních těžebních strategií. Na druhé straně je metoda snadno použitelná a uživatelé jsou spokojeni s její transparentní strukturou.

model lesního hospodářství; dlouhodobé plánování v lesním hospodářství; inventarizace lesů; produkce; Finsko

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Upozornění pro autory vědeckých časopisů

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Týká se to samozřejmě těch grafických příloh, které byly vytvořeny v nějakém programu PC (např. CorelCHART, Quatro Pro, Lotus 1-2-3, MS Excel). Vzhledem k tomu, že nejsme schopni upravit a použít pro tisk všechny typy (formáty) grafických souborů, žádáme Vás, abyste nám také kromě originálních souborů (např. z MS Excel typ *.XLS) zasílali grafické předlohy vyexportované jako bodovou grafiku v jednom z těchto formátů:

Bitmap	*.BMP
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Graphic Interchange Format	*.GIF
Mac paint	*.MAC
MS Paint	*.MSP
Adobe Photoshop	*.PSD
Scitex	*.SCT
Targa	*.TGA
Tag Image File Format	*.TIF

Redakce časopisu

FOREST SCENARIO MODEL FOR THE CZECH FORESTS

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The Czech forestry is faced with new challenges due to changes in forest management, political changes and other problems that are rather common for the Central Europe forestry. The most harmful factors influencing the Czech forests are wind and snow damage, damage caused by red deer, insects, fungi and air pollution. A new issue could also be possible extensive afforestation of non--forest land. There is a clear symptom of the increasing unstability of forest ecosystems: the increasing amount of salvage cutting during the last twenty years. The main target of forest policy is to achieve the stability of forests. Forest scenario models are one of the instruments helping in this target. The input data for the scenario model is the data from the Czech national inventory. The basic unit of the model is the age degree broken down by species group and management system where information about stand area, growing stock, planned thinning and final cutting is available. The most important 20 influences were chosen for scenarios of future situation in the Czech forests and all their variations (432 scenarios together) were taken into account. These 432 possible scenarios represent to a certain extent the future situation of Czech forestry. The most frequent simulation results in this spectrum will most probably become a reality. The results of this model show that we cannot expect any increase in the growing stock in our forests for the next 60 years. When the unfavorable synergetic influence occurs, then a decrease in the growing stock by 15 to 20 % can be very probable. A decrease in possible commercial cutting can also be expected from the current level.

forestry scenario model; forecast in forestry; Czech forests

INTRODUCTION

Models are now used for the testing of data synthesis and hypothesis or for the explained observed phenomena very widely. But we have to realize that models are still an imperfect abstraction of reality and because critical data are not always available all predictions are subject to uncertainty (Gardner et al., 1990). This is the case for all kinds of models. The data availability is the crucial point for many models. Nilsson et al. (1992) stated that there are surprisingly much fewer models suitable for large area analysis than the others kind of models. Some models can be used on different levels of resolution (Rondeux, 1993) but only to a restricted extent.

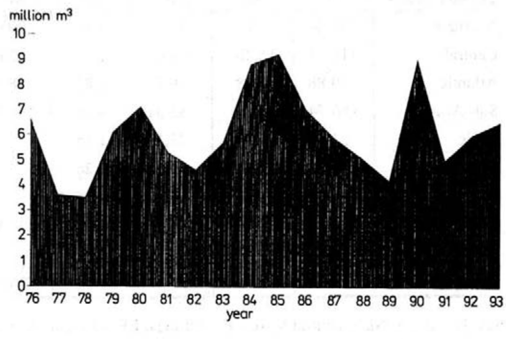
The forest inventory data have a very different composition from country to country. The recent changes in forest policy lead to the obligation to change the structure of inventory data (Tomppo, 1992). The data which are not only restricted to classical mensuration system give the opportunity to prepare model which can use habitat classification to reflect ecological dynamics (Solomon, Leak, 1993).

The preparation of forest scenarios should be based on the current forestry science with a special focus on problems of the country in question.

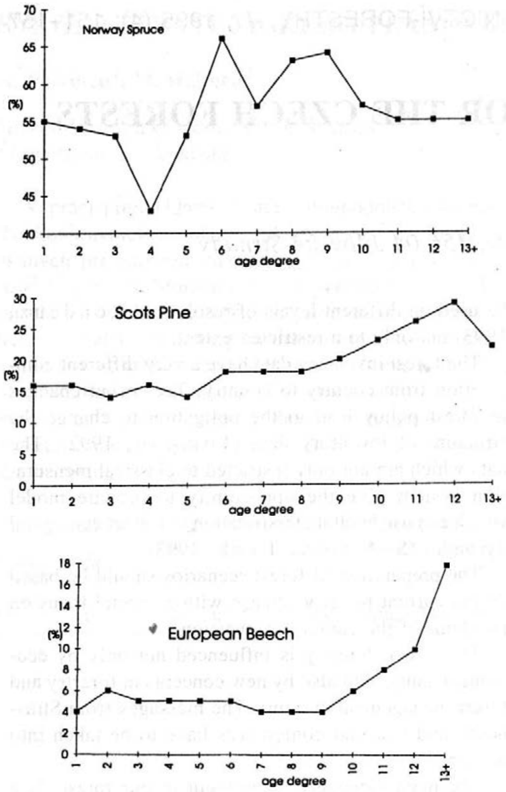
The Czech forestry is influenced not only by economic changes but also by new concepts in forestry and forest management systems. The messages from Strasbourg and Helsinki conferences have to be taken into account.

The main management problem in our forests is a too high amount of salvage cuttings (Fig. 1). The unstability of forest ecosystems is the cause of these cuttings. The immediate influences causing the salvage cuttings are wind, wet snow, red deer, insects, fungi and air pollution. So the main target of forestry in the Czech Republic now is to achieve the stability of forests, which cannot be done in few years.

The species composition is one of the systematic changes leading to the higher stability of our forests. The effort in changing species composition can be seen from Fig. 2, where the relative composition of the species in age degrees is shown. The changes of Norway spruce in the species composition are the most illustra-



1. The volume of salvage cuttings in the Czech forests in the years 1976–1993



2. The proportion of species in age degrees for all Czech forests (National Inventory 1991)

tive one. There is a clear diminishment of Norway spruce in the reforestation in the 1950's (40 years ago) but in the 1960's foresters gave up this effort and came back to our most productive species but also to that which is very sensitive to damage on sites where it is not in its climax stadium. The situation with our second main coniferous species is somewhat better (Fig. 2). It is more stable but still too high from the point of view of stable forest ecosystems. On the other hand our most important broadleaved species, i. e. beech, is not represented well enough in our forests. Unfortunately the increase of beech in Czech forests is a very difficult task also for the reason of insufficiency in the seed supply of this species.

There are other management decisions which should be taken as basic decisions in our forestry: the average rotation period, the main silvicultural systems including final cutting systems and species composition to mention only some of them.

The rotation period is very closely connected with the discrepancy between the increment and cutting. The situation is very similar in the whole Europe as pointed by Kuusela (1994). Calculated ratio of drain (D), i. e. total cut and gross annual increment (GAI) or the ratio of felling (F) and net annual increment (NAI) for the country groups is given in Tab. I. This ratio which expresses how the actual increment in forests in Europe is used with the exception of eastern Mediterranean countries (Bulgaria, Greece and Turkey), is only 70%. This in turn leads to an increasing level of growing stock in forests mainly by the accumulation of overmature stands – a very unfavorable situation for the forest threatened by many harmful abiotic and biotic influences. The situation is very much the same in the Czech forests. Another question is how these cuttings are situated in the forests and how the management plans deal with the necessary cuttings from the silvicultural point of view. The air pollution is a special point of interest in the Czech Republic. While the phenomenon attracted a lot of speculation during the last thirty years the situation is still rather unclear. While the high levels of SO_2 in the Northern part of the Czech Republic is the most harmful gas there killing thousands of hectares of forests in the 1970's and 1980's, the European

I. The inventory data of country groups 1990 (the explanation for abbreviations is in the table)

Forest resources in Europe											
Country group	D	NL	F	LR	Rob	B	Rub	GAI	NAI	D/GAI	F/NAI
Northern	137.20	6.76	130.44	9.46	120.98	14.16	106.83	192.40	185.64	0.71	0.70
Central	110.31	16.28	94.03	1.98	92.05	6.10	85.95	151.44	135.17	0.73	0.70
Atlantic	9.88	0.18	9.70	0.82	8.89	1.07	7.82	14.56	14.38	0.68	0.67
Sub-Atlantic	56.54	3.23	53.31	4.85	48.46	0.61	47.85	78.42	75.19	0.72	0.71
Alpic	23.42	0.26	23.16	1.25	21.91	1.91	20.00	30.30	30.04	0.77	0.77
Pannonic	28.73	3.71	25.02	1.26	23.76	2.19	21.57	45.29	41.58	0.63	0.60
Medit. West	32.41	2.63	29.78	0.55	29.23	6.30	22.93	47.91	45.28	0.68	0.66
Medit. Mid.	32.89	0.48	32.41	3.55	28.87	4.47	24.40	48.62	48.14	0.68	0.67
Medit. East	40.55	1.39	39.16	6.39	32.76	0.91	31.86	38.10	36.71	1.06	1.07
Europe	**471.93**	**34.92**	**437.01**	**30.11**	**406.91**	**37.72**	**369.21**	**647.04**	**612.13**	**0.73**	**0.71**

Notes: D – drain, NL – natural losses, F – fellings, LR – logging residues, Rob – removals over bark, B – bark, Rub – removals under bark, GAI – gross annual increment, NAI – net annual increment

(K. Kuusela: Forest Resources in Europe, EFI Res. Rep., 1994) monitoring system concludes that there is no improvement of crown conditions after a 50% to 70% reduction of SO_2 concentrations since 1987 in most European countries (Kandler, 1993). The reason for this is probably that NO_x and ozone have remained at the original level.

DATA

Are degree is a model basic unit. The age degree includes stands within the range of 10 years age. This basic unit should be homogeneous as much as possible. It means that the stands not only within the same age range but also belonging to the same management system unit, similar species composition, similar site quality and so on, should belong to the same basic unit. Of course the homogeneity of the unit depends on the availability of data. The more homogeneous data is available, the more precise can be the simulation of growth and other changes over the time.

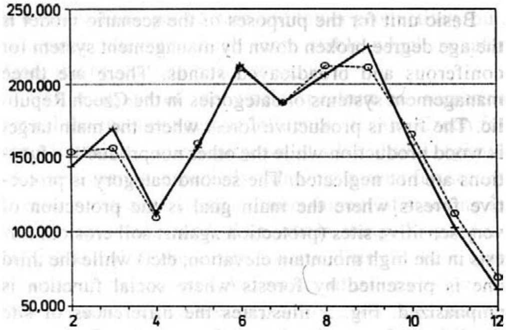
Data from the national inventory 1990 was used for this model. The Czech national inventory is based on stand level information. It means that the stand data which is collected for the management plans is used and updated for the inventory purpose as well. Forest management plans are prepared for one tenth of the Czech forest area every year and that is why the stand data from nine tenths of the forest area has to be actualized by using growth models. The inventory system has also to take into account the influences of salvage cuttings.

Strip management system, i. e. clear cutting on small areas, has been the main silvicultural system in the Czech forests until now and that is why the most important driving variable for this model is the basic unit area. The changes of this area are caused not only by final cuttings but also by so called reconstruction of stands which means that stands are cut down before their maturity for the silvicultural reasons and the area is reforested again. These planned cuttings (final and reconstructive ones) are influenced by large salvage cuttings as well. Usually the volume of the salvage cutting can be „included" (by diminishing the planned cuttings) in the volume of the regular cutting, but this is not always the case. That is why the first step of this work was to check how much these „disturbances" caused by salvage cuttings influenced the planned cuttings during the decennium. The calculation was done by the following equation:

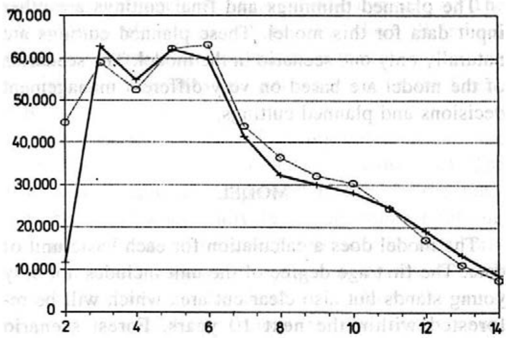
$$P_{(i+1)90} = P_{(i)80} - P_{(icut)80} \quad (1)$$

where: $P_{(i)}$ and $P_{(i+1)}$ – the area of (i) and $(i + 1)$ unit respectively,
P_{icut} – planned final cutting in (i) unit for the data from 1990 and 1980 inventory respectively.

The data from the National Forest Inventory 1980 was used in the calculation and the results were compared with the reality given by the data from forest inventory 1990. The results for coniferous and broadleaved stands are in Figs. 3 and 4, respectively.



3. Comparison of coniferous age degree areas calculated from National Inventory 1980 and given by National Inventory 1990



4. Comparison of broadleaved age degree areas calculated from National Inventory 1980 and given by National Inventory 1990

For Figs. 3 and 4: figures from National Forest Inventory (dotted line), calculated from forest management plans (thick line) by the equation (1)

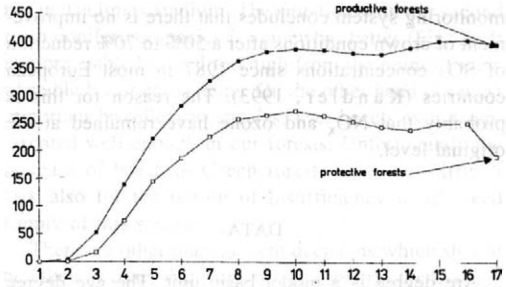
The first findings can be drawn from this calculation and Figures. Young coniferous stands in the third and fourth age degrees are influenced by unplanned cuttings very heavily. The same results are given for the ninth age degree. Results are quite opposite in old coniferous stands, older than average rotation period, i. e. of 11 or higher age degree. If we look at the broadleaved stands (Fig. 4) there is a different situation in old stands. It means that the main part of overmature stands in Czech forests are composed of coniferous stands which are less stable and more susceptible to harmful influences than younger coniferous and broadleaved stands of any age. The young broadleaves are affected by salvage cutting in the same way as coniferous ones, but surprisingly the area of middle aged broadleaved stands (from 6 to 10 age degrees) is higher than predicted by calculation from inventory and planned management. This means that a great portion of planned reconstruction of broadleaved stands has not been done.

Basic unit for the purposes of the scenario model is the age degree broken down by management system for coniferous and broadleaved stands. There are three management systems or categories in the Czech Republic. The first is productive forest where the main target is wood production while the other nonproductive functions are not neglected. The second category is protective forests where the main goal is the protection of very sensitive sites (protection against soil erosion, forests in the high mountain elevation, etc.) while the third one is presented by forests where social function is emphasized. Fig. 5 illustrates the differences of site conditions for productive and protective forests expressed by volume per ha. The protective forests are mostly located on poor sites where growing conditions are much worse than in productive forests.

The planned thinnings and final cuttings are other input data for this model. These planned cuttings are naturally only one scenario in the model. The scenarios of the model are based on very different management decisions and planned cuttings.

MODEL

The model does a calculation for each basic unit of data. The first age degree of the unit includes not only young stands but also clear cut area which will be reforested within the next 10 years. Forest scenario model simulates the development of forests over time by moving the area of unit (*i*) into the unit (*i* + 1) during a ten-year-period. Depending on the scenario situation, not whole of the area is moved to the next unit (*i* + 1). A part of the area becomes a clear cut area and returns back to the first unit (1). The other variables of each unit are then calculated with given status variables as volume per ha, percent of thinning, percent of final cuttings, etc. The final results are the aggregation of the results from basic units.



5. Comparison of growing stock per hectare of productive and protective forests

The preparation of the scenarios for the model is the next crucial step. The first scenario would show the result of the prolongation of the actual situation and trends in the Czech forests. A choice of the others depends on the expert judges and expectations. The main problems and changes which can be found in the current Czech scientific forest literature were chosen and they are listed in Tab. II. The 20 basic scenarios can be prepared from this table. The most objective approach was decided to be the preparation of all possible com-

II. List of basic scenario influences for Czech forests

No	Influence	Change
1	Afforestation of non forest land	0
2		+100,000 ha (+4%)
3		+400,000 ha (+15,2%)
4	Reforestation in favor of broadleaves	0
5		ratio C : B = 6 : 4
6		ratio C : B = 5 : 5
7	Level of thinning	0
8		–25%
9		no thinning in 2.–5. AD[1]
10	Level of final cutting	0
11		15 AD = 90% area, 16 AD = 100%
12		for AD > 14 cutting but without useful logs
13	Level of salvage cutting	0
14		for AD 2–8 + 10%
15		for AD 5–10 + 10%
16		for AD 2–4 + 20%
17		for AD 7–13 + 10%
18	Level of growing stock per ha	0
19		for all AD + 10%
20		for all AD – 10%

[1] AD means age degree (e. g. 1 = 0–10 years old stand, 2 = 11–20 years etc.)

binations of these 20 main influences which gave 432 scenarios.

RESULTS

The results of the simulations of these 432 scenarios were aggregated into 10 statistical classes. To get more readable results we calculated the probability in percent of each statistical class value (Pv) according to the equation:

$$Pv = (Nv/N) \cdot 100 \quad (2)$$

where: Nv – the frequency of the value in statistical class,
N – the total number of cases.

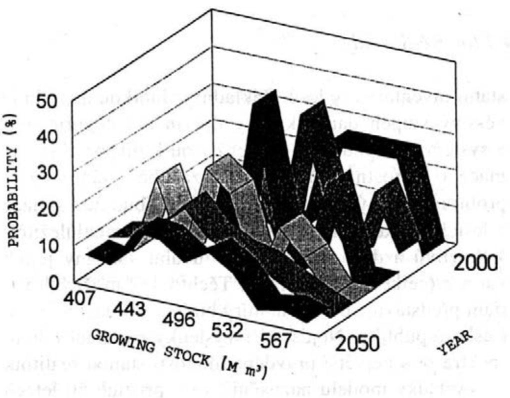
The most important results from these simulations are, of course, those showing the most probable future development of the Czech forests and/or the second and third probable ones. The other important result is to analyze the influences which are always or nearly always included in the scenarios which give the worst results in future developments. These influences are the most dangerous ones for the Czech forests and should be avoided as much as possible. The diminishment of the growing stock in the Czech forests can be expected during the next fifty years within the scenarios which covered the above mentioned influences. The results are expressed in Fig. 6. The most probable diminishing of growing stock in the Czech forests is about 13.4% while the second most probable is only 3% in comparison with the current situation. This is slightly surprising because the prolongation of actual trends gives much better results. But if we look at the diminishing stability of forest ecosystem in the Czech forests expressed by the increasing amount of salvage cuttings during the last decades we have to note that there is a very small probability for continuation of these rather favourable conditions. Also, the new forest policy stresses the increasing area of broadleaved species in reforestation and afforestation which would lead to diminishment of growing stock. Broadleaved stands have a lower volume per hectare and lower productivity but, of course, they are much more stable which is safer from the production point of view.

The analyses of the whole spectrum of scenarios reveal the most dangerous influences for the Czech forests in real life. The negligence of silvicultural regimes in young stands, especially thinning, means further increase in salvage cuttings, diminishment of stocking in middle-age stands and, thus, diminishing the production potential of the Czech forests. This can be a type of admonitory scenario. At first the situations following this scenario can be seen relatively good. The diminishment of precommercial thinning in young stands leads to a better financial situation of the owners and also to a better composition of assortments. The proportion of small wood also diminishes as the result of increasing salvage cutting in middle-age stands. The situation would change after 2010 when all indices would be worse. It seems that in that time it could be too late to change these dangerous trends in the Czech forests.

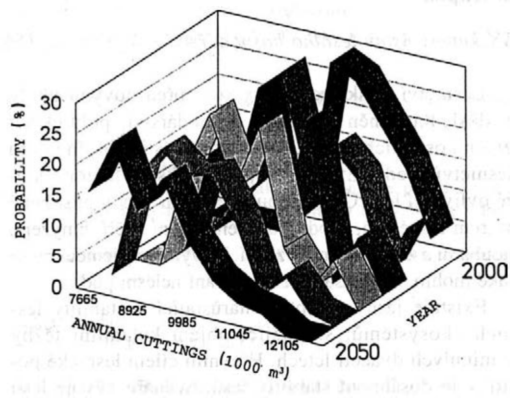
The development of final cutting potential until the year 2050 is quite similar to that of growing stock. The results are graphically expressed in Fig. 7. The same conditions influence badly future allowable final cutting possibilities of the Czech forests. The most probable situation according to these scenarios is diminishing the final cut by about 10%. When the worst scenario, so called admonitory, is taken into account then the drop in intermediate thinnings and large salvage cuttings giving a part of useless wood, can lead to a much more dramatic decrease in allowable cut, i. e. less than 23% in comparison with the actual situation.

CONCLUSIONS

The forest scenario model is a useful tool for the evaluation of strategic decisions and basic management systems for forests in large areas. This model for the Czech forest uses as the basic unit a 10 year age degree



6. The results of forest scenario model: the probability of future development of growing stock in Czech forests



7. The results of forest scenario model: the probability of future development of commercial cuttings in Czech forests

area as the driving variable. This is the truth in forests with a clear cutting management system. The importance of good quality data from forest inventory is clear and the data available for the basic data unit should be homogeneous as much as possible.

The second important base of the model is the preparation of relevant scenarios and evaluation of their probabilities for the future development. This would be based on solid scientific forestry knowledge and hypotheses.

The scenarios for the Czech forests were prepared for the base influences given in Tab. II. The combinations of all these influences give 432 scenarios which were put into the model and the results concerning future growing stock and possible commercial cuttings are shown in Fig. 6 and 7, respectively.

A decrease in the growing stock in the Czech forests can be expected during the next fifty years within the scenarios which covered the above mentioned influences. The most probable decrease in growing stock in the Czech forests is about 13.4% while the second most probable decrease is only 3% in comparison with the present situation. This is a little bit surprising because the prolongation of actual trends gives much better results. But if we look at the diminishing stability of forest ecosystem in the Czech forests expressed by the increasing amount of salvage cutting volume during the last decades we have to note that there is a very small probability for continuation of these rather favorable conditions.

The same conditions badly influence future allowable final cutting possibilities of the Czech forests. The most probable situation according to these scenarios is a decrease in the final cut by about 10%.

The results of admonitory scenario for the Czech forests were also calculated and interpreted.

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SCÉNÁŘE VÝVOJE LESŮ ČESKÉ REPUBLIKY

I. Kupka

Výzkumný ústav lesního hospodářství a myslivosti, 156 04 Jíloviště-Strnady

Lesnictví České republiky stojí před novými úkoly v důsledku změn v lesním hospodářství, politických změn i ostatních otázek, které jsou zčásti společné i pro lesnictví střední Evropy. Nejškodlivějšími faktory, které ovlivňují lesy České republiky, jsou škody působené větrem a sněhem, škody působené jelení zvěří, hmyzem, houbami a znečištěním ovzduší. Novým problémem by se také mohlo stát rozsáhlé zalesňování nelesní půdy.

Existuje jasný symptom narůstající nestability lesních ekosystémů: stoupající objem kalamitní těžby v minulých dvaceti letech. Hlavním cílem lesnické politiky je dosáhnout stability lesů. Scénáře vývoje lesů jsou jedním z nástrojů, který může pomoci dosáhnout tohoto cíle. Vstupními daty pro model jsou data celostátní inventarizace lesů. Základní jednotkou modelu je věkový stupeň dané skupiny dřevin a kategorie lesa a systému hospodaření, u nichž jsou k dispozici informace o porostní ploše, dřevní zásobě, plánovaných probírkách a mýtní těžbě. Pro varianty budoucí situace v lesích České republiky bylo zvoleno 20 nejdůležitějších vlivů a dále byly vzaty v úvahu všechny jejich variace (celkem 432 variant). Těchto 432 možných variant představuje do určité míry budoucí situaci v lesích České republiky. Nejčastější výsledky simulací tohoto spektra se s největší pravděpodobností stanou realitou.

Výsledky modelu naznačují, že v příštích 60 letech nemůžeme v našich lesích očekávat vyšší dřevní zásoby. Když dojde k souběhu nepříznivých vlivů, pokles dřevní zásoby o 15 až 29 % bude potom velmi pravděpodobný. Lze také očekávat pokles možné celkové těžby ve srovnání se současnou úrovní.

scénáře vývoje lesů; lesnické prognózy; lesy České republiky

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RECENZE

Weißtannen-Herkünfte. Neue Resultate zur Provenienzforschung bei *Abies alba* Mill. (Provenience jedle. Nové výsledky provenienčného výskumu *Abies alba* Mill.)

H. Wolf (Hrsg.)

Contributiones Biologiae Arborum 5, E. Führer – P. Schütt (Hrsg.) ECOMED Verlagsgesselschaft, Landsberg am Lech, 1994, 150 pp. (nemecky, anglické súhrny)

Ťažisko výskumu problematiky spojenej s objasnením príčin chradnutia jedle bielej sa v poslednom čase čoraz viac presúva do oblasti jej vnútrodruhovej premenlivosti. Dielčie výsledky výskumu sú uverejňované v najrozličnejších odborných časopisoch, takže k uceleným poznatkom majú často prístup iba špecialisti. Preto treba uvítať snahu zostavovateľa zborníka poskytnúť širšiemu odbornému publiku pokiaľ možno ucelený komplexný prehľad súčasných poznatkov v tejto z hľadiska praktického lesného hospodárstva vysoko aktuálnej problematike.

J. B. L a r s e n sa pokúša vysvetliť problémy spojené s pestovaním jedle bielej v strednej Európe na základe najnovších génekologických poznatkov. Za hlavnú príčinu chradnutia jedle považuje nízku ekologickú amplitúdu druhu spôsobenú nedostatočnou genetickou premenlivosťou a následným nedostatkom adaptability.

Z premenlivosti morfologických znakov usudzujú G. A a s, F. K i r c h n e r a J. M a i e r na introgresiu s *A. cephalonica* u proveniencií z juhovýchodnej Európy a diskutujú o možnosti introgresie medzi *A. alba* a *A. nebrodensis* v Kalábrii.

Najväčší počet prác (štyri) sa po práve venuje najprogresívnejším metódam zisťovania premenlivosti pomocou biochemických analýz genetických markérov.

D. T r e u t t e r a W. F. R u e t z sa pokúsili charakterizovať druhy a proveniencie jedlí na základe zloženia fenolov v ihličí. Zistili, že rozlíšenie druhov je možné, avšak charakterizovať proveniencie jedle bielej na základe zloženia fenolov sa im nepodarilo.

H. W o l f zisťoval premenlivosť zloženia monoterpénov v ihličí na rozsiahlom materiáli 155 proveniencií z celej oblasti prirodzeného rozšírenia jedle bielej. Rozlíšil päť skupín proveniencií, medzi ktorými zistil výrazné rozdiely v zložení monoterpénov. Populácie zo západnej, strednej a východnej časti areálu majú výrazne nižšiu premenlivosť ako populácie z južnej a juhovýchodnej časti areálu.

Pri nasledujúcich dvoch prácach sa použili k stanoveniu genetickej premenlivosti izoenzýmové analýzy. M. K o n n e r t zisťovala genetickú diverzitu vnútri a genetické diferencie medzi 27 populáciami z juhozápadného Nemecka na základe frekvencií enzýmov z 10 lokusov. Aj na tak malom území rozlíšila klustrovou analýzou štyri skupiny. Výsledok pokladá za predpoklad pre identifikáciu pôvodu semien a vylíšenie provenienčných oblastí.

F. B e r g m a n n porovnáva navzájom genetickú štruktúru jedľových populácií zo strednej a južnej Európy. Zistil, že materské stromy vykazovali vyšší, potomstvá nižší stupeň heterozygotnosti oproti očakávaniu. Iba v potomstve kalábrijskej populácie bol inbredný efekt nízky.

Posledné tri práce sa zaoberajú hodnotením provenienčných pokusov. Prvé dve prinášajú hodnotenie juvenilného materiálu z provenienčného pokusu IUFRO 1982–83. H. W o l f, V. F. R u e t z a A. F r a n k e referujú o prvých výsledkoch z provenienčného pokusu založeného v južnom Nemecku, B. R. S t e p h a n a A. P a d r o z pokusu založeného v španielskych Pyrenejách. Nakoniec L. P a u l e a V. H y n e k sa pokúsili o komplexné zhodnotenie výsledkov z 27 provenienčných pokusov založených v bývalom Československu.

Hoci z rôznych aspektov hodnotený materiál je z prípadu na prípad iný a aj rozsah spracovávaného materiálu je z prípadu na prípad rozdielny, výsledky všetkých prezentovaných prác sa zhodujú prinajmenšom v nasledujúcich aspektoch:
- zistila sa značná vnútropopulačná diverzita a vnútrodruhová premenlivosť jedle bielej,
- populácie zo západnej, strednej a východnej časti areálu majú výrazne nižšiu premenlivosť ako populácie z južnej a juhovýchodnej časti areálu,
- oblasti chradnutia jedle sa zhodujú s oblasťami so sníženou genetickou premenlivosťou.

Práca znamená cenný teoretický prínos k riešeniu hospodársky významného problému chradnutia jedle bielej.

Contributiones Biologiae Arborum (CBA) je nová edícia, ktorá uverejňuje v nepravidelných intervaloch rozsiahlejšie pôvodné práce, literárne prehľady a výskumné správy z morfológie, anatómie, fyziológie a patológie lesných drevín vrátane ochrany lesov, biológie dreva a šľachtiteľského výskumu. Prijímajú sa aj výsledky výskumu imisií.

Každý zväzok je uzavretý a obsahuje vedecky uznávané poznatky. Rozsah jedného zväzku je 100 až 300 strán. Zväzky uverejnené v nemčine obsahujú súhrn v angličtine a popisy k obrázkom a tabuľkám v oboch jazykoch.

Doteraz vyšli tieto zväzky:

CBA 1: L. J. K u č e r a – H. H. B o s s h a r d: Holzeigenschaften geschädigter Fichten
CBA 2: H. S c h i l l: Triebbildung, Verzweigungverhalten und Kronenentwicklung Junger Fichten und Lärchen
CBA 3: F. G r u b e r: Verzweigungsystem, Benadelung und Naderfall der Fichte (*Picea abies*)
CBA 4: P. M. W a r g o – D. R. B e r g d a h l – D. R. T o b i – C. W. O l s o n: Root vitality and decline of Red Spruce
CBA 5: H. W o l f (Hrsg.): Weißtannen-Herkünfte.

Ing. Ladislav G r e g u s s, CSc., Lesnícky výskumný ústav, Výskumná stanica Banská Štiavnica

FOREST SUCCESSION MODELLING USING THE LOKI SOFTWARE ARCHITECTURE

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This paper describes a software architecture being developed at the Intermountain Fire Sciences Lab to quickly create, maintain, and modify large scale, spatially-explicit ecosystem simulations. The Loki architecture enables any number of concise, domain-specific process models to operate and communicate concurrently as an integrated, holistic simulation. Large simulations are quickly constructed from a „tool box" of ecological process, display, conversion, and analysis programs for a variety of applications including research, training, management, education, decision-support, and policy-making. Computer models can be developed by context experts around the world and later incorporated into various cooperative simulations. The Loki application programming interface simplifies model development by managing the details of data location, format, type, extent, resolution, and units of measure for the programmer. The use of Loki in the Coarse Scale Succession Model for the Columbia River Basin Assessment is discussed.

ecosystem simulation; process model; holistic simulation; forest policy; USA

INTRODUCTION

The capacity, speed, and capability of computers continues to double every several years even as their cost declines. This happy state of affairs is especially appealing to those of us who attempt to simulate ecological and environmental processes. It is now tempting, and even feasible, to develop complex, spatially-explicit ecological models on desktop work stations. Holistic, multi-disciplinary simulations are often useful in research, education, decision-support, and policy-making. Unfortunately, while computer hardware is increasingly capable of supporting such complex models, our ability to implement and maintain them lags far behind.

Researchers at the Intermountain Fire Sciences Lab are concerned with the influence of weather regime and ecosystem condition on fire danger, fire occurrence, and fire behavior in wildland environments. Smoke production, forest growth, and long term succession are also important consequences of fire. This requires an understanding of a broad spectrum of physical and biological processes including (but certainly not limited to) diurnal, synoptic, seasonal, and climatic weather trends in mountainous terrain; fuel wetting and drying cycles; wildland litter, surface, and crown fuels description; fuel flammability and combustion; fire spread and intensity; smoke particulate production, plume development and dispersion; forest stand description; fire-induced plant mortality, and succession patterns.

Our attempt to simulate these processes and resultant states in an ecosystem context obviously requires the combined cooperative efforts of many individuals with expertise in a variety of disciplines. The products of these efforts include process-specific models that can subsequently be incorporated into larger, holistic simulations of fire in the wildland environment.

Several challenges must be met when knitting together such a large scale simulation. How can many small, process specific, individually developed models best interact together in a larger whole? How do the models share spatially explicit data? How do models resolve their differences in spatial resolution, temporal resolution, and units of measure? How are individual models updated as they undergo their inevitable evolutionary changes? How is such a large, complex block of computer code to be maintained and updated?

The Loki software architecture is our attempt to address such issues faced during cooperative simulation development.

THE LOKI SIMULATION ARCHITECTURE

The main concept behind the Loki architecture is to allow every model to be its own program on the computer (Bevins, Andrews, 1993). Any number of these models may run simultaneously and communicate with one another to form larger simulations, with interaction between models and their shared spatial data sets handled by Loki.

There are a number of advantages to this approach. First, each model is a small, self-contained simulation of a specific physical or biological process. The model's development can be managed by a single context expert; smaller models require less computer code to develop, debug, and maintain, and are more easily revised.

Second, the model developer is not concerned with the file name, location, format, datum type (integer or floating point), units of measure, or regional extent of the underlying spatial data. Instead, the model notifies Loki (through a function call) that it needs to read or write spatial data with some well-known name, and it expects the data values at any requested location to be returned in a specified datum type and units of measure. A fuel moisture model, for example, could request read access to „air temperature" values as single precision floating point degrees Celsius, read access to „relative humidity" values as integral percentages, and write access to a „fuel moisture" map as double precision fractions. All the details of 1. locating or creating the „air temperature", „relative humidity", and „fuel moisture" files, 2. converting between file formats, datum types, and units of measure, and 3. resolving differences in spatial data resolution and map registration are handled by Loki.

Third, the model developer is not concerned about synchronizing the model with other models. In fact, each model is developed without knowing with which other models it will eventually interact. Loki automatically notifies each model in a Loki simulation whenever any of its input spatial data has been altered, so the model can recalculate its outputs. The cooperative simulation is thus „event driven" as opposed to „time driven"; one model updates the inputs of a second model, which updates the inputs of subsequent models, and so forth. The fuel moisture model is therefore activated only when its air temperature or relative humidity input maps change. If need be, any model can still force itself to be „time driven" by scheduling callback times with Loki.

Fourth, the model developer is not concerned with the display of model output. There are other Loki-aware programs available that display their inputs in charts, graphs, 2–, 3–, or 4– dimensional contour maps, or combinations of these. The output map of the fuel moisture model, for example, could be the input into a 4–dimensional contour map showing fuel moisture classes draped over mountainous terrain.

The concept of display programs as separate „models" within a cooperative simulation is easily extended. Other Loki-aware programs have been and can be developed to translate data files between popular geographic information system (GIS) formats, submit spatial data to GIS analysis programs, perform statistical analyses, read and write into relational data bases, submit spatial data to scientific visualization packages, capture screen images on video tape, and so forth.

Fifth, because models are totally encapsulated and have well defined interfaces with their inputs and outputs, they are easily swapped in and out of larger simulations; newly revised models can replace their precedents, new functionality may be introduced into a simulation by using a new model or set of models, and multiple instances of a single model can be run concurrently. The models and spatial data files used by a simulation are specified to Loki in a simple script file, making simulation design a simple edit-and-run procedure. Models become „tinker toys" used to create simple or elaborate simulations, and simulation designers can borrow state-of-the-art models developed by others and incorporate them into their own applications.

Finally, because models are separate programs, they may be distributed across multiple computers in a network. During a simulation, computation intensive models such as weather and fire behavior forecasters can run on the fastest computers while all other models run on the local host. If a simulation has lots of display programs, these can be run and/or displayed on several consoles.

LOKI TECHNOLOGIES

The current implementation of Loki is based upon three key technologies; the X Window System („X"), the Network File System (NFS), and the Loki Application Programming Interface (API).

The X Window System is an industry-standard mechanism by which programs can draw graphical user interfaces (containing windows, menus, buttons, icons, scrollbars, etc.) and gather user input from a keyboard and mouse on a variety of hardware devices connected to a computer network. To accomplish this feat, X gives its client programs the ability to communicate between computers and/or displays across a variety of networks. Loki derives the following benefits from the X Window System:

- All Loki programs are X clients and have a graphical user interface that can be moved, resized, or iconified.
- Loki programs are event driven; programs can respond to events generated by the user via the keyboard or mouse, such as pressing an on-screen button.
- Loki programs can also respond to events generated by other Loki programs, such as being notified of input updates. This gives Loki programs the ability to communicate with one another, even between different computers on a network.
- Where Loki programs execute on a computer network is independent of where they draw their graphical user interfaces. A Loki program can run on one computer and have its graphical display appear on any console on any other computer on the network.

The Network File System is an industry standard method for sharing files among networked computers. This allows multiple Loki programs to simultaneously share and synchronously update spatially-explicit map information.

The Loki API is a set of C functions that manage all the details of model communication, event notification, and data location, format, resolution, type, and units of measure. The programmer's model simply (1) requests read or write access to a well-known spatial data set (such as „elevation"), (2) requests information as needed on the simulation location and extent, (3) requests spatial data values at specified sample locations, and (4) updates spatial data values at specified sample locations. The API fetches and stores the data from the required files, performs format, datum type, and units conversion, and notifies other Loki models that their inputs have changed.

PROOF OF CONCEPT

During the past two years Loki has evolved in parallel with our fire behavior modelling efforts. A „proof of concept" simulation was first created demonstrating seven Loki programs working together in a simulation (Fig. 1).

1. A weather reader program (wxreader) monitors a weather data stream and updates the „air temperature" shared variable. Posting a new air temperature generates a notice to the „temperature adjustment model", which has requested read-access to air temperature.
2. A program that adjusts air temperature for terrain characteristics (wxterrain) then adjusts the air temperature according to local elevation and aspect and stores it in an air temperature map. Updating the air temperature map results in the notification of two instances of a map viewer program and two instances of a map statistics display program.
3. One instance of the map viewer program (agxmap) displays the air temperature as a colored surface draped over the 3–dimensional terrain.
4. A second instance of agxmap displays the air temperature map as a colored contour map.
5. One instance of a simple statistical analysis and display program (mapstats) samples the air temperature map, computes a mean value, and plots it against time in a strip chart.
6. A second instance of mapstats displays the mean temperature in a thermometer.
7. Finally, a screen capture program (capture) takes a snapshot of the console, converts it into TIFF format, and sends it to a slide film recorder.

The Loki architecture has continued to evolve since this proof of concept, primarily in support of our work on simulating fire occurrence, behavior, and effects on stand succession in wildland environments.

LOKI AND THE COLUMBIA RIVER BASIN SUCCESSION MODEL

As part of his plan for ecosystem management in the Pacific Northwest, President Clinton in May 1993 directed the Forest Service to develop a scientifically sound, ecosystem-based strategy for the management of federal forest lands. The Chief of the Forest Service further directed that an ecosystem management framework and assessment be developed for the 800,000 km^2 Columbia River Basin by the end of 1994. The assessment requires a long term succession model to serve as a prognostic tool in predicting subsequent landscape changes under a variety of management scenarios. The model, CRBSUM (Columbia River Basin SUccession Model), uses a combination of deterministic and stochastic approaches to simulate spatially-explicit landscape changes under various management regimes at a 1 km^2 spatial scale (Keane, 1994).

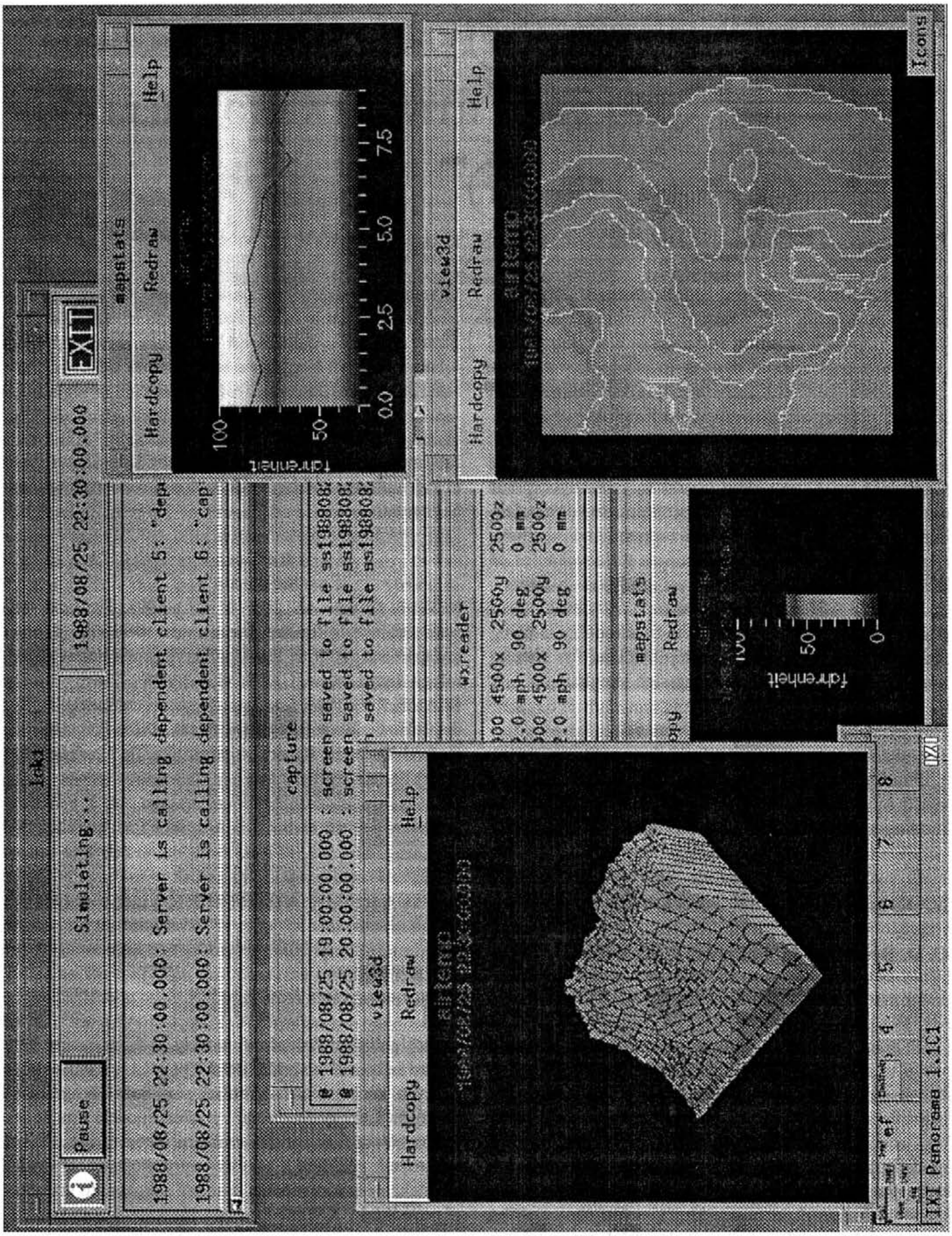
CRBSUM is primarily a rule-based decision module that evaluates the probable impacts of management scenarios on successional pathways over several decades. Each 1 km^2 cell is characterized by its cover type, structural stage, successional age, and potential vegetation type (PVT). A general land use plan, or „scenario", is then defined specifying the proportion of land in each characterization class that will annually experience a particular management action or disturbance. At each annual time step in the simulation, every cell is visited. A disturbance (or no disturbance) is stochastically selected from the land use plan for the cell based upon the cell's characterization class. Depending upon the stochastic selection, the cell is aged, moved back, or moved along the successional pathway appropriate for the cover type-structural stage-PVT combination (Fig. 2).

CRBSUM model inputs include the general use plan table, successional pathway descriptions, a PVT map, a stand structure map, a successional age map, and a cover type map. Model output includes the updated structure map, successional age map, and cover type map, and a host of summary tables.

While CRBSUM is a spatially-explicit model that reads from and writes to various maps, its deterministic and stochastic processes did not lend itself to implementation using traditional GIS tools. The decision was made to use the Loki API because it could 1. query and update spatially-explicit map data, 2. convert its map data into GRASS and Arc/Info ASCII format files, 3. display the output maps using previously developed and available map viewers, and therefore 4. remove the need to code, test, and debug any map access and display functions.

Loki is used to incorporate the CRBSUM into a simulation application that includes:

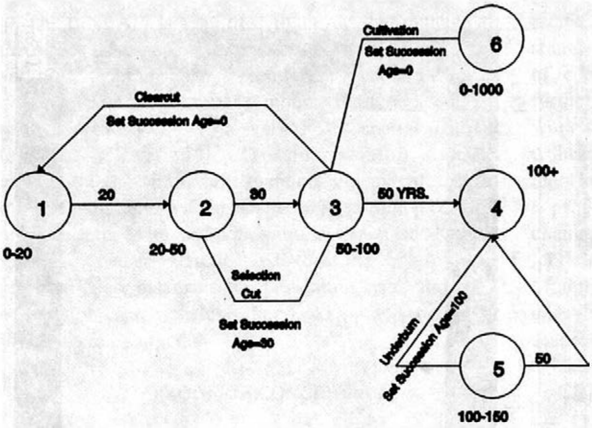
- the CRBSUM simulation model,
- a map viewer program to display one or more of the output maps,
- a program that converts Loki map data into a format compatible with the GRASS GIS,
- the SPADIS spatial disturbance contagion model for spatially-dependent disturbances.



1. Screen shot of Loki „proof of concept" simulation

SUMMARY

Loki was designed to ease the development of large-scale, holistic, spatially-explicit simulations by incorporating multiple, domain-specific, and individually-developed models and programs into a cooperative application. The Loki architecture is based upon the X Window System, Network File System, and Loki API, allowing Loki simulations to run across Unix computer networks.



2. Successional development pathways for a theoretical Douglas-fir potential vegetation type

Loki has proven useful in the rapid development of CRBSUM by 1. providing access to spatially-explicit data bases, 2. using other Loki programs to summarize, convert, and display CRBSUM outputs, and 3. allowing the model developer to focus on the mechanics of the succession model itself.

The Loki API is still in the research and development phase. Improved stability and new functionality is being realized as we continue to develop wildland fire simulations and forest growth and succession simulations.

Acknowledgement

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MODEL SUKCESE LESA PŘI POUŽITÍ SOFTWAROVÉ ARCHITEKTURY LOKI

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V práci se popisuje softwarová architektura, která se vyvíjí v Laboratoři pro zkoumání lesních požárů pro rychlé vytváření, uchování a modifikaci velkých prostorově vyjádřených simulací ekosystémů. Architektura Loki umožňuje současné provádění a komunikaci jakéhokoli počtu modelů, oborově specializovaných, jež integruje do jedné holistické simulace. Velké simulace jsou rychle sestavovány pomocí nástrojů, které umožňují simulaci ekologického procesu, zobrazení, konverze a analytických programů pro řadu aplikací včetně použití ve výzkumu, při instruktáži, řízení, vzdělávání, jako podklad pro rozhodování a při formulaci politiky. Počítačové modely mohou vyvíjet kontextoví odborníci po celém světě a později je zabudovat do různých kooperujících simulací. Aplikační programové propojení Loki zjednodušuje vytváření modelů tím, že pro programátora řídí nejnižší strukturu umístění dat, formát, typ, rozsah, rozlišení a jednotky míry. Popisuje se využití architektury Loki v modelu primární sukcese pro hodnocení povodí řeky Kolumbie.

simulace ekosystémů; model; holistická simulace; lesnická politika; USA

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MODELLING GROWTH WITH TIMPLAN

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A simple growth model is described which forms part of a much larger, comprehensive model of the forest sector, including forest resources, harvesting, wood processing and trade. The sector model is designed for policy analysis and planning, and enables sector activities to be treated holistically, so that when alternative ways of managing forest crops are simulated, the full range of their likely consequences is revealed, including changes in output, costs, income, employment, capital formation, profits and foreign currency earnings. The sector model is contained within a modelling system called TIMPLAN. This is a computer software package that enables users to build and operate their own models, suited to the structure and characteristics of the forest sector in the country, region or area with which they are dealing. The modelling system is based on „system dynamics" principles and uses standard components called levels, rates, auxiliaries, delays, supplementary arrays and supplementary variables; each component is used many times to represent different parameters in the system and the components are arranged in eleven functional modules. The growth model is contained in the „supply" module; this module is repeated for each crop. The user prepares a data file in a standard format and enters age class data for the base year, the length of rotation or felling cycle, the volume increment per ha, per year in young, immature and mature age classes and the amount to be removed annually by thinning. Regeneration and felling rates are specified and controlled by the user. For each crop, the computer calculates projections of areas, growing stock and removals, year by year, for up to 100 years. The system can handle both natural forest and plantation crops. A national model for the forest sector in the Czech Republic is described which illustrates the modelling technique.

growth model; forest sector model; forest policy; production

INTRODUCTION

Models are representations of actual structures, situations or events which occur in time and space. The representation may be three-dimensional (eg. toy soldiers), two-dimensional maps or diagrams, or simplified conceptual and mathematical descriptions. The particular concern of this Conference is with the last category and with modelling which represents forests as systems to assist calculations and prediction. For this purpose, attention is focussed on models of forest growth designed to elucidate policy and planning decisions, i. e. the role of growth models in the strategic management of forest resources.

This paper therefore deals with the growth process over time of trees and tree communities, in particular the increase in size, volume and value of forest crops under various types of management. The viewpoint is primarily commercial and biological or ecological considerations (eg. the growth of biomass, species populations or biodiversity) are only addressed indirectly through their effects on forest crop production.

Modelling is a purposeful activity and the growth model described in this paper is designed to enable the growth of forest crops to be simulated in a computer. The model portrays the response of forest crops to changes in their management. It enables the effects of variation in the rates of planting, volume increment, thinning, felling, rotation length etc. to be investigated quickly and easily in different forest crops by providing projections of important variables in future years (eg. areas, timber volumes, growing stock and removals). Alternative forest management regimes can be simulated interactively with the computer to discover their likely consequences. Modelling therefore assists decision making and provides a powerful tool of management.

The growth model contributes to the decision making process. Many other factors also affect the outcome of policy decisions, eg. price changes, economic effects, employment, social and environmental consequences. A growth model is necessary but not sufficient for deciding policy. Therefore the growth model which is described here, forms part of a much larger simulation model representing the whole range of activities in the forest sector, including harvesting (i. e. logging activities), primary wood processing (eg. sawmilling, plywood and particle board manufacture) and trade in forest products. This sectoral simulation model is designed to assist decision making for policy and planning, i. e. it is a tool for strategic management of the forest sector as a whole.

For policy decisions to be soundly based, it is essential to consider forest sector activities *holistically* and to simulate the interactions which link together activities taking place in different parts of the sector at different times. For example, a change in the rate of felling in a forest crop alters the quantity of roundwood output, the scale of logging activities and the consequential impact on processing operations. Similarly, extra planting in the present is expected to lead to greater output from the forest in future years from thinnings and final felling. These linkages are represented in the sectoral simulation model so that changes in the supply of roundwood generated by the growth model generate corresponding changes in other parts of the sectoral model. This makes is possible to judge the relative desirability of forest management policy options by looking at the full range of their likely consequences and not simply by reference to the quantity and value of output from the tree crop.

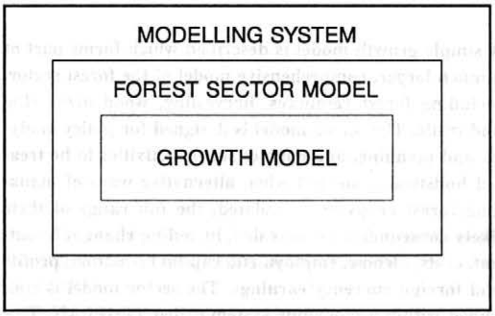
It is also necessary to allow for variations in the make-up of the forest sector from place to place and country to country. The forest sector is a distinct, recognisable entity, but its composition is not everywhere the same. It can be defined in the following way (Gane, 1991):

„Forestry is taken to mean all the activities connected with forests and forest resources and includes everything to do with the growing, harvesting and processing of woody vegetation, whether for wood or non--wood products. It also embraces forest ecosystems, the conservation of the flora and fauna found in the forests and the protection of forest landscapes and heritage sites. Forestry is concerned with people as well as trees – the people living in and around the forests and all those who work in them and in forest-related activities. Forestry activities may also extend to forest-based tourism and national parks. By 'forestry sector' is meant that part of the national economy which is concerned with forestry activities, including the inputs, outputs, incomes and employment associated with it."

The forest sector of each country, state or region can be modelled to portray the range of resources and activities that occur there. Each national model will have its own distinctive structure, consisting of the various forest products and crops which contribute to sectoral output, employment and development. Embedded within the sectoral model, is a growth model which enables the changes that occur in the various forest crops to be represented. For example, in the Czech Republic, a sectoral model has been constructed which contains eight products (including sawnwood, panel products, pulp and paper, fuelwood etc.) and two crops (coniferous and broad-leaved forests). The function of the growth model is to simulate the changes in the crops that are expected to occur in future years under various assumptions.

It is possible to go one step further and design a *modelling system* instead of a model. A modelling system is a software package that enables users to set up and operate their own purpose-built models, suited to each particular situation which is being dealt with. It is flexible modelling tool which can be used to build a wide range of different models and can be applied anywhere in the world. With the aid of a modelling system, forest sector models for each country can be constructed easily and quickly. These national models can then be run with the software provided, to simulate the behaviour of the sector, including the growth of the forest crops which contribute to sectoral activity.

Therefore we can distinguish three levels of modelling, inside one another, as shown in the diagram below.



1. Levels of modelling

Modelling systems specially designed for forest sector planning and policy formulation have been created by the writer during the last 12 years. Three systems (TIMPLAN, VOLPLAN and GROPLAN) have been developed and tested under a wide range of conditions in different parts of the world (Gane, 1992). They are based on the technique first devised by J. W. Forester, known as „Systems Dynamics", which provides a convenient way of describing the important features and dynamic interrelationships of any „system" in the form of a model. All three modelling systems work in a similar way and contain the same type of growth model. Information about the availability of the systems is reproduced in the Annex.

The remainder of this paper describes the main features of these modelling systems with particular reference to TIMPLAN, which is the largest and most comprehensive of the three systems. The growth model contained within the TIMPLAN system is then explained in detail. Finally, the application of the system in the Czech Republic, where a national model has recently been set up, is used as a practical illustration of the modelling technique. It is intended to demonstrate the Czech model during the Conference.

GENERAL FEATURES OF THE MODELLING SYSTEMS

Each modelling system provides a generalised model of activities in the forest sector, which is stored in the computer program. Users of the system adapt the generalised model to suit their particular circumstances by creating specific models contained in data files which they assemble and name. Specific models may cover the whole country, or relate to a particular region, district, area or project.

The models are built up from six standard components, combined in various ways, to make functional modules which represent different aspects of sectoral activity. The standard components, called *levels, rates, auxiliaries, delays, supplementary variables* and *supplementary arrays*, are used many times to represent different parameters in the system. They are comparable to types of building material used to construct a house – used in different combinations, they can produce different designs of house.

The functional modules, such as *demand, supply, processing* and *trade*, contain different arrangements and combinations of standard components. The components interact with each other in accordance with equations in the computer programs to represent the activities of each module. Models are formed by assembling the modules so that they combine to represent the behaviour of the sector. This modular structure simplifies model-building and makes it easier to understand how the models work.

The models are „dynamic" and behaviour of the sector over time is described by a sequence of difference equations which are solved by the computer at annual intervals. Thus, when a model is run through the computer, it provides sets of annual projections of important variables in the system, such as future demand, supply, growing stock, costs, revenues, employment, imports and exports.

Forest sector behaviour is simulated in a way which allows the user of the model to investigate the likely consequences of alternative strategies and management decisions under a wide range of assumptions about the future. It is possible to discover how to develop the sector to best advantage and how conditions in the sector need to be modified to overcome restrictions in its performance. The potential and sustainability of the sector can be investigated interactively, by interrogating the model and evaluating each option by its expected results. This approach contrasts with the more usual linear/dynamic programming type of model which aims at providing a single „optimum" solution.

The specific models vary in size and structure. The size varies according to the number of products and crops that are included, depending on the user's specification in the data file. Modules are used repeatedly, based on the products and crops; for example the demand module is used once for each product and a supply module is required for every crop. In principle there is no limit to the size, although practical limitations can make very large models unwieldy to use. The structure is controlled by the arrangement of the products and crops and the order in which they appear.

The data file for each specific model contains sets of variables (i. e. parameters) stored in a prescribed format. Each module requires a separate set of variables, which control the way it operates. Values are assigned to each variable by the user, eg. the rate of change in demand is prescribed for each product and the mean annual increment per ha for each crop. The size of the model determines the length of the file.

Each time the model is run, the information in the data file is used to calculate sets of annual projections of all the important variables in the system, eg. future demand and supply, costs and prices, income and employment. During each run, the data is first used unchanged to generate a *standard* set of projections. The process is then repeated using data changes which are supplied by the user through the keyboard. Each repeat, using modified data, is known as an *option* and generates another set of projections. Comparison between the standard and the options are printed out in the form of tables for each option, showing the increases or decreases in the annual values of selected variables.

Once the model has been set up, the computer program can be run repeatedly to test the consequences of changes which simulate alternative strategies, management decisions or assumptions about the future (eg. different regeneration methods, rotations, yields, felling programmes or estimates of demand). Any of the parameters in the data file can be altered (singly or in combination) so that it is possible to test almost any conceivable planning option and to carry out sensitivity analysis. There is no restriction on the options that may be tested, provided they do not affect the basic structure of the model.

Furthermore, the standard data held in the data file can be updated or improved at any time as circumstances change and fresh information becomes available. This enables forestry sector strategy and development to evolve step by step, with growing confidence, as data reliability and planning skills improve.

MODULES AND STANDARD COMPONENTS

The modelling systems are made up of combinations of modules. Each module handles a different aspect of forest sector activities. The number of different modules and their precise function depend on the system; thus VOLPLAN contains four and TIMPLAN uses eleven different modules. The *supply* module deals with the areas and volumes of forest crops and contains the generalised growth model which is of particular interest to this Conference.

Actual models are assembled in named data files. Their size and structure are controlled by the contents of the file. The data file also supplies detailed information about each of the parameters or variables which make-up the modules. The file is read sequentially when the model is run through the computer and the information it contains is used by the computer program to calculate year by year projections of demand, supply, costs, employment, financial returns etc.

Each module requires a specific data set in the data file. The data set lists, in a set order, the variables needed for that particular module, together with the values which the user assigns to those variables. When a module is used several times, the data set for that module must be repeated each time. Thus, if a model contains three products, the data set for the *demand* module is used three times. However, the values assigned to the variables in the data set will be different for each product.

Every variable is coded for easy reference, eg. RS10 represents the area felled annually. Note that the second letter in the ref code shows the module to which the variable belongs – in this example „S" indicates that it forms part of the *supply* module.

Different kinds of variables make-up the modules. Each is represented by one of the six types of standard component. The standard components are the basic units from which the modelling systems are constructed. They perform distinctive functions and are arranged in different combinations, to represent different sectoral activities.

Each type of component has a particular form, which is easily recognised, no matter what variable a component may represent. The data requirements of each type are also different. In the computer programs, procedures for handling the components are standardised in the form of subprograms.

In the code which identifies each variable, the type of component is shown by the first letter. Thus the „R" in RS10 indicates that it is a *„rate"*. Groups of similar variables, which use the same type of component, are serially numbered in each module.

The functions of the standard components are as follows:

Levels describe the condition of the system as a particular time, i. e. they are the „stocks" in the system. They have values which are calculated at annual intervals and are comparable with the levels in a tank, which fluctuate according to the rates of inflow and outflow.

The starting value of a level, i. e. its value in the base-year, may be supplied from data or calculated from other variables in the model. Subsequent annual values of the level are calculated and stored on disk by the computer. These annual values provide the main source from which the results of simulation runs are subsequently selected and displayed.

Levels are coded by „L", followed by a letter to indicate the module and a reference number, eg. LS2, total area of young, even-aged stands.

Rates provide the inflows and outflows to the levels, i. e. they are the „flows" in the system. They can only be measured over a period of time which, throughout these models, is taken as one year, i. e. they are annual rates.

Rates may be controlled by other variables in the model, using control words in the data, or determined exogenously, taking values obtained from information given in the data file. In the latter case, the user can set the rate to change over time in one of several ways by means of a *switch number* in the data. Depending on the switch no. which is chosen, the alternatives are:

switch no. 0 – a nil rate (i. e. a rate equal to 0),
1 – a flat rate (i. e. a given amount per annum) for a given number of years,
2 – a percentage rate (i. e. a given percentage of the value of a designated variable) for a given number of years,
3 – a rate read from a table of values by years,
4 – a step rate (i. e. a given annual amount) starting and ending in specified years.

Rates are coded by „R", followed by the module code and a reference number, eg. RS13, annual rate of final felling by volume.

Auxiliaries either supply additional information which helps to determine rates, or substitute for rates by directly controlling the relationship between different levels at the same point in time.

All auxiliaries are determined exogenously, their values being obtained from information given in the data file. As with rates, the user can set the auxiliary to change over time in one of several ways by means of a *switch number* in the data. The alternatives are:

switch no. 0 – a constant value,
1 – a value which changes incrementally (i. e. by a given amount per annum) for a given number of years,
2 – a value which changes exponentially (i. e. by a given percentage of the auxiliary's value in the previous year) for a given number of years,
3 – a value read from a table by years,
4 – a value with a step change (i. e. a change of a given amount) starting and ending in specified years.

Auxiliaries are coded by „A", followed by the module code and a reference number, eg. AS5, mean annual increment per ha of young even-aged crops.

Delays represent time lags in the system or periods of years which govern the relationships between rates and levels. All delays are specified in the data file. Delays are designated by 4-letter codes beginning with „D".

Supplementary arrays are used to store year by year information with which to calculate the values of rates and levels when the model is run, or to provide detailed information relating to age classes. Some supplementary arrays are generated by the computer program when the model is run, others are provided by the user in the data file. Supplementary arrays are recognisable by their distinctive names, eg. AREA.

Supplementary variables are used to simplify complex calculations in the program. All supplementary variables are generated by the computer program; none are derived from data. Like supplementary arrays, they are recognisable by their descriptive names, eg. COUPE, total area felled.

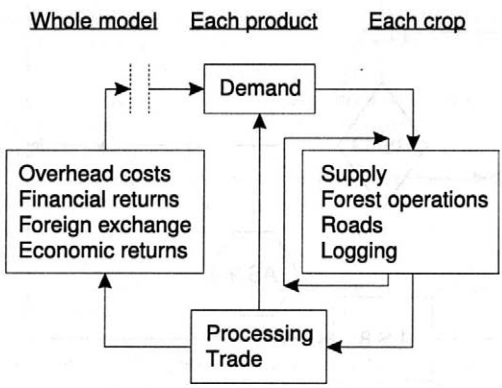
THE TIMPLAN MODELLING SYSTEM

The TIMPLAN modelling system is designed for comprehensive physical, financial and economic planning of production in the forest sector. It links together forest management, harvesting, processing and trade activities, so that increased output from the forest leads in due course to greater production and value added in forest-based industries. The system allows for supply and demand analysis, and provides projections of future costs, returns, employment and capital formation. It is capable of giving a complete cost-benefit analysis of wood-producing activities at national, regional, district or project level, including comparison of alternatives and discounted cash flow tables.

TIMPLAN is the largest of the three systems. It consists of eleven modules, containing a total of 319 variables:

	Code
Demand	D (product related)
Supply	S (crop related)
Forest operations	F (crop related)
Roads	R (crop related)
Logging	L (crop related)
Processing	P (product related)
Trade	T (product related)
Overhead costs	O
Financial returns	N
Foreign exchange	X
Economic returns	E

Each module plays a distinct part in the operation of the modelling system and makes an essential contribution to the functioning of the whole. In an actual model, products and crops are specified by the user and modules are used repeatedly depending on the number of products and crops. The product-related modules are repeated for each product; crop-related modules are repeated for each crop. The last four modules relate to the whole model and are used only once. The repeat sequences and their order of computation are shown below:



2. Flow chart of TIMPLAN computation sequence

Products are defined by the user. A product may be any type of primary output from the forest sector, eg. plywood, sawnwood, poles, fuelwood or pulp and paper. Even non-woody outputs can be classed as products. The choice of products depends on the industries that exist or are planned, the differences of price and quality that distinguish types of output, and the availability of data. Thus, all sawmill output might be aggregated as one product, or sawn softwood and hardwood might be classed as separate products, or the production of pine might be separated from other softwood lumber. Similarly, plywood can be lumped together, or divided into different categories. Poles may be classified by their size and use, eg. transmission poles or fence posts. There is no limit to the possible permutations or extent of disaggregation.

The choice of crops is also unrestricted. They may consist of natural or man-made forest. The whole productive forest area may be combined as a single crop, or it can be divided into forest types. Distinctions can be made between species, sites, quality classes and locations. Thus, all coniferous plantations throughout the whole country might form one crop, or they could be divided between uplands and lowlands, or separated according to site productivity and accessibility. Uneven-aged natural forest, made up of mixed species and worked on a felling cycle, can be classed as a crop producing a mixed output. Alternatively, crops may consists of even-aged plantations or areas of natural regeneration, which are divided into age classes and managed on a fixed rotation.

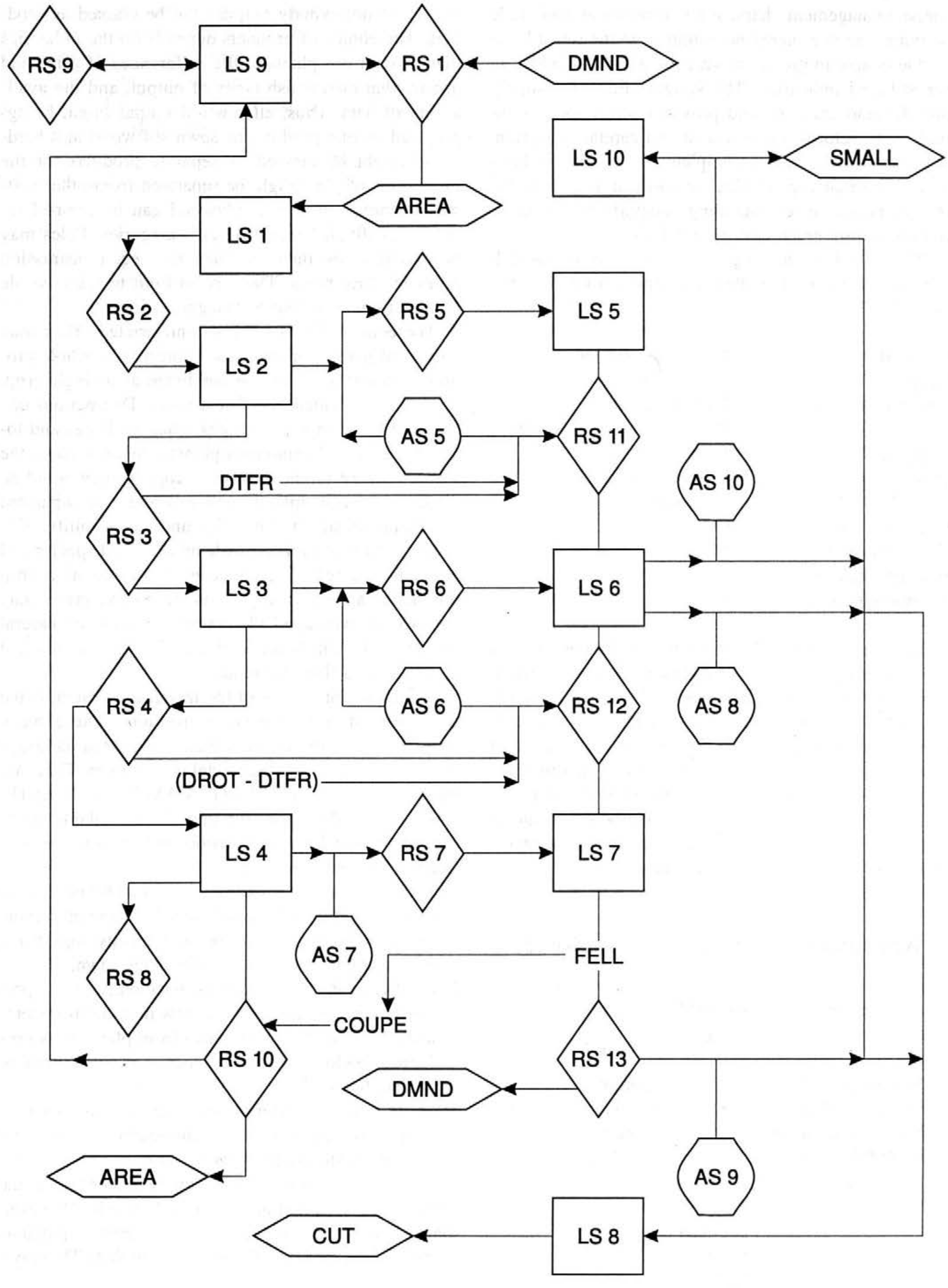
An important feature of the modelling system is the provision of links between products. These work through temporary stores, which are created as arrays in the computer while the model is being run. There are three arrays, called USLOG, SMALL and WASTE, which are used to store the quantities available annually of unused logs, smallwood and residues respectively. These provide for:

1. a proportion of the roundwood supplied for processing into one product to be stored for subsequent processing into a different product, eg. best quality logs being used for plywood, the remainder being sawn,
2. smallwood derived as a subsidiary output from previous crops and then used as raw material for a subsequent product, eg. thinnings from plantations producing sawlogs, which are used for paper pulp or particle board,
3. residues derived from processing one product providing raw material for a subsequent product, eg. sawmill waste used for paper pulp.

Normally, one or more crops supply timber to meet the requirements specified in the demand module. However, some products may utilize only the outputs of previous crops stored in the USLOG, SMALL and WASTE arrays.

THE SUPPLY MODULE

This module contains a simple, generalized growth model which provides projections of areas, growing stock and utilizable volumes of roundwood for each crop. The flow chart in Fig. 3 shows the structure and



3. Supply module diagram

List of variables:

LS1 – Area prepared for planting or being regenerated (ha)
LS2 – Total area of young, even-aged crop (ha)
LS3 – Total area of immature, even-aged crop (ha)
LS4 – Either the total area of overmature, even-aged crop (ha) or the total area of uneven-aged natural forest managed on a felling cycle (ha)

LS5 – Growing stock, volume of young, even-aged crop (m^3)
LS6 – Growing stock, volume of immature, even-aged crop (m^3)
LS7 – Either growing stock, volume of overmature, even-aged crop (m^3) or the total merchantable volume of uneven-aged natural forest (m^3)
LS8 – Volume of logs from thinning and final felling (m^3)
LS9 – Stock of land for planting/regeneration (ha)
LS10 – Volume of marketable smallwood from thinning and final felling (m^3)
RS1 – Annual addition to area being prepared for planting or being regenerated (ha) [controls CUT or DEMAND or DATA (% of LS9)]
RS2 – Area of which planting/regeneration operations are completed annually (ha)
RS3 – Area on young crop transferred to immature crop annually (ha)
RS4 – Area of immature crop transferred to mature crop annually (ha)
RS5 – Annual increment of young stands (m^3)
RS6 – Annual increment of immature stands (m^3)
RS7 – Either annual increment of mature/overmature even-aged stands or annual increment in uneven-aged natural forest (m^3)
RS8 – Loss of mature/overmature forest to agriculture and other uses (ha) [control DATA (% of LS4)]
RS9 – Acquisitions (+) or disposals (–) of land for planting/regeneration (ha) [controls NEW or DATA (% of LS9)]
RS10 – Area of final felling (ha) [controls SUPPLY or DATA (% of LS4)]
RS11 – Volume of young crop transferred to immature crop (m^3)
RS12 – Volume of immature crop transferred to mature crop (m^3)
RS13 – Volume (logs plus smallwood) from final felling (m^3) [controls: CYCLE (% of LS7) or SUPPLY or DEMAND or DATA (% of LS7)]
AS5 – Mean annual increment per ha of young, even-aged crop (m^3)
AS6 – Either mean annual increment per ha of immature, even-aged crop, or mean annual increment per ha of uneven-aged natural forest (m^3)
AS7 – Either mean annual increment per ha of overmature, even-aged crop (m^3) or average yield per ha, of merchantable timber in uneven-aged natural forest (m^3)
AS8 – Average annual merchantable yield of logs from thinnings per ha of either even-aged, immature crop or, total uneven-aged natural forest (m^3)
AS9 – Proportion of logs in volume of final crop (min. 0, max. 1)
AS10 – Average annual merchantable yield of smallwood from thinnings per ha of either even-aged, immature stands or total uneven-aged natural forest (m^3)
DRGN – Regeneration period (years) (min. 1)
DTFR – Transfer age, young to immature stands (years)
DROT – Rotation length or length of felling cycle for uneven-aged natural forest (min. 1)
AREA – Array for areas of crop by age classes (max. DRGN for uneven-aged forest; min. 1, max. DROT + 9 for even-aged crops)

operation of the module. A reference list of the variables with their codes is also provided; those marked with an asterisk require input from the data file, the others are generated automatically by the computer.

The module diagram shows areas on the left and volumes on the right hand side. Looking first at the areas, each year, the stock of available land (LS9) is reduced by the area taken for planting/regeneration (RS1) and replenished by land acquisition (RS9) and felling (RS10). In even-aged crops, new land is added each year to the total area under regeneration (LS1) and, as planting/regeneration (RS2) takes place, a new age class is added to the total area of young crop (LS2). Similarly, the oldest age class in LS2 is added to the total area of immature crop (LS3), the transfer age (DTFR). At maturity (DROT), the crop is either felled (RS10) or is allowed to continue to grow and classed as overmature (LS4). The AREA array keeps track of the areas of the age classes and is updated at annual intervals by the computer.

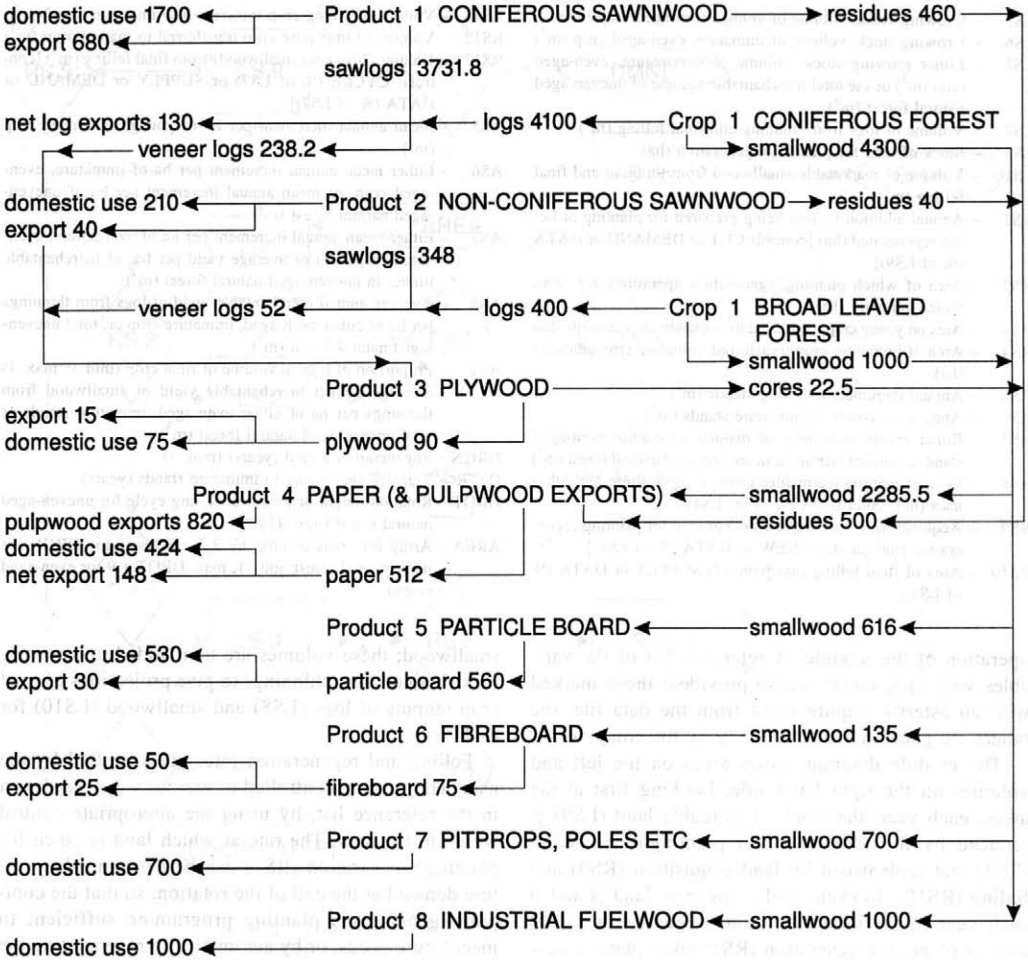
Growing stock volumes are recorded separately for young crops (LS5), immature crops (LS6) and overmature crops (LS7). The user specifies the age at which a young crop transfers to immature crop (DTFR) and the rotation age (DROT). Mean annual increment per ha is supplied from data for young, immature and overmature crops (AS5, AS6 and AS7 respectively). Increment rates (RS5, RS6 and RS7) are derived by multiplying the increments per ha by the areas of LS2, LS3 and LS4 respectively. Thinning takes place during the period of immaturity (DROT–DTFR) and is allowed for by specifying the average yield per ha per year for logs (AS8) and smallwood (AS10) throughout this period. The volume derived from final felling (RS13) is divided proportionately (as set by AS9) into logs and smallwood; these volumes are then added to the volumes obtained from thinnings to give projections of total crop outputs of logs (LS8) and smallwood (LS10) for each year.

Felling and regeneration rates are specified by the user. They can be controlled in various ways, as shown in the reference list, by using the appropriate control words in the data. The rate at which land is taken for planting/regeneration (RS1) can be determined by future demand at the end of the rotation, so that the computer generates a planting programme sufficient to meet future needs, or by automatically regenerating the area felled, or by specifying a planting programme. The felling rate can be determined by felling each age class as it reaches maturity (the SUPPLY control), or by felling sufficient to meet demand year by year; alternatively the user can use the DATA control by specify a felling programme either by area (RS10) or by volume (RS13).

Uneven-aged crops are handled by recording the total area of forest in LS4, the total volume of growing stock in LS7 and the yield per ha of merchantable timber in AS7. The felling rate (RS13) controlled by CYCLE enables the forest to be cut over at a specified rate on a given felling cycle (DROT). Regeneration can either follow felling (when controlled by CUT), or be determined by future DEMAND, or be specified by DATA. Increment on regenerated areas is specified in AS6.

THE CZECH REPUBLIC NATIONAL MODEL

A forest sector model for the Czech Republic was set up in July, 1994 using VOLPLAN, which is now



4. Czech Republic national model diagram

being developed into a TIMPLAN model. This work was undertaken as part of a forest sector policy review undertaken by Landell Mills Ltd as part of the EC-PHARE programme. The model will be demonstrated during the Conference.

The structure of the model is shown in Fig. 4. It consists of eight products and two crops. The flows are for 1993 and are in thousand cubic metres (or thousand metric tonnes for paper).

The total commercial forest area in the Czech Republic is approximately 2,542,700 ha, made up of 1,994,800 ha of coniferous and 547,900 ha of broad-leaved forest. Rotations of 100 years were used for both types. These crops supply roundwood for export and for processing into a total of eight products. Logs are utilized for coniferous and non-coniferous sawnwood and for plywood production; smallwood (pulpwood, poles and fuelwood) and processing residues provide the raw material for the remaining five products – pulp and paper, particle board, fibreboard, pitprops and poles and industrial fuelwood.

Six per cent of the coniferous log supply consists of prime logs for plywood, the remaining 94 per cent goes to sawmills; the corresponding percentages for broad-leaved logs are 13 per cent and 87 per cent. Sawmill residues (12.5% of sawlog input) and plywood cores (10% of input) are utilized for pulp and paper production.

The age class distribution of the forest is uneven, but data was available to show the areas by decades from which average yearly figures were derived to build up the AREA arrays for the model. It was estimated that 297,900 ha of coniferous and 78,000 ha of broad-leaved forest are more than 100 years old.

The mean annual increment of conifers up to rotation age was put at 5 m^3 per ha per annum; for older stands an increment rate of 3 m^3 per ha per annum was used. The corresponding increment rates for broad-

-leaved forest were 3 and 2 m^3 per ha per annum. It was assumed that felling would be immediately followed by replanting and that the volume felled would be determined by the demand for sawn timber.

Exponential increases in annual demand for the various products (based on FAO, 1993) were put at 2 per cent for sawnwood, 4 per cent for panel products, 3 per cent for pulp and paper and 1 per cent for pitprops, poles and industrial fuelwood.

The standard version of the model, represented by the data and assumptions in the data file, was used to obtain projections for the next 50 years. These indicated that felling at the rate required to satisfy demand would progressively reduce the area of overmature crops until, in about 30 years time for conifers and 20 years for broad-leaved forest, demand is likely to overtake supply. Assuming an average rotation length of 100 years, the forests of the Czech Republic are in no danger of being overcut in relation to their sustainable productive capacity for many years to come; it would appear to be advantageous to increase the present felling rate and reduce the overmature age classes faster if markets for the extra output can be found.

Various options were tested with the model to explore the policy implications of increasing the felling rate by exporting more sawn timber. Doubling the rate of increase of export demand, from 2% to 4%, reduces the time taken to extinguish the overmature age classes by about five years. An increase in coniferous sawn timber exports from 680,000 m^3 at present to 1.5 million in three years time would have the effect of removing the overmature coniferous growing stock in about 20 years.

Increased felling will affect the quantity of smallwood available for pulp and paper production and processing into subsequent products unless the proportion of logs in total roundwood also changes. Either additional markets for the products which utilize smallwood will need to be found or sawmills will have to process more small logs.

In the long run, demand increases at the forecast rates will lead to a shortfall in wood supply unless steps are taken to raise productivity by forest management improvements. Reliable data is needed to enable various management options, such a heavier thinning and shorter rotations, to be related to changes in rates of tree growth, but preliminary indications obtained from the model suggest than the supply/demand imbalance would be delayed for at least 10 to 15 years if the mean annual increment could be increase from 5 to 6 m^3 per ha per annum.

The VOLPLAN model therefore provides a tool for starting to develop forest management strategy in the Czech Republic. As new data becomes available, it can be fed into the model to give more reliable and informative sets of projections. Furthermore, the model itself can be elaborated to include more crops or products. The national model could also be subdivided to obtain district forest models.

Development of a TIMPLAN model is desirable to explore the financial and economic consequences of alternative strategies for the forest sector. A preliminary national model has been set up, using the VOLPLAN model as a basis, but this will need to be refined before it can yield useful results. Relevant questions to be investigated with the TIMPLAN model include:

1. how to obtain the best return on investment in the forest sector?
2. the effect on employment of different strategic choices?
3. the effects of various forest management alternatives on forest industries, including value added and investment requirements?
4. forest sector effects on the trade balance and foreign currency earnings?
5. the sustainability of different strategies?

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RŮSTOVÝ MODEL LESA TIMPLAN

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Popisuje se jednoduchý růstový model lesa, který je součástí mnohem většího, komplexního sektorového modelu lesa, zahrnujícího lesní fond, těžbu, zpracování dřeva a obchod. Tento sektorový model má sloužit pro analýzu a plánování lesnické politiky a umožňuje holistické zpracování aktivit v daném sektoru, takže když simulujeme alternativní způsoby obhospodařování lesních porostů, v plném rozsahu odhalíme jejich pravděpodobné důsledky včetně změn produkce, nákladů, příjmu, potřeby pracovní síly, tvorby kapitálu, zisků

a výdělku cizí měny. Sektorový model je obsažen v modelovém systému nazvaném TIMPLAN. Jedná se o počítačovou sadu programů, která umožňuje uživatelům vytvářet a provozovat jejich vlastní modely, přizpůsobené struktuře a vlastnostem lesnického sektoru v dané zemi, regionu nebo oblasti, kterou se zabývají.

Modelový systém vychází z principů „systémové dynamiky" a používá standardní prvky nazývané úrovně, stupně, pomocné úrovně, zpoždění, doplňková pole a doplňkové veličiny; každý prvek se používá mnohokrát, aby v systému reprezentoval různé parametry, a dále se prvky organizují do jedenácti funkčních modulů. Růstový model je obsažen v modulu „dodávka"; tento modul se opakuje pro každý porost. Uživatel připraví soubor dat ve standardním formátu a zadá údaje o věkových třídách pro základní rok, obmýtní nebo těžební cyklus, objemový přírůst na hektar za rok ve věkových třídách mladého, středního a mýtního porostu a množství dřeva, které je třeba každoročně vytěžit probírkami. Uživatel upřesňuje a upravuje rychlost obnovy lesa a výši těžby. Počítač vypočítá pro každý porost a pro každý rok porostní zásobu a vytěženou dřevní hmotu až na období 100 let. Systém může pracovat jak s přirozeně zmlazenými, tak s uměle založenými porosty.

V práci se popisuje celostátní sektorový model pro Českou republiku, který ilustruje metodiku modelu.

model růstu; růstový model lesa; lesnická politika; produkce

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Cape, J. N.: Environmental influence on the development of spruce needle cuticles (Vlivy prostředí na vývoj kutikul smrkových jehlic)

New Phytol., 1993, s. 787–799 – 3 obr., 6 tab., lit. 39

Vosková vrstva na kutikule listu zabraňuje ztrátě vody kutikul odrazovým povlakem, aby se snížila teplota povrchu listu. Jedná se o fyzikální bariéru proti pronikání houbových hyf nebo proti napadení hmyzem. Nebylo prokázáno, že by biosyntéza pokračovala za první vegetační dobu. Bylo zjištěno, že u smrku *Picea rubens* klesá množství vosku na jehlici se stoupajícím věkem jehlice. Kromě tohoto smrku byl předmět výzkumu sledován i u dalších smrků, a to *Picea abies, P. mariana a P. glauca.* Semenáčky byly sledovány ve skleníku a v komorách s kontrolovaným prostředím. Byly zkoumány účinky růstového prostředí na epikutikulární produkci vosku jehlic, na morfologii a na smáčivost jehlic. I když relativní tempo růstu bylo podstatně nižší u semenáčků pěstovaných ve volnu, neexistovaly rozdíly v morfologii vosku na semenáčcích pěstovaných ve volnu a ve skleníku. Depozity vosku na semenáčcích s kontrolovaným prostředím byly významně krystalické. Zastíněné smrky *P. rubens* a *P. mariana* produkovaly podstatně více vosku než nezastíněné. Množství a morfologie povrchových vosků a smáčivost čtyř druhů smrku se mohou upravit růstovými podmínkami. – *M. Pagač*

McCormack, M. Jr.: Reductions in herbicide use for forest vegetation management (Snížené používání herbicidů pro obhospodařování lesní vegetace)

Weed Technology, 1994, s. 344–349 – 3 obr., 2 tab., lit. 8

Herbicidy mají významnou úlohu při vylepšování druhové skladby, při zvyšování přírůstu a při zkracování délky obmýtí. Používání herbicidů se ale v poslední době redukuje. Pro tuto skutečnost se uvádějí čtyři důvody. Prvním důvodem je celková ekonomická situace, kdy se krátí položka rozpočtu na pěstování lesa. Dále byly změněny provozní podmínky a došlo ke změnám v těžebních metodách. Technologie a strategie pěstování je záměrně zaměřena na snížené množství herbicidů. Emoční tlaky veřejnosti vytvořily náladu tzv. návratu k přírodě a prosazuje se jasná redukce nebo dokonce odstranění herbicidů z lesů. Všeobecně je používání herbicidů v lesích v různých oblastech odlišné. Různé vlastnictví lesů ovlivňuje politiku i praxi. Také pojetí ekonomických dřevin se liší uvnitř oblastí i mezi nimi. Uvádějí se faktory, které budou ovlivňovat budoucí redukci množství používaných herbicidů: nová chemie, zlepšená technologie, zapojení obhospodařování vegetace do všech aspektů pěstování mladých porostů, využití alternativních metod. – *M. Pagač*

THE MELA SYSTEM AS A FORESTRY MODELLING FRAMEWORK

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The Finnish MELA System is reviewed as a forestry modelling framework. MELA is an operational information system, or a synthesis tool, for solving problems related to how to manage forest stands in order to achieve the overall (usually forest level) goals for forestry in each particular decision situation. The system was originally designed in the late 1970s for the analysis of long term timber production possibilities at regional and national levels based on the sample plot and sample tree data of the Finnish National Forest Inventory. Besides the regular determination of the regional cutting possibilities, the large-scale applications of MELA include two rounds of national timber production analysis since the middle of the 1980s. Now, the system is also widely applied in practical forestry in stand level applications and in forest research in Finland. The first international pilot project was started in 1994 in Lithuania. The FORTRAN 77 software is portable to DOS, OS/2, OSF/1, VMS, and several UNIX environments.

forest management planning; forest policy; stand management; synthesis methods; simulation; individual trees; linear programming; hierarchical constraints

INTRODUCTION

When considering any given activity, one should be aware of the factors and consequences influencing the decision in question. In forestry, when deciding the national forest policy as well as the management of an individual forest stand, attention needs to be paid to forest resources and their growth potentials, the goals of forest owners, the demand for forest products, the costs of operations, the general exploitation rate of forests and the intensity of silviculture, the goals for national forestry, and the whole physical and economic environment of the forestry unit over time.

Planning means the analysis of future potentials, decisions and operations taking into account the pertinent factors and their interactions. Planning plays the role of a consultant, for example, in complex decision situations and in regulating such decision objects as national or enterprise's forest production over time, by charting the production and decision potentials, by selecting effective solutions, and by reconciling conflicting demands. In forestry, the interest horizon may reach one century or even more because of the long production cycle, and therefore decisions can be based on uncertain assumptions of future needs and potentials only. Even if the principal interests in forest management decisions have a short time horizon, more far-reaching studies have to be carried out to ascertain the sustainability of forestry.

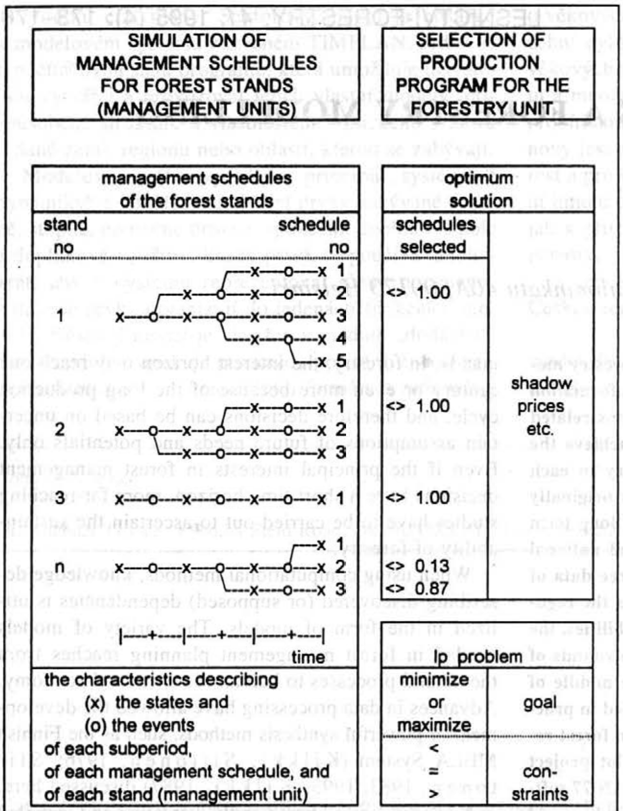
When using computational methods, knowledge describing discovered (or supposed) dependencies is utilized in the form of models. The variety of models needed in forest management planning reaches from the natural processes to human activities and economy. Advances in data processing have allowed the development of powerful synthesis methods, such as the Finnish MELA System (Kilkki, Siitonen, 1976; Siitonen, 1983, 1993; Kilkki, 1987) discussed here, and consequently increasingly versatile and detailed analyses on the different levels of forest production.

This paper summarizes recent experience and visions concerning the Finnish MELA System as a forestry modelling framework.

THE MELA SYSTEM

MELA is an operational information system, or a synthesis tool, for solving problems related to how to manage forest stands in order to achieve the overall (usually forest level) goals for forestry in each particular decision situation. The system was originally designed in the late 1970s for the analysis of long term timber production possibilities at regional and national levels based on the sample plot and sample tree data of the Finnish National Forest Inventory (Siitonen, 1983). Now, the system is also widely applied in practical forestry in stand level applications and in forest research in Finland. The FORTRAN 77 software is portable to DOS, OS/2, OSF/1, VMS, and several UNIX environments.

The method applied in the MELA System is to simulate automatically a finite number of feasible (or biologically, technically, ecologically, economically, socially sound and acceptable) optional management schedules for the stands over time, and to select simultaneously both a production program for the whole for-



1. The principle scheme of the MELA System (Siitonen, 1993)

estry unit and the management for the stands based on the actual (or hypothetical) goals of the decision maker. The management schedules define the search space in solving each individual decision problem. These principal steps are illustrated in Fig. 1.

Rather than just finding an optimum solution, optimization should be primarily understood here as a tool to effectively select effective solutions with several simultaneous conditions (or performing the synthesis over forest resources, goals, physical production, economic aspects and efficiency, etc., over time).

The method is based on the general assumption that the development of the natural processes in the forest stands – and consequently the development of the forest resources – can be predicted, and the limited number of management schedules can describe the future potentials of the forest with sufficient accuracy concerning the decisions under consideration. Relevant forest resource data and forest development, forest management and forest economy models are required to accomplish any calculations. One should also make a difference between the general simulation-optimization paradigm, and the actual forest data and models having a large influence on the actual results and their relevance.

Typical MELA tasks consist of the following iterative steps:

- Generation of stand and individual tree level input data.
- Generation of application dependent parameters and instructions for simulation.
- Simulation of feasible management schedules for stands over a desired calculation period.
- Formulation of the optimization problem on forest level.
- Selection of the forest level solution and the management of the stands (synthesis).
- Re-simulation of the management schedules in the forest level solution (for non-stored details).
- Return of stand level results into stand data base.

The forest resources are described in MELA by all the stands or a representative sample. The stands may be grouped in advance into management units that consist of one stand or a set of homogeneous stands. A management unit is described in the simulation by one or more „sample plots" and the growing stock on the sample plots with sample trees. The sample plots represent the variation within the management unit. The sample plots and the trees are furnished with variables necessary for further calculations, such as the number of stems/ha (that each tree represents), tree species, diameter, height and age of each tree. The simulation variables of trees are transformed into volumes, timber assortments and values etc. using respective general models.

The simulation of the management schedules consists of natural processes (for example, ingrowth, growth and mortality of the trees) and human activities (for example, cuttings, silvicultural treatments, drainage of peatland, fertilization, and changes in land use). A set of detailed models based on individual trees describing natural processes (Ojansuu et al., 1991), treatments, timber prices, costs, management instructions etc. is utilized.

In the current version of MELA, linear programming is applied in the simultaneous selection of the forest and the stand level solutions over time. For the details of the linear programming software (JLP) and the optimization problem (Lappi, 1992; Lappi et al., 1994). In the JLP model, the management schedules are activities. There are hundreds of variables available as optional decision criteria (goal and constraints in the JLP problem) both for the whole forestry unit and for its subsets (any sets of stands). The decision variables describe the state and the development of the forests, as well as forest production and its economy over the whole calculation period. The optional decision variables make it possible to solve various planning problems depending on the actual needs of the decision makers. A JLP solution gives one efficient management policy from the management schedules. Multiple goal problems are solved through the iterative use of JLP, analysis of the primal and dual solutions and regulation of the constraints.

Tab. I gives a summarized example of MELA results on forest (national) level. For further details, illustrations, numerical examples and requirements for models (Siitonen, 1993) and for backgrounds also Kilkki (1987) and Siitonen (1994).

The MELA System as a whole can be regarded as an upper level decision model consisting of lower level models describing natural processes, forest production

I. A timber production program for the whole of Finland as a combination of 23 regional MELA solutions. The net present value of the future revenues was maximized subject to even or increasing flow of timber, saw logs and net income over a 50–year period for each region. The data consisted of about 8,000 management units and 200,000 management schedules in total. The calculations were carried out in 1990 (Siitonen, 1993)

	1990	2000	2010	2020	2030	2040
Forest area, mill. ha	21.2	21.2	21.2	21.2	21.2	21.2
Volume, mill. m^3	1,789	1,924	1,983	2,077	2,284	2,594
Pine	790	861	986	1,208	1,477	1,743
Spruce	675	690	613	515	515	599
Birch	265	304	315	299	253	220
Other species	59	69	68	55	39	32
Saw logs	696	690	656	641	662	785
Pulpwood	914	1,048	1,147	1,269	1,471	1,668
	1990–2000	2000–2010	2010–2020	2020–2030	2030–2040	
Increment, mill. m^3/a	83.6	85.6	92.7	104.9	117.2	
Pine	36.6	42.3	53.5	66.2	75.4	
Spruce	28.3	25.5	23.5	25.9	31.7	
Birch	14.6	14.1	12.9	10.8	8.7	
Other species	4.0	3.6	2.9	2.1	1.5	
Drain, mill. m^3/a	70.1	79.7	83.3	84.2	86.2	
Natural	3.4	4.3	4.7	4.4	4.3	
Cut	66.7	75.3	78.6	79.8	82.0	
Cutting removal, mill. m^3/a	61.5	71.1	74.1	75.9	78.8	
Pine	26.4	26.8	27.7	35.5	44.8	
Spruce	25.1	31.6	31.7	24.6	22.1	
Birch	8.1	10.3	11.7	13.0	10.1	
Other species	1.8	2.4	3.0	2.9	1.7	
Saw logs	34.1	37.9	36.8	36.0	36.6	
Pulpwood	27.3	33.1	37.4	39.9	42.1	
Cutting, mill. ha/a	0.61	0.67	0.63	0.65	0.65	
Regeneration, mill. ha/a	0.25	0.23	0.22	0.20	0.19	
Tending, mill. ha/a	0.28	0.33	0.36	0.28	0.22	
Gross income, mill. FIM/a	12,744	14,393	14,501	14,757	15,338	
Costs, mill. FIM/a	3,902	4,308	4,369	4,329	4,377	
Net income, mill. FIM/a	8,842	10,085	10,132	10,428	10,961	

and its economy with the details of individual trees and forest stands. The MELA System is intended to be a framework for gathering, managing and synthesizing all relevant information for forest management planning (for example, forest resources, forest models, goals for forestry) from the stand and tree levels to decisions concerning the whole forestry unit.

APPLICATIONS

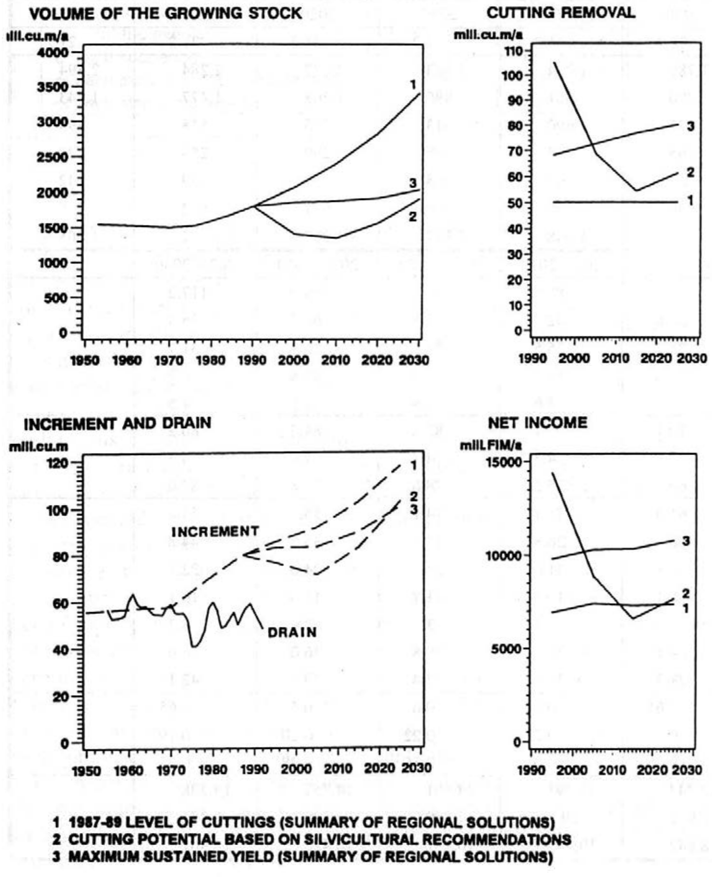
The applications of the MELA System fall into four overlapping categories, research projects, strategic analyses, stand level analyses, and updating of forest resource data. Besides the regular determination of the regional cutting possibilities, the large scale applications of MELA include two rounds of national timber production analysis in Finland since the middle of the 1980's (The Forest 2000 Programme 1986, The Presentation of the Revised Forest 2000 Program 1992). The national level calculations of the third generation will be carried out in 1994 to 1996. MELA has been (or is being) installed by a limited number of customers in state, company and private forestry to be the forest management planning module of their own forest (stand) information systems. The first international pilot project, in Lithuania, was started in 1994.

As an example of applications, alternatives 1–3 in Fig. 2 indicate the utilization and the development possibilities of the Finnish forest resources based on the information included in the current MELA version and on the hypothetical goals. According to the results, the forest resources as such allow a remarkable increase of cuttings besides other uses of the forests, if the silvicultural intensity of the 1980s is kept (see also Tab. I).

The results of syntheses also seem to suggest more options and a more dynamic way of thinking in forest management on stand level than the conventional restrictions and formal regulations.

FURTHER DEVELOPMENTS

The experience up to now reveals that the current MELA version may finally be reaching the critical mass in substance, versatility, applications and functionality via such contributory factors as production planning paradigm, simultaneous forest and stand level synthesis, detailed and automated simulation of forest processes, open hierarchical decision problem, integra-



2. A summarized comparison of three cutting options and their consequences during the period 1990–2030. The development up to 1990s is based on forest statistics, and the future estimates are a sample of recent planning results (Siitonen, 1993)

tion of conventional decision levels as well as physical production and economy, and capacity for practical problems.

The MELA Team is carrying out in 1994–1996 the project *The Production Potential of the Finnish Forests in 1996–2025*. In this third regional and national analysis of its kind since the middle of the 1980s, we intend to include transportation costs from forests to the mills (in addition to the costs of logging and extraction), other uses of forests than timber, land use allocation questions, etc. into the synthesis. For example, we try to calculate the regional production possibilities boundaries between timber production and other uses of forests assuming different production technologies (such as the prohibition of clear cuttings and the protection of the oldest forests). The calculations will be based on the data of the eighth National Forest Inventory (NFI) being finished in 1994 (Salminen, 1993). The multi-source information of the NFI on pixel level (interpreted from Landsat information, digital maps and the NFI field measurements – Tomppo, Siitonen, 1991) should be useful, for example, when presenting planning results on large-scale maps over the whole country.

The next steps of the system development will comprise the finish of the current system generation of prototype character towards a complete product. Besides the project tasks mentioned above, supplements to synthesis (such as the indicators of ecosystem state and dynamics), new or improved forest models (natural processes including timber quality, stand management, production, and economy), preparing for international applications by separating general (simulator and optimization framework) and local (actual data and models) system components, and publishing the module and interface definitions, need to be accomplished. In fact, the MELA simulator and the LP solver should be put together with the decision support system components (graphical user interface, GIS and maps, economic short term analyses) to constitute a forest manager's toolbox (for example Nuutinen, 1994).

The trends in computer capacity and prices seem favorable still further. The maximum size test problems solved today are illustrated by the materials of more than 100,000 management units, 2–3 millions of management schedules in total with 10 or so decision variables in one optimization problem (a 64-bit Digital Alpha AXP3000/600S server, 128 Mb). Memory appears clearly the limiting resource in larger optimization problems. The increasing computing capacity can be allocated to broader and deeper syntheses, larger data, more complex structure of forestry units, faster runs, etc. depending on each problem being solved.

CONCLUSIONS

The stand level applications of the MELA System in the 1990s seem to prove a breakthrough of the goal-oriented synthesis paradigm also in practical forestry, besides large-scale strategic analyses in Finland. The local case-by-case methods of forest management planning are being replaced by more universal tools making deeper and broader syntheses possible in each particular decision situation based on more detailed information. The universality requirement for the synthesis tools implies also getting beyond the everyday driving forces or philosophies of forest management.

The hierarchical goal-oriented synthesis based on the detailed description of forests and forestry, is now changing from a research instrument to a planning tool of practical scale. Besides the usual problem solving, the planning system also transfers research results to practical forestry as well serves as a platform for new aspects in synthesis and for further development efforts and advances in data, models, methods and technologies.

Tens or soon hundreds of thousands of management units, actual stands or items of a sample, are fit in one single optimization problem, to say nothing of the decomposition of problems, the aggregation of data, and trends in computing capacity. The lack of synthesis tools and computing power is no more a valid excuse to refuse strengthening the information infrastructure for forest management, such as reliable data and relevant models, and solving practical forest management planning problems. For example, the quantitative facts about the existing lands and forest resources with their future potentials, the estimates of human needs, and the syntheses covering the forest production as a whole should constitute a basis for the reconciliation of today's conflicting demands in forest management.

Strategic forest policy questions as well as individual stand management decisions have a common basis in the management of the forest resources in a satisfactory way, though there are differences in such details as the scale and the time horizon. The selection of the upper level solutions (or performing forest level synthesis) from the lower level options (or the management schedules of stands over time) based on decision makers' actual preferences, is a universal and simple paradigm in planning. Several strategic and operational forest management problems can be solved as variations in this basic theme. The modifications may appear, for example, in the scope of the problem, in the variables of the actual utility function, in the lengths of the planning horizon and the resulted calculation periods in different situations, and in the size and complexity of the hierarchical structure of forestry units.

The future of forests is open and regulable by human activities even if numerous uncertainties have to be taken into account. The upper level synthesis from the optional lower level „management schedules" furnished with standard variables, or the simultaneous regulation of the whole and the details, gives a more comprehensive characterization of the future of forests than the conventional predictions of the „probable" development. If applied on a large international scale, local information in this framework may originate from any source or software just able to produce relevant future options. The level of aggregation and the number of hierarchical levels may vary region from region from one or few prepared scenarios for each region to the management schedules of all the (sample) stands, depending on the available information and computing resources, and the ambitions of the synthesis in question.

According to our experience, the hierarchical goal-oriented synthesis seems a valid and operational paradigm for the analyses of potentials, operations and trends in forest production, from forest holdings to national level, and also on a larger scale if local information production (data and models) can be generally organized.

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SYSTÉM MELA JAKO RÁMCOVÝ MODEL LESNÍHO HOSPODÁŘSTVÍ

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Na finský systém MELA lze pohlížet jako na rámec pro modelování lesního hospodářství. MELA je operační informační systém neboli syntetický nástroj pro řešení problémů jak hospodařit v lesních porostech, abychom v každé jednotlivé rozhodovací situaci dosáhli globálních cílů (obvykle na úrovni porostu). Systém byl původně vytvořen koncem sedmdesátých let pro analýzu dlouhodobých možností produkce dřeva na regionální a celostátní úrovni, která vycházela z údajů získaných pri celostátní velkoplošné inventarizaci lesů ve Finsku. Kromě pravidelného stanovování možností regionální těžby od poloviny osmdesátých let obsahují aplikace MELA ve velkém měřítku dvě kola analýzy celostátní produkce dřeva. V současné době se systému bohatě využívá také v lesnické praxi na úrovni porostu a v lesnickém výzkumu ve Finsku. První mezinárodní pilotní projekt začal v Litvě v r. 1994. Program je napsán v jazyce FORTRAN 77 a je použitelný pro operační systém DOS, OS/2, OSF/1, VMS a UNIX.

hospodářskoúpravnické plánování; lesnická politika; hospodaření v porostu; syntetické metody; simulace; jednotlivé stromy; lineární programování; hierarchické omezení

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PREDICTION OF FOREST DEVELOPMENT UNDER CHANGED ENVIRONMENTAL CONDITIONS

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From 1986 to 1988 a National Forest Inventory (BWI), was carried out, for the first time, on a sampling basis in the Federal Republic of Germany. This produced objective and reliable information about the condition of the forest and its production possibilities. It was obvious that this current information could also be used to estimate future forest development possibilities. For this purpose a PC-supported prediction program was developed which allows the user to examine area structures, growing stock structures, type structures etc. using evaluation factors chosen by the user. During the conduct of this project growth came to be seen as a critical variable because trees have been growing considerably faster in the last decades compared to previous decades. No one can say if this is a lasting condition or if environmental influences will lead to a further deterioration of the state health of the forest and to decreases in growth. The reliability of mid-term predictions, however, is directly dependent upon the reliability of growth predictions.

forest inventory; growth prognosis; growth changes; environmental conditions; forest decline

THE DATA BASE OF THE NATIONAL FOREST INVENTORY (BWI)

The sampling network of the National Forest Inventory was established using a systematic grid with an interval of 4 kilometers between grid lines. In some regions a compression of the grid intervals to 2.83 km or 2 km occurred. The intersection points of the lines formed the southwest corner of a square (tract) with a 150m side length. In the four corners of the square circular sampling plots were established. For trees with less than 10cm diameter at breast height (dbh) the sample plots consisted of concentric circles with 1, 2 and 4m radius. Above this diameter threshold sample trees were selected using the horizontal point method and basal area factor 4. For each sample tree the dbh, height, diameter at a height of 7 m, the polar coordinates, trunk damage and some additional characteristic were recorded. For trees less than 10 cm the number of recorded characteristics was less comprehensive. A total of 12,850 forest tracts in the Federal Republic of Germany with about 230,000 horizontal point sample trees were surveyed.

DATA MANAGEMENT AND EVALUATION PROGRAMS

In addition to the sequential file structure developed in the mid-1980s a PC-oriented, dBASE supported data management with corresponding evaluation programs was established. This data structure proved to be advantageous for the construction of a prediction model. Using this and appropriate models, the growth process of a tree was carried out by replacing original measurements of diameter, height, etc. with predicted values. Then necessary sets of data were removed (production) from the file or added (ingrowth). None of these changes alters the data structure. Therefore software that was developed for the inventory evaluation can also be used for the evaluation of the forest condition at the end of the prediction period. Only for the calculation of growth and of production as well as for the prediction process with its alternatives was the development of additional software necessary.

The use of the BWI-evaluation software is important in two aspects: firstly, much software development effort was saved; secondly, this practice led to the integration of the prediction model into the BWI-information system complex. The prediction of forest development and wood availabilities has become an integral part of this information system and makes a more intensive use of the inventory data possible.

The BWI-information system contains a high degree of flexibility concerning the selection of the evaluation variables and the modes of evaluation. It has a user friendly interface with menus and a screening card for selecting and checking spatial elements. The results are listed standardly in tables with tree species and age class subdivisions and are supplemented with bar diagrams. For questions which cannot be sufficiently answered using the available evaluation tables, the dBASE file structure allows a special evaluation with little additional developmental effort.

THE PREDICTION MODEL

The basis for the prediction of the future development of the forest is the modelling of the processes of growth and of the silvicultural measures. Growth and silviculture exist in a reciprocal relationship: silvicultural measures can influence the height and structure of the growth and vice versa silvicultural actions are formed through the growth processes. Growth can only be controlled by silviculture. External influences such as depositions, climate etc. have to be taken as given and are not variable within the prediction model. This determines the possible selections for the user: circulation period, thinning cycle, type of thinning, thinning grade as well the type of stand establishment are modifiable and can be entered according to the user's desires.

THE PROBLEM OF GROWTH

The research programs which arose due to the appearance of new types of forest disease at the beginning of the 1980s have caused a controversial discussion concerning the growth of trees and stands. On the one hand, diseased trees showed a considerable reduction in growth compared to healthy trees; on the other hand, a growth increase measured against yield tables or preceding stands could not be overlooked. Definite statements were difficult or even prevented, because there is no „normal growth" against which growth changes can be measured. Even yield tables do not portray a norm, since these contain past growth with its differing growth conditions and do not consider the changed climatic conditions. The use of reference periods is not without problems either, since the results have already been determined by the more or less arbitrary selection of the reference period.

Seen as a whole, both effects, general growth increase and growth decrease for diseased trees, do not contradict one another. Only the onesided emphasis on the one effect and the trivialization of the other effect produced a distorted picture of the actual growth situation and the whole state of the forest.

A detailed analysis of the growth processes for spruce in the southwest area should produce more detailed information about the course of growth over time and as a result a well-founded basis for a midterm prediction of wood availabilities.

THE DATA BASIS FOR GROWTH STUDIES

For this study the data of several special surveys were available. The most prominent of these were the growth measurements for the years 1983 and 1988 within the framework of the immissions-ecological research program (IWE) of the Forest Experiment and Research Station of the State of Baden-Württemberg (FVA). In addition data from Mitscherlich for the Black Forest for the years 1955 and 1956 and data from the National Forest Inventory (BWI) was applied.

For the immissions-ecological condition survey 1,618 spruces were cut down in 1983 and 1,496 in 1988. Their distribution over the State of Baden-Württemberg was considered to be representative. Height growth for the last 25 years or 20 years, annual ring width of dbh trunk sections, sociological position, state of health of the sample trees and other data were recorded. The data from Mitscherlich comprises the period 1929 to 1954 and with 129 sample plots only represents the western part of the country. The original data was not available, instead the average values for the sample plots were used. Only the age-height relation and not the growth values were taken from the data of the National Forest Inventory (BWI).

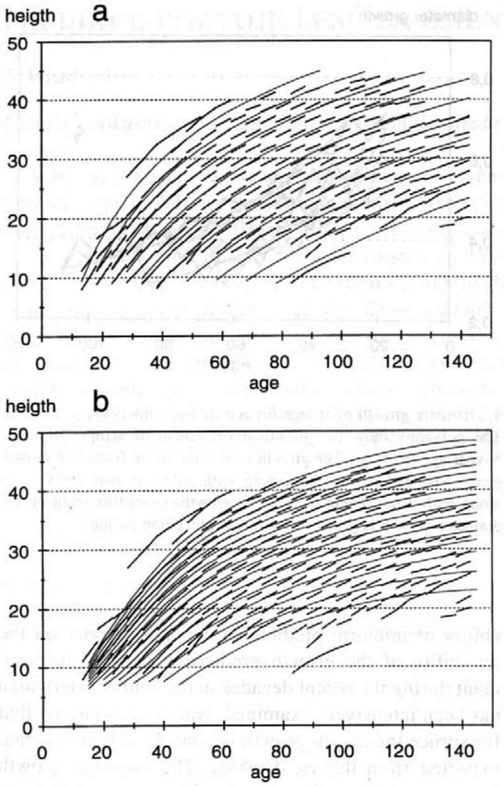
RESULTS AND DISCUSSION

The *height growth* of the IWE-sample trees (growth period 1963–1983 or 1963–1988) is shown in Fig. 1a. The height development of the sample trees is shown by short line segments for 5–year age intervals and 2.5 m height intervals. As a whole these line segments form an empirical directional field. The slope of the line represents the yearly height growth. The corresponding fitting model which expresses growth as a function of age and height is shown by the lighter lines. The graphs have been calculated by summing up the calculated growth values for selected factors such as age, height.

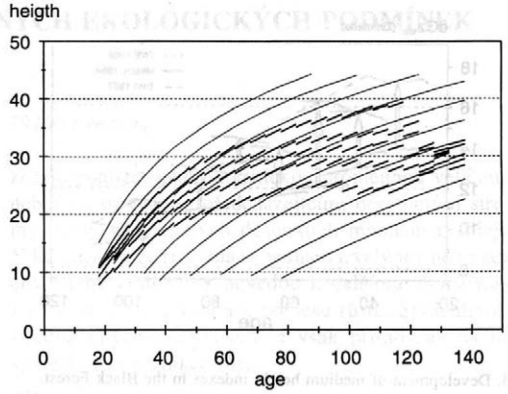
Fig. 1a leads directly to an obvious conclusion: older trees – with the exception of the best site quality classes – show a height growth for the given period, which was not possible in earlier times. Using present growth rates these trees would have had a very minimal height in earlier years. There is only one explanation for this phenomenon: the sample trees had a lower height growth rate earlier than in the period examined. This means that the directional field was flatter.

In Fig. 1b the lighter continuous lines are derived from the age – height graph (site quality assessment fan) of the yield table by Wiedemann. The directional field of the sample trees is clearly steeper than the yield table curves. The discrepancy between height growth during the survey period and the yield tables is considerable.

The changed growth behavior becomes even more obvious when the sample trees are categorized into relative yield classes based on height development. Fig. 3 shows the height development of these yield classes for the same IWE-sample trees. The graphs show a step-shaped course. The beginning height of the next older age level is less than the growth in the previous stage would lead one to expect. This is also a result of higher growth in recent decades. The older the



1. Height growth of spruce for the period 1963–1988.
The short lines connect the medium heights of the sample trees at the beginning of a 5–year age interval with the height at the end of the age interval. Their slope reflects the height growth. Together they build an empirical directional field. All age intervals are subdivided into 2.5 m height intervals. In Fig. a the lighter lines are the calculated fitting graphs. In Fig. b they are based on the site index determination fan from the Wiedemann yield table



2. Height growth of spruce for individual growth classes.
The short lines connect the medium heights of the sample trees at the beginning of a 5–year age interval with the height of the same set at the end of the age interval. The beginning height of the following age interval is, as a rule, less than the ending height of the previous interval. This is caused by the older age and the smaller portion of the entire height that is connected with a higher growth rate. The growth classes were based on the ages and heights of the sample trees for the year 1983. Every class comprises a fifth of the sample trees and can be considered as homogeneous up to an age of about 90 years

trees are, the smaller the portion of higher growth compared to the life of the tree. As a result the final heights deviate even more from the attainable heights based on current growth rates. The result is an apparent site quality class drop with increasing age. If the present height growth continues the step-shaped graphs will conform to the smooth model graphs in the course of time.

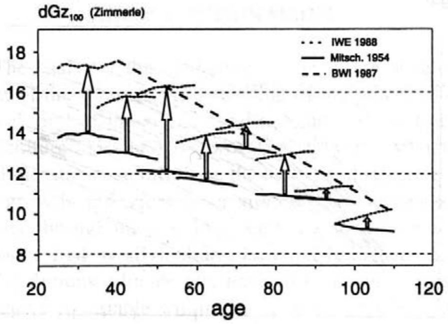
A limitation must be noted: for higher age levels, forest utilization based on a target diameter also leads to a shift in the direction of lower site quality classes. Up to an age of about 90 years, however, one can conclude that for all age levels the entire site quality class spectrum is evenly represented and that the individual yield classes are more or less homogeneous.

Fig. 2 shows clearly and impressively how problematical the site index determination is with respect to growth in the time of changed growth behavior. The actual growth is – at least for older trees and stands – considerably greater than the estimated value based on site quality class. This is also true even when during the site class determination the greater height of the trees, as a result of the higher growth rate, is taken into account. Not only the conventional yield tables become useless, the yield table principle itself becomes questionable.

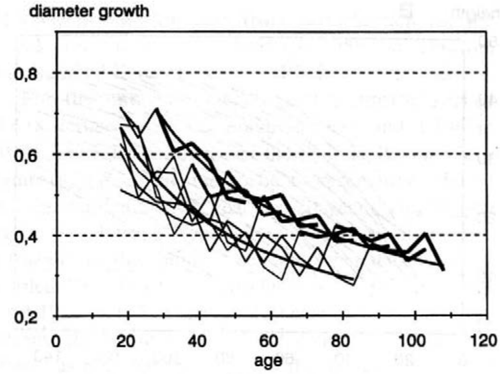
The decrease in site quality class with increasing age, which one observes frequently today, or the increase in site quality class with decreasing age, is a logical consequence of the higher growth in recent decades. This is also cinfirmed by the data of the National Forest Inventory (BWI) as Fig. 3 shows. The magnitude of the changes corresponds to those of the IWE data. The data from Mitscherlich from the 1950s shows only a comparatively small site quality class reduction. This points to a period of relatively stabile growth. Therefore there was, until the middle of the 1950s, no contradiction between the then current growth and growth in earlier times.

The survey of *diameter growth* was somewhat more difficult, since the silvicultural measures have a greater effect on the diameter growth than on the height growth. On the other hand there was a longer series of observations of the diameter growth than for the height development for the immissions-ecological survey material.

As one would expect the diameter has also shown an increase in growth in recent decades. Based on a longer series of observations the beginning of the periods of greater growth can be localized in the middle of the 1950s. This increase is clearly recognizable in Fig. 4. For the sample trees for 1988 the diameter growth for 5–year age intervals of selected age classes



3. Development of medium height indexes in the Black Forest.
The course of the mean dGz_{100} (mean total increment at age 100) for a 15–year time span is shown. The increase in the site quality class with decreasing age is almost the same for BWI and IWE data. For the Mitscherlich data, however, it is considerably less. Within the 15–year period there is a site quality class increase for the IWE data and slight site quality class decrease for Mitscherlich data



4. Diameter growth of spruce for selected age intervals.
The polygons show the growth development of sample trees for 5–year age intervals. The growth is also the mean from five growth years. The darker lines beginning with calendar year 1954 occur along with a noticeable increase in growth. From this point on the diameter growth is greater than in the preceding period

is shown above the age. The dark extended lines which represent the growth periods starting with the middle of the 1950s are clearly above the lighter extended lines for the preceding time. The fitting graphs also show an increase of about 30%.

These results cannot be transferred directly to volume growth per hectare. The available data does not suit for this purpose due to the missing relationship to area. Regardless of this one can assume a definite increase in volume growth per hectare since the middle of the 1950s. The question of future development remains unanswered since the causes of the growth increase are not clear. Possibilities are the increased amounts of nitrogen inputs, higher levels of CO_2 in the air, altered silvicultural methods, discontinuance of forest litter utilization, better seed, changed climate, etc. In particular a further continuing elevated nitrogen input could lead to a destabilization of the stands and possibly to growth losses in the future.

SUMMARY

For purposes of midterm predictions for forest development and for wood availabilities a PC-supported prediction program was developed based on the data from the National Forest Inventory (BWI). It allows the user to study the development of area structures, growing timber structures and type structures using independently selected evaluation factors. Since the reliability of midterm predictions depends heavily on the reliability of the growth prediction, growth development during the recent decades in the southwestern area has been intensively examined. One must point out that for spruce the height growth is considerably above that expected from the yield tables. The diameter growth increase, which is also considerable, already begun, in comparison with earlier times, in the middle of the 1950s. Growth development is an uncertain factor for midterm predictions of forest development. A solution is the development of possible scenarios which contain certain recognizable principles, but as a rule are not sufficient for clear decisions.

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PREDIKCE ROZVOJE LESŮ ZA ZMĚNĚNÝCH EKOLOGICKÝCH PODMÍNEK

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V letech 1986 až 1988 se prováděla celostátní inventarizace lesů (BWI) ve Spolkové republice Německo poprvé na výběrovém základě. Získaly se tak objektivní a spolehlivé informace o stavu lesa a jeho produkčních možnostech. Bylo zřejmé, že těchto současných informací lze také použít pro odhad možností budoucího vývoje lesů. K tomuto účelu byl sestaven počítačový program predikce, který uživateli umožňuje zjišťovat strukturu lesních ploch a porostních zásob, typologickou skladbu atd. s použitím hodnotících faktorů, které si zvolí. Během realizace tohoto projektu se na růst začalo pohlížet jako na kritickou proměnnou veličinu, neboť ve srovnání s předcházejícími desetiletími stromy rostly v uplynulých decenniích mnohem rychleji. Nikdo nedokáže říci, zda se jedná o trvalý jev nebo zda environmentální vlivy povedou k dalšímu zhoršování zdravotního stavu lesa a k poklesu růstu. Spolehlivost střednědobých předpovědí je však přímo závislá na spolehlivosti predikce růstu.

inventarizace lesů; prognóza růstu; změny růstu; ekologické podmínky; ústup lesa

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Willis, M. A. – David, C. T. – Murlis, J. – Cardé, R. T.: Effects of pheromone plume structure and visual stimuli on the peromone-modulated upwind flight of male gypsy moth (*Lymantria dispar*) in a forest (*Lepidoptera: Lymantriidae*) (Účinky oblakové struktury feromonu a vizuální stimuly na feromonem stimulovaný let samců bekyně velkohlavé proti větru v lese)

Journal of Insect Behavior, 1994, č. 3, s. 385–409 – 2 obr., 4 tab., lit. 59

Výzkum probíhal v rámci spolupráce amerických a anglických pracovišť. Popis materiálů a metod zahrnuje data o použitém hmyzu, syntetickém feromonu a o celkovém postupu. Let samců bekyně velkohlavé proti větru modulovaný feromonem odpovídající různým strukturám pachového mraku a vizuální stimuly se zaznamenávaly na videu v lese. Náhradní strom v pokusu tvořil válec ze dvou sekcí kouřové roury o průměru 20 cm. Celková výška zařízení byla 2,20 m. Pokusy nebyly prakticky ovlivněny populací bekyně z volného terénu. Všechny rychlosti samců létajících v mraku z bodového zdroje byly pomalejší než rychlosti samců létajících v širších, rozptýlenějších mracích vycházejících z válcové přepážky. Ukazuje se, že samci orientující se na zdroje feromonu (atrahující samičky) spojené s viditelnými vertikálními válci (stromy) používají pro lokalizaci zdroje převážně olfaktorické podněty a že struktura feromonového mraku zřetelně ovlivňuje orientaci letu a jeho výslednou dráhu. Předpokládá se, že struktura pachového mraku má specifické parametry, které se musí kromě jiného osvětlit pokusy v oblasti neurofyziologie a v behaviorální. Tato struktura může být např. významná při uchování identity feromonového signálu na pozadí šumu chemického pozadí apod. – *M. Pagač*

Burkhardt., J. – Eiden, R.: Thin water films on coniferous needles (Tenké vodní filmy na jehlicích jehličnanů)

Atmospheric Environment, 1994, č. 2, s. 2001–2017 – 5 obr., 6 obr. v příloze, 2 tab., početná lit.

Na jehlicích jehličnanů jsou tenké vodní povlaky nepozorovatelné zrakem. Z toho důvodu se měření vlhkosti prováděla přímo na povrchu jehlic speciálně konstruovanými čidly vlhkosti v různých výškách 40letého smrku ztepilého v terénu v blízkosti Wülfersreuthu v oblasti smrčin v severovýchodním Bavorsku. Čidla byla nasazena na jednotlivé smrkové jehlice za použití pozorovací věže. Při laboratorních měřeních byla prokázána silná vazba relativní vlhkosti a elektrické vodivosti na povrchu jehlic. Elektrická vodivost se na povrchu měřila za použití napětí střídavého proudu. Data byla zaznamenána pomocí zařízení na registraci dat. Byla ověřena obecná schopnost tenkých vodních povlaků rozpouštět stopové plyny. Experimentálně byly prokázány okem nepozorovatelné vlhčící povlaky i na hydrofobním povrchu rostlin. Měření byla prováděna v roce 1992 po dobu pěti měsíců. V příloze je – jako technická poznámka – popis nového zařízení pro výzkum kondenzace vodních par a plynné depozice na povrchu rostlin. Je osvětleno použití zařízení na smrkové jehlice a na aerosolové vzorky deponované na umělé sběrné povrchy. – *M. Pagač*

MODELLING THE GROWTH OF MANAGED AND EVEN-AGED STANDS

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In forest management planning, growth and yield models are used to forecast the development of the forest resources. Information about the existing forest resources obtained from forest inventories forms the basis for future forecasts. The input of the growth models must be consistent and compatible with the data available in these forest inventories. For decision making in forest policy, long term forecasts about the development of forests are needed. The model structure should have valid biological and ecological basis, so that the models are able to produce reasonable growth predictions even when applied outside the range of the data they are developed from. Evaluation of the alternative management schedules is an essential part of forest management planning. Therefore, the growth and yield models should be able to predict reliably the effects of various silvicultural treatments on the development of managed stands. Methods are discussed by which the growth response to thinning and fertilization can be predicted. In model development, data from forest inventories as well as from purpose-designed experiments are needed. Designed experiments provide the information about the effects of various silvicultural treatments on growth and yield, which is important in developing the model structure. Inventory data provide a representative sample of the forests, and therefore needed in fitting the final models.

management planning; forest policy; long-term forestry; silviculture; thinning; fertilization; Finland

INTRODUCTION

In Finland, sustained-yield forest management has been practised for many decades. Forests are regenerated either naturally or artificially, and most of them have even-aged stand structure. Stands are thinned one to four times prior to the regeneration felling and some of them might also have been fertilized at a certain time.

Forecasting growth and yield is an essential part of forest management. In Finland, MELA System (Siitonen, 1983) is widely used as an analysis tool in forest management planning. The system was originally designed for the analysis of long term timber production possibilities at regional and national levels, but today the system is also used in practical forestry in stand-level applications and in forest research. In MELA System growth is predicted by using individual-tree distance-independent growth models. Individual-tree models provide detailed information about stand structure and dynamics, yet the input data those models require are compatible with data available in most forest inventories. Currently, new growth models for MELA System are under development. The aim is to develop growth models that give reliable prediction in managed stands and can be used for evaluation of the effects of silvicultural alternatives. The purpose of this presentation is to discuss the principles that have to be kept in mind in developing growth models for managed stands, especially when the aim is to develop models for a growth simulation system used as a tool in forest management planning and forest policy.

MODEL CHARACTERISTICS

The models that are developed to be directly applicable in forest management planning programs are often called empirical models (Munro, 1974). The name empirical comes from the fact that models are based on periodic tree measurements and make no attempt to measure every factor that may affect tree growth (Bruce, Wensel, 1987). However, many empirical models that estimate tree sizes and stand development, include mathematical functions that are well suited for describing biological processes.

There are many requirements that the models should fulfil, but at the same time there are several restrictions that a modeller has to keep in mind in model development. One of the most important restriction arises from the data available. Information about the existing forest resources is obtained from forest inventories. It forms the basis and the starting point for future forecasts. Information gathered in inventories that usually cover large land areas cannot be very detailed with regard to individual stand and tree data. There are many stand and tree characteristics that certainly would be valuable to measure from the growth modellers' point of view, but measuring all of them would be so time consuming, and therefore so expensive that it is not possible to accomplish. Therefore, modellers must restrict their models to those variables available in forest inventory data (Burkhart, 1993). In selection of the driving variables of the models, we have to keep in mind not only what variables are available in modelling data, but also what variables are available in that data models are applied to. It is of little use to develop detailed growth models that include a large number of variables, if those variables are not available in the database that is used as the basis of simulations in practice.

For decision making in forest policy, long term forecasts about the development of forests are needed. For a biometrician, to develop this kind of models is a challenging task. On the other hand, growth and yield models that are compatible with forest inventory data, should be as simple and straightforward as possible, after all, they are based only on few measured stand and tree variables. On the other hand models should be well designed to be reliable and at least logical also in long term forecasts. Therefore, the relationships between variables should be described on the valid biological and ecological basis and the description should preferably reflect biological causality. Only with well-designed models it is possible to produce reasonable predictions even when applied outside the limits of the data models are developed from. Growth models made for direct practical purposes have not very often been too well designed; they might give unbiassed and logical prediction in the limits of the modelling data, but outside these limits the model behavior is no more logical.

Illogical model behavior can be prevented by paying more attention to the model structure and design in addition to the emphasis put on the good statistical fit. As one example of sound model structure is a model assumption according to which growth is stratified into potential and modifier effects. This kind of structure is present in many empirical growth models that are applied in simulators used for forest management planning purposes (Ek, Monserud, 1974; Leary, 1979; Arney, 1985; Burkhart et al., 1987). In these models, potential tree diameter growth refers usually to the growth of open grown tree, modelled as a function of site quality and phase of development. In height growth models, it is often assumed that increments of dominant trees refer to the potential growth (Arney, 1985; Burkhart et al., 1987). Potential growth is then modified with a function including variables referring to the stand density and the relative tree size. Models in which growth is not stratified in this way become easily complex mathematically and are difficult to evaluate in a biological cause and effect sense (Arney, 1985). However, in practice, problems may arise in modelling potential growth. It may be difficult to find enough qualified data to model open grown tree growth.

EVALUATION OF SILVICULTURAL ALTERNATIVES

Evaluation of the alternative management schedules is an essential part of forest management planning. Therefore, the growth and yield models should be able to predict reliably the effects of various silvicultural treatments on the development of managed stands. We cannot assume that current silvicultural practices would not change in future. The environment is changing, forest policy and forest management are changing, therefore we have to be able to predict the development of forests undergoing silvicultural treatments that today may seem to be extreme and are not applied in practice currently.

The silvicultural practices that are usually included in the growth models are thinning and fertilization. In most of the growth models, the growth response to thinning is included implicitly through the variables referring to stand density (Burkhart et al., 1987; Ojansuu et al., 1991), but there are also models in which thinning response is explicitly included by incorporating variables referring to the thinning intensity and the time of thinning (Jonsson, 1974; Hägglund, 1981; Shafii et al., 1990). In modelling the growth response to fertilization, research efforts so far have mainly concentrated on developing stand-level models for fertilized stands (Kukkola, Saramäki, 1983; Ballard, 1984; Bailey et al., 1989). Individual-tree models for predicting fertilizer response were developed by Shafii et al. (1990) and Hynynen (1993).

In the model of Hynynen (1993), tree growth is assumed to be stratified into reference growth and modifier function referring to the effects of fertilization. Model for reference growth predicts the level of tree growth if trees were not fertilized at all, including the relevant factors affecting growth except fertilization. The effect of fertilization is described by a growth modifier function. It predicts the relative growth response after fertilization. Response function predicts the magnitude and the temporal distribution of growth response. Duration and temporal distribution of the fertilization effect are predicted using Weibull probability density function. To include the magnitude of the response, Weibull function is multiplied by an equation referring to the effects of fertilizer dose, type of fertilizer and site quality. The possibility to predict the individual-tree growth response to thinning in Scots pine stands by using a similar model structure is currently under research.

MODELLING DATA

What kind of data would be ideal for developing models for forest management planning? First, the data should be a representative sample of the forests in the region to which models will be applied. Forest inventory data fulfil this requirement. Second, modelling data should include wide variation of silvicultural treatments (spacing, thinning, fertilization, genetic improvement, etc.), like in many purpose-designed experiments. Third, the data should include repeated observations during the long-term time period, like in the oldest permanent experimental plots. Obviously, there is no single database that would fulfil all the requirements mentioned above. Thus, compromises must be made in selecting the modelling data.

If both inventory data and purpose-designed experimental data are available, both of them are needed in model development. If we could assume that treatment of our commercial forests will not change in the future, it would be enough to use the data collected from commercial forests that include all the treatments applied in practical forestry. In this case, forest inventory data would serve well growth and yield modellers. But when the aim is to predict reliably the effects of extreme silvicultural treatments as well, we can no more rely on forest inventory data only, because the extreme treatments usually do not exist in that data. Being so, the only source of information are purpose-designed permanent experiments for growth and yield research.

There are some well-known disadvantages of using arranged experiments as modelling data (Hägglund, 1981). Permanent plots in the experimental stands are subjectively chosen, and their silvicultural treatments are on the higher level and better controlled than in commercial forests on the average. Therefore, they certainly are not representative samples of commercial forests. The growth models based on this kind of data will very likely overpredict growth and yield when applied to commercial forests. But, by using designed experiments, we are able to get valuable information about the responses to various silvicultural treatments in the environment where other disturbing variation is being removed. Information from designed experiments helps growth modellers to understand interaction between the factors that affect tree and stand growth, and how these relationships change due to silvicultural treatment. Thus, data from designed experiments is needed for developing the basic structure of the models. After that, the final parameter estimates can be obtained by either refitting the models to the data that is more representative or by calibrating models using representative data.

CONCLUSIONS

In this presentation, few of the relevant factors are discussed that a growth modeller has to keep in mind when developing models for forest management planning purposes. To elaborate growth and yield models for growth simulation programs, includes the development of a large number of models. In addition to growth models, also models for regeneration and mortality need to be developed. Further, models predicting the development of tree crowns, as well as volume equations and models to predict tree quality are needed. Discussion of this presentation has concentrated on the modelling of the development of even-aged and single species stands. Modelling the development of mixed stands and unevenaged stands brings about many other problems to be considered (Mielikäinen, 1994). However, no matter what kind of models we are developing, most of the requirements and restrictions discussed above apply to all of them.

There is no single data base nor modelling approach that can be optimal for all purposes (Burkhart, 1993). Finally, the needs of forest management planning and forest policy determine the requirements for growth and yield models; their complexity and the degree of sophistication. Developing empirical models for forest management and forest policy is often quite a straightforward type of work resulting in models with relatively simple structure with only few driving variables. Yet, the model structure, even if it were simple, should be well designed so that the resulting models are capable to predict the most essential factors that affect the development of stand dynamics. It is up to professional skills of growth modellers how well these demands are fulfilled in the form of reliable growth and yield models.

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RŮSTOVÝ MODEL VYCHOVÁVANÉHO STEJNOVĚKÉHO POROSTU

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V hospodářskoúpravnickém plánování se pro prognózu vývoje lesního fondu používají růstové modely. Informace o existujícím lesním fondu získané při inventarizaci lesů vytvářejí základ budoucích prognóz. Vstupní data růstových modelů musejí být shodná a kompatibilní s údaji dostupnými při této inventarizaci lesů. Pro rozhodovací procesy v lesnické politice jsou nutné dlouhodobé prognózy vývoje lesů. Struktura modelu by měla spočívat na platné biologické a ekologické bázi, takže modely mohou vytvářet racionální predikce růstu, i když se použijí mimo rámec dat, z něhož byly sestaveny.

Základní součástí hospodářskoúpravnického plánování je hodnocení alternativních programů hospodaření. Růstové modely by tedy měly spolehlivě předpovídat vlivy různých pěstebních opatření na vývoj obhospodařovaných porostů. Popisují se metody, jejichž pomocí lze předpovídat růstovou reakci na probírky a hnojení.

Pro sestavení modelů jsou nutná data získaná při inventarizaci lesů i v účelových pokusech. Navrhované pokusy poskytují informace o vlivech různých pěstebních opatření na růst a produkci, které jsou důležité pro vypracování struktury modelu. Údaje o inventarizaci poskytují reprezentativní vzorek lesů a proto jsou potřebné pro úpravu konečných modelů.

lesní hospodářské plánování; lesnická politika; dlouhodobé lesní hospodářství; pěstování lesů; probírky; hnojení; Finsko

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MODELLING TREE-RING CLIMATIC RELATIONSHIPS

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Methodically, there are two approaches to simulate the annual ring structure and process of stem radial growth which also determine two different types of models – empiric and mechanistic. Empiric model is based on the correlations of the parameters of radial growth with organ characteristics (tree-ring width, cell number of tree-ring in the radial line, wood density) and the environmental characteristics (monthly climatic values) without any requirement to understand the system response at its structural level. Empiric model is based on statistical processing of the empirically determined relationships between the time series of tree-ring parameters and monthly climatic characteristics. Multiple linear regression and the correlation which was successfully used for modelling the relation of tree-ring parameters are used for statistical processing. The presented empiric model is a synthesis of the changes in the average growth potential with age expressed by the age trend of the tree-ring growth, and annual variations of the actual values round this trend. The second type of model approach consists in the understanding of the behaviour of the system from the knowledge of the response at the level of structural components. The model is described mathematically and the expected causal relations come into the equations of state depicting the system behaviour. The mechanistic model employs daily values of the climatic data as limiting and modelling factors influencing the radial growth of tree species, and this type of model is tested by a comparison of the estimated values with the recorded ones.

radial growth; quantitative analysis of growth; empiric model; mechanistic model; dendroecology

INTRODUCTION

The environmental factors which model to modify the physiological and growth processes in trees are permanently deposited in structure of the biomass being produced and, by the building of their growth rings, trees literally monitor the environmental status (Fritts, 1976; Schweingruber, 1983). Accordingly, the structure of tree rings provides for detection of captured climatic variations (Fritts, 1976; Hughes et al., 1982; Brubaker, Cook, 1983; Briffa et al., 1990), changes in ecological conditions within the forest stand (Fritts, Swetnam, 1989), geomorphological changes in the environment including earthquakes (Jacoby et al., 1988) and eruptive activities (LaMarche, Hirschboeck, 1984; Yamaguchi, 1986; Scuderi 1990), potential effect of increased CO_2 concentration in the atmosphere (Kienast, Luxmoore, 1988) and a lot of other effects causing annual and seasonal variations in the parameters of growth. This variability in the structure of tree rings that quantify the radial growth of stems has been studied by experts in the fields of dendrochronology, dendroclimatology and dendroecology for a long time (Fritts, 1976; Schweingruber, 1983). The data thus obtained are analyzed using up-to-date statistical techniques (Cook, Kairiukstis, 1990) and utilized for reconstruction of the climate in the last years (Fritts et al., 1990; Brubaker, Cook, 1983; Graumlich, 1991), and for assessment of the tree-ring structure response to fluctuations in the climate (Fritts et al., 1991).

SIMULATION OF THE GROWTH PARAMETERS

Anatomic parameters serve us as an aid for characterizing in more detail the growth processes taking place during the growing season and for denoting the factors that are responsible for determining the rate of growth in various parts of growing season (Vaganov, 1990). The potential growth rate is limited by environmental factors and at the time when any of them becomes deficient the rate is reduced due to extension of the cell division cycle. The result is decreased potential total production of cells during the period observed.

The current growth models at the level of tree and stand, such as JABOWA (Botkin et al., 1972), SPRUCE (Bossel, 1986), FICHTENWALD (Lenz, Schall, 1989), TREEDYN (Bossel et al., 1989), SPRUCOM (Krieger et al., 1990), TREEGROW (Schäfer et al., 1992) cannot simulate factual growth of a tree – shape and structure – for the reason that they do not start from growth and activity of meristematic tissues and do not deal with the number and structure of produced cells that represent the basic element controlling the mechanical and conductive function of tree stems.

The models mentioned above do not allow to exploit the plenty of data available on the environment status and the physiological conditions of growth as contained in the structure of produced wood (Fritts et al., 1993). Most of the models operate with long time intervals and generalize the algorithms based on cumulative characteristics, such as the sums of temperature and indices of drought. These long-term values are utilised as the primary limiting factors of growth (Schäfer et al., 1992). However, the growth analyses have furnished enough evidence many times that the growth processes become affected by fluctuations in climatic regimes in diurnal, maximum in month intervals (Cook, Kairiukstis 1990). That is why appreciable pains have recently been taken to develop such models that are able to simulate the tree-ring structure in relation to the limiting factors of environment – PRECON (Fritts, 1990; Fritts et al., 1991, 1992) and TRACH (Shashkin et al., in print).

Methodically, it is possible to approach the simulation of tree-ring structure and the process of radial growth of stem from two aspects, these determining also two different types of modelling – empiric and mechanistic (Thornley, 1976). The former, empiric model is based on correlation dependence of the radial growth parameters at the organ level (tree-ring width, wood density) and the characteristics of environment (such as the climatic values per month) without the necessity of understanding the system's response at its structural level. The latter, mechanistic model makes use, as a basis, of our understanding the system's behaviour as concluded from the knowledge of response at the level of structural components. The model relationships are described mathematically and expected causal dependence appears in the equations describing behaviour of the system. This mechanistic model is based on diurnal values of climatic data as the limiting and modelling factors affecting the radial growth in woody species. This type of model is tested using a comparison of estimated values with values obtained by measurement.

THE EMPIRIC MODEL

Empiric models use, as a basis, statistical assessments of empirically concluded dependences between the time series of tree-ring parameters and climatic characteristics per month. A statistical assessment is essentially a multiple linear regression and correlation which was utilised successfully for the modelling of tree-ring parameters and monthly climatic characteristics (average monthly temperatures and sum of precipitation per month) (Fritts, 1976; Fritts, Xiangding, 1986):

$$\hat{y}_i = \sum_{k=0}^{K} x_{i,k}\,\beta_k + a + \varepsilon_i \qquad (1)$$

where: $\hat{y}_i$ – stands for estimation of the tree-ring parameter value,
x_i – designates the statistical variable representing the climatic characteristics per month in the year i,
β_k – stands for the coefficient of regression,
a – a constant,
ε_i – a residuum after estimation of the regression (Hughes et al., 1982; Cook et al., 1987).

The multiple regression models enable to retest a large amount of variables and then select among them the ones that participate most distinctly in the variation of values of the dependent variable. There are a few preconditions, namely stationarity and homogeneity of the time series, which are attained by removing the age trend. The separation of long term trends in series of annual tree-ring widths is a key issue. Growth trend is generated by various causes which can be summarized as follows (Cook, 1985):

$$R_t = A_t + C_t + D_t + E_t \qquad (2)$$

where: R_t – the observed tree-ring width,
A_t – represents the growth trend associated with increased age,
C_t – climatic signals,
D_t – the tree disturbance signals (pollution or CO_2 effects),
E_t – stands for random signal unique for each tree.

Accordingly, standardization is performed by means of the growth functions determined for the typologically defined site conditions. Hugershoff's growth function (Warren, 1980) corresponds to every vegetation zone and ecological series under similar silvicultural treatment with constant coefficient that characterize the age trend in given site conditions (Horáček, 1994):

$$y_{(t)} = a\,.\,t^b\,.\,e^{-ct} \qquad (3)$$

where: $y_{(t)}$ – the tree-ring width value at the age t,
a, b, c – coefficients of function describing trophic state of the site and the ontogenetic drift,
t – denotes the age of tree.

Value of the annual radial growth represents both qualitative and quantitative indication of the state of development in the course of the growth period and during this particular period is exposed to regulation by the limiting environmental factors. Our aim is seen in expression of the annual increment as a function of physiological variables that quantify effects of growth and development.

Of the functions applied to the growth analysis the one described by Gompertz (Thornley, 1976) was chosen as the most suitable for characterization of the annual radial growth dynamics:

$$W = W_0\,.\,e^{\frac{\mu}{S}(1-e^{-S.t})} \qquad (4)$$

where: W_0 – the initial value of growth at time $t = 0$,
μ – the average relative rate of growth (RGR),
S – the average rate of aging (senescence).

Behaviour of equation (4) then depends on the values of parameters μ (RGR) and S (senescence). For the growing season as a whole, at the termination of which the state variable W – growth approximates its asymptote W_k, the final value of growth is given in the equation:

$$W_k = W_o \cdot e^{\frac{\bar{\mu}}{\bar{S}}} \quad (5)$$

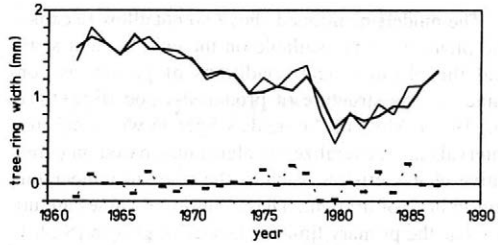
where: W_o – stands for the initial value of growth in time $t = 0$,
$\bar{\mu}$ – stands for the average relative rate of growth,
$\bar{S}$ – the average rate of aging.

The average relative rate of growth and the average rate of aging (senescence) are the only two variables that have to be statistically estimated using the multiple regression models for the purpose provided that the initial value of growth in time $t = 0$ is held for constant equalling to one. The primary aim of estimates is seen in the determination of decisive climatic factors that influence the growth dynamics. The values of tree-ring widths, the summarized radial growth in individual years, are then given (1) by a „fixed" course of the growth potential corresponding to permanent potential capacity of the ecotope as expressed by the age-trend and (2) by oscillation of concrete annual values that represents the annually changing environmental conditions, those of climate above all, on the site.

Other parameters than the ones currently applied – average relative growth rate (μ) and average rate of senescence (S) – were used in the empiric model suggested here for characterisation of radial growth at the organ level during the growing season. According to this model approach the ratio of this physiological parameters, μ and S, then describes average dynamics of the growth process the consequence of which is the resultant value of annual radial growth – the tree-ring width. Influencing these descriptive characteristics of radial growth by environmental factors corresponds more to factual mechanism of the environmental effect exerted on wood formation than is the case when only a statistical assessment of resultant structure is involved.

This empirical model assumes independent influencing of μ and S using climatic factors. RGR stands for a function primarily of the temperatures at onset of the growing season (April – May), summer temperatures exert the modifying effect (July – August) of the year immediately preceding. Senescence of the growth acts against μ and in the course of time it gradually comes into the fore. The effect of senescence is in direct proportion to μ and furthermore, it is exposed to the stressing effects of environmental factors. The rate of senescence is affected by summer precipitation. The well-known finding follows from suggested dependence of either physiological parameter, μ and S, on temperature and precipitation: the variables that reveal stressing action, i. e. the factors in minimum, are decisive for the growth process.

Verification and application of the model built on one study plot were performed on the other one. Simulated were tree-ring widths from the sixties to eighties, their behaviour with age did not permit any satisfactory explanation by means of dendroclimatologic analysis. Our interest centred about the question if the distinct deviations in measured values of tree-ring widths in those years can be attributed to behaviour of changed climatic factors or to a synergic effect exerted by some



1. Comparison of measured and estimated annual values of radial growth in the Bílý Kříž locality (Moravian-Silesian Beskids, Czech Republic) over 1960–1988 (thin line – measured, thick line – calculated, dashed line with marks – residua)

other stressing factors of environment. A comparison of the behaviour of measured and estimated tree-ring width of Norway spruce on the study plot together with illustration of residual deviations is presented in Fig. 1.

The behaviour of climatic variations offers explanation for the variability of tree-ring widths with respect to expected age trend at a level of 78%. Using the model estimate for radial growth in the years of observation it is possible to confirm the assumption that radial growth distinctly responds to climatic variations and the sudden decrease in the values of tree-ring widths which occurred in the seventies and eighties, can be explained as due to the effects of climatic variations.

THE MECHANISTIC MODEL

When formulating the model action of the critical factors of environment on radial growth as a basis we use the model for the limiting action of factors. The extensive literature given over to the effect of climate exerted on cambial activity has failed furnishing invariable results. In general, the authors have arrived at the agreement that in the case in which such complexity is represented by the process of cambial activity, any environmental factors may become limiting. Under certain conditions it may be a shortage of water, while under other conditions it may be a low temperature or insufficient illumination (low intensity of light or short photoperiod). Provided that none of these external factors has got the stressing character, cambial activity is controlled by internal correlations and the trophic regime of the source – sink type.

Of the potential ecological factors, the average diurnal temperature of air in the stand at a level of 2 m above ground (T) and the supplies of soil water (moisture) within the physiological soil layer of 0 to 40 cm (W) were assessed. The photoperiodic length of the day (L), the regime of illumination, means a constant of information for us, which is an indispensable factor for application of the effects of temperature and water supplies. The effect of the environmental factors on the structural changes in the tree rings was assessed in time, so it was possible to determine the potential delay of the impact of these factors. The model of limiting effect of factors has the following form (Fritts et al., 1991; Horáček, 1994):

$$G_t = G_t(L) \min\{G_t(T_{t-T_d}), G_t(W_{t-T_d})\} \quad (6)$$

$$t \in I$$

where: G_t – stands for the resultant impact on growth,
$G_t(L)$ – stands for response to light,
$G_t(T_{t-T_d})$ – stands for response to temperature with a time delay,
$G_t(W_{t-T_d})$ – the response to soil water supplies with a time delay,
t – diurnal measurements from interval I representing the growth period.

The limiting effects of either low temperature or of a shortage of soil water supplies, on assumption of sufficiently long day, can be expressed using equation with the binary coefficient a, the value of which equalling one or zero is determined by minimum value of the growth response to one of the factors (Horáček, 1994):

$$G_t = a \cdot G_t(T_{t-T_d}) + (1-a) \cdot G_t(W_{t-T_d}) \quad (7)$$

$$G_t \Leftrightarrow (L) \geq 12\ hrs$$

$$a = 0 \Leftrightarrow G_t(T_{t-T_d}) \leq G_t(W_{t-T_d})$$

$$a = 1 \Leftrightarrow G_t(T_{t-T_d}) \leq G_t(W_{t-T_d})$$

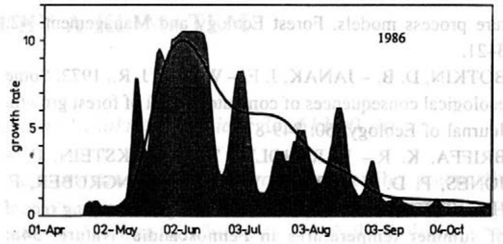
where: G_t – stands for the resultant impact on growth,
$G_t(T_{t-T_d})$ – stands for response to temperature with a time constant delay,
$G_t(W_{t-T_d})$ – the response to soil water supplies with a time constant delay,
t – diurnal measurements,
T_d – stands for time delay of growth response,
a – binary coefficient.

Concrete dependence of the growth rate on temperature and water supplies in soil is expressed, in model form, by the equations that are based on assumed non-linear dependence of growth and the structural response to selected factors of environment.

A comparison of calculated values for the rate of radial growth of Norway spruce (according to equation 7) with the measured ones at study plot in one of observed years is illustrated in Fig. 2. The model was calibrated over several years and it renders quite exactly the dynamics of radial growth in Norway spruce in all of the years observed.

The placing of the onset of mitotic cambial activity of spruce on the turn point of April – May is coherent with the rise of average diurnal temperatures of air above the critical value of 5 °C on the assumption of sufficient soil water supplies (above the point of decreased availability). Gradual rising of temperature is accompanied by gradually increasing the rate of radial growth.

A decrease in the radial growth rate is caused by an immediate response to reduction of the soil water supplies at the physiological depth. Water deficit (stress due to drought) assuming that duration of its effect



2. Comparison of calculated values of radial growth rate of Norway spruce as obtained via mechanistic model, with the values measured in 1986 in the Rájec locality (area – model behaviour, line – measured behaviour)

does not last too long, leads to retardation of the rate of radial growth to minimum level. Completion of the soil water supplies may restore activity of the radial growth and the original one-peak curve may alter to a two-peak curve (false-ring). This case can be simulated using a model, but in fact this type of radial growth has not been observed in the locality relatively well supplied with water.

Culmination of radial growth occurs at the time when both chosen environmental factors reveal the least stressing pressure. When the radial growth attains its culmination it comes to the effects exerted by both these factors and the prevailing effect is achieved by the most stressing factor.

The model behaviour of the rate of radial growth can furnish explanation for about 75% variability in measured values, which indicates satisfactory probability and accuracy for simulation of the given phenomenon.

CONCLUSION

Empiric and mechanistic models represent the initial effort to clarify the effects of the external environmental factors on the mechanism of wood production. The models are a simplified approach in comparison with much more complex and complicated models of all growth processes at the level of the tree. In spite of this fact we believe on the basis of the results from our procedures that the presented models involve basic processes influencing the tree-ring structure. The model approach is derived from the present knowledge of the mechanisms of the control of growth processes by the environmental conditions and of the general procedures used in the growth analysis and dendrochronology.

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MODELOVÁNÍ VZTAHŮ MEZI LETOKRUHY A KLIMATEM

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Z metodického hlediska je k simulování struktury letokruhu a procesu radiálního růstu kmene přistupováno ze dvou přístupů, které určují i dva rozdílné typy modelů – empirického a mechanistického.

Empirický model je založen na korelačních závislostech parametrů radiálního růstu na orgánové úrovni (šířka letokruhu, počet buněk letokruhu v radiální linii, hustota dřeva) a charakteristik prostředí (např. měsíčních klimatických hodnot) bez požadavku na pochopení odezvy systému na jeho strukturální úrovni. Empirický model vychází ze statistického hodnocení empiricky odvozených závislostí mezi časovými řadami letokruhových parametrů a měsíčních klimatických charakteristik. Podstatou statistického hodnocení je vícenásobná lineární regrese a korelace, která byla s úspěchem použita při modelování vztahu letokruhových parametrů. Předkládaný empirický model představuje syntézu změn průměrného růstového potenciálu v závislosti na věku, který je vyjádřen jako věkový trend ročního radiálního růstu, a ročního kolísání konkrétních hodnot kolem tohoto trendu.

Druhý typ modelového přístupu je založen na pochopení chování systému na základě znalosti odezvy na úrovni strukturálních komponent. Model je vyjádřen matematicky a předpokládané kauzální závislosti se objevují ve stavových rovnicích popisujících chování systému. Mechanistický model vychází z denních hodnot klimatických dat jako limitujících a modelujících faktorů, které ovlivňují radiální růst dřevin. Tento typ modelu je testován srovnáním odhadnutých hodnot s hodnotami měřenými.

radiální růst; kvantitativní analýza růstu; empirický model; mechanistický model; dendroekologie

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Evans, S. P. – Del Re, A. A. M. – Trevisan, M. et al.: The effect of pesticides on forest species (Účinek pesticidů na lesní dřeviny)

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Cílem práce bylo osvětlit možné spojení mezi účinky a ošetřeními pesticidy. Jsou uvedeny výsledky pokusu, který je prováděn jako součást dlouhodobého programu hodnotícího hypotézu, že pesticidy mohou přispět ke změnám obrazu růstu lesních dřevin, necílových organismů ošetření pesticidy. Pesticidy byly aplikovány postřikem. Ošetřovaly se sazenice pětiletého buku a tříletého habru. Ošetření se realizovalo dvakrát měsíčně. Výsledky se týkají transpirace, fotosyntézy, stomatální vodivosti, hladiny chlorofylů. V pokusu se habr i buk pěstoval ve studeném tunelu. Sazenice byly ošetřovány po celý růstový cyklus směsí herbicidů a insekticidů. Aktivní složky ve směsi byly z herbicidů Alachlor, Atrazin, Dichlobenil, 2,4 D, MCPA a Trifluralin. Použité insekticidy: Carbaryl, Diazinon, Parathion a Phorate. Nejnižší dávka se rovnala průměrným koncentracím zaznamenaným po každém dešti ve dvou italských lesích. Fyziologické parametry zaznamenaly zvýšení hodnot transpirace a stomatální vodivosti u habru se stoupajícími dávkami pesticidu. Hladiny chlorofylu u buku byly významně rozdílné od kontroly. – *M. P a g a č*

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Palynologický výzkum v minulosti často pomíjel skutečnost, že se pyl v určitých klimatických podmínkách přepravuje i na velké vzdálenosti. Zde se uvádí několik nedávno ověřených příkladů: jde jmenovitě o hnědý sníh z ledna 1987, o červený déšť z října 1987, o přepravu pylových zrn břízy v r. 1989, o žlutý sníh v březnu 1991 a o červený sníh z dubna 1992. Jak výzkum ve Skandinávii ukazuje, ukládá se značné množství pylu daleko od místa svého původu. Množství exotického pylu je ve vzorcích sněhu vysoké, obvykle v rozsahu 500 až 2 000 pylových zrn na cm^2. Je vyslovena hypotéza, že ukládání exotických pylů bylo běžné po celou dobu holocénu. To vedlo k mylným interpretacím pylových diagramů z této doby. V popsaných fenoménech byl počet afrických/středozemních pylových zrn ve Skandinávii vyšší než pylových zrn severských/středoevropských. Prach a většina pylových zrn se může za určitých okolností dopravovat na vzdálenost 7 000 km. – *M. P a g a č*

MODELS OF VOLUME, QUALITY AND VALUE PRODUCTION OF TREE SPECIES IN THE SLOVAK REPUBLIC

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In this structure the given models represent the system of original production models for the main species in Slovakia. They represent „continuous mathematical models" of domestic growth tables for 13 commercially important species.

growth table; growth model; production; forest management; Slovakia

INTRODUCTION

The growth and production models are the most important foundation in forestry for finding and assessment of forest stand production. The models usually give forest state on the basis of stand quality and age, but they give especially the development of basic production variables. The production variables can be expressed by quantitative, qualitative as well as by monetary units. Based on that expression the following models can be created. They are as follows:
- of volume,
- quality,
- value production.

In this structure the given models represent the system of original production models for the main tree species in Slovakia.

CHARACTERIZATION OF THE SYSTEM OF PRODUCTION MODELS OF TREE SPECIES

MODELS OF VOLUME PRODUCTION

They represent continuous mathematical models of domestic growth tables for 13 commercially important tree species. The mathematical models of growth tables were first constructed for five principal tree species, namely spruce, fir, pine, oak and beech from the empiric material according to Halaj et al. (1987). Not only data on the development of mean and hectare variables for coppice with standards, main and secondary stands but also data on total production and its increments can be found out from these models. The growing stock and total production of stands are given here even in five volume units. The basic model relation of variables in stand can be expressed in the following form:

$$Mv = f(t, q, zú) \tag{1}$$

where: Mv – model variable,
t, q – stand age, absolute height stand quality,
$zú$ – growing stock level which is the rate of specific gravity and production capacity of full stocking.

The growth tables can be used as the general ones with the average growing stock level for the whole Slovakia or as the local or site ones according to the growing stock of a concrete region, locality and site.

Production models for other tree species such as Douglas fir, hornbeam, alder, coppice oak, poplar, locust and birch were calculated from the original growth tables compiled by various authors, also by foreign ones. For Douglas fir, the growth tables according to Bergel (1969) and Schober (1975) were used, for hornbeam, alder, coppice oak and poplar according to Korsuň (1966, 1956, 1969 and 1967). For locust the Hungarian growth tables according to Fekete (1960) were taken over and for birch the Russian ones according to Tjurin (1931) were adopted. Especially the data for coppice with standards as well as for the system of absolute height stand quality were derived from the original data at their adjustment. All the other values were preserved in an original state. The aim of their adjustment consisted only in smoothing the table data by suitable mathematical functions and in the subsequent insertion into a continuous mathematical model in a logical way according to the following form:

$$Mv = f(t, q) \tag{2}$$

where: Mv – model variable,
t, q – stand age, absolute height stand quality.

Similarly, according to form (2) Petráš, Halaj (1993) calculated the production models for European larch. A combined method was used when the mean variables were taken over from Schober (1975) and the hectare variables which express stand density were derived from the empiric material of research plots in the territory of Slovakia.

MODELS OF QUALITY PRODUCTION

They are modification and extension of the models of volume production and similarly like them they express the development of production quality. Namely it is the question of the volume of raw timber assortments in dependence on stand quality and stand age according to the relation:

$$Vs = f(t, q) \quad (3)$$

where: Vs – volume of assortments in m^3 or in per cent of growing stock,
t, q – stand age and quality.

The models according to relation (3) are also known under the name „assortment growth tables" and they were elaborated by Petráš, Halaj (1990) and Petráš et al. (1992) for eight commercially important forest trees, namely spruce, fir, pine, larch, oak, beech, hornbeam and birch. These models were constructed from the mathematical models of volume production, the models of stand assortment tables (Petráš, Nociar, 1991) as well as from the models of the development of stems quality and damage in stands.

The models of quality production of stands give the percentile quotients of basic quality and diameter classes of logs (assortments) in dependence on stand age and quality. The quotients of these assortments are derived for main and secondary stands and total production as well. The analysis of these quotients results in the finding that the combination of three factors, namely tree species, stand quality and stand age, has a decisive importance for assortments, commercially the most important and best quality. Their influence is transferred through the diameter structure of trees in stands, their quality and stem damage.

MODELS OF VALUE PRODUCTION

In case that the models of quality production of tree species show the development of quality of stand timber production in the quotient of basic assortments, then the models of value production give not only the development of gross and net financial returns as well as the costs of logging operations in main and secondary stands but also the development of total production. These models are also known under the name „value growth tables" and their basic model relations can be expressed in the form:

$$V_h = f(t, q, zú) \quad (4)$$

where: V_h – value of production in monetary units,
$t, q, zú$ – stand age, stand quality and level of growing stock.

Similarly like the models of quality production, the models of value production were also elaborated by Petráš, Halaj (1990) and Petráš et al. (1992) for the following tree species: spruce, fir, pine, larch, oak, beech, hornbeam and birch. The models of volume and quality production according to relations (1) to (3), actual prices of raw timber and the costs of all the logging operations inclusive of tree harvesting up to timber hauling to the consumers represent the basic data for their construction.

Based on the description of constructional data it is evident that gross and net value returns from wood production will be not only the result of natural, i. e. of volume and quality tree species production but also to a large extent the result of raw timber prices, it means its price relations and prime costs of all the logging operations. The stability and validity of derived results are also important at assessment of value production. Considering that the prices of raw timber and prime costs of logging operations are liable to certain changes in market economy, it is therefore necessary to update the values of net returns all the time. The models of value production of tree species represent, according to form (4), a purposeful insertion of partial mathematical model functions into a continuous global model and for that reason the updating of value production to the changed wood prices and the costs of logging operations is very simple.

Conclusions can be drawn on the basis of the analysis of calculated results that net returns according to the models of value production depend especially on tree species, stand age and quality. In the matter of tree species, spruce, fir and larch reach the highest financial returns. They are overtaken only by oak approximately at the age over 100 years. Pine with beech reach approximately half returns and birch and especially hornbeam reach the lowest net returns, often negative.

SUMMARY

The paper informs on the system of production models of tree species in Slovakia. It is formed by:
- models of volume production for 13,
- models of quality production for 8,
- models of value production for 8 principal, commercially, important tree species.

All three types of models are based on the basic input variables which are as follows: absolute height yield class, age and growing stock level of particular tree species. The models of volume production were constructed for five principal tree species from the domestic empiric material and for the other tree species they were adapted and adjusted to the same form according to growth tables compiled by various authors. The models of quality and value production were constructed from the models of volume production and the models of domestic stand assortment tables, wood prices as well as from prime costs of logging operations. The construction of production models and their introduction into forestry practice have concluded to a considerable extent 25 years lasting research programme aimed at growth and production of the principal tree species in the Slovak Republic.

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MODELY OBJEMOVEJ, KVALITOVEJ A HODNOTOVEJ PRODUKCIE DREVÍN V SLOVENSKEJ REPUBLIKE

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Práca informuje o sústave produkčných modelov drevín v Slovenskej republike, ktorú tvoria:
- modely objemovej produkcie pre 13,
- modely kvalitovej produkcie pre osem,
- modely hodnotovej produkcie pre osem hlavných hospodársky významných drevín.

Všetky tri druhy modelov sú založené na základných vstupných veličinách akými je absolútna výšková bonita, vek a prípadne i zásobová úroveň dreviny. Modely objemovej produkcie boli skonštruované pre päť hlavných drevín z domáceho empirického materiálu a pre ostatné dreviny sa prispôsobili a upravili na rovnaký tvar podľa rastových tabuliek rôznych autorov. Modely kvalitovej a hodnotovej produkcie sa skonštruovali z modelov objemovej produkcie a modelov domácich porastových sortimentačných tabuliek, cien dreva a vlastných nákladov ťažbovej činnosti. Konštrukciou týchto produkčných modelov a ich zavedením do lesníckej praxe sa v podstatnej časti ukončil rozsiahly 25-ročný výskumný program o raste a produkcii hlavných drevín v Slovenskej republike.

rastové tabuľky; rastový model; produkcia; lesné hospodárstvo; Slovensko

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A GLOBAL GROWTH MODEL FOR EUCALYPT PLANTATIONS IN PORTUGAL

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***Eucalyptus* spp, originally from Australia, was introduced in Portugal for ornamental purposes 150 years ago. Its economic potential was soon recognized and eucalypt plantations cover nowadays ca. 500,000 ha (17% of the total forested area). A decision support system concerning most of the decisions involved in eucalypt plantation management is being developed through a cooperative research project between universities and industry. One of the main components of such a system is a growth model that: 1. is applicable to the whole country, but giving locally adapted predictions; 2. is able to predict responses to improved silvicultural practices; 3. is able to predict responses to non-controllable variables, namely soil and climatic variables. The results of the efforts made to achieve the first objective of such a global model are described in the paper. Some information is also given from the ongoing research into increasing the model capacities to predict responses to environment and silvicultural techniques. Data from first rotation permanent plots established in the central coastal region, characterized by high productivities and low mortality were the basis for a whole stand model, the GLOBUS model, which was later reparametrised for the central interior. Another model, the EUSOP model, including a mortality component, financial analysis and applicable also to the second rotation was independently developed with continuous forest inventory data from the south and central interior of Portugal. The *GLOBAL* (growth model for *Eucalyptus GLOBulus* in PortugAL) model we are looking for must systematize all the information available.**

***Eucalyptus* sp.; growth model; global model; silviculture; soil and climatic variables; Portugal**

INTRODUCTION

Eucalyptus globulus is a fast growing species that grows exceptionally well in Mediterranean countries. In central Portugal production at 10 years of age ranges from more than 30 $m^3.ha^{-1}.year^{-1}$ near the coast to less than 2 $m^3.ha^{-1}.year^{-1}$ on the worst sites in the interior and it can be as high as 43 $m^3.ha^{-1}.year^{-1}$ at 5 years of age under optimal conditions of irrigation and fertilization (Tomé, 1994); the dominant height can increase up to 4 meters in one year. It is used mainly by the pulp industry, being managed in a single stem rotation followed by 2 or 3 coppice stands, with average rotation cycles of 10 years. Although the species has been used in Portugal in managed stands for more than 40 years, the efforts to make a reliable growth model began only very recently. The need for such a model emerged as the great expansion of the pulp industry in the last few years made the availability of eucalypt wood for industry increasingly crucial. Some individual modelling efforts were made generating predictions of future wood availability that are not always compatible with one another, which is by no means convenient. This problem gave impetus to an ongoing cooperative research project between universities and industry focused on developing a global model that systematizes all the information available. The final objective of the project is to use this global model in a decision support system covering most of the decisions involved in eucalypt plantation management. In order to fulfil the needs of a useful decision support system the growth model must: 1. be applicable to the whole country, but giving locally adapted predictions; 2. be able to predict responses to improved silvicultural practices; 3. be able to predict responses to non-controllable variables, namely soil and climatic variables. This paper describes the first results of the above mentioned project, beginning with the description of the two most representative growth models available, the GLOBUS and EUSOP models, followed by the methodology that is being used to build the GLOBAL model. One of the main problems when trying to model eucalypt growth is a consequence of its very high growth rates that are heavily weather dependent. For instance, a dry year can cause a decrease in growth that no existing model can predict; if the weather runs favorably during one year, alternating dry and hot periods with wet and rainy periods, the growth will be exceptionally high and the mortality very low, in a way almost unpredictable without taking into account these weather factors. Eucalypt is also very sensitive to soil characteristics, namely to microenvironmental variation as can be seen for instance in the productivities of four contiguous plots of 1,000 m^2 each on a gentle slope near Óbidos, Portugal: at 16 years of age the estimated volume ranged between 123 m^3 on the slope and 527 m^3 in the valley (unpublished data). This is the reason for the need to add the influence of non-controllable variables, namely weather and soil factors, to the GLOBAL model. Of course the simulation of the response to silvicultural practices will be essential for a decision support system.

PREVIOUS GROWTH MODEL EFFORTS

A survey of all whole stand growth models available for eucalypt plantations in Portugal was considered the starting point. Although some whole stand models of the yield table type could be found (T o m é, 1983), the

I. Structure of the GLOBUS and EUSOP models

Submodel	Parameters
GLOBUS model Dominant height growth: $Hdom_2 = A\left(\frac{Hdom_1}{A}\right)^{\frac{t_1^n}{t_2^n}}$	A = 140.38822 n = 0.3469 (Ez = 1) = 0.2545 (EZ = 2)
Stand basal area growth: $Bha_2 = (A_0 + A_1\,Hdom_1)^{1-\left(\frac{t_1}{t_2}\right)^n}\ Bha_1^{\left(\frac{t_1}{t_2}\right)^n}$	A0 = 43.5499 A1 = 1.35663 n = 0.6490
Stand volume prediction $Vha = \beta_0\,Bha^{\beta_1}\,Hdom^{\beta_2}$	β0 = 0.3636 β1 = 0.9171 β2 = 1.1025
EUSOP model Dominant height growth: $Hdom_2 = A\left(\frac{Hdom_1}{A}\right)^{\frac{t_1^n}{t_2^n}}$	A_1 = 36.9292 n_1 = 0.6210 A_2 = 67.7900 n_2 = 0.2201
Stand basal area: $Bha_2 = \frac{M}{1-\left(1-\frac{M}{Bha_1}\right)\left(\frac{t_1}{t_2}\right)^a}$	M_1 = 42.8372 a_1 = 1.0922 M_2 = 33.6088 a_2 = 1.0284
Stand volume prediction $Vha = \beta_0\,Bha^{\beta_1}\,Hdom^{\beta_2}$	$\beta0_1$ = 0.7331 $\beta1_1$ = 1.0263 $\beta2_1$ = 0.7682 $\beta0_1$ = 0.8053 $\beta1_1$ = 1.0294 $\beta2_1$ = 0.7324

where: *Ez* – the ecological zone (1 – central coastal; 2 – central inland), *t* – age, *Hdom* – dominat height, *Bha* – stand basal area per hectare, *Vha* – volume per hectare

GLOBUS and EUSOP models were the two most recent modelling efforts, based on up-to-date methodology, and an analysis of their structure and of the methodologies used was thought to be important for the definition of the methodologies to be used in the future model.

THE GLOBUS MODEL

Data used

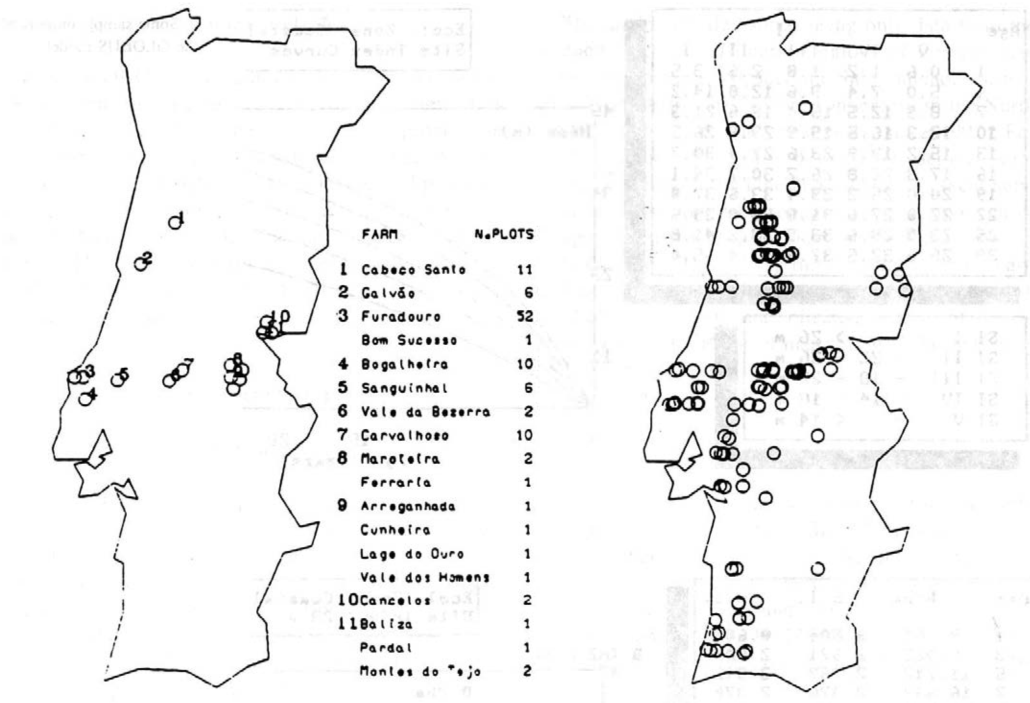
Data used to build the model came from CELBI's pulpwood enterprise permanent plots established since 1970 in 1st rotation eucalypt plantations and mainly located in the central coastal region of Portugal (Fig. 1A). These plots have been annually remeasured several times, with some exceptions of longer periods. On each permanent plot diameter at breast height (dbh) has been measured for all trees, and the heights in sample trees. Heights have also been measured for dominant height determination in the largest dbh trees, at the ratio of one per 100 m^2. Data available for the study included 77 permanent plots and 37 plots from two spacing experiments, generating 748 growth periods. An independent data set, gathered by ACEL (an association of Portuguese pulp companies), was used for model validation. The 126 plots of the validation data set began to be established in 1989 with the objective of complementing the data already available in order to cover different ecological zones (Fig. 1B), different site preparation methods, different rotations and a significant sampling of young ages (not always present in the existing data). The plots had been measured two or, in some cases, three times generating 157 growth periods.

Model structure

GLOBUS (growth model for *Eucalyptus* GLOBUluS) is a stand level growth model that brings together several previously published submodels (Tab. I). It has been available since 1992 but no manual or other publication describes its structure, which is summarized in Tab. I. As can be seen it is quite a simple model but, as shown by the results of validation with an independent data set, it gives reasonably good predictions. Its main drawback is the assumption that there is no mortality, which is true for most of the sites in central Portugal close to the coast (except for the occurrence of some natural disasters) but that can not be observed inland or on the poorer sites. The simulation of yields for different initial spacings is also poor as it is based only on the information from two spacing experiments near the coast.

Submodels selection and fitting

The growth functions used as submodels were selected from a broad range of candidate functions using



1. Location of the permanent plots used to fit (A) and to validate (B) the GLOBUS model

a multicriteria decision-making approach (Carvalho, Tomé, in preparation). Both empirical growth functions and the so-called biologically based growth functions, such as the Freese, Hossfeld, Korsuň, Lundqvist-Korf, Richards and Chanter functions (described, for instance in Tomé, 1988; Carvalho, 1992), were tested. The method is based on the fitting of several candidate growth models to each one of the growth series (plots) available with the simultaneous computation of several measures not only of fit but also of prediction ability and of their performance from a biological standpoint. Non-linear regression techniques were used to fit the candidate functions during the selection procedure. The two best ranked growth functions were then fitted to a subset of the whole data set as difference equations; several formulations were tested for each growth function. Selection of the final model was made on the basis of the criteria already mentioned for the growth functions selection and also of the results of validation done with the subset not used in the fitting procedure. The parameters presented in Tab. I were estimated with the whole data set. The allometric function to predict total stand volume was selected using a simplification of the methodology described above.

II. GLOBUS model: characterization of the model error

	Dominant height (m)	Stand basal area ($m^2.ha^{-1}$)	Stand volume ($m^3.ha^{-1}$)
Minimum	3.3	0.23	0.3
Mean	13.75	11.2	70.64
Maximum	28.2	28.03	257.21
	whole validation data set		
Mrp	0.22	0.03	−0.92
Marp	1.17	1.02	9.27
	excluding stands younger than 2 years		
Mrp	0.46	0.16	0.25
Marp	1.02	0.96	9.8

where: Mrp – the mean of the prediction residuals. The maximum, mean, and minimum refer to the end of the growth period

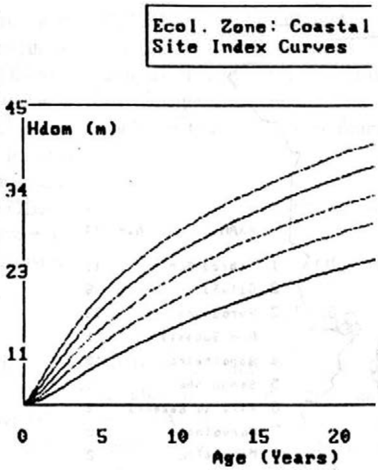
Model validation

The version in use of the GLOBUS model was validated according to the principals described in Soares, Tomé (1993) or Soares et al. (accepted for publication). The adequate biological behavior of the model was tested simultaneously by the model building through successive simulations using different values for the input variables. The adequate biological behavior of the model can be seen in Fig. 2. Some statistics useful in characterizing the model error are shown in Tab. II. More detailed results of the validation of the model can be obtained from the authors.

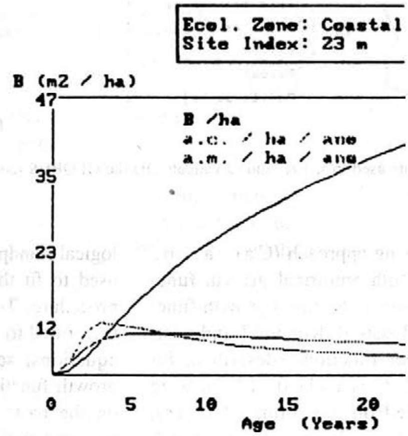
2. Some sample outputs of the GLOBUS model

Age	SI V	SI IV	SI III	SI II	SI I
1	0.6	1.2	1.8	2.6	3.5
4	5.0	7.4	9.6	12.0	14.2
7	8.9	12.5	15.4	18.6	21.3
10	12.3	16.5	19.9	23.5	26.5
13	15.2	19.9	23.6	27.4	30.7
16	17.8	22.8	26.7	30.7	34.1
19	20.0	25.3	29.4	33.6	37.0
22	22.0	27.6	31.8	36.0	39.5
25	23.9	29.6	33.9	38.2	41.8
30	26.6	32.5	37.0	41.4	45.0

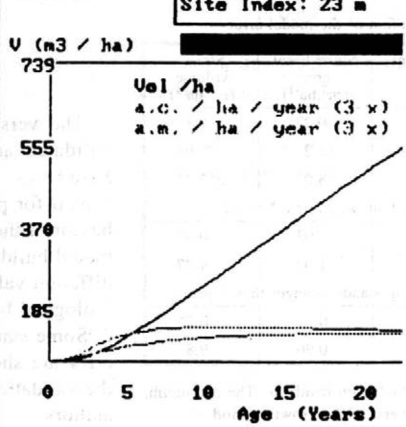
SI I - > 26 m
SI II - 22 - 26 m
SI III - 18 - 22 m
SI IV - 14 - 18 m
SI V - < 14 m



Age	B/ha	c.i.	m.i.
1	0.604	0.604	0.604
3	6.023	2.971	2.008
5	11.712	2.757	2.342
7	16.649	2.376	2.378
9	20.919	2.061	2.324
11	24.580	1.775	2.235
13	27.844	1.588	2.142
15	30.791	1.438	2.053
17	33.478	1.314	1.969
19	35.949	1.211	1.892
21	38.237	1.123	1.821
23	40.367	1.047	1.755
25	42.360	0.981	1.694
27	44.234	0.923	1.638
29	46.002	0.872	1.586



Age	V/ha	c.i.	m.i.
1	0.634	0.634	0.634
3	21.284	14.062	7.095
5	64.048	23.221	12.810
7	116.934	27.236	16.705
9	174.064	28.877	19.340
11	232.317	29.029	21.120
13	290.303	28.948	22.331
15	347.664	28.573	23.178
17	404.027	28.042	23.766
19	459.200	27.430	24.168
21	513.088	26.781	24.433
23	565.660	26.121	24.594
25	616.918	25.465	24.677
27	666.883	24.823	24.699
29	715.592	24.200	24.676



Software available

The GLOBUS model can be used as an interactive PC version, running under DOS, or implemented as a FORTRAN77 subroutine in a computer program to make forecasts based on forest inventory data. The PC version works through successive menus and produces graphical outputs for each stand variable (dominant height, basal area or total volumes). It also produces yield tables and allows for the comparison of growth in different ecological zones. Some examples of these outputs can be seen in Fig. 2.

THE EUSOP MODEL

Data used

PORTUCEL is the major pulp company in Portugal, and the lands that are directly managed by the company are spread throughout the whole country focusing 7 major zones, as shown in Fig. 3. The company began developing a growth model in 1993 when there was enough data collected from the company's continuous forest inventory. The inventory has been conducted since 1989 with the same methodology. Plots are randomly selected in aerial photographs, and then installed in the field. The sampling intensity is about 1 plot per 15 ha. Plot area is 400 m^2. The dbh is measured on all the trees inside the plot. Height is measured for every fifth tree in each diameter class and also for the 4 largest trees in the plot for dominant height estimation. Only stands more than 4 years old are subject to inventory.

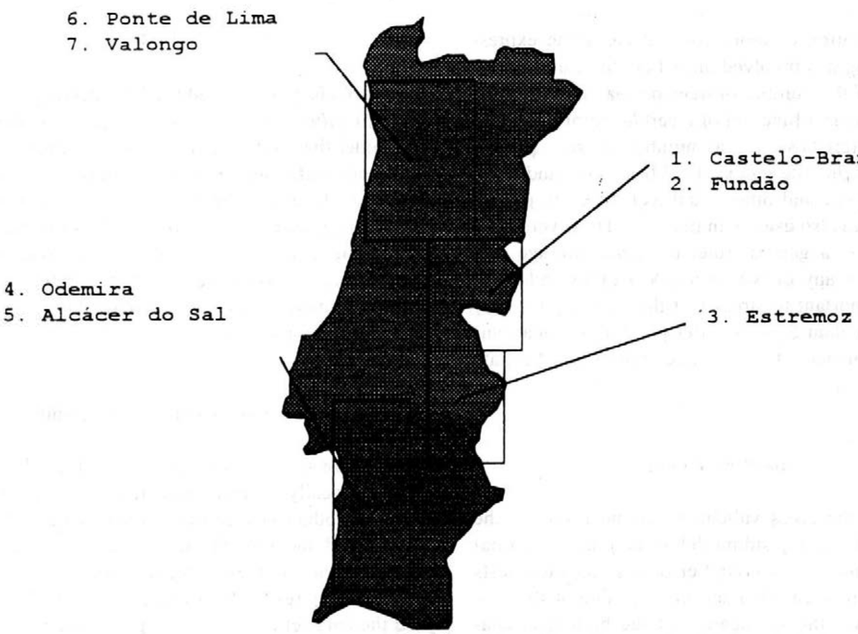
The model was developed using only data from the southern and central interior regions of Portugal (regions of Odemira, Alcácer do Sal, Fundão, Castelo Branco and Estremoz) as forest inventory in the North had been running for only two years (since 1991). For all the regions 981 and 1 438 growth periods were available for the 1st and the 2nd rotations, respectively. Data was first sorted by rotation and then by each of 5 regions and stored in magnetic support accordingly. Data from each region was further split for cross validation purposes (one third of the data for validation). As there is no other data collected in most of the regions covered by Portucel data this was the only way to do the validation.

Model structure

EUSOP is also a stand level model that was recently developed by Portucel. As in GLOBUS, basal area and dominant height submodels are the main components of the model, parametrised both for the 1st and the 2nd rotations, the volume being predicted through an allometric model (Tab. I). Mortality is simulated by a constant mortality rate set by the user or equal to 2% by default.

Submodels selection and fitting

Some preliminary tests were made before the model was developed, trying to understand the fitting ability of several equations in relation to the inventory data



3. Location of the stands where continuous forest inventory data were taken

and, most important of all, to get some sensibility to the modelling of the second rotation data that had never been modelled. A set of candidate functions was selected from this preliminary study including the functions already used with success during the development of GLOBUS, all of them biologically based growth functions, and also the McDill, Amateis (1992) model. The selected candidate functions were then tested to model both basal area and dominant height growth using a similar procedure for the 1st and the 2nd rotations. In a first step, the functions were fitted individually to each of the regions and the model that exhibited the best overall fit was selected. The ranking of the models was based on several criteria: 1. convergence in all cases: a good model must converge when individually fitted to each zone, a property that was very difficult to obtain for most of the models used; 2. adequacy of the parameter estimates: a model was discarded if the estimate obtained for one of the parameters was illogical from a biological standpoint; 3. good statistical properties such as a good R^2 and fairly low MSE and PRESS residuals; 4. results of the cross validation. Some problems related to the modelling of the 2nd rotation stands are discussed later on when discussing the model validation. The best model was then fitted to the whole data set and no statistical advantage was found in fitting separate models to each region, so a common model applicable to the 5 regions present in the data set was chosen.

Several functions were tested for stand volume prediction and to maintain the model as compatible as possible with GLOBUS, and also because the differences both in fitting and prediction ability between the models tested were very small, the allometric model was chosen.

The simulation of mortality that has some expression in the regions involved turned out to be a problem. Prediction of the number of trees per ha, mortality and mortality rate as a function of a certain combination of stand characteristics such as number of trees per ha, dominant height, site index, stand basal area and stand age is very poor and other usual techniques to predict mortality were also useless in that case. However it was found that, as a general rule, mortality average was about 2%, for any of the rotations, regions and stand age. It is important to stress that this rate applies only to ages older than 5 years (after planting or clear-cut) as a consequence of the characteristics of the data available.

Model validation

Although the cross validation has been one of the criteria used during submodel selection, no formal characterization of the model error nor statistical tests with an independent data set are available at the moment. However the verification of the biological characteristics of the model was as complete as possible. No problems were found for the model developed for the 1st rotation. However it was impossible to obtain biologically adequate estimates for the parameters in the dominant height submodel selected for the 2nd rotation stands. For instance, the values obtained for the parameters are not logical, namely the asymptotes seem too low and are attained at a very old age. The behavior of this model for the first ages (from 1 to 4 years) is also highly improbable, predicting in some cases 12 m of growth for the first year after the cut. It is a severe handicap for the model, but as there are no studies concerning the behavior or modelling of the 2nd rotation eucalypt stands and the results of the cross validation were very reasonable, we had no better choice, although it is important to be aware of the limitations of the model.

Software available

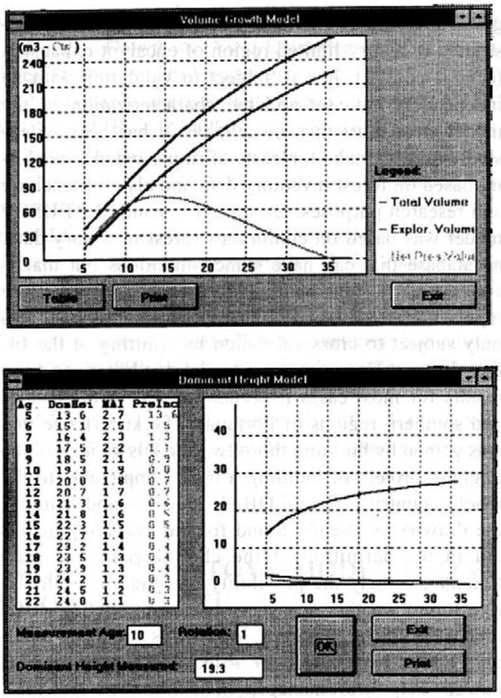
To make the model useful for practical purposes an interactive computer program was written. The program was written in Visual Basic 3.0 for Windows, taking advantage of its intuitive controls and easy programming. The program is very easy to use even for a person with very little experience in computers. To respond to the real needs of the company a financial analysis, taking into account conservation costs, timber price and interest rate, has also been added to the program. For management purposes the program is being used to determine the optimal cutting age according to the maximization of the net present value. Fig. 4 shows some sample outputs taken from the program.

THE GLOBAL MODEL

As previously mentioned the GLOBAL (growth model for *Eucalyptus GLOBulus* in PortugAL) model will be a model that systematizes all the information available, both data and growth modelling efforts, in a model applicable to the whole country and that simulates the response of eucalypt growth to different annual weather conditions as well as to different silvicultural practices. Several steps that are being taken into account to obtain the GLOBAL model are described in the next paragraphs.

Definition of spatial modelling units

One of the objectives of the GLOBAL growth model is to give locally adapted predictions. The relationship between productivity profiles (characterized both by the shape of the growth curves and the productivity range) and environmental factors has been studied in some previous research. Tomé (in publication) analyzed the data set used to develop GLOBUS and found evidence of the influence of climatic variables on eu-



4. Some sample outputs of the EUSOP model

calypt plantations productivity indicating that, among the climatic variables used, the number of days with rain and the number of days with frost are the most important for determining productivity level and that there is no clear association between the environmental variables tested and the shape of the growth curves. In that case it is important to classify the area of eucalypt expansion in Portugal as a set of homogeneous regions according to the environmental factors controlling eucalypt plantation productivity, namely climatic and soil factors. The basis for this classification will be the Portuguese thematic mapping (CNA, 1971, 1974, 1979, 1982, 1984, 1987 and Daveau, 1985). One of the methodologies that will be used has already been tested by Amaro et al. (in preparation) to classify the plantations owned by SOPORCEL, one of the Portuguese pulp and paper companies. In this study two administrative units („concelho" and „freguesia") were tested as the scale unit for data acquisition and only the administrative divisions with SOPORCEL plantations were classified. Principal component and cluster analyses were used in a broad set of climatic and soil factors in order to find out which of these potential productivity inductive variables are responsible, and to what extent, for the different productivity profiles. The results of the principal component analysis show the 1st PC related to water and sun availability and the 2nd PC related to frost occurrence. The results of the cluster analysis were discussed in an expert panel meeting with the objective of selecting the best basic framework, leading to a consistent mapping with a minimum set of units misclassified in respect to eucalypt productivity and the reclassification of the 14% misclassified administrative units was made. In the ongoing project the objective is the classification of all the Portuguese territory leading, if possible, to the definition and mapping of a set of regions with a similar productivity profile and that can be characterized by indicators of climatic and soil factors.

Systematization of the data: the GFD database

The second step is to look for and systematize all data available on eucalypt growth, not only from permanent plots and experiments but also from continuous forest inventory. At the moment a survey as complete as possible has just finished and data is being organized on magnetic support in a common structure, the GFD (Global Forest Database). This database includes a set of interrelated files that can be created and updated by a set of computer programs that: 1. perform the validation of new measurement data sets (that can be created by editing or through another interactive computer program); 2. proceed to the updating of the database; 3. produce several outputs (complete or thematic); 4. prepare working files for model building. The programs are written in Visual Basic 3.0 for Windows.

Model building

The GLOBAL model that is the basis of the ongoing project will be built using all data available and taking advantage of the knowledge obtained with the previous modelling efforts already described. The first analysis of the data base must be made in order to find an adequate subset for validation purposes. Data in the remaining subset will be split according to the rotation and to the spatial modelling units defined as described. Individual models, by rotation, will be fitted for each unit using a methodology similar to that used to develop the GLOBUS and EUSOP models. Appropriate statistical analysis will be used to find out if there is any advantage of keeping so many separate models; the growth functions will then be refitted to the appropriate combined data set. At the final stage of model building a simultaneous fitting of all the growth functions involved in each individual model will be made in order to improve the properties of the parameter estimates. A validation as complete as possible will then be undertaken using the methodologies described in Soares, Tomé (1993) and Soares et al. (accepted for publication). Finally the set of models obtained will be used to obtain both interactive and batch computer programs for practical purposes.

Simulation of non-controllable variables

As mentioned before the weather is one of the most important factors controlling annual variation in eucalypt growth and it must be taken into account in the GLOBAL model. In order to model eucalypt growth response to annual weather variations two different approaches are being used. The first is based on the gathering (when possible) of climatic data for the already available growth data (permanent plots) while the second is based on the simultaneous gathering of climatic and growth data in specially chosen permanent plots or in newly established permanent plots. The selection of plots to be used for this last methodology was based on the results of the definition of spatial modelling units with SOPORCEL plantations. In each of the 7 homogeneous regions that were defined (A m a r o et al., in preparation) 3 plots of different age classes and that were thought to be representative of the mean productivity for the region were selected and weather and growth data are beginning to be gathered at 2–month intervals. At the moment there is not enough data available to evaluate its adequacy to model eucalypt growth responses to weather.

Simulation of silvicultural practices

Eucalypt is known to be very sensitive to silvicultural practices. For instance T o m é (1994) describes the influence of site management, namely site preparation (including fertilization at planting), spacing, irrigation and fertilization, verified through analysis of data both from the permanent plots used to build the GLOBUS model and from experiments purposely established to study eucalypt productivity under different silvicultural treatments. Great differences can be found, showing that it is essential that the GLOBAL models allow for the simulation of their effects. The GFD database aims to bring together all data available for eucalypt growth, including data from experiments which will be used to simulate the effect of silvicultural practices in eucalypt growth. Several projects are being developed with the main objective of studying the growth response of eucalyptus to environmental stresses and different silvicultural treatments, such as spacing, fertilizer application, control of pests and diseases, site preparation and weed control. Some data is already available, some experiments are still running and some new experiments are being established. The simulation of the effect of silvicultural practices will be made in a dynamic way, using at each moment all the information available, and correcting the model every time new important information is made available.

FINAL REMARKS

The two most important efforts to model eucalyptus growth were described. GLOBUS was based on a very good database (long term permanent plots) but restricted to a very limited region of eucalypt expansion (central coastal). It was subject to validation with an independent data set and the characterization of the model error must then be reliable. It has been extensively used to make forecasts of future wood availability based on forest inventory data and also for teaching and research purposes. On the other hand, the EUSOP model was based on continuous forest inventory data, a database that can have some limitations but that is considered by some authors (K ö h l at al., 1993) more representative of the forest than permanent plots. It was only subject to cross validation by splitting of the fitting data set. However it is a model that has given good results for most cases in stands located in the central and southern regions of Portugal. The knowledge that was gained by building those two models generated the ongoing project of building a model applicable to the whole country – the GLOBAL model – and some of the drawbacks already found for the available models aid in the definition of the characteristics of such a model, namely the possibility of simulating alternative future weather scenarios and of simulating different silvicultural practices. When this model is available it will be included in a decision support system that can help forest managers in making their decisions.

Acknowledgements

Financial support for this project was given by several research projects, namely: „Estudo para a Criação de um Modelo de Produção a Nível Nacional" PEDIP No 1180, programa 5, medida B4), „Improvement of Eucalypt Management. An integrated approach: breeding, silviculture and economics" (CE AIR 92.1678) and „Contribuição para a modelação matemática dos ecossistemas florestais de produção" (STRIDE AGR0024).

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GLOBÁLNÍ RŮSTOVÝ MODEL PRO EUKALYPTOVÉ VÝSADBY V PORTUGALSKU

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Eucalyptus spp. původem z Austrálie byl do Portugalska přivezen před 150 lety k okrasným účelům. Brzy byl rozpoznán ekonomický potenciál tohoto druhu a v současné době pokrývají eukalyptové plantáže asi 500 000 hektarů (17 % z celkové zalesněné plochy). V rámci společného výzkumného projektu, na kterém se podílejí univerzity a průmysl, se vytváří systém podporující rozhodování, který se týká většiny rozhodnutí při obhospodařování eukalyptových výsadeb. Jednou z hlavních složek takového systému je růstový model, který: 1. lze aplikovat pro celou zemi, ale také poskytuje lokálně upravené předpovědi; 2. může předpovídat reakce na zdokonalenou pěstební praxi; 3. může předpovídat reakce na neregulovatelné veličiny, a to na půdní a klimatické charakteristiky.

V práci se popisují výsledky úsilí, které je vynaloženo na dosažení prvního cíle tohoto globálního modelu. Práce také přináší některé informace ze stále pokračujícího výzkumu jak zvětšit kapacitu modelu při předpovídání reakcí na přírodní prostředí a na pěstební techniku. Údaje získané na trvalých plochách s první obmýtní dobou, které byly založeny v přímořské oblasti ve středním Portugalsku a které lze charakterizovat vysokou produktivitou a nízkou mortalitou, se staly základem modelu celého porostu, modelu GLOBUS, do něhož byly později dosazeny parametry pro vnitrozemí středního Portugalska. Nezávisle na tomto modelu byl vytvořen další model, model EUSOP, který obsahuje prvek mortality a finanční analýzu; lze ho také použít pro druhou obmýtní dobu. Pro něj byly přitom použity údaje z inventarizace lesů ve vnitrozemí jižního a středního Portugalska. Model GLOBAL (model růstu pro *Eucalyptus GLOBulus* v PortugALsku), který se snažíme nalézt, musí systemizovat všechny dostupné informace.

eukalyptus; růstový model; globální model; výchova; půdní a klimatické proměnné; Portugalsko

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ABSTRACTS

FUTURE TRENDS IN GROWTH MODELLING

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Four new methods can be quoted as an example of possible tools that will be available to the forest modeler in the dawn of the new millennium:

1. Fractals and dynamic systems. Some research is now conducted with promising results. Concerning fractals, it is possible that forest stands can be explained better with the use of fractal dimensions and so making more clear the structure of stands. The work of Prof. B. Zeide is pioneer and is one way to explore the „fractal realm". Dynamic systems have a fractal behavior, but that is not the most important feature: Forests, as any other biological systems are dynamic systems, so they should be studied with dynamic equations. Several years ago this was a problem, because there was no sure way to solve nonlinear dynamic equations, but now with such new computers available there should be some efforts in this path to accomplish this.
2. Cellular automata. The work concerning cellular automata applied in forestry in its most incipient form, being used practically only in the modelling of fire. Some work could be now done applying those dynamic methods, trying to predict stand growth and also the evolution of other dendrometric variables.
3. Fuzzy logic and expert systems. The development of fuzzy systems can be a major help in the modelling of forest stands, as they can provide a possible link for equations used in process based models with the reality.
4. Neural networks. There are currently about 80 (?) types of neural networks. As this new method can provide new ways to explore data and make forecasts, it can be a very helpful tool forest growth modelers and also a vast field for research for its possibilities are very far from being reached.

These new tools for growth analysis should not be „compulsory" for the forest scientists of the next decade. They are just an illustration of what next can be done in the field of growth modelling. We should not either expect that, at last, these new methods will enable us to make correct projections, but they will certainly contribute to much better knowledge of forests and at least, they can give us clues for the exploration of new methods that are to come.

A FOREST POLICY MODEL FOR THE NEW ENGLAND REGION, U.S.A

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Forest growth modelling in New England, U.S.A., has traditionally dealt with an integration of existing knowledge to project timber volumes in response to silvicultural treatment. However, current policy issues across the region reach beyond timber values and must include a variety of ecological and environmental concerns. To address the needs of policy makers, traditional tree and stand models must be based on ecological processes to project a broader consideration of resource values. The growth forest model FIBER is being extended to interrelate projections of forest succession, wildlife habitat, biodiversity, deadwood production, and economic returns – all within the context of a GIS system that will facilitate spatial analyses based on land classification. With these added features, FIBER should provide the tools to meet the growing needs of both ecosystems managers and environmental policy analysts.

MAXIMUM DIAMETER GROWTH OF DIFFERENT TREE SPECIES IN FINLAND

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The aim of this work was to study the maximum diameter growth of Norway spruce, Scots pine, silver birch, white birch, aspen and alder. In addition, one aim was to model the maximum growth of different tree species. The data used were sample trees from the 7th and 8th National Forest Inventories of Finland and special growth sample tree data. The sample trees were dominant trees on mineral soil sample plots. Maximum diameter growth in different parts of Finland was determined as the upper quartile of frequency distribution of growth. The country was divided into six growth regions according to maximum growth. These regions were formed by tree species and they followed the zones of effective temperature of Finland. Growth regions were confirmed with the growth sample tree data.

Maximum growth on the southern coast was lower than in the inland. Maximum growth was lowest for all tree species in northern Finland. In southern Finland, the highest maximum growth was found for spruce, 2.79 mm/a, and silver birch, 2.60 mm/a, and in northern Finland, for pine, 1.91 mm/a. Finally, models for maximum growth were calculated.

Jeltsch, F. – Wissel, C.: Modelling dieback phenomena in natural forests (Modelování jevu hynutí v přírodních lesích)

Ecological Modelling, 1994, 75/76, s. 111–121 – 5 obr., lit. 17

Modelování lesních ekosystémů je obtížný úkol, protože zde má svůj význam dlouhodobá dynamika a prostorové aspekty. Základ pro postup řešení bylo zjištění, že hynutí deštných lesů na Havajských ostrovech se nedalo vysvětlit tím, že by se znečištění ovzduší nebo biotické činitele jako choroby nebo škodlivý hmyz daly určit jako primární příčina tohoto jevu. Verbální teorie byla převedena na matematický model. Je uveden typ modelu zvaný dynamický robotový model (dynamical automata model). Pro modelování předčasného stárnutí stromů se rozlišuje mezi fyziologickým věkem a časem. Fyziologický věk je definován jako inverzní míra vitality stromu. O abiotickém aktivujícím faktoru se předpokládá, že má určitý synchronizující účinek na dynamiku. Jsou zkoumány příklady přirozeného hynutí přírodních lesů v různých částech světa. Je to především hynutí druhu *Metrosideros polymorpha* na Havaji, dále hynutí *Chamaecyparis nootkatensis* na Aljašce (pozorované od r. 1880), hynutí *Nothofagus solandri* a jedlí *Abies* v Severní Americe a v Japonsku. Opakující se hynutí stejnorodého lesa jsou na úrovni porostu v uvedených podmínkách přirozeným jevem. Práce je příkladem matematického modelování zejména v oblastech stejnorodých přírodních lesů. – *M. Pagač*

EUROPEAN FOREST INSTITUTE - NEW INSTITUTION IN EUROPE

EFI was established in 1993 in Joensuu, Finland as a non-governmental association. Its purpose is to undertake research on forest policy including its environmental aspects on the ecology, multiple use, resources and health of European forests, and on the supply of and demand for timber and other forest products. It will also prepare forecasts of the future development of European forest resources and their utilisation.

The EFI Director is Birger Solberg from Norway. He has a four-person secretariat and currently five research staff. EFI is managed by a Board of Management (the chairman is Tim Peck previously with FAO) a Scientific Advisory Committee and its Members. The latter can be any legally constituted body which would like to participate in EFI activities with a membership fee of 1,000 ecus/annum. At present there are over 45 members in over 24 European countries. The benefits of membership are receipt of EFI publications contacts through the membership network and voting at the annual Conference of Members. The first Conference was held in Joensuu in September 1994.

EFI aims to fill a niche that complements not competes with those occupied by national research institutions. It has perhaps five comparative advantages. First, EFI will concentrate on internationally-oriented analyses at the European level (not least on countries with economies in transition) and on comparative studies. Secondly, EFI will establish special expertise in forest policy analysis particularly on the policy consequences of changes in the biophysical environment and in socio-economic structures – recognising that many of the changes that affect forestry occur outside the forestry sector. Thirdly, EFI can use its seed money from the Finnish Government and its network of members to respond rapidly and flexibly to put together teams to address issues as they arise. Fourthly, EFI aims to establish databases and meta databases (i. e. information on where data exists) on European forests so that researchers do not have to spend time searching among the numerous national databases. Fifthly, as mentioned EFI is non-governmental and will remain totally independent of political or other external constraints.

EFI Members in Europe

The modus operandi of EFI are to appoint researchers who can work at Joensuu or at their home institutions for some of the time to grant forest scholarships and to hold workshops seminars and training courses. EFI will have no field facilities of its own.

During its first year EFI established five priority areas for its research. These are (I) forest policy analysis, (II) forest sector informations services and research methodology, (III) structural changes in markets for forest products and services, (IV) forestry and possible global climate change and (V) forest sustainability.

EFI informs about its activities through EFI News which is distributed to 3,200 individuals and organisations. Subscription is free of charge. In order to obtain a copy, please send your full address to: European Forest Institute, Torikatu 34, FIN–80100 Joensuu, Finland.

Pokyny pro autory

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