Experiences in the use of forest management planning models

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TIIVISTELMÄ: KOKEMUKSIA MALLIEN KÄYTÖSTÄ METSÄTALOUDEN SUUNNITTELUSSA

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Model-based information systems have proved valuable planning tools for analyzing the production possibilities of forests as well as for understanding forest resource dynamics, stand management practices and forest economics. Computerized forest models implemented in the users' information systems facilitate the transfer and application of research results in practical forestry.

Conclusions and visions concerning modelling are drawn from experiences in developing the MELA system and its application in solving timber production problems on both the national and forest holding level. The precondition for predicting forest resource dynamics and for planning the utilization of forests is to accept conditions, uncertainties and a restricted period of time.

The iterative process of forest resource, growth and drain monitoring, and forest management planning supported by forest research and modelling, are the means to enable an operational information base for a dynamic regulation and adaptation strategy for forest resource management under changing conditions and uncertainty.

Malleihin perustuvien tietojärjestelmien avulla voidaan mm. arvioida metsien käyttömahdollisuuksia ja ymmärtää metsävarojen kehityksen, metsien hoidon sekä metsätalouden perusteita. Varsinaisten tulosten ohella tietojärjestelmät mahdollistavat metsäntutkimuksen mallimuotoisten tulosten hyväksikäytön metsätalouden päätöksien tukena.

Katsauksessa tarkastellaan malleja ja mallitusta metsävarojen käytön suunnittelussa sekä esitetään mallien käyttöä koskevia näkemyksiä sen kokemuksen nojalla, joka on saatu käytettäessä MELA-järjestelmää niin suurilla alueilla kuin myös metsälötasolla. Esimerkkilaskelmat kuvaavat Suomen metsien puuntuotantomahdollisuuksien viimeaikaisia arvioita. Tällaiset arviot samoin kuin metsien kehitysennusteet ovat kuitenkin ehdollisia, epävarmoja ja koskevat metsän koko kehitykseen nähden lyhyttä aikaa.

Koska metsävarojen kehitystä ja tulevia käyttötarpeita ei voida täsmällisesti ennustaa, vasta jatkuva metsävarojen, kasvun ja poistuman seurantaan sekä metsien tutkimuksen perusteella ennakoituun kehitykseen perustuva suunnittelu tuottavat perusteet käyttää metsävaroja tulevaan varautuen ja välttämättömään sopeutuen muuttuvissa ja epävarmoissakin olosuhteissa (eli toteuttaa kestävää metsätaloutta käytännössä).

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Introduction

When considering any given activity, one should be aware of the factors and consequences influencing the decision in question. In forestry, even when deciding the management of an individual forest stand, attention needs to be paid to forest resources, the demand for forest products, the costs of operations, the growth potential of the forest, the goals of forest owners, the exploitation rate of forests, 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 possibilities, decisions and operations taking into account the pertinent factors and their interactions. Planning is needed in order to manage a complex decision situation and to regulate the decision object, e.g. national forest production, in a desired way.

Even if the principal interests in forest management planning have a short time horizon, more far-reaching studies have to be carried out to ascertain the sustainability of forestry and to avoid predictable future surprises. The interest horizon in timber production may be as long as one century, and even longer in some other sectors of forestry. The synthesis in forest management planning and decisions based on it are based on the assumption that the future development of the forests can be predicted with sufficient accuracy. One cannot prepare for future needs without assumptions on future potentials.

When using computational methods, knowledge describing discovered (or supposed) dependencies is utilized in the form of models. Consequently, models are necessary components of forestry planning.

In forest management planning, models have developed from volume tariffs, formulae of allowable cut and yield tables to the present taper curves, computerized models and planning systems. Advances in data processing have also allowed increasingly versatile and detailed analyses of forest production.

The aim of the paper is to review recent methodologies, results and experiences in the use of models for forest management planning of large forest areas and at the national level in Finland.

The MELA system

Outlines of the system

MELA is a forest management planning system designed in the late 1970's for the analysis of long term timber production possibilities at regional and national levels based on the sample plot data of the Finnish National Forest Inventory (Kilkki and Siitonen 1976, Siitonen 1983, Kilkki 1987).

The MELA system is considered a frame for gathering and managing all relevant information for forest management planning from individual trees and forest stands to decisions concerning the whole forestry unit.

The MELA system consists of two principal parts (see Figs. 1 and 2):

(1) the individual tree level simulation of feasible management schedules for forest stands over a desired calculation period (see Table 2) and
(2) the simultaneous selection of the production program for the forestry unit (see Table 1) and the management of the stands (see management schedules in Table 2) based on the user supplied goals at the forestry unit level.

Linear programming has proved a versatile and a computationally feasible method for solving large-scale multilevel decision problems with multiple interactive factors over time, as applied in the MELA system (the original problem formulation, see Kilkki and Siitonen 1976). A dedicated linear programming software (JLP, see Lappi 1992) is currently used. Transformations for on-line compiling of restrictions, and for defining more ambitious decision problems, e.g. goal programming, are available in the JLP repertory. The marginal analysis of the linear programming solution (shadow prices, etc., see Lappi 1992) gives useful information of both the biological and economic aspects of the solution.

The aim of the simulation part of the model is to produce, automatically, a choice of management schedules (i.e. individual yield tables) for each stand in order to predict the future development potentials of the stands. In the selection part, the standwise management schedules in the input matrix of the linear programming model represent the management possibilities of the whole forestry unit. The goal and the restrictions of linear programming problem regulate the iterative search of the production program for the whole forestry unit and the relevant management schedules for the stands (see Fig. 2).

Over the calculation period, there are hundreds of variables available as optional decision criteria in the selection both for the whole forestry unit and for its subsets. The variables describe the state and the development of the forests, as well as forest production and its economy. Table 1 gives a summarized sample of available information. The choice of decision variables makes it possible to solve various planning problems depending on the actual needs of decision makers.

The MELA system as a whole can be regarded as a high level decision model consisting of a compatible family of lower level models describing natural processes, forest production and its economy with the details of individual trees and forest stands.

Simulation of forest dynamics

In the MELA system, the forest resources are described by all the stands or a representative sample, depending on the size of the forestry unit and the available computing capacity. The stands may be grouped into management units. A management unit consists of one stand or a set of stands homogeneous with regard to the present stand characteristics and the expected future management and development.

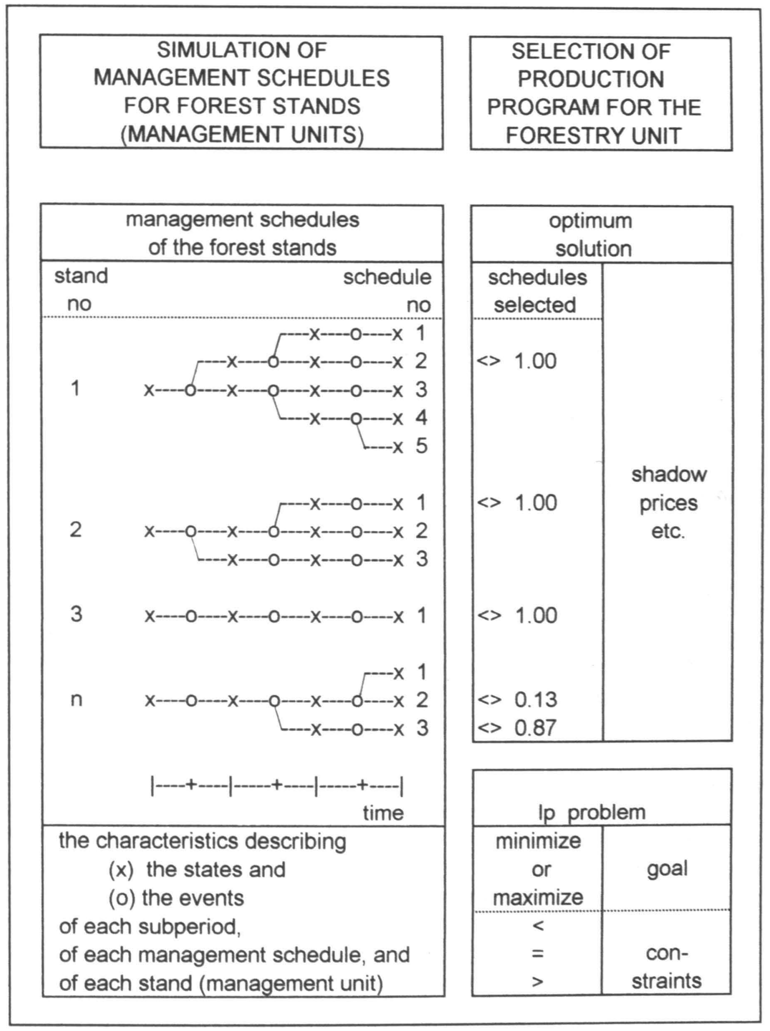

Fig. 1. The principle scheme of the MELA system.

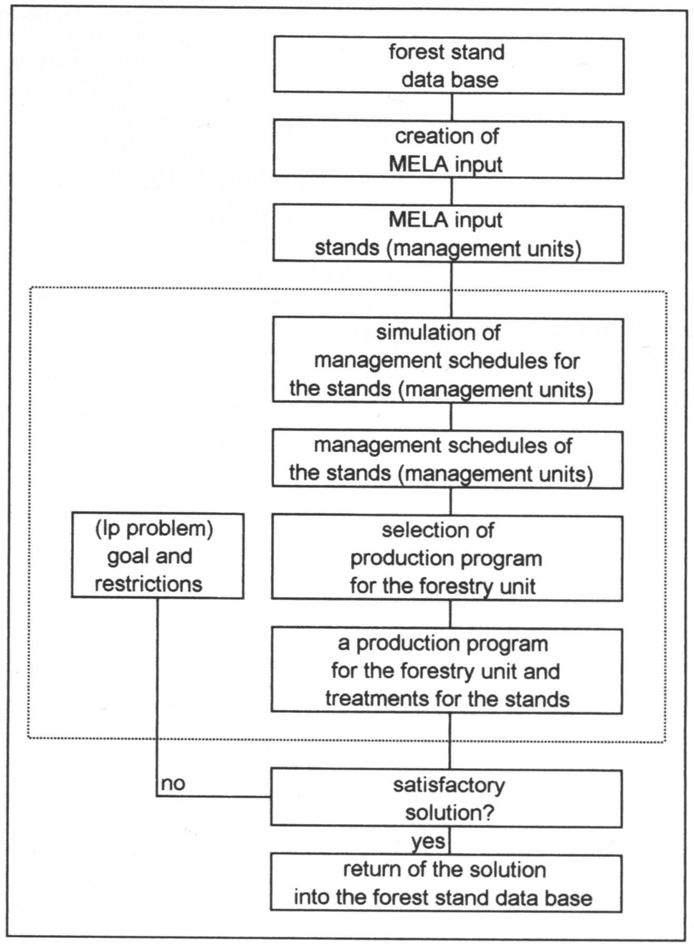

Fig. 2. The MELA system and its iterative use in the search for the production program.

A management unit is described by one or more sample plots, each with a set of sample trees. The number of the sample trees may vary from one to the whole tree population of the management unit. The sample plots represent the variation within the management unit.

The sample plots and the trees have to be furnished with the site and tree variables necessary for further calculations. The main simulation variables for trees in the current simulator version are the number of stems/ha, tree species, diameter, height and age. These simulation variables are transformed into volumes, timber assortments and values etc. using respective general models.

For each management unit, a finite number of feasible management schedules is simulated. The simulation of the management schedules consists of chains of states and events (see Fig. 1 and a numerical example in Table 2). Events are natural processes (e.g. ingrowth, growth and mortality of the trees) or human activities (e.g. cuttings, silvicultural treatments, drainage of peatland and fertilization). Branches of the simulation (see Fig. 1) are due to several alternative human activities.The development of the growing stock is predicted via sample trees on sample plots (see Table 3). A set of detailed models, based on individual trees, describing natural processes, treatments, timber prices, costs, management instructions etc. is employed, e.g. the growth of the trees is predicted by using stem diameter and height increment models. The statistical models are based on the 5-year increment measure-

Table 1. A timber production program for the whole of Finland as a combination of 23 regional MELA solutions. The regional net present value of the future revenues was maximized subject to an even or increasing flow of timber, saw logs and net income over a 50-year period for each region. The data consisted of 8000 management units and 200000 management schedules.

	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	1789	1924	1983	2077	2284	2594
Pine	790	861	986	1208	1477	1743
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	1048	1147	1269	1471	1668
	1990	2000	2010	2020	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	
Pulp wood	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	12744	14393	14501	14757	15338	
Costs, mill. FIM/a	3902	4308	4369	4329	4377	
Net income, mill. FIM/a	8842	10085	10132	10428	10961	

ments of the sample trees in the National Forest Inventory in the 1970's. In the model, the increment of diameter, for example, is a function of species, diameter and height of the tree, basal area of the stand, site type, geographical situation, etc. (Ojansuu et al. 1991). The volume of the stems and timber assortments are obtained from stem curve models as a function of tree species, diameter and height (Laasasenaho 1982). The value of the stems is calculated from timber assortments and unit prices. The total figures of the sample plots, and also of the management units, are obtained as the sums of the trees. The development of the trees is predicted by the characteristics of each tree and its site on the sample plot. The treatments are chosen on the basis of the average characteristics of the management units, but the simulation is carried out for each individual sample plot.

Only expected values of the models are used

Table 2. A sample of management schedules for one management unit. The management activities in this simulation take place in the middle of each 10-year subperiod.

SCHEDULE 1: thinnings in 1992 and 2012; natural regeneration in 2022

year	stems	s	age	diam	ba	volume	value	incr	mor	c	dr	income
1987	1469	1	43	13.4	16.0	89.6	12977	7.6	0.3	1	41	6066
1997	1005	1	46	16.4	18.8	122.4	19705	8.5	0.5	0	0	0
2007	972	1	55	19.7	27.2	203.7	35583	7.5	0.5	1	98	18102
2017	557	1	65	22.7	24.2	176.4	34710	3.8	0.1	5	175	35482
2027	912	1	84	32.5	16.0	38.0	9400	0.6	0.0	4	43	11218
2037	1595	1	11	2.1	0.2	0.5	0					

SCHEDULE 3: thinnings in 1992 and 2012; clear cutting etc. in 2022

year	stems	s	age	diam	ba	volume	value	incr	mor	c	dr	income
1987	1469	1	43	13.4	16.0	89.6	12977	7.6	0.3	1	41	6066
1997	1005	1	46	16.4	18.8	122.4	19705	8.5	0.5	0	0	0
2007	972	1	55	19.7	27.2	203.7	35583	7.5	0.5	1	98	18102
2017	557	1	65	22.7	21.3	176.4	34710	3.2	0.1	2	207	43065
2027	4536	1	2	0.0	0.0	0.0	0	0.3	0.0	0	0	0
2037	2145	1	12	3.5	1.1	2.8	0					

SCHEDULE 40: no treatments

year	stems	s	age	diam	ba	volume	value	incr	mor	c	dr	income
1987	1469	1	43	13.4	16.0	89.6	12977	8.0	0.4	0	0	0
1997	1415	1	52	16.4	25.5	167.2	26166	9.4	1.0	0	0	0
2007	1335	1	61	19.0	34.0	253.4	42258	9.0	1.9	0	0	0
2017	1230	1	71	21.3	40.1	327.2	59734	7.7	2.7	0	0	0
2027	1120	1	82	23.2	43.6	380.2	73106	7.0	3.1	0	0	0
2937	1020	1	93	25.0	46.1	421.2	86607					

Stand characteristics:

stems	stems/ha	value	value, FIM/ha
s	dominant tree species	incr	increment, m^3/ha/a
age	mean age	mor	mortality, m^3/ha/a
diam	mean diameter, cm	c	cutting method
ba	basal area, m^2/ha	dr	total drain, m^3/ha/a
volume	volume, m^3/ha	income	net income, FIM

in the simulation. The stochastic variation in natural processes, e.g. in the growth of the trees, has not been directly taken into account. Nonetheless, the detailed and accurate initial description of the simulation objects and processes, and the avoidance of improper aggregation, diminish possible biases. Finally, attaining reasonable reserves of mature growing stock is the means of adapting to the consequences of prediction errors and future uncertainties in practical timber production.

In the practical application of MELA, sampling or a minimum aggregation of input data, restricted calculation periods, and heuristic decision rules for simulating only a sample of feasible management schedules for each stand, are examples of how to minimize computing.

Using the MELA system for forest management planning

Timber production possibilities in Finland

In addition to the regular determination of regional cutting possibilities based on the Finnish National Forest Inventory (NFI), the large scale applications of MELA include two rounds of analysis of national timber production possibilities since the middle of the 1980s (The Forest

Table 3. Simulation of the natural processes and a thinning cutting on a sample plot.

INITIAL STATE IN 1987

tree	stems	s	age	h	d	ba	volume	logs	value
1	150	1	43	10.2	13.0	0.013	0.071	0.000	10.9
2	150	1	43	10.2	13.0	0.013	0.071	0.000	10.9
3	113	2	63	11.9	15.0	0.018	0.104	0.000	14.9
4	129	1	45	10.6	14.0	0.015	0.085	0.000	13.1
5	397	1	31	8.1	8.0	0.005	0.023	0.000	2.7
6	519	1	28	7.5	7.0	0.004	0.017	0.000	1.5
7	210	1	38	9.5	11.0	0.010	0.048	0.000	7.1
/ha	1672	1	42	9.7	11.6	14.0	72.1	0.0	9984

NATURAL PROCESSES IN 1987–1992

tree	stems	s	age	h	d	ba	volume	logs	value
1	149	1	48	11.5	15.2	0.018	0.108	0.000	16.8
2	149	1	48	11.5	15.2	0.018	0.108	0.000	16.8
3	113	2	68	12.6	16.4	0.021	0.130	0.000	19.0
4	129	1	50	11.8	16.1	0.020	0.123	0.000	19.3
5	387	1	36	9.5	9.9	0.008	0.039	0.000	5.6
6	502	1	33	9.0	8.8	0.006	0.030	0.000	4.0
7	207	1	43	10.8	13.0	0.013	0.075	0.000	11.5
/ha	1638	1	46	10.9	13.3	19.3	109.1	0.0	16180

THINNING FROM BELOW SAVING DOMINANT TREE SPECIES IN 1992

tree	stems	s	age	h	d	ba	volume	logs	value
1	118	1	48	11.5	15.2	0.018	0.108	0.000	16.8
2	118	1	48	11.5	15.2	0.018	0.108	0.000	16.8
4	103	1	50	11.8	16.1	0.020	0.123	0.000	19.3
5	295	1	36	9.5	9.9	0.008	0.039	0.000	5.6
6	380	1	33	9.0	8.8	0.006	0.030	0.000	4.0
7	161	1	43	10.8	13.0	0.013	0.075	0.000	11.5
/ha	1180	1	43	10.7	13.0	13.2	74.0	0.0	11012

Tree characteristics:

stems	stems/ha	ba	basal area, m^2
s	tree species	volume	volume, m^3
h	height, m	logs	saw log volume, m^3
d	diameter, cm	value	value, FIM

2000 Programme (1986), and The Revised Forest 2000 Program (1992)).

A summary of the Finnish forest resource data is given in Fig. 3. The overall rate of the exploitation of the Finnish forests is illustrated by the facts that from 1950 to 1990 the growing stock increased 22 percent even though during the same period the accumulated total drain was higher than the volume of the growing stock in 1990.

The total volume of the growing stock was fairly stable from the early 1920s until the 1970s, varying between 1500 and 1600 million m^3. The effects of intensified forest management and silviculture started to show at the end of the 1960s in the form of greater volume and growth of the growing stock.

The volume estimate of the growing stock was 1880 million m^3 in 1990 and the annual increment estimate was 79 million m^3 for the period 1985–89. These figures come from a computa-

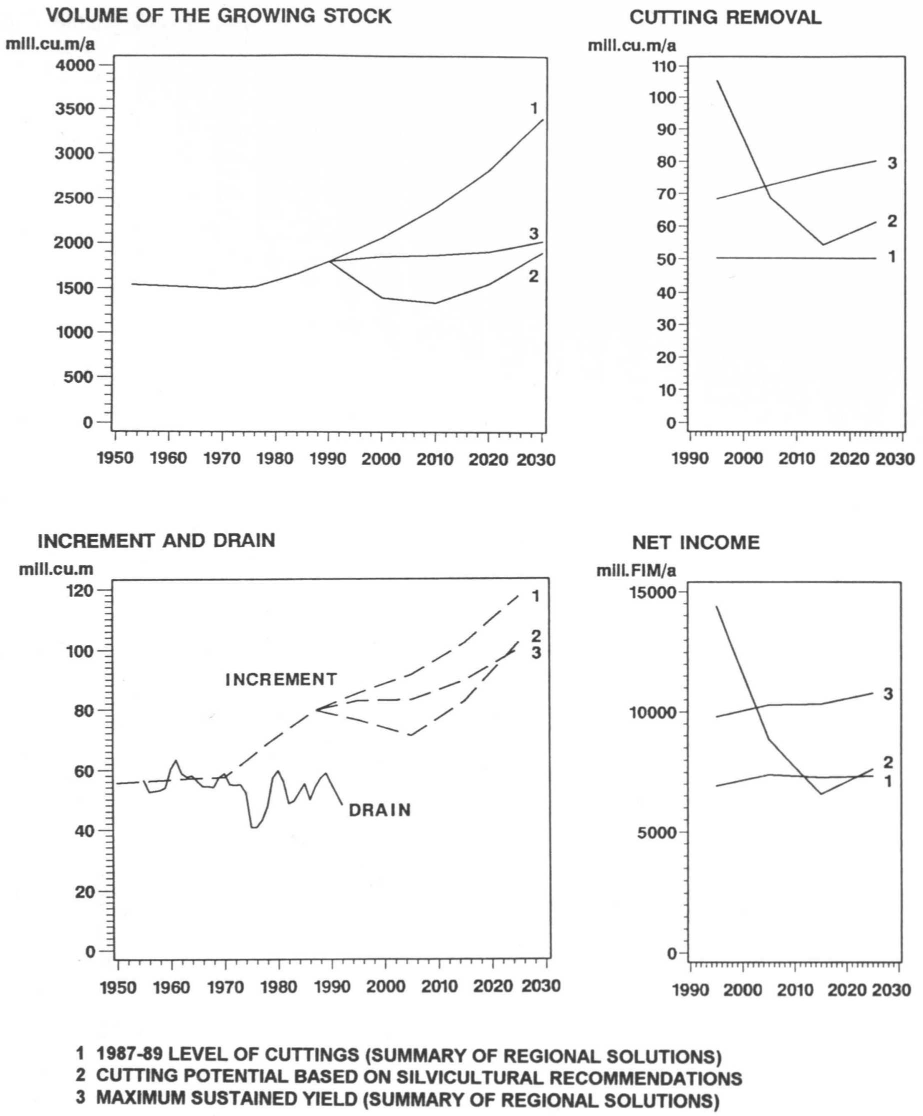

Fig. 3. Comparison of three cutting options and their consequences during the period 1990–2030. The development up to the 1990s is based on the forest statistics, and the future estimates are a sample of recent planning results. In addition to the absolute levels, the figures show the interdependence of cuttings, increment and volume of growing stock with time.

tional updating of the NFI data based on the cutting statistics and the MELA simulation calibrated with the growth measurements of the NFI.

Since the beginning of the 1970s, the annual cuttings have been lower than the annual increment. By and large, the cuttings have stayed constant while the increment has started to increase. During the period of 1985–89 the annual drain (55 million m^3) was two thirds of the average annual increment. In the early 1990s, the difference has markedly increased due to decreased fellings.

The alternative 40-year estimates of cutting possibilities (Fig. 3) are based on the 1990 estimates of the forest resources and on the general assumption that growth factors, response of the trees, natural losses, and silvicultural intensity will stay at their recent average levels.

Starting from the assumption that the annual drain, including fellings and natural losses, will stay at 55 million m^3 (alternative 1) the growing stock will double in 40 to 50 years.

According to the present silvicultural recommendations, more than 100 million m^3 could be cut annually in the 1990s. Consequently, the growing stock and the cutting possibilities would decrease markedly in the next few decades compared with the 1990s (alternative 2).

The third alternative indicates that the annual cutting removal could be increased immediately to 68 and later to 80 million m^3 on a regionally sustainable basis.

The total increment of the growing stock is predicted to increase still further. The trend in the increment is caused by the low cuttings, and by the increase of the growing stock and its favourable structure during the next few decades. The future estimates of the increment and the growing stock are highly dependent on future cuttings, as can be seen in Fig. 3.

Each of the three alternatives indicate the utilization and the development possibilities of the Finnish forest resources based on the information included in the present MELA system and upon hypothetical goals. According to the results, the forest resources as such allow a considerable increase in cuttings (besides other uses of the forests), if the silvicultural intensity of the 1980s is maintained.

Reliability of the predictions

The first increment predictions made with the MELA system in 1984 proved to be underestimated by more than 10 percent compared with the updated results of the NFI data in 1990. Consequently, the estimates of the cutting possibilities and the future growing stock were also lower than the results in 1990. Two obvious reasons are evident. First, without updating of the NFI data, the difference of increment and drain and the consequent rapid increase of the growing stock passed unnoticed. Secondly, the growth models were apparently not calibrated on the intended level in 1984.

Preliminary comparisons of the 1990 updated results with the recent NFI measurements in Southern Finland show a good fit for the volume and a 3 percent overestimate of the increment of growing stock. The calibration of the growth models was based on NFI increment and volume data available in 1990. The limited temporal correspondence of the increment estimates should, however, be taken into account .

The compared results indicate the need for a revision of the current model-set in the MELA system.

Further applications

In 1993, the MELA system is being installed by several organizations of private, company and state forestry to be the stand level forest management planning module of their own forest information systems. In these applications, optimization tasks of tens of thousands individual stands and hundreds of thousands management schedules in total are to be solved on work station computers.

In forest companies, the expected benefits from the MELA system are familiarization with the cutting possibilities and the derivation of the allowable cut of the company-owned forests, as well as the management of individual stands with respect to the company's goals, taking into account the predicted future production potential of the forests, i.e., the simultaneous management of the operative and the strategic aspects.

User feedback in forestry practice calls for still more detailed simulation, e.g. predicting the development of the technical quality of the trees and the use of authentic price and cost information. The model requirements for forest stand applications are probably higher than at the regional level.

For the planning of sustained timber production at the national level, monitoring forest growth and knowledge of the past long-term increment variation of trees and forests are of key importance for estimating the level of growing stock reserves needed under various natural conditions. The pixelwise forest resource data of the multisource forest inventory (Tomppo and Siitonen 1991), and digital terrain models and transportation networks are essential for determining the total costs of timber procurement, as well as for optimizing the local use of forests in national forest policy planning.

Considerations and conclusions

User requirements for forest models and modelling

The success of the planning results and the decisions based upon them are to large extent dependent upon the models used to predict forest dynamics.

The generally accepted description of the planning objects with their characteristics is the cornerstone of forest modelling. The details of individual trees are required in the simulation of the complicated and often noncontinuous forest processes, e.g., to calculate the value of the stems and the timber produced, or the structure and the effects of thinnings. The descriptive units and their characteristics should have measurable equivalents in reality in order to facilitate an understanding and validation of the simulation results.

In addition to giving realistic results, the models should form consistent and balanced members of the information system. The models need to cover the whole range of variation of forest development with respect to time, place, entities, events, and phenomena. The models should be modular and interchangeable. The computational feasibility of the models is of considerable significance in large scale applications. The variables used in the models have to be measurable, or derivable from measurable ones, in the initial state of the simulation. The input variables of the simulaion models also need to be predictable.

The principal goal of professional (user-oriented) modelling is to assemble all decision related knowledge onto a sigle data base, avoiding the fragmentation of earlier efforts. It is the modellers´ task to solve the evident conflict between the requirements of the models and the perpetually insufficient data material. The needs of the model users should guide the aims, the criteria for evaluation and the productivity of professional modelling, in addition to meeting the needs of traditional research work.

Taking all these aspects into account calls for rather more systematic work, coordination and cooperation between modellers and users than that required in pure scientific modelling or just examining interesting phenomena. On the other hand, the needs of and feedback from the users are also likely to promote the advance of modelling sciences.

Predicting forest resource dynamics

Predicting the development of forest resources is complicated by the considerable number and complexity of the relevant factors. Moreover, knowledge concerning the dynamics of these factors and their interactions is imperfect. This is because such knowledge is based on past observations only, and because there is no absolute measure to validate the predictive models in advance. Forest data and models will remain approximate at best. There are also noteworthy differences between the predictability of the natural forest processes and the dynamics of managed forest resources.

Natural forest processes, such as the average growth of the trees, and the effects of human activities on them can be predicted to some extent even with simple statistical models. For large areas, e.g. the whole of Finland, the level of the models can be calibrated with the recent measurements of the National Forest Inventory. Consequently, predictions for the natural forest processes over a period of decades seem justified, on the condition that the external conditions remain stable, i.e. that the level and variation of the main growth factors can in fact be drawn from the past empirical observations. Unexpected events may place constraints on such conditions.

The dynamics of forest resources as a whole, in addition to their deterministic and stochastic components, appears to be an open, adaptive and highly regulable process. From any given step of a stand's development, various possible choices can be made by man, each with their individual consequences (cf. the stand simulation scheme in Fig. 1). This means that within the limits of the structure of the forests, biological and other natural laws, the number of possible futures of the forest resources is infinite. Thus, the development to materialize is regulated by human activities (cf. the timber production alternatives in Fig. 3). Selective information describing these human activities is needed in order to indicate specific future predictions.

A difficulty in forecasting the likely development of forest resources is that human activities are likely to change over time, e.g. as a consequence of changing social and economic circumstances, and as the result of changes in forest ownership during the rotation period of the forests. A precondition for further forecasting is to predict human activities, e.g. cut behaviours and silvicultural intensity (in addition to forecasting the variations in the natural processes).

Another approach to prediction is to map a sample of relevant possibilities by obtaining the selective information from the conditions set by the desired future. In the MELA system, the forestry unit level goals, actual or hypothetical, over time regulate the selection of and the developments in the forest stands, as can be seen in Fig. 1. In this way, the problems of practical production management can be solved; for example, what are the production possibilities? What kind of goals are feasible? And by which means the goals can be achieved? This information may also be useful for deciding which goal and which activities should be chosen.

The planning results (Fig. 3 and Table 1) indicate the operational feasibility of the goal-based future analysis and its relevance with respect to forest resource management at levels ranging from forest stands to the whole nation. However, the analysis and the predictions remain conditional and uncertain, depending on the quality of available information, the unavoidable biases of prediction, future forest owner behaviours, and the stochastic processes of nature.

Predicting the future or deciding national forest policy?

The principal part of removals from Finnish forests derives from forest stands established about one century ago. The growing stock now existing will guarantee the current level of removals for several decades, even with no efforts in regeneration or silviculture. In fact, the regeneration of forests and other forestry costs (and consequently the availability of timber in the future) may be less profitable when accepting such criteria as the net present value of future revenues based on a positive interest rate alone, i.e. paying attention to short term revenues rather than the returns over the whole forest production cycle.

The regeneration of forests and silviculture measures regulate the possibilities to utilize forests after a certain period (rotation). Consequently, explicit long term goals, one rotation period or longer, are the foundation both for maintaining a sufficient forest productivity in the future, and for the proper planning and regulation of current forestry practices given the long production cycle.

In the absense of quantitative considerations of future needs and potentials, forest management may adopt unnecessary and inconvenient practices. Thus unstable solutions may appear in the modelling, even if, for example, the regeneration of forests and silviculture measures are taken as absolute values without considering the future (see alternative 2 in Fig. 3).

Human needs or timber markets cannot be predicted accurately over decades or centuries. Thus, expressing the quantitative long term goals of forestry (or what options on the use of forests the present human generation wishes to maintain for the future), is one of the key decisions of national forest policy, supported by careful analysis of the alternatives and their costs (see Lappi and Siitonen 1985 for interactions of interest rate and sustained timber production). Details such as current cutting potential (and allowable cut), standwise forest management regimes, appropriate level of silviculture and its financing, and adjusting timber production and other forest uses over time can then be derived from the long term goals by means of forest management planning. The same general planning procedure applies to national forestry as to an individual forest holding.

Instead of simply forecasting the future, the iterative process of forest resource, growth and drain monitoring, and forest management planning supported by forest research and modelling, are the means to enable an operational information base for a dynamic regulative and adaptive strategy for forest resource management under changing conditions and uncertainty (i.e. for putting into practice the sustainable or long term aspects of forestry). The task of planning (and of information systems) is to examine both the present and the future possibilities and to estimate the consequences of the actions proposed.

Optimization of stand management

As long as manual calculation methods were used in forest management planning, cutting budgets and stand management regimes could only be prepared separately. Developing an integrated analysis was one of the key tasks to be solved by forest management planning when computers became accessible (see e.g. Kilkki and Siitonen 1976).

Without further considerations, the standwise analysis of forest management, even when based on economic criteria, fails to take into account the actual structure of the forests (except the hypotethical case of the fully regulated forest). Concentrating on one stand at a time, the standwise optimization neglects the synergies from other stands of the forestry unit and all other aspects influencing the forestry decisions concerning other than the one standwise goal being optimized. For example, when maximizing the net present value of standwise future revenues (see alternative 2 in Fig. 3), many kinds of temporal variation is likely to occur in the forestry unit level solution.

The bases of the decisions are also likely to change during the rotation period. Solutions based on static criteria may be far from optimal ones in terms of timber needs, timber markets, or the desired development of the forest resources over time. Stand optima will change when actual conditions are introduced. For these reasons, the optimization of stand management based on standwise criteria alone will give less relevant solutions with respect to forest management in practice. However, the shadow prices obtained from the forestry unit solutions (cf. Kilkki 1987, Lappi 1992) may serve an interesting starting point for further standwise analyses based on broader economic considerations than, for example, just a fixed interest rate.

When applying a repeated multilevel planning procedure for forest resource management, such as the MELA system, there is no urgent need to prepare separate stand management regimes. Dedicated management instructions can always be obtained for each stand from the actual forestry unit plan based on the individual goals of the forest owner. If general "average" stand management regimes are still desired, one of them should apparently come from the forest production goals (or national forest policy) based on the actual regional forest resources.

The role of models in forest management planning

In forest management planning, model-based information systems have it made possible to manage forestry as a whole at the stand and tree levels. Operational planning systems are proving to be valuable tools for analyzing the future production possibilities of forests and to combine various aspects of forestry in order to solve forest management problems in practice, as well as to understand forest resource dynamics, forest economics and stand management practices. In addition to the actual planning results, the computerized models included in the users' information systems also make possible the transfer and operational utilization of research results in forestry practice.

Considerable modelling research challenged by practical problems is required to turn the modelling visions into the systematic production of user-oriented forest models and trustworthy information systems. Due to recent advances in information and computer technology, the expansion of model-based decision support systems in forestry seems inevitable. However, models will remain poor images of reality because of the uncertainties in the underlying predictive information.

In a complex decision system, one bad or missing factor may spoil the whole result. In addition to all the professional skills of the modellers and the expertise of the model users, common sense is also required in order to realize when imaginary results or absurd decisions result from defective analyses or poorly understood models.

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