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Pekka Kilkki and Raimo Pökälä

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PEKKA KILKKI and RAIMO PÖKÄLÄ

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PREFACE

This presentation has resulted from close cooperation between the two authors. PEKKA KILKKI drew up the original plan, and wrote the final manuscript. RAIMO PÖKÄLÄ was in charge of the computer programming, and treatment of the data; he also prepared a Master's thesis, which is incorporated in sections 1, 2, 3, 4, 5, and 6 of this paper.

During the course of the work, we received valuable assistance from a number of persons and institutions. The third member of our working group, Mr MARKKU SIITONEN, prepared a part of the data, and spent a great deal of his time in discussions and perusal of the manuscript. Messrs MATTI KUJALA, HARRI LALLUKKA, and LARS REHNSTRÖM assisted in various phases of the work. Dr KALERVO SALONEN of Kemira made available the data from fertilized plots. Professor KULLERVO KUUSELA, Professor AARNE NYYSSÖNEN, Dr KUSTAA SEPPÄLÄ, Dr RISTO SEPPÄLÄ, and Mr HANNU VALTANEN read the manuscript, and offered helpful comments.

Ms MARJATTA MÄÄTTÄ and Ms LEENA SAARI carried out the necessary typing, and the figures were drawn by Ms SINIKKA HIETALA. The English text was checked by Messrs KARL-JOHAN AHLSVED and FRED FEWSTER.

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Helsinki, October 1974

PEKKA KILKKI RAIMO PÖKÄLÄ

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1. INTRODUCTION

11. Long-term planning in forestry decision-making

Planning is a tool in conducting action to a desired direction (v. Malmborg 1971, p. 11). The task of planning is illustrated in Figure 1. Palo (1971) has divided the forestry ecosystem into a production-consumption system, and a control system. The control system is in turn divided into decision and information systems. The information system collects, processes, and transmits the information needed by the parent system (Jahnukainen 1970, p. 40). By several iterations of the feedback loop ($Fa_1 - Fa_2 - Fb - Fa_2 - Fa_1$), the control system aims at a homeostatic situation. The success of this endeavour depends largely upon the effectiveness of the decision and information systems (Palo 1971, p. 23). In Figure 1, planning is regarded as a part of the information system. As the information system further comprises the collection and primary processing of data, planning is focused upon anticipations of different policy alternatives. Consequently, although planning is a part of the information system, it is closely related to the decision system.

Langefors (1973, p. 195) does not accept separation of the decision system from the information system, but regards the decision system as a part of the information system. A similar pattern of thought has has been followed by Kilkki (1973). His mensuration-oriented analysis of the forestry information system is illustrated in Figure 2. The information is collected from the forest ecosystem by means of various measurements.

The measurement data are fed into a data processing system which yields information to the planning system. The planning system serves the decision system, by providing it with alternative choices of action and anticipations concerning the results. The decisions are made at the stage represented by the last box, and their implementation affects the forest ecosystem, in which the changes can again be measured.

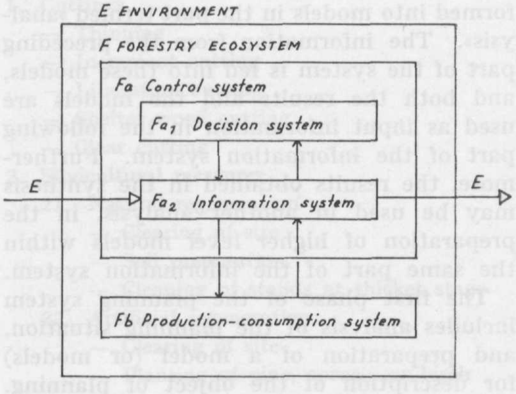


Fig. 1. A frame model for a control system of the forestry ecosystem (Palo 1971, p. 23)

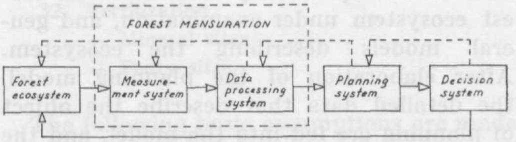


Fig. 2. A mensuration-oriented forestry information system

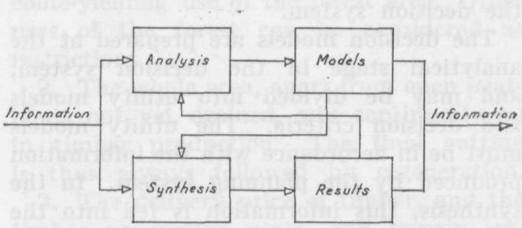


Fig. 3. Structure of the data processing, planning, and decision systems

Feed-back arrows (broken lines) go from the measurement, data processing, planning, and decision systems to their preceding systems. These arrows transmit requests for information, and this information acts as guidance in the design of the system. For instance, the measurement system may need fertilized sample plots for growth and yield measurements; and in this case, such plots have to be set up in the forest ecosystem.

Figure 3 indicates both the structure of the data processing and planning systems, and the main characteristics of the decision system. Invariances are located and transformed into models in the part termed »analysis». The information from the preceding part of the system is fed into these models, and both the results and the models are used as input information in the following part of the information system. Furthermore, the results obtained in the synthesis may be used in another analysis, in the preparation of higher level models within the same part of the information system.

The first phase of the planning system includes analysis of the planning situation, and preparation of a model (or models) for description of the object of planning. Construction of the model presupposes preliminary information on the data which are available. These data comprise both that which specifically describes the forest ecosystem under examination, and general models describing the ecosystem. After elaboration of the planning model, the detailed data that describe the object of planning are fed into the model, and the model is activated. The results may be utilized either as input data for higher-level planning models, or as information for the decision system.

The decision models are prepared at the analytical stage in the decision system, and may be divided into utility models and decision criteria. The utility models must be in accordance with the information produced by the planning system. In the synthesis, this information is fed into the utility model. The results of the utility model are evaluated by the decision criteria, and the results or the decisions are implemented in the forest ecosystem.

Long-term planning is characteristic of forestry. As a rule, it implies planning for time periods of a length of 10 years or more. In forestry, long-term planning is of less value if the time horizon of the decision-maker is short and if a great deal of uncertainty is associated with the future. These features are emphasized if the decision-maker is a private forest owner. For instance, if the forest owner cuts his forest only when timber prices are high, or if he does not intend to continue his forest ownership for a lengthy period, to him personally long-term planning is of doubtful value. If forestry is regarded from the standpoint of the community, the position and the significance of long-term planning assume a different aspect. On the national level, forestry cannot be practised with an eye to cyclical profits. Moreover, it is impracticable to replace timber growing by another industry, at least in a country such as Finland. Accordingly, the aims of forestry on the national level are not of so vague a nature that the utility of long-term planning comes into question.

Further emphasis is laid upon the importance of planning by the fact that planning does not call for a great deal of material input. As the prices of material input, such as oil and fertilizers, will probably increase as compared with the unit planning costs, intensive planning will become more profitable in the future.

When planning models are being prepared one everpresent necessity is that the planning situation be simplified with a view to restriction of the amount of information to be handled. In the main, this simplification becomes the task of the model builder. The authors are convinced that emphasis needs to be laid upon the aspects of national economy rather than upon private economy. The construction of tailor-made models for special groups of forest owners means a waste of scarce resources for research. Furthermore, the application of these models may also lead to divergence from the common interest; this is by no means the aim of research work sponsored by public funds.

The models employed in long-term forest planning have frequently been termed cutting budget models (cf. Kuusela and Nyyssönen 1962; Kilkki 1968 b). The term »cutting budget» indicates that the aim of models is that of acting as an aid in determination of the amount of timber to be cut during a given period (cf. Lihtonen 1959, p. 200). The term has been appropriate for use in the traditional models, which have been based upon manual calculations. Automatic data processing and operations research methods, have enabled the handling of a great deal more information than was earlier the case. Moreover, the number of decision variables which can be taken into account in planning models has increased markedly in recent years. The development of cutting budget models has led to a situation in which the calculations, originally timber-oriented, have developed into many-sided economic models. Accordingly, the term »timber production model» is used here instead of the term »cutting budget model». However, the the central task of the timber production model is that of predicting the consequences of a given cutting policy during the planning period. The information yielded by the timber production model is further utilizable in short-term planning.

12. Outline of the study

This paper is aimed at the development and testing of a long-term timber production model for forest areas. The model is mainly based upon the principles of the income-oriented cutting budget (Kilkki 1968 b), and will be computerized to the degree that seems reasonable. As no general algorithms are applied, the model could be referred to as a simulation model (cf. Gould and O'Regan 1965).

This timber production model is suitable for use in the case of any forest lot, or major forest area in Southern Finland. The area may comprise forest land, poorly-productive peatland, and open swamp (for definitions, refer to Kuusela and Salminen 1969). The area is divided into calculation units. Each calculation unit may comprise either a single subcompartment, or a group of stands. The second of these alternatives is particularly applicable to large forest areas for which information on every single stand is either unavailable, or unpractical in use. In this work, the terms »stand» and »calculation unit» are employed as near-synonyms. Furthermore, the calculation units can be grouped into blocks, which are called compartments.

It is required that the model can simulate the development of each calculation unit over a given period of time. The length of the calculation period can be chosen freely, to a degree of precision of one cutting year. Each cutting year begins on July 1, and ends on June 30. The simulation specifies the following measures taken in each calculation unit during the calculation period.

1. Cuttings
  - Thinning
  - Increment cutting
  - Liberation cutting
  - Shelter wood cutting
  - Clear cutting
2. Silvicultural measures
  21. Natural regeneration
    - Clearing of site
    - Soil preparation
    - Cleaning of stands at thicket stage
  22. Artificial regeneration
    - Clearing of site
    - Planting of pine, spruce, or birch
    - Beating up and weeding
    - Cleaning of stands at thicket stage
3. Forest improvement
  31. Peatland drainage
  32. Fertilization
    - Mineral sites
    - Peaty sites

The following basic assumptions are made as regards the forest area under examination:

1. Timber production is the only income-yielding use of the forest area. Other uses of the forest can be considered as restrictions.
2. The whole area, apart from open peatlands not yet drained, will continuosly be in timber production. The final cutting is thus always followed by regeneration.
3. The delivery price of timber, and the timber production costs, will remain unchanged in the future.
4. The stumpage price is derived by subtraction of the logging costs from the delivery price of timber.
5. Cuttings and payments are made in the middle of the cutting year.

The timber production model has two main parts: (1) Forecasts and (2) Decisions. The »Forecasts» section keeps up to date the records of all calculation units during the entire calculation period, and »Decisions» determines the measures to be taken in each calculation unit within a given cutting year.

The decisions are sub-divided into genuine and automatic decisions (cf. Törn-

QVIST and NORDBERG 1968). The values of the parameters of the automatic decision rules also constitute one class of the genuine decisions. It is assumed that the genuine decisions for the calculation period can be made at the time of carrying out the calculation. Genuine decisions are generally applied to the whole forest area, and automatic decisions to the calculation units; the only expections to this are the decisions concerning drainage and fertilization. Currently, they still require genuine decisions for each calculation unit. The most important genuine decisions directed at the whole forest area are the annual drain in volume or monetary units, and the annual regeneration area.

As a rule, the decisions relating to the cutting sequence and method, and the silvicultural measures to be adopted, are made automatically. This practice results first of all from an attempt to keep the number of decision variables at a reasonable level, and thus to facilitate the use of the model. Secondly, it is unnecessary to make detailed determinations of the measures to be adopted in the remote future. Thirdly, it is normally quite easy for the decision-maker to define his decision rules in routine decisions. The rules of automatic decisions are of central importance in preparation of the timber production model, since they have to be incorporated into the model.

The goal of the timber production model can now be defined. It is designed for forecasting the development of a forest area during a given period of time, and for making the automatic decisions which guarantee that the action taken is in conformity with the genuine decisions, and which maximize the timber-producing value of the forest area at the end of the period. A model aiming at this goal could be formulated by mathematical programming. Unfortunately, a model of this type easily becomes too large in a realistic situation (cf. KILKKI 1968 b, p. 40). As a consequence, it is appropriate to cut the decision process into smaller parts, each of which corresponds to a certain cutting year. In one part, automatic decisions required by the genuine decisions are made independently of the future genuine decisions.

When the decisions have been implemented, the calculation units are updated to the next decision situation. Accordingly, the timber-producing value of the forest area, estimated as the sum of the values of the calculation units, is maximized in each decision situation. This procedure does not guarantee any absolute optimum for the whole calculation period, but deviations from the optimum are negligible if the optimization process is suitable (cf. KILKKI 1968 b).

It would be possible to provide the optimization part of the model with the shape of a linear programming model. Since the number of restrictions is relatively small, heuristic optimization procedures have been applied, based primarily upon classic investment calculations. If more restrictions were taken into account, such classic partial models would prove inadequate (cf. HÄMÄLÄINEN 1973, p. 47).

After the genuine decisions have been made, it is possible to predict both the development of the forest during the calculation period, and the value of the forest area at the end of the calculation period. Furthermore, the model provides a detailed list of automatic decisions for each calculation unit. The decision-maker can either accept the result, or change his genuine decisions and calculate a new plan (cf. Figure 1, loop $Fa_1-Fa_2-Fa_1$).

In the present study the timber production model is applied to the joint area of two forestry board districts, Keski-Suomi and Pohjois-Savo. The differences between alternative production policies are analysed in the light of decision theory. Special attention is paid to the stand treatment rules, which are in accordance with the given production policies.

The timber production model is a part of the forest inventory and planning system (MISS) developed in the Department of Forest Mensuration and Management of the University of Helsinki. The inventory part of the system has been reported on by KILKKI et al. (1971) and by MIELIKÄINEN (1972). The timber production model has been described (in Finnish) in a report by PÖKÄLÄ (1973), and the ADP-system by MIELIKÄINEN and PÖKÄLÄ (1974).

2. DESCRIPTION OF THE FOREST AREA

The data for the calculation units are obtained through forest inventories. This information has to be fed into the timber production model, in the format of the MISS stand form (cf. MIELIKÄINEN 1972). The input data of each calculation unit include the following information.

1. Number of the calculation unit
2. Number of the compartment
3. Area
4. Site class
5. Degree of drainage of peatlands
6. Storey structure
7. Treatment class
8. Method of regeneration

Furthermore, the following information is attached to each tree storey.

9. Dominant tree species
10. Age
11. Basal area
12. Basal area median diameter
13. Mean height
14. Distribution of the volume by tree species

If the calculation unit corresponds to a stand, the number of the calculation unit, and that of the compartment, indicate its geographical location. When it is a matter of a group of stands, the corresponding numbers may describe the site, age class, volume class, and so on, or solely denote the group as such. Seven site classes are possible. The first five of them represent forest land, the sixth poorly-productive peatland, and the seventh open peatland. Site classes 1 and 2 are spruce sites, and correspond to tax classes I A and I B (cf. KUUSELA and SALMINEN 1969). Site classes 3, 4, and 5 are pine sites, and correspond to tax classes II, III, and IV.

The degree of drainage indicates whether peatland is in its virgin state, recently drained, a transforming peaty site, or a transformed peaty site. Virgin and recently drained spruce swamps fall within site class 4, and transforming and transformed spruce swamps site classes 1, 2 or 3, depending upon the fertility of the site. Pine swamps on forest land are in site class 5 if they are in a virgin state, or if they have been recently drained. Transforming and transformed pine swamps on forest land are in site classes 2, 3 or 4. Poorly-productive peaty sites are included in site class 6 when in a virgin state, or recently drained. Open peatlands are in site class 7, when they are in a virgin state or have recently been ditched; as drainage exercises an influence, they are transferred to site classes 3 or 4.

Three storey structures are possible:

1. Single-storey stands.
2. Two-storey stands, with the lower storey capable of forming a new stand.
3. Two-storey stands, with the lower storey incapable of forming a new stand.

Although no treatment proposals are required, use can be made of treatment class information with young low-yielding stands, as otherwise it becomes difficult to discover the need for regeneration. Similarly, the treatment class forms a basis for the identification of shelter wood stands. Shelter wood stands will automatically be dealt with as two-storey stands at the beginning of the calculation period.

The information of the method of regeneration is also optional; if the automatic regeneration rules are accepted, this information is not required.

Four dominant tree species are possible: (1) pine, (2) spruce, (3) birch, and (4) the group »other broadleaved trees». All volumes are expressed in terms of solid cubic metres excluding bark.

The data indicated for each calculation unit are employed as variables in various models, for prediction of the volume of the stand, the volume of the mean tree, the volumes of different timber assortments, and the unit value of the growing stock (cf. PÖKÄLÄ 1973).

3. DEVELOPMENT OF THE STANDS

31. Volume growth

It is assumed that the volume of the growing stock increases annually according to certain growth functions, which are applied to both mineral and peaty sites. They are expressed either as mathematical formulae, or as numerical series. The formulae used in this study were derived by means of regression analysis, from data published by NYYSSÖNEN (1954) and VUOKILA (1956), and supplemented by unpublished data obtained by NYYSSÖNEN. The predicting variables in the formulae comprise the site class, dominant tree species, age, and volume of the growing stock. The growth rate of the formulae is adjusted to the growth level, as determined in the 5th national forest inventory (cf. RAJALA 1970). The formulae will be published in later studies. As the mathematical formulae are unreliable in very young stands, the volume growth in stands of less than 20 years of age has been predicted by reference to the series presented by KOIVISTO (1959) and VUOKILA (1967).

In the case of two-storey stands, it is assumed that the growth of the lower storey is 5 per cent below the growth of of the corresponding one-storey stand in storey structure class 2, and 10 per cent in storey structure class 3.

The difficulty experienced in fitting together the growth functions derived from various studies obliged the authors to apply a greatly simplified method for estimation of the growth on drained swamps. The effect of drainage upon the growth rate is introduced by a change in site class (cf. p. 9). It is assumed that the site class remains unchanged for 10 years after drainage, and subsequently makes a direct change to the final site class of transformed peaty sites. This procedure is no more than approximative, since such aspects as the site, age, and tree species are not taken into account (cf. SEPPÄLÄ 1969; HEIKURAINEN and SEPPÄLÄ 1973). The reverse effects of the tree species and the site class imply that to some extent they will offset each other. The procedure further leads to underestimation of the growth during the first 10 years after drainage, and to overestimation during the years immediately succeeding this period (cf. SEPPÄLÄ 1969).

32. Value growth

The first assumption in regard to the volume of the mean tree was that it rose in accordance with the increment percentage of the total volume (cf. SIITONEN 1972). However, it was subsequently discovered that in the long run the predictions led to unsatisfactory results in respect of stands which had an exceptionally high or low original volume for the mean tree. For this reason, the increment percentage of the total volume was multiplied by a correction factor with a view to the derivation of better predictions for the volume increment of the mean tree:

$$c = \left(\frac{\bar{v}}{v}\right)^k \qquad (1)$$

where c = correction coefficient
$\bar{v}$ = volume of the mean tree, from KOIVISTO's series (1959)
v = actual volume of the mean tree
k = a parameter with a value which can be estimated

Coefficient c ensures that no great deviation occurs from the average development of the mean tree. Nevertheless, to some extent account is taken of individual variation, attributable either to an exceptional original situation or, to an exceptional growth rate. The volume of the mean tree derived from KOIVISTO's series (1959) is expressed as a function of the site class, tree species, and age of the stand. Tests were made of a number of values for parameter k. The correct values probably lie somewhere between 0 and 1.0; in this study, 0.5 has been introduced in all stands as an estimate for k.

It is assumed that thinning may also

change the volume of the mean tree. The mean volume of the trees removed is derived by the following heuristic formula:

$$(2) \qquad v_1 = \left(1 + r\,\frac{V - V_1}{V}\,\frac{v - \bar{v}}{\bar{v}}\right) v \text{ if } v < \bar{v}$$

$$v_1 = \left(1 + r\,\frac{V - V_1}{V}\,\frac{v - \bar{v}}{v}\right) v \text{ if } v > \bar{v}$$

where v_1 = mean volume of the trees removed
V = volume of the stand before thinning
V_1 = volume of the removal
r = a parameter with a value which can be estimated

The formula indicates that the difference between the mean volume of the removed trees, and that of all trees before thinning, attains a maximum when the removal is close to zero, and a major difference exists between the actual mean volume (v) and the expected mean volume ($\bar{v}$). The mean volume of the trees removed is less than that of all trees, if their mean volume is less than the mean volume expected; the reverse also applies. Parameter r regulates the thinning practice. Large values for parameter r indicate extreme thinnings from below or from above. In this study the value of the parameter is taken as 1.0.

The following formula is derivable for determination of the mean volume of the stand after thinning (v_2):

$$(3) \qquad v_2 = \frac{Vv - V_1 v_1}{V - V_1}$$

Since the degree of dependence between the unit price of the timber and the volume of the mean tree is not linear, the sum of the delivery value of the removed trees, and the value of the trees left standing, is not equivalent to the delivery value of the original growing stock; however, this inconsistency is quite insignificant.

Formulae (1) and (2) were tested by some experiments, and the development of mean volumes was found to be satisfactory. However, it is necessary to point out that hardly any empirical data were available to support these artificially constructed formulae.

The value of the stand is expressed either as its delivery price, or as its stumpage price. In both cases, the value growth is calculated by means of the following formula:

$$(4) \qquad Z_t = U_{t+1} V_{t+1} - U_t V_t$$

where Z_t = value growth in year t
U_t = unit value of the growing stock at the beginning of year t
V_t = volume of the growing stock at the beginning of year t

33. Effect of fertilization

The effect of fertilization on the growth rate was determined from sample plot data obtained in conjunction with a forest fertilization campaign (Operaatio . . 1969). The material included all the stands on mineral site classes 2 and 3 (cf. p. 9) in climatic region I, of an age exceeding 30 years, and with either pine or spruce as the dominant tree species. Accordingly the foundation for the analysis was constituted by a total of 864 plots representing stand ages between 30 and 155 years, and volumes between 3 and 241 cu. m. per hectare. Of this total number, 505 stands were dominated by pine, and 359 by spruce.

Keltikangas and Seppälä (1973 b) have developed a procedure which enables prediction of the volume growth percentage after fertilization as a function of the growth percentage before fertilization, and the volume at the time of fertilization. This procedure has been applied in this study. The growth functions were arrived at by regression analysis. In correspondence with the results obtained by Keltikangas and Seppälä, the growth percentage before fertilization and the volume at the time of fertilization proved to be the best predicting variables. Furthermore, the tree species and the age of the stand were statistically significant variables. Nevertheless, the age was omitted from the final function with a view to simplification of the formula. The increment percentage after fertilization on mineral sites is predicted by the following formula:

(5) $Y = 9.52 \cdot 1.032^{X_1} X_2^{0.836} X_3^{-0.335}$

where $Y = \frac{100}{5} \; \frac{V_5 - V_0}{V_0}$

$X_1 = 0$ if the dominant tree species is pine
$= 1$ if the dominant tree species is spruce

$X_2 = \frac{100}{5} \; \frac{V_0 - V_{-5}}{V_0}$

$X_3 = V_0$

V_i = volume of the growing stock i years after fertilization

It is assumed that the effect of fertilization in hardwood stands is equivalent to that in pine stands.

Formula (5), after some remodelling, has also been applied to peaty sites. The annual increase in growth on peaty sites after fertilization remains below that on mineral sites (cf. KELTIKANGAS and SEPPÄLÄ 1973 b). Thus, on peaty sites the increase in growth due to fertilization is reduced by 30 per cent of that derived by means of formula (5).

It is assumed that the period during which fertilization yields a growth increase is 5 years on mineral sites, and 15 years on peaty sites (cf. KELTIKANGAS and SEPPÄLÄ 1973 b, p. 211). Subsequently, the stands continue their growth in accordance with the normal growth functions (cf. p. 10), unless the fertilization is repeated. The growth increase attributable to a single fertilization is approximately 10 cubic metres on mineral sites, and 21 cubic metres on peaty sites.

Many uncertainties are involved in the use of formula (5); one of them is the applicability of the formula if the fertilization is repeated. Since the growth before fertilization (variable X_2) is derived from the normal growth functions, there is probably no great danger of overestimation. The observation is also due that the fertilization effect is markedly dependent upon the amount of fertilizer utilized.

4. DECISIONS

41. Theoretical background for stand-treatment decisions

Basically, optimization of the stand treatment presents an economic problem for the whole forest holding. Cuttings assume the central position among the measures adopted in a stand. As a consequence, in this study special attention has been paid to the theoretical foundations of the automatic decision rules which regulate the cuttings.

The factors that affect the cutting programme for a stand can be divided into three main categories. The first of these is concerned with the characteristics that describe the state of the stand. The factors in the second category are connected with the aims of the one making decisions. One expression of these aims, for instance, is the planned cut. A planned cut even implicitly determines the desirable growing stock for a whole forest area, and correspondingly, for each single stand. The third category includes the factors of logging technology which depend upon the location of the stand; this frequently often determines when and how the stand will be cut. The marginal effect of the cutting upon neighbouring stands also falls within the third category.

Traditionally, the treatment rules for stands have been decided upon during the the course of field work in forest inventories. As a rule, these instructions do no more than reflect the state and location of the stand. During the field work, it is difficult, and even impossible to take into consideration the planned cut of the whole area, as normally the necessary information becomes available only after completion of the inventory. This implies that the cutting instructions given during the course of the field work can rarely be implemented as such. Thus the final cutting plan should be prepared only after compilation of all the data that have a bearing upon the plan. A cutting plan for a single stand can then be adjusted to the total plan.

In Finland, stand treatment standards have principally been founded upon biological and silvicultural standpoints. A stand has been regarded as an ecological unit cut off from its economic and areal background. This means that only some of the factors in category one, and no factors in the other two categories have affected the treatment standards. These treatment standards have been compiled in growth and yield tables (cf. KOIVISTO 1959), and thinning models (cf. VUOKILA 1971).

The optimization of stand treatment has for a long time been considered as an economic problem as well (cf. ENDRES 1923; DUERR and BOND 1952; NYYSSÖNEN 1958; CHAPPELLE and NELSON 1964; BENTLEY and TEEGUARDEN 1965; KILKKI 1968 a). Nevertheless, in many cases insufficient consideration has been given to the requirements of the whole economic unit to which a given stand belongs.

Below, an examination has been made of cutting decisions concerning single stands with respect to the opportunity cost theory (see e.g. LIPSEY and STEINER 1969). The benefit that a production factor would yield if it were utilized in another production process, or in consumption, is termed the opportunity cost of the factor in its present use. It is profitable to use the production factor in a certain production process only to the extent that the benefit it yields exceeds its opportunity cost.

Timber growing in a stand is a production process. The major production factors that man can regulate in this production process are the land and the growing stock. In the main, the regulation of these factors is effected by cuttings. For the sake of simplification, it is assumed that land and growing stock are the only variable inputs, and that value growth is the only output in the timber production process. It is further assumed that neither the size of the stand, nor the neighbouring stands, exercise any influence upon the timber production process. If the time period under observation is only one year, the production process can be described by the following production function:

$$Y = g(W \mid X_3, \ldots, X_n) \cdot X_1 \tag{6}$$

(Kilkki 1971)

in which Y = annual value growth of the stand
$W = X_2/X_1$
X_1 = area of the stand
X_2 = growing stock of the stand
$X_3, \ldots, X_n$ = other factors influencing the value growth (here assumed to be constants)

With a view to having a rational alternative use for the land and growing stock, the stand is taken to be a part of a larger forest holding, which is associated with a timber-growing, production-consumption unit. Moreover, the decision-maker is assumed to be »an economic man», endeavouring to maximize the sum of the short- and long-term benefits from his forest holding (cf. Hämäläinen 1973, p. 43). The short-term benefits are presumed to arise immediately from the timber cut, and the long-term benefits from the land and growing stock left to produce more timber in the future. It is further assumed that thinning and regeneration cutting are the only alternatives of action.

The opportunity cost of the growing stock in a given stand is equivalent to the benefit that this growing stock would yield either if removed to other stands of the forest area, or utilized as timber in consumption. Although it is impossible to remove growing stock from one stand to another, cutting makes it practicable to regulate the level of the growing stock in each stand. On the one hand, the opportunity cost of one unit of growing stock equals the lowest marginal productivity of the growing stock in all stands of a forest holding. The symbol D denotes this opportunity cost. On the other hand, the opportunity cost of one unit of growing stock equals the marginal benefit of one unit of timber in consumption; this is often regarded as a product of two components: the rate of interest (p/100), and the unit stumpage price of the growing stock (U). With economic equilibrium, the rate of interest is equivalent to the internal rate of return of the economic unit, and both of these opportunity costs of one unit of growing stock are equal:

$$D = \frac{p}{100} U \tag{7}$$

As the possibility of thinning a stand is under consideration, the marginal productivity of the growing stock needs to be calculated as the ratio between the loss in the value growth attributable to thinning (ΔY), and the amount of timber to be thinned (ΔX_2). If the ratio exceeds the opportunity cost of one unit of growing stock, the stand can be left for future growth:

$$\frac{\Delta Y}{\Delta X_2} \geq D \quad \text{or} \tag{8}$$

$$\frac{\Delta Y}{\Delta X_2} \geq \frac{p}{100} U \quad \text{or} \tag{9}$$

$$\frac{\Delta Y}{U \Delta X_2} \geq \frac{p}{100} \tag{10}$$

The ratio between the loss in the value growth and the stumpage value of the timber to be thinned (cf. formula 10) is here termed the thinning criterion.

When the practicability of regeneration is under consideration, the opportunity cost of the growing stock (P_V) is equivalent to the product of the total growing stock and the opportunity cost of one unit of growing stock:

$$P_V = DX_2 = \frac{p}{100} UX_2 \tag{11}$$

The opportunity cost of land (M_V) also needs to be taken into account; it corresponds to the benefit derived from the land area of the stand to be used for growing future timber generations. One year's benefit is often expressed as the product of the rate of interest and the value of the bare land (L):

$$M_V = \frac{p}{100} LX_1 \tag{12}$$

One method for derivation of estimates of the land values is to be found in the Faustmann formula. However, in many cases a fully regulated forest model provides a more appropriate basis for determination of the land value estimates (cf. Kilkki 1968 a). Emphasis is due that these two methods yield estimates alone. The real land values emerge as shadow prices of the land from solution of the total economic model of the forestry unit. Moreover, it should be noted that the guiding rate of interest (p/100) does not necessarily correspond to that applied in the land value calculation.

The opportunity cost of growing of a forest stand, as opposed to regeneration, is equivalent to the sum of the opportunity costs of the growing stock and the land:

$$P_V + M_V = \frac{p}{100}(UX_2 + LX_1) \tag{13}$$

Accordingly, it is worthwhile to grow the stand to the extent that the annual value growth exceeds the opportunity cost of growing the stand:

$$Y \geq \frac{p}{100}(UX_2 + LX_1) \tag{14}$$

The regeneration criteria generally applied, the v-value (v), and the indicating percentage (w), can be derived from formula (14):

$$v = Y - \frac{p}{100}(UX_2 + LX_1) \tag{15}$$

$$w = \frac{100\,Y}{UX_2 + LX_1} \tag{16}$$

The indicating percentage derived from formula (16) will subsequently be referred to as the regeneration criterion.

In this context, an erroneous result, presented by Kilkki (1971, p. 6), should be corrected. The author suggested that the financial maturity of a forest stand could be determined from a comparison between the marginal productivity of land and the opportunity cost of land. This reasoning, however, failed to comprehend that a part of the land occupied by the growing stock in an even-aged forest cannot be removed to grow a new timber generation. The correct way to assess financial maturity lies in comparison of the value growth of the stand and the sum of the opportunity costs of the land and growing stock (formulae 14, 15, and 16). The erroneous deduction made in the earlier paper arose from the fact that the financial maturity criterion derived from the marginal productivity of land yields the correct result if the growing stock is at the optimum density, as defined by Kilkki (1971, p. 6). This financial maturity criterion is also valid if a fully regulated forest is under surveillance, instead of a single forest stand.

Figure 4 provides a graphic illustration of the thinning and regeneration decisions expressed by formulae (10) and (14); here is indicated a cross section at a given point of time. It is observable that at a given age the stands are divisable into a maximum of four treatment classes.

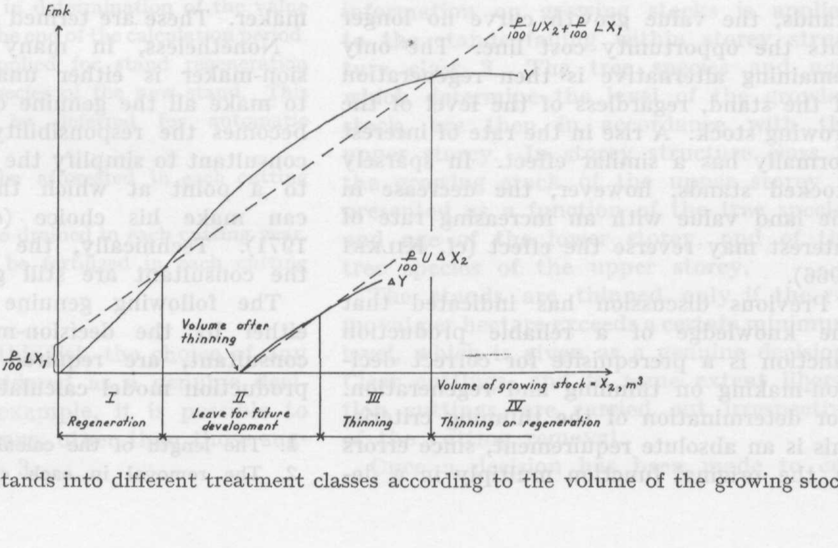


Fig. 4. Division of stands into different treatment classes according to the volume of the growing stock

The first class (I) comprises stands in which the volume of the growing stock is so low that the value growth does not exceed the sum of the opportunity costs of land and growing stock. These stands are understocked, and need to be regenerated.

The second class (II) comprises stands in which the value growth exceeds the sum of the opportunity costs of land and growing stock. Furthermore, the potential loss in value growth exceeds the opportunity costs of the part of the growing stock to be thinned. These stands are left for future growth.

The third class (III) consists of stands in which the value growth of the growing stock exceeds the sum of the opportunity costs of land and growing stock, but in which the potential loss in the value growth falls below the opportunity cost of the timber to be thinned. Thinning is the best treatment alternative for a stand in this class. If thinning is impracticable, the most satisfactory alternative is that of leaving the stand for future growth.

In the fourth treatment class (IV) the value growth falls below the sum of the opportunity costs of land and growing stock. Consequently, a stand which falls within this class needs to be regenerated if it cannot be thinned. However, in this class, thinning is the most profitable treatment alternative.

As the growth intensity decreases, and the ratio between the value and volume growth becomes less favourable in old stands, the value growth curve no longer cuts the opportunity cost line. The only remaining alternative is then regeneration of the stand, regardless of the level of the growing stock. A rise in the rate of interest normally has a similar effect. In sparsely stocked stands, however, the decrease in the land value with an increasing rate of interest may reverse the effect (cf. KILKKI 1966).

Previous discussion has indicated that the knowledge of a reliable production function is a prerequisite for correct decision-making on thinning and regeneration. For determination of the thinning criteria, this is an absolute requirement, since errors in the original function multiply in a derivate of the function (cf. KILKKI 1971, p. 7). As thinning is often out of the question in a stand close to final cutting, the financial maturity is solely determinable by assessment of the value growth. In practice, the value growth may be estimated reliably, without a priori information on the timber production function, by measurement of the growth of previous years.

The theory outlined above is applicable as such to determination of the optimum cutting policy of the stand only if the assumption can be made that the present treatment of the stand cannot change the timber production function in the future. The application of dynamic programming, for instance, allows of models in which changing production functions are acceptable (cf. KILKKI and VÄISÄNEN 1969; RISVAND 1970; SIITONEN 1972; KILKKI 1972). However, as yet no such timber production functions are available. Moreover, a dynamic model is not always practical as part of a larger system, since its use is rather time-consuming. Nonetheless, the major drawback of the above theory lies in the absence of the time factor. Consequently, the applicability of the theory is limited to old stands in which the values of the thinning and regeneration criteria are already declining (cf. KILKKI 1966).

42. Genuine decisions

To ensure that the timber production model is made more flexible, a number of decisions have been left to the decision-maker. These are termed genuine decisions.

Nonetheless, in many cases the decision-maker is either unable or unwilling to make all the genuine decisions. It then becomes the responsibility of the forestry consultant to simplify the decision situation to a point at which the decision-maker can make his choice (cf. KELTIKANGAS 1971). Technically, the decisions left to the consultant are still genuine decisions.

The following genuine decisions, made either by the decision-maker or by the consultant, are required in each timber production model calculation.

1. The length of the calculation period.
2. The removal in each cutting year during

the calculation period. This is expressed by
- a) a volume drain requirement, or
- b) a net income requirement, or
- c) a guiding rate of interest

3. A list of the compartments in which cuttings can be made in each cutting year. A concentration of cuttings within given compartments in each cutting year helps to preclude the uneconomic cutting of scattered stands.
4. The maximum regeneration area in each cutting year. Only one half of the area treated by shelter wood cutting is taken into account. The other half is added to the regeneration area after liberation of the new generation. The liberation cuttings during the first ten-year period, however, are not added to the regeneration area.
5. The land values applied in each cutting year. The land values are expressible either explixitly, or the land values may correspond to the internal rate of return of the cutting year.
6. The level of the growing stock left after thinning or shelter wood cutting.
7. The minimum removal per hectare in thinning, increment cutting, and shelter wood cutting.
8. A list of the young stands that are classified as of low-yielding, and which are consequently regenerated through first cutting.

Decision 4 in itself determines the maximum regneration area in each cutting year, but decisions 5, 6, 7, and 8 are also usable for regulation of the ratio between the areas of selection and regeneration cuttings.

9. The length of the discounting period and the rate of interest in determination of the value of the forest at the end of the calculation period.
10. The method applied for stand regeneration and the tree species of the new stand. This decision can be deferred for automatic determination.
11. The areas to be afforested in each cutting year.
12. The stands to be drained in each cutting year.
13. The stands to be fertilized in each cutting year.

In addition to this list, the choice of any data can be considered as a genuine decision. Thus, for example, it is possible to use growth functions, other than those suggested in section 3.

43. Automatic decision rules

As was stated in section 12, the majority of the decisions that apply to single treatment units are made automatically. The rules for these decisions are programmed into the timber production model, and as a rule the parameters of these rules are fed into the model as input data. Among the most important of these rules are those that regulate cuttings. These are applied after a genuine decision has been made to cut a specific amount of timber, or to follow a certain rate of interest.

The single-storey stands and two-storey stands in storey class 3 are sub-divided into young and old stands, by age and site class, as follows.

Site class	Young stands	Old stands
	age, years	
1–2	0–55	56+
3	0–60	61+
4	0–65	66+
5–6	0–70	71+

In regard to old stands, the decision rules are for the most part based upon the theory presented in section 41. In young stands, and in stands of storey structure class 2 (cf. p. 9), the traditional rules have been applied.

In the case of single-storey stands, the volume of the growing stock after thinning is presented as a function of the site, the tree species, and the age. The same information on growing stocks is applied to the stands falling within storey structure class 3. The tree species and age, which determine the level of the growing stock, are then in accordance with the upper storey. In storey structure class 2, the growing stock of the upper storey is presented as a function of the tree species and age of the lower storey, and of the tree species of the upper storey.

The stands are thinned only if the removal per hectare exceeds a certain minimum level, which is given as a genuine decision. Clear cuttings, and to some extent liberation cuttings, are carried out irrespective of the cutting removal.

Once a decision has been made to cut

stated compartments in a stated year, thinnings are first performed in young stands, and liberation cuttings in two-storey stands. This order of procedure is followed because these cuttings are regarded as necessary to the future development of the stands. It may thus occur that the removal exceeds the target set up by the genuine decisions. However, a situation of this type is quite uncommon in practice if the cutting cycle extends over more than two or three years.

Cuttings in old stands are made later than is the case with young stands, and stands in storey structure class 2. The decision rules for old stands are based upon the thinning and regeneration criteria presented in formulae (10) and (16).

In determination of the thinning and regeneration criteria only one year's growth was taken into account. Consequently, if the cutting cycle exceeds one year, it becomes necessary to consider the change in the criteria. With a view to investigation of the rate of change in the criteria, some experiments were made, and the results were taken into account in determination of the final criteria.

Both the thinning criterion and the regeneration criterion diminish more rapidly in young and in high-volume stands. In sparsely stocked stands, the regeneration criterion may even rise. Cutting that is aimed at natural regeneration needs to be started earlier than that designed for artifical regeneration (cf. NYYSSÖNEN 1958). With natural regeneration, accordingly, the regeneration criterion has to be multiplied by a constant less than 1.0.

In the main, those decisions connected with silvicultural measures are made automatically with due regard to the site. The afforestation of open peatlands after drainage always presupposes spot fertilization. The clearing and the preparation of the regeneration area require genuine decisions as far as natural regeneration is concerned. These measures are implemented immediately after cutting aimed at natural regeneration. It is further assumed that planting is done immediately after clear cutting. Beating up and weeding are effected three years after artificial regeneration, and cleaning and repeated weeding ten years subsequently. Young stands that have emerged naturally are also cleaned ten years after the shelter wood cutting. In those stands that are currently under twenty years of age, cleaning is performed ten years from the beginning of the calculation period.

5. THE ADP-SYSTEM

The timber production model was divided into modules prior to programming. The module structure did not hold satisfactorily, and as a consequence, in the present version of the system some modules include rather diversified jobs. The programming language was FORTRAN IV, and the system was designed for the UNIVAC 1108. Currently, the system comprises 37 programs and approximately 2 500 statements.

The system can be presented in eight modules; it is illustrated in Figure 5, along with the interrelationships of the modules. Unbroken lines indicate the general flow in the system, and broken lines indicate optional links between the modules.

In the first module (1), the data discussed in section 3 and the price and cost data are fed into the system.

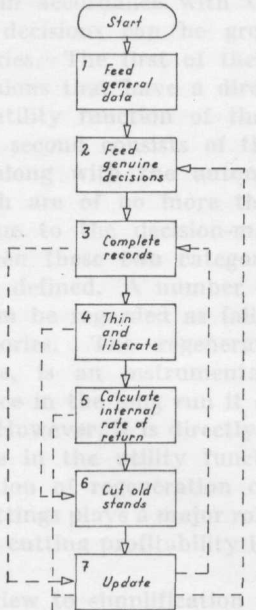


Fig. 5. Structure of the ADP-system

In the second module (2), the inventory data and the genuine decisions are fed in. Detailed output instructions are also given in this module.

In the third module (3), the records of all calculation units are complemented with the data concerning such details as growth, value, value growth, and thinning and clear cutting criteria. Each record comprises a total of 125 variables. Of course, many of these variables include only temporary information, never seen as an output. The silvicultural measures not directly linked with cuttings are taken into this module. Similarly, here are fed the drainage and fertilization decisions. If it is not intended that any cuts will be effected in the cutting year under observation, the system is switched to the seventh module (7). Otherwise, the treatment of young stands, and of stands in storey class 2, are in order in module four (4), in which the necessary thinnings and liberation cuttings are treated.

In the fifth module (5), there is determined either the relationship between the internal rate of return and the drain, or only the internal rate of return in conformity with a given drain requirement. The dependence of the regeneration area upon the drain is determined at the same time.

If there comes into question only the relationship between the internal rate of return and the drain, the following modules are passed, and the system moves to the end. Otherwise, the system moves to the sixth module (6), in which all the necessary cuttings, and the silvicultural measures linked to the cuttings are handled in the old stands. In this module, there can be used the information on the internal rate of return obtained in the previous module. It is also possible to use a guiding rate of interest, given as a genuine decision, for determination of the cuts in this module. The guiding rate of interest may be founded upon earlier calculations in which has been determined the relationship between the internal rate of return and the drain. In these cases, the system has passed the fifth module (5).

In the seventh module (7), the calculation units are updated to the following cutting year. This module also updates the variables which relate to the timing of the silvicultural measures, the effect of drainage and fertilization, and so on. From the seventh module, the system can either move to the end, revert to the beginning of the next cutting year (3), or move to a completely new calculation either for the same forest area or another one (2). It is also possible to move to the eighth module (8), in which is received the net present value of the forest area, both at the beginning and at the end of the calculation period.

At any time during the calculation, the system yields detailed lists of the calculation units; these lists indicate both the situation in the calculation unit, and the measures taken during each cutting year. The system also provides the decision-maker with a number of tables, in which this information is presented in more concise form.

The cost involved in the computation depends upon the number of calculation units, the length of the calculation period, the complexity of the calculation, and the amount of output. For instance, a fifty-year calculation for a forest area comprising 226 calculation units costs approximately 500 Fmk.

A detailed description of the ADP-system is presented, in Finnish, in a report by Mielikäinen and Pökälä (1974).

6. CHOICE OF THE TIMBER PRODUCTION POLICY

Timber production policy can be defined as a set of genuine and automatic decisions. The timber production model aims at providing the decision-maker with information on the consequences of applying different production policies (cf. Figures 1, 2, and 3). The genuine decisions made for a timber production model calculation do not presuppose acceptance of a certain production policy. To the contrary, the genuine decisions are conditional, and will be reviewed after the results of the calculation are available. To summarize, it may be said that the timber production model should yield values to the predicting variables in the utility function of the decision-maker. The rational decision-maker then chooses the timber production policy which maximizes his utility, and subsequently implements the genuine decisions which are in accordance with this policy.

Genuine decisions can be grouped into two categories. The first of these consists of the decisions that have a direct bearing upon the utility function of the decision-maker; the second consists of the genuine decisions (along with the automatic decisions) which are of no more than instrumental value to the decision-maker. The limit between these two categories is not always well defined. A number of genuine decisions can be regarded as falling within both categories. The regeneration area, for example, is an instrumental decision variable since in the long run it determines the drain. However, it is directly a predicting variable in the utility function, since the proportion of regeneration cuttings in the total cuttings plays a major role in determination of cutting profitability in the near future.

With a view to simplification of the decision situation, it is assumed below that the utility function has only two predicting variables: (1) the drain during the working period, and (2) the largest sustained drain after the working period; the length of the working period may, for example, be 10 years. The timber production model enables discovery of the sets of genuine decisions that yield the maximum combinations of these predicting variables, although a large number of calculations may be required to determine, say, the optimal regeneration area in each combination. All of these combinations indicate the production possibility boundary (cf. Lipsey and Steiner 1969, pp. 5—8). Curve S in Figure 6 provides an example of the production possibility boundaries. In this case, the curve is concave to the origin. Each point on curve S represents a timber production policy.

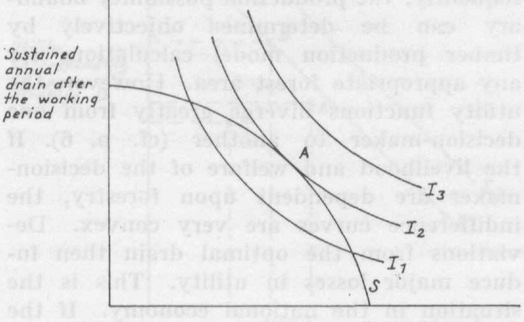


Fig. 6. A production possibility boundary (S) and three indifference curves (I_1, I_2, and I_3) of a utility function

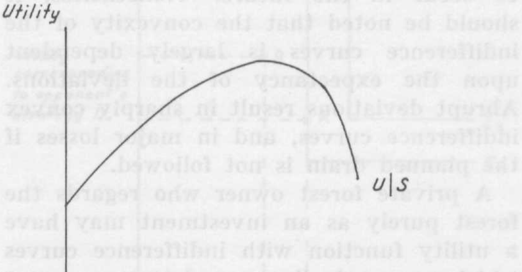


Fig. 7. Dependence of the utility upon the drain during the working period

I_1, I_2, and I_3 represent indifference curves derived from a utility function. Point A, in which curve I_2 touches the production possibility boundary S, indicates the optimal drain for the working period, and simultaneously the maximum sustained drain after the working period. Curve $U|S$ in Figure 7 indicates the dependence of the utility upon the drain during the working period, with a given production possibility boundary S. Examination of Figures 6 and 7 indicates that if the production possibility boundary is extremely concave, and the indifference curves are extremely convex to the origin, losses in the utility are large if deviations occur from the optimum drain.

The production possibility boundary is dependent upon the number of production factors, of which land, growing stock, and man's action are the most important. Consequently, the production possibility boundary can be determined objectively by timber production model calculations for any appropriate forest area. However, the utility functions diverge greatly from one decision-maker to another (cf. p. 6). If the livelihood and welfare of the decision-maker are dependent upon forestry, the indifference curves are very convex. Deviations from the optimal drain then induce major losses in utility. This is the situation in the national economy. If the cuts in the next ten years fall markedly below the planned level of drain, serious disturbances are to be expected. Correspondingly, if the cuts clearly exceed the planned drain, similar problems are due to occur in the future. Nonetheless, it should be noted that the convexity of the indifference curves is largely dependent upon the expectancy of the deviations. Abrupt deviations result in sharply convex indifference curves, and in major losses if the planned drain is not followed.

A private forest owner who regards the forest purely as an investment may have a utility function with indifference curves which are nearly linear, and in some cases, even concave to the origin. As his livelihood is not dependent upon the income derived from forestry, sustained drain is not a necessity for him. He is not bound to any planned drain, and may regulate his cuttings in accordance with timber prices and other investment opportunities.

Figure 8 illustrates a situation in which improved forest management has moved the original production possibility boundary (S_1) to a new position (S_2). The utility functions $U_1|S_1$ and $U_2|S_2$ are presented in Figure 9. Curve $U_1|S_1$ indicates the utility of the decision-maker who is prepared for drain A_1, and curve $U_2|S_2$ the utility when he is prepared for drain A_2. The increase in the utility (ΔU), for instance, is attributable to employment of the timber production model.

Figure 9 further illustrates the consequence of an erroneous timber production model. If the calculations yield boundary S_1, although S_2 would be the correct one, a loss in the utility amounting to l_1 is inflicted. Correspondingly, if the timber production model has yielded boundary S_2, and the correct one is S_1, the loss in the utility amounts to l_2.

These examples illustrate a decision situation in which the future and the utility function are known. In a realistic situation, these conditions are never completely fulfilled, and thus a more sophisticated study of the decision problem is needed. The decision problem can then be regarded as a two-person game. If it is assumed that an opponent does not knowingly set himself in opposition to the player, the problem can be regarded as a game against nature or the timber product market (cf. Baumol 1972, p. 575). This assumption is probably applicable to the national level.

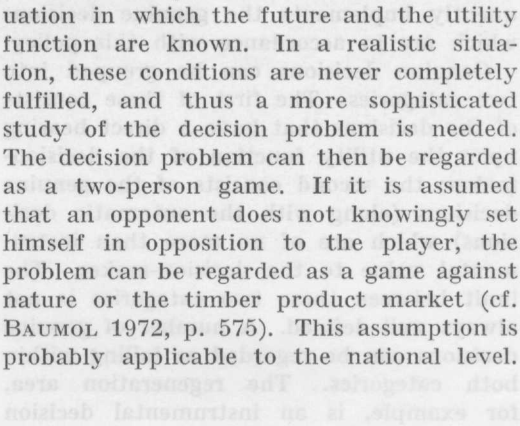


Fig. 8. Influence of improved forest management upon the production possibility boundary

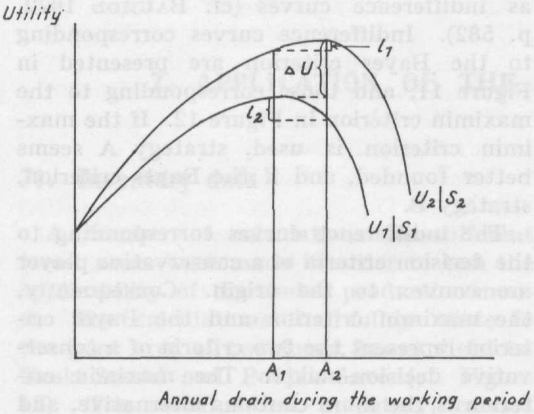


Fig. 9. Utility losses (l_1 and l_2) arising from an erroneous timber production model

Finnish forestry, at least, is a relatively small factor in international trade, and presumably the forest policy the country decides to pursue in the future will not exercise any marked influence upon the economic decisions of other nations.

The strategies available for choice by the decision-maker are different timber production policies. The opponent, in turn, can choose between different forest product prices. Below, the previous simplified example is brought one step further. It is assumed that the opponent has in reserve two possible strategies, C and D. Strategy C means stable prices for timber products in the foreseeable future. Strategy D means increasing prices for timber products, as compared to other products. The decision-maker does not know which of these two strategies the opponent will choose.

On the assumption that knowledge is possessed of the utility functions that correspond to both strategies, it is possible to derive the respective indifference maps, and to discover the optimal pure strategies that will meet the opponent's strategies. The solutions are derived graphically in Figure 10, in which I_C and I_D represent indifference curves of the utility functions of the opponent's strategies C and D, respectively. Strategy A which here indicates equal drains in all years to come, is the optimal strategy for the opponent's strategy C. Strategy B, which here indicates increasing cuts, is the optimal strategy for the opponent's strategy D.

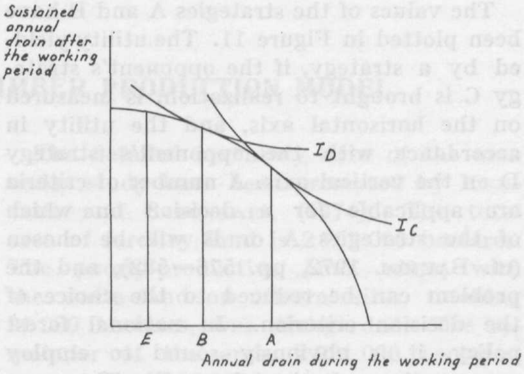


Fig. 10. Graphical solutions of the optimal strategies A and B corresponding to the opponent's strategies C and D. I_C and I_D are indifference curves derived from the utility functions corresponding to the opponent's strategies C and D.

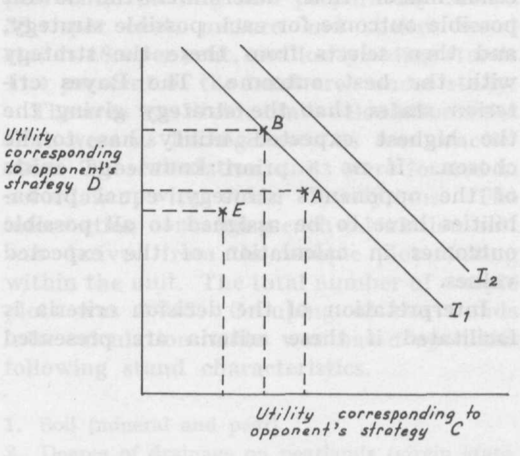


Fig. 11. Choice of the optimal strategy by the use of the Bayes criterion (indifference curves I_1 and I_2)

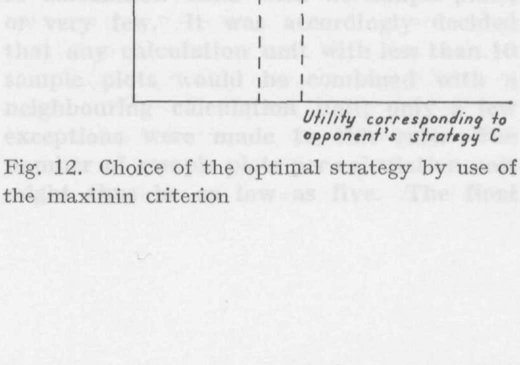


Fig. 12. Choice of the optimal strategy by use of the maximin criterion

The values of the strategies A and B have been plotted in Figure 11. The utility yielded by a strategy, if the opponent's strategy C is brought to realization, is measured on the horisontal axis, and the utility in accordance with the opponent's strategy D on the vertical axis. A number of criteria are applicable for a decision on which of the strategies A or B will be chosen (cf. Baumol 1972, pp. 576–582), and the problem can be reduced to the choice of the decision criterion. In national forest policy, it is obviously sound to employ conservative criteria (cf. p. 6). The most obvious criteria are thus the maximin criterion, and the Bayes (Laplace) criterion, or any compromise between these two. If the maximin criterion is applied, the decision-maker first determines the lowest possible outcome for each possible strategy, and then selects from these the strategy with the best outcome. The Bayes criterion states that the strategy giving the the highest expected utility has to be chosen. If no a priori knowledge exists of the opponent's strategy, equal probabilities have to be assigned to all possible outcomes in calculation of the expected values.

Interpretation of the decision criteria is facilitated if these criteria are presented as indifference curves (cf. Baumol 1972, p. 582). Indifference curves corresponding to the Bayes criterion are presented in Figure 11, and those corresponding to the maximin criterion in Figure 12. If the maximin criterion is used, strategy A seems better founded, and if the Bayes criterion, strategy B.

The indifference curves corresponding to the decision criteria of a conservative player are convex to the origin. Consequently, the maximin criterion and the Bayes criterion represent the two criteria of a conservative decision-maker. The maximin criterion is the more cautious alternative, and the Bayes criterion the more daring. All the other conservative decision criteria that are possible are compromises between these two.

Decision making remains a matter for speculation after the previous analysis has been made. However, the analysis is of assistance, at least in the elimination of the strategies that will not under any circumstances prove to be the best. For example, strategy E (cf. Figure 10) appears to be strongly dominated both by strategy A and by strategy B when plotted in Figure 11. Apparently, it should not be chosen if there holds the assumption of only two possible opponent's strategies, C and D.

7. APPLICATION OF THE TIMBER PRODUCTION MODEL

71. Inventory data

A number of calculations for different forest areas were made in order to test the applicability of the timber production model. The calculations that follow relate to the joint area of two forest board districts, Keski-Suomi and Pohjois-Savo (cf. Figure 13). The recent forest inventory, carried out in the summer of 1973, led to the choice of this area, which was regarded as highly representative of the forests of Finland. The areas of two forest board districts were combined as it was thought that the area of one district would be too small to provide accurate estimates for calculation units.

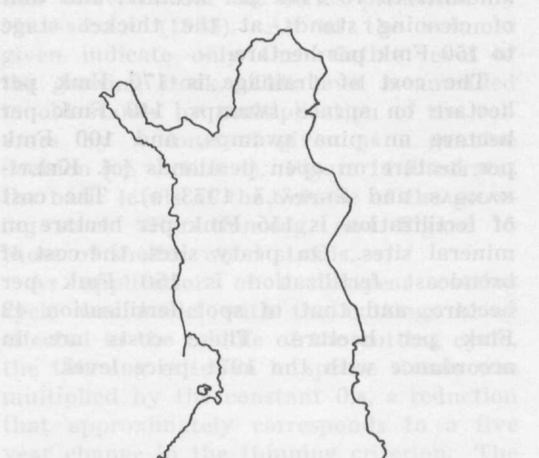


Fig. 13. Location of forest board districts Keski-Suomi and Pohjois-Savo

The detailed inventory data of the area under study have been presented by KUUSELA and SALOVAARA (1974). The total area of forestry land is 2 752 000 hectares. The poorly-productive land, along with the waste land on mineral sites, totalling 21 000 hectares, was disregarded. The remainder of the area, 2 731 000 hectares, comprises 1 959 000 hectares of mineral sites, and 772 000 hectares of peaty sites. The open peatlands comprise 2.5 per cent, other open areas and seed tree stands 4.5 per cent, seedling and sapling stands 24.7 per cent, thinning and preparatory stands 38.9 per cent, mature and shelter wood stands 18.4 per cent, and low-yielding stands 11.0 per cent of the total area under study.

The area was divided into calculation units that were as homogeneous as was practicable. The calculation units were formed in accordance with stand descriptions. The information concerning each calculation unit was derived from the sample plots falling within the unit. The total number of sample plots was 8 718. Grouping of the stands into calculation units was based upon the following stand characteristics.

1. Soil (mineral and peat)
2. Degree of drainage on peatlands (virgin state, recently drained, transforming and transformed site)
3. Site class (1, 2, 3, 4, 5, 6, and 7)
4. Dominant tree species (pine, spruce, birch, and other broadleaved trees)
5. Age (open area, 1–10, 11–20, 21–40, 41–60, 61–80, 81–100, and 101+ years)
6. Basal area (0–6, 7–13, 14–20, 21–27, and 27 + m²/ha)

The grouping resulted in a large number of calculation units with no sample plots, or very few. It was accordingly decided that any calculation unit with less than 10 sample plots would be combined with a neighbouring calculation unit; only a few exceptions were made to this rule. The number of sample plots per calculation unit might thus be as low as five. The final number of calculation units amounted to 134 on mineral sites, and 92 on peaty sites, giving a total figure of 226 calculation units. All of the stand description variables required were derived as averages from the data of the sample plots. For variables measured by ratio scale, means were used, and the mode was generally used for variables measured by nominal or ordinary scales. The volume growth level of the timber production model was reduced by 6 per cent to give the level measured in the inventory.

The basic work in the grouping was effected by means of a computer program which is a part of the data processing system of the national forest inventory, but the final design of the calculation units called for some manual work. This is in fact the only phase in which manual work is still required, apart from final analysis of the results.

72. Price and cost data

The timber prices used are those of the 1971—72 price level in Southern Finland, with delivery prices as follows:

Sawlogs

Pine	56.40	Fmk/cu.m. excluding bark
Spruce	52.75	»
Birch	75.00	»

Pulpwood

Pine	37.50	»
Spruce	43.00	»
Birch and other hardwoods	32.80	»

The prices of sawlogs were raised slightly with variation in log size (cf. Selin 1957).

The logging costs relate to the same period of time as the timber prices; they were derived from the studies of the Hako-committee (cf. Kilkki 1972, pp. 123—126). The logging costs are presented as a function of the logging method, volume of removal per hectare, and the mean volume of the felled trees.

The costs of silvicultural measures were derived from a study relating to the year 1965 (Metsänviljelykustannusten . . 1971). Reference was made to the wholesale price index for conversion of the prices to the price level of 1971.

Clearing of the site in natural regeneration costs 50 Fmk, and soil preparation an additional 100 Fmk per hectare. The planting cost, which includes clearing of the site and the necessary soil preparation, depends upon the site class, as shown below:

Site class	Planting cost, Fmk/ha
1	445
2	440
3	325
4 and 5	210

The joint cost of beating up and weeding amounts to 75 Fmk per hectare, and that of cleaning stands at the thicket stage to 150 Fmk per hectare.

The cost of drainage is 170 Fmk per hectare on spruce swamps, 140 Fmk per hectare on pine swamps, and 100 Fmk per hectare on open peatlands (cf. Keltikangas and Seppälä 1973 a). The cost of fertilization is 155 Fmk per hectare on mineral sites. On peaty sites, the cost of broadcast fertilization is 150 Fmk per hectare, and that of spot fertilization 42 Fmk per hectare. These costs are in accordance with the 1971 price level.

73. Decision data

It was assumed that the afforestation, drainage, and fertilization were effected in accordance with the figures listed in Table 1. The afforestation area consists of agricultural land, open bog, and open forest area.

The cuttings were assumed to be concentrated in the middle of ten-year period. The minimum removal was 25 m^3/ha in the thinning of young stands, 40 m^3/ha in increment cutting in old stands, 40 m^3/ha

Table 1. Afforestation, drainage, and fertilization areas (1 000 ha) in the standard policy

Measure	Years				
	1973—83	1983—93	1993—03	2003—13	2013—23
Afforestation	128.14	—	—	—	—
Drainage	145.07	50.75	—	—	—
Fertilization					
mineral sites	200.52	97.75	—	—	—
peaty sites	210.22	128.16	53.27	76.45	59.85

in liberation, and 25 m³/ha in shelter wood cuttings. The method of regeneration was in conformity with the automatic decision rules.

In one-storey stands, the volumes of the growing stock after thinning were arrived at by application of the series presented by Kuusela and Nyyssönen (1962) and Vuokila (1971). In shelter wood stands the volume of the upper storey was derived from the series presented by Nyyssönen (1958). All of the volumes given indicate only the relative level of the growing stock. This level is amended in old stands by multiplication of the volumes by a constant given as a genuine decision (cf. section 4). Figure 14 illustrates the basic levels of the volume of the growing stock after thinning, and Figure 15 those of shelter wood stands.

As application of a ten-year cutting cycle was made, with the cuttings being effected in the middle of the cutting cycle, the thinning criterion in spruce stands was multiplied by the constant 0.8, a reduction that approximately corresponds to a five year change in the thinning criterion. The reduction is too heavy for sparsely stocked stands. In any event, thinning is out of the question in these stands, and there does not arise any major error attributable to this practice.

In pine stands, the thinning criteria were obviously too low as a consequence of use of an erroneous growth function. In view of this, the thinning criteria in pine stands were multiplied by a constant of 1.3, to set them on a par with the spruce stands. As a ten-year cutting cycle was applied, the regeneration criteria were multiplied by a constant of 0.9, to arrive at the average reduction in the criterion during a period of five years. In young and sparsely stocked stands, this reduction leads to slight underestimation. Artificial regeneration was employed on site classes 1 and 2, and

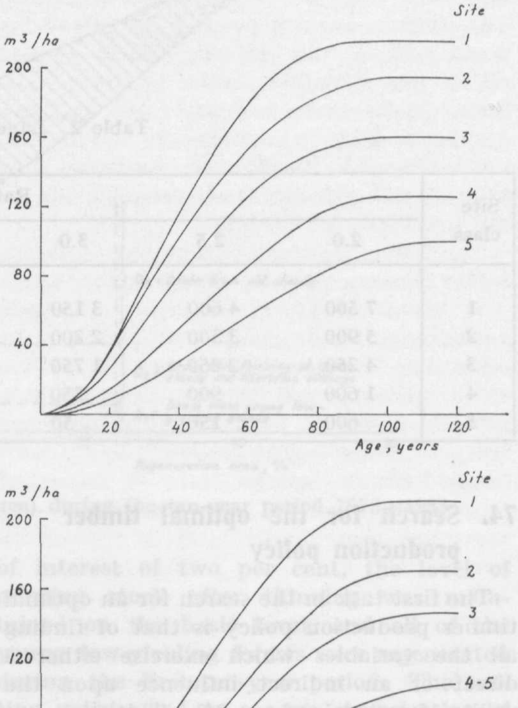


Fig. 14. Volume of the growing stock after thinning. Upper: Pine. Lower: Spruce.

natural regeneration on site classes from 3 to 6 if the dominant tree species was pine. In the case of natural regeneration, the regeneration criteria were multiplied by a constant of 0.8. This implies that shelter wood cutting is carried out approximately ten years earlier than is clear cutting in similar stands.

The land values needed in determination of the regeneration criteria were calculated by means of the Faustmann formula, and are in accord with the growth and yield data presented in this section and in section 3. The land values are presented in Table 2 as a function of the site class and the rate of interest. The negative land values have been rounded off to zero.

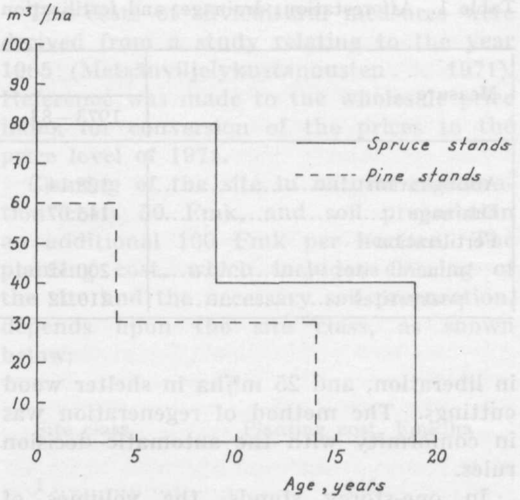


Fig. 15. Volume of the growing stock after shelter wood cutting and the time of liberation cutting as a function of the tree species and the age of the lower storey

Table 2. Land values, Fmk/ha

Site class	Rate of interest						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1	7 500	4 600	3 150	2 150	1 400	900	550
2	5 900	3 500	2 200	1 400	850	450	250
3	4 250	2 650	1 750	1 150	700	400	200
4	1 600	900	550	300	100	50	0
5	600	150	50	0	0	0	0

74. Search for the optimal timber production policy

The first task in the search for an optimal timber production policy is that of finding all the variables which exercise either a direct or an indirect influence upon the utility function (cf. p. 21). This task has in fact been carried out in part in design of the output of the timber production model. However, the output may include variables that posses little or no value as far as the decision-maker is concerned, or the output may be inadequate, so that the model cannot be used. If the information yielded by the timber production model is considered adequate, alternative calculations can be made with a view to discovering a set of feasible solutions, or in other words an estimate of a multidimensional production possibility boundary.

The second task is that of discovering the possible strategies of the environment, and of associating a utility for each timber production policy and future combination.

The third task is that of determining the decision criteria, and of choosing the optimum timber production policy.

In similarity to the examples given in section 6, the following discussion on production possibility boundaries is first limited to a situation with only two decision variables. One variable is the volume drain, and the other the regeneration area during the first ten-year period (1973—83). Another variable, the largest sustained yield after the first ten-year period, for instance, might have been superior to the regeneration area as a predicting variable in the utility function; however, its determination is rather tedious. Nonetheless, the regeneration area is derivable by a very simple calculation which covers only the first ten-year period (cf. p. 19).

In view of the possibility of regulating the ratio between the selection and regeneration cuttings up to a certain limit, a number of feasible production possibility boundaries can be found. Different production possibility boundaries were effected by allowing variations, during the first ten-year period in (1) the land values, in (2) the level of the growing stock after thinning, and in (3) the extent of the low-yielding young forests which have to be regenerated.

Figure 16 illustrates two extreme production possibility boundaries. All of the other production possibility boundaries lie within the shaded area between these two lines. Contrary to the examples in section 5, the decision variables now stand in positive correlation, and the production possibility boundaries are ascending lines.

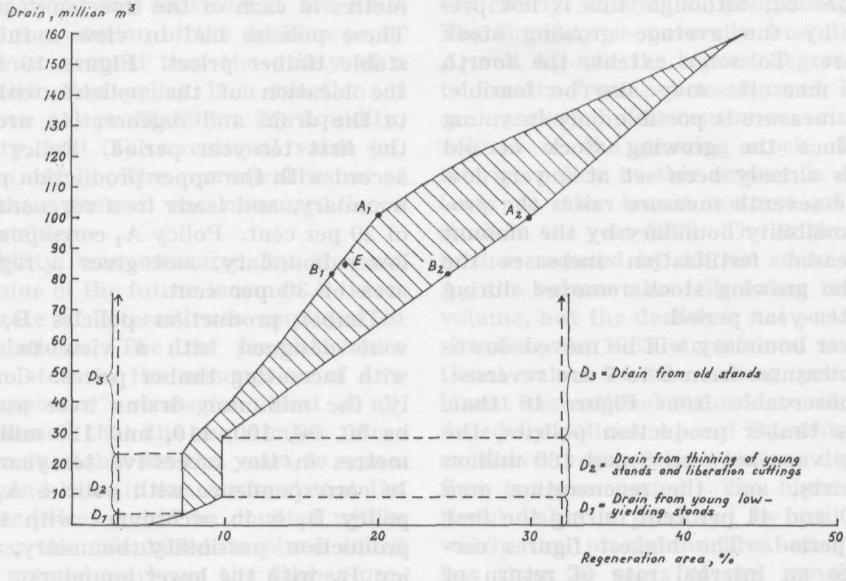


Fig. 16. Feasible production policies (shaded area) during the ten-year period 1973—1983

The upper line is in accord with the cutting policies, which tend to avoid regeneration to the greatest possible extent. To minimize the regeneration area, land values corresponding to a rate of interest of five per cent were employed; the level of the growing stock after thinning was reduced by 40 per cent from the basic level (cf. Figure 14), and 52 per cent of the low-yielding young stands were transferred to normal stands.

The lower line is in accord with the cutting policies which strive to achieve the largest possible regeneration areas. The land values were in accordance with a rate of interest of two per cent, the level of growing stock after thinning was maintained on the basic level, and all of the young low-yielding forests were regenerated during the first ten-year period. The cutting policies led to a complete rejection of thinnings in old stands.

The set of feasible timber production policies can still be extended. The upper production possibility boundary can be moved upwards, at least by the following measures.

1. All open areas are not regenerated during the first ten-year period.

2. The definition of low-yielding young stands is further relaxed.
3. The level of the growing stock in young stands is diminished.
4. Liberation cuttings are effected at a faster rate.
5. The cutting cycle is shortened from the present ten years.
6. The minimum cutting removal is reduced.
7. Fertilization in mature stands is increased.

The first, and in all probability the second measure as well, are completely negative, and cannot be recommended under any circumstances. The third measure may be given consideration, in view of the constant existence of young stands in which thinning is needed, although this is not presupposed by the average growing stock per hectare. To some extent, the fourth and fifth measures may also be feasible. The sixth measure is possible only in young stands, since the growing stock in old stands has already been set at a very low level. The seventh measure raises the production possibility boundary by the amount the increased fertilization increases the part of the growing stock removed during the first ten-year period.

The lower boundary will be moved downwards if measures from 2 to 7 are reversed.

It is observable from Figure 16 that, in feasible timber production policies, the drain may vary between 0 and 160 million cubic metres, and the regeneration area between 0 and 44 per cent during the first ten-year period. The highest figures correspond to an internal rate of return of 5 per cent. In reality, of course, the choices are much more limited. It is difficult to imagine the drain not falling between 70 and 100 million cubic metres, or the regeneration area between 10 and 30 per cent. In the years 1968—72, the average drain in the area concerned amounted to 8.14 million cubic metres per year, and the regeneration area to approximately 1.3 per cent per year (Metsätilastollinen . . . 1970, 1971, 1972, 1974). Nevertheless, the decision-maker still has a wide variety of choices at his disposal. For instance, a drain equivalent to that of past years is achievable by the agency of regeneration areas varying from 16.9 to 24.5 per cent during the ten-year period.

Nonetheless, it is evident that the drain and the regeneration area during the first ten-year period do not provide sufficient information for determination of the utility of a given timber production policy. As a result, analysis of the production policies needs to be extended to provide additional predicting variables. The practicability of discovering exact production possibility boundaries has thus diminished, since the number of calculations is limited. The following analysis is limited to four timber production policies, each covering a fifty-year period.

The first two policies, A_1 and A_2, assume even drains of at least 100 million cubic metres in each of the five ten-year periods. These policies had in view a future with stable timber prices. Figure 16 illustrates the location of the policies with respect to the drain and regeneration area during the first ten-year period. Policy A_1 is in accord with the upper production possibility boundary, and leads to a regeneration area of 20 per cent. Policy A_2 corresponds to the lower boundary, and gives a regeneration area of 30 per cent.

Timber production policies B_1 and B_2 were designed with a view to a future with increasing timber prices. Consequently, the minimum drains were assumed to be 80, 90, 100, 110, and 120 million cubic metres in the successive ten-year periods. In correspondence with policies A_1 and A_2, policy B_1 is in accordance with the upper production possibility boundary, and policy B_2 with the lower boundary. In policy B_1, the regeneration area is 17.0 per cent, and in policy B_2, 24.6 per cent during the first ten-year period.

Subsequent to the first ten-year period, the volume drain requirements were, except as regards drainage and fertilization, the only real genuine decisions. Nonetheless, some other genuine decisions were needed in regulation of the drain requirement, as at times the integer solution led too far from the drain desired.

It proved practicable to satisfy the volume drain requirements during the fifty-year period in each of the four production policies. However, the development of the forests varied widely in different policies. The most abrupt changes in the age-class structure were produced by policy A_2, which assumes even drains throughout the fifty-year period. The same features are perceptible in policy B_2, although development of the age-class structure of the forests was slightly less radical. Policies A_1 and A_2 led to a fall in the volume of the growing stock during the first two decades, a phenomenon which did not become apparent on following policies B_1 and B_2.

Measurement of the desirability of a timber production policy presupposes knowledge of the utility function (cf. p. 21). In this work it was impracticable to enter more deeply into this problem. As a result, a simple and completely subjective utility function was constructed for illustration of the solution of the decision problem. It was assumed that the utility of a timber production policy is a function of four factors: (1) profitability, (2) liquidity, (3) security, and (4) recreational value (cf. RUNEBERG 1959). The numerical value of each of these factors was measured by a single variable.

Profitability was measured by the net present value of the future income. A three-per-cent rate of interest was employed in the calculations. The net present values were calculated on the assumption of two possible opponent's strategies. First of all, it was assumed that the real timber prices would remain stable for the years to come. In the second case, it was assumed that the real timber prices would be doubled within fifty years; the calculation involved called for some manual work, as the timber production model employs only one price level for the whole period. Liquidity was measured by the volume of the merchantable drain during the first ten-year period. The minimum volume of the growing stock after the first ten-year period was taken as a measure of the security, and the recreational value of the forest area was measured as the percentage proportion of the forests exceeding 20 years of age.

Table 3 contains the relative values of the predicting variables of the utility function. The profitability figures for the four production policies remain almost identical on the materialization of a future with stable timber prices. Under conditions of rising timber prices, policies B_1 and B_2 are clearly superior to policies A_1 and A_2. The liquidity is naturally best in policies A_1 and A_2, and the highest degree of security results from policies B_1 and B_2, which are marked by a continuous rise in the volume of the growing stock. The most inferior policy in this respect is A_2, which leads to the lowest volume of growing stock in the year 1993. The original volume is then reduced by 12 per cent. In policy A_1, the volume also falls below the original volume, but the decline is not so large. The situation in 1983 determines the recreational values of the cutting policies. The lowest recreational values are clearly produced by policies A_2 and B_2, which assume excessive regeneration areas during the first ten-year period. The highest recreational value is produced by policy B_1, in which the maximum area of forests of less than 20 years of age remains at 40 per cent in the year 1983.

Table 3. Values of the utility function variables

Variable	Policy			
	A_1	A_2	B_1	B_2
Profitability				
stable timber prices	100.0	99.4	102.5	101.2
rising timber prices	138.3	138.0	148.3	145.8
Liquidity	100.0	99.0	80.1	81.7
Security	100.0	96.1	116.0	114.0
Recreational value	100.0	81.0	106.0	91.0

The utility function was taken simply as the product of the predicting variables. The assumption of such a form for the utility function finds support in that a policy which yields a very poor value for particular vital factor should have a low utility as a whole. The utility function yielded the following relative utilities.

Policy	Stable prices	Rising prices
A_1	100.0	138.0
A_2...................	76.6	106.3
B_1	101.0	146.1
B_2	85.8	123.6

It is probable that the measurement scale in which the figures are expressed is closer to the interval scale than the ordinal scale (cf. Ellis 1966). Consequently, the magnitude of the differences of the utilities can, at least to some extent, be taken into account in a comparison of the policies.

The utilities have been plotted in Figure 17; it is observable that policy B_1 strongly dominates the other three policies. Policy B_1 would consequently be the best choice, irrespective of the decision criterion. However, the differences between policies B_1 and A_1 are not significant. The poorest choice would be policy A_2, which is strongly dominated by the other three policies. It is further evident that, given the previous utility function, policies (A_1 and B_1) with aversion to regeneration during the first ten-year period, are superior to policies (A_2 and B_2), which favour regeneration.

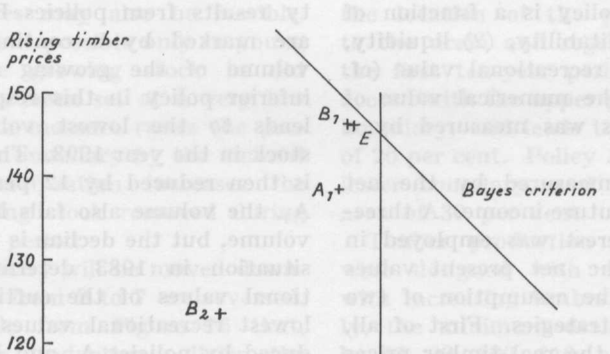


Fig. 17. Utilities of various cutting policies corresponding to two different opponent's strategies with examples of the Bayes and maximin criteria

Comparison of the utilities also indicates that the policies that favour regeneration during the first ten-year period are relatively inferior if the drain requirement is high. The conclusion can be drawn that with a low drain requirement the optimal policy is close to the lower boundary, and moves toward the upper boundary with increase in the drain requirement of the first ten-year period (cf. Figure 16). Nevertheless, determination of the optimal expansion path would call for a number of supplementary calculations.

It here becomes necessary to make two critical comments on the utility function. First of all, it fails to take into account a number of important variables, such as the distribution of the volume drain into timber assortments and manpower requirements. Secondly, the form of the function is unsatisfactory. As the community is already prepared for a stated timber production policy, the dependence of the utility upon the volume of the merchantable drain during the first ten-year period cannot be linear. Evidently, moreover, the linearity assumption does not hold good with the other variables.

75. Description of a feasible production policy

The preceding section provided some conceptions in regard to determination of the optimal timber production policy. If the utility function holds approximately true, the optimal policy may lie somewhere between policies A_1 and B_1. The allowable cut estimate presented by KUUSELA and SALOVAARA (1968) satisfies this condition with respect to the liquidity. More detailed examination was given to policy E, which takes this drain figure as a starting point. This fifty-year timber production policy is characterized by the following genuine decisions.

1. The minimum volume drain amounts to 84.5, 92.5, 100.0, 107.5, and 115.0 million cubic metres in successive ten-year periods.
2. The volume of the growing stock after increment cutting amounts to 70, 70, 75, 90, and 100 per cent of the basic level in successive ten-year periods.
3. The land values are in conformity with rates of interest of 5.0, 5.0, 4.0, 4.0, and 3.0 per cent in the successive ten-year periods.
4. The definition of low-yielding young forests corresponds to that of policies A_1 and B_1.
5. The minimum removals in selection cuttings are those listed on pages 26 and 27.
6. Afforestation, drainage, and fertilization follow the programme presented in Table 1.

The position of policy E with respect to the volume drain and regeneration area during the first ten-year period is illustrated in Figure 16. Additional information on the development and distribution of volume drain, cutting areas, income, and costs, is given in Figures 18, 19, 20, and 21. It is seen from Figure 18 that the share of old stands in the volume drain gradually diminishes during the fifty-year period. The only exception is that between the first two ten-year periods. This phenomenon arises from the assumption that all of the necessary thinnings in young stands are carried out during the first ten-year period. Apparently this assumption is not absolutely realistic, as some of these thinnings are still due in the second ten-year period.

Development of the cutting areas is much more dramatic than that of the volume drain (Figure 19). The proportion of thinnings increases from 24 per cent during the first ten-year period to 66 per cent during the fifth ten-year period. It might accordingly be expected that radical changes are due to occur in the assortment distribution of the drain during the fifty-year period. However, this is not the case (Figure 20). Since it is assumed that the volumes in the mature stands increase appreciably from their present level, the saw timber percentage will remain above the 50 per cent limit after the first ten-year period, althoug the maximum figure, 68 per cent, has already been attained during the second ten-year period. The proportionate share of wastewood reaches its maximum level, 11 per cent, during the fourth period. Thus the amount of merchantable timber does not increase between the third and fourth ten-year periods.

Figure 21 illustrates the distribution of the delivery value of the drain between the net income drawn by the forest owners, the logging costs, the silvicultural costs, and the costs of drainage and fertilization. The delivery value, along with the net income, increases until the year 2000. Subsequently, they both experience temporary declines, but rise again during the last ten-year period. The net income of the forest owner remains, quite invariably, between 78 and 81 per cent. The only exception is to be found during the first ten-year period. The percentage is then only 76 by reason of the expensive cuttings and large areas of regeneration, drainage, and fertilization.

Figure 22 illustrates the development of some growing stock characteristics during the fifty-year period. The volume growth

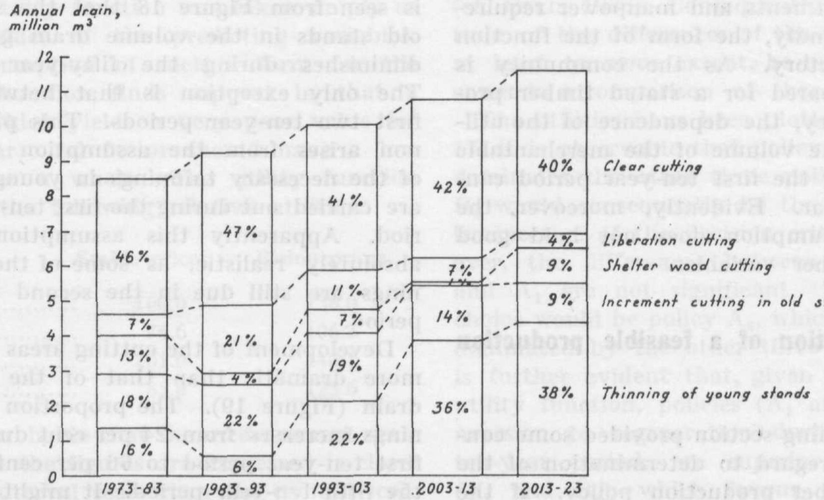


Fig. 18. Distribution of the volume drain, by different cuttings

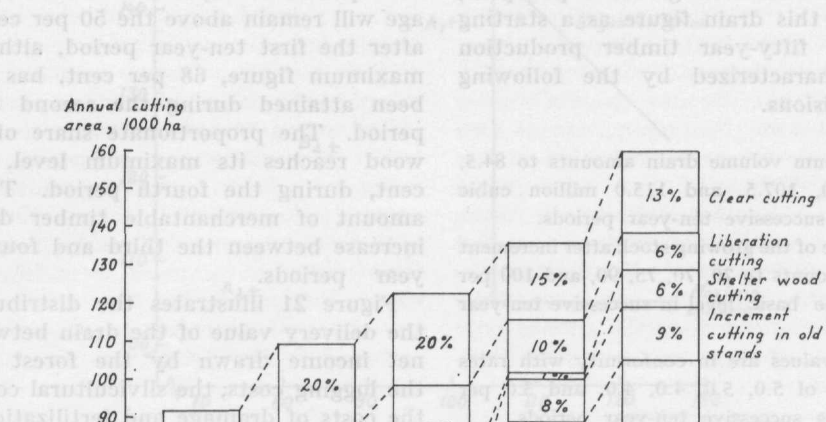


Fig. 19. Distribution of the cutting area, by different cuttings

is increasing continuously and will be 47 per cent higher in 2023 than is the case now. The volume also increases continuously, exceeding the original volume by 36 per cent in 2023. The value growth measured by delivery prices increases first, but later declines close to its original level before the year 2000. Subsequently it rises rapidly, to 35 per cent over the present level in 2023. The delivery value increases continuously. Towards the end of the fifty-year period, the delivery value arises, to exceed the original figure by 25 per cent in the year 2023.

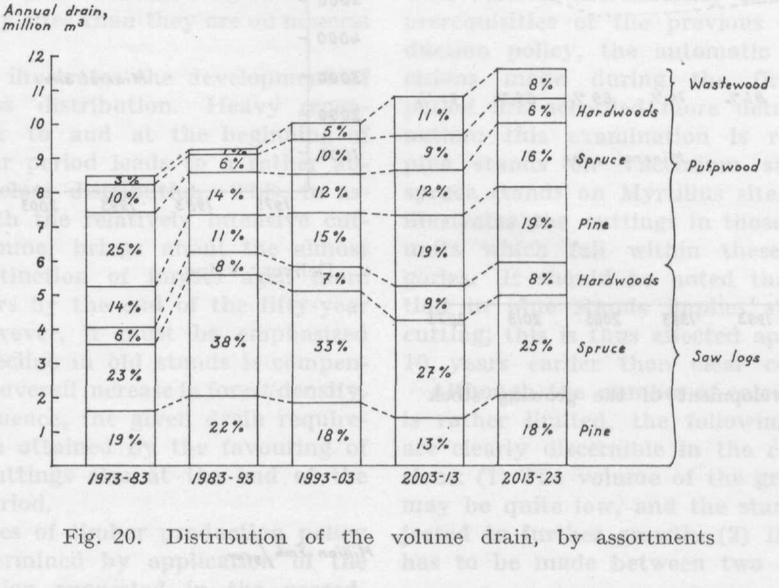


Fig. 20. Distribution of the volume drain, by assortments

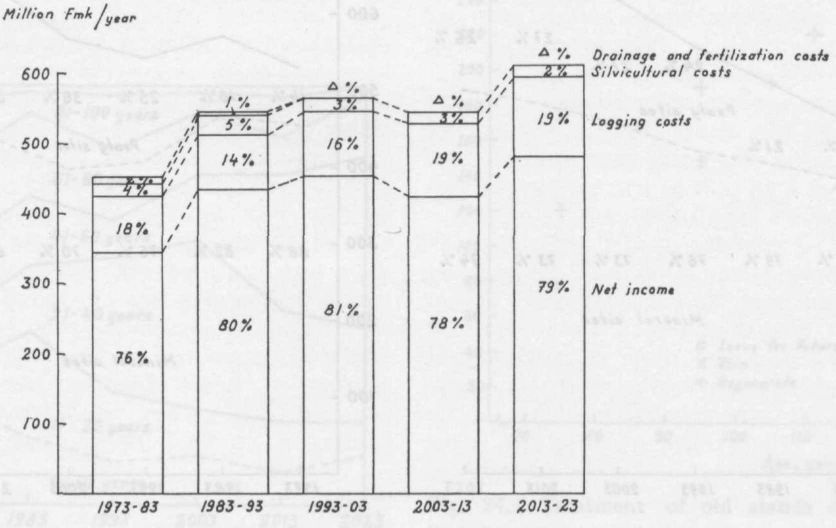
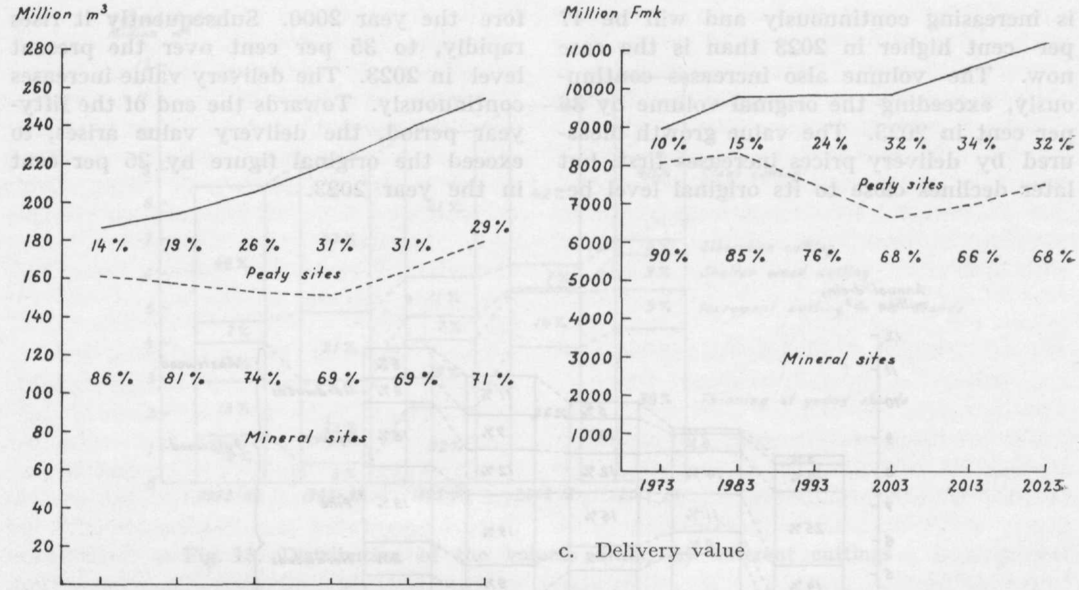
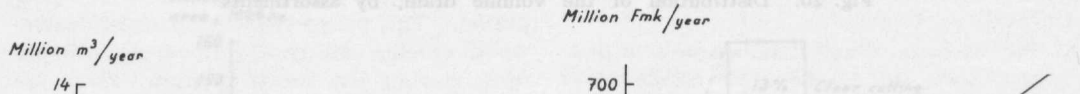


Fig. 21. Development of the gross income and its distribution between net income and costs



c. Delivery value

Fig. 22. Development of the growing stock
a. Volume



b. Volume growth

d. Value growth

Figure 22 further indicates a major increase in the importance of peaty sites towards the turn of the century as a result of past drainage. For instance, the proportionate share of peaty sites in the total volume will rise from the present 14 per cent to 31 per cent in 2003. It is also important that peaty sites markedly balance the age-class structure, as currently age-classes from 21 to 61 years are relatively more common on peaty sites than they are on mineral sites.

Figure 23 illustrates the development of the age-class distribution. Heavy regeneration prior to and at the beginning of the fifty-year period leads to a rather abnormal age-class distribution. This, in association with the relatively intensive cutting programme, brings about the almost complete extinction of forests aged more than 81 years by the end of the fifty-year period. However, it must be emphasized that this decline in old stands is compensated by the overall increase in forest density. As a consequence, the given drain requirement can be attained by the favouring of increment cuttings also at the end of the fifty-year period.

The utilities of timber production policy E were determined by application of the utility function suggested in the preceding section. The profitability index with stable timber prices was 102.4, and that with rising timber prices 146.8, the liquidity index 84.1, the security index 113.5, and the recreational value index 104.0. The utilities were 101.7 for stable timber prices, and 145.7 for rising timber prices. According to these figures, policy E is approximately equivalent to policy B_1 (cf. Figure 17).

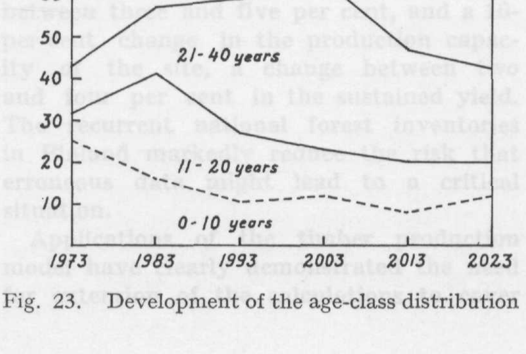


Fig. 23. Development of the age-class distribution

In view of the necessity of knowing the prerequisities of the previous timber production policy, the automatic cutting decisions made during the first ten-year period are accorded more detailed examination; this examination is restricted to pine stands on Vaccinium site, and to spruce stands on Myrtillus site. Figure 24 illustrates the cuttings in those calculation units which fall within these two categories. It should be noted that regeneration in pine stands implies shelter wood cutting; this is thus effected approximately 10 years earlier than clear cutting.

Although the number of calculation units is rather limited, the following principles are clearly discernible in the cutting decisions: (1) The volume of the growing stock may be quite low, and the stand still subjected to further growth. (2) If the choice has to be made between two stands with

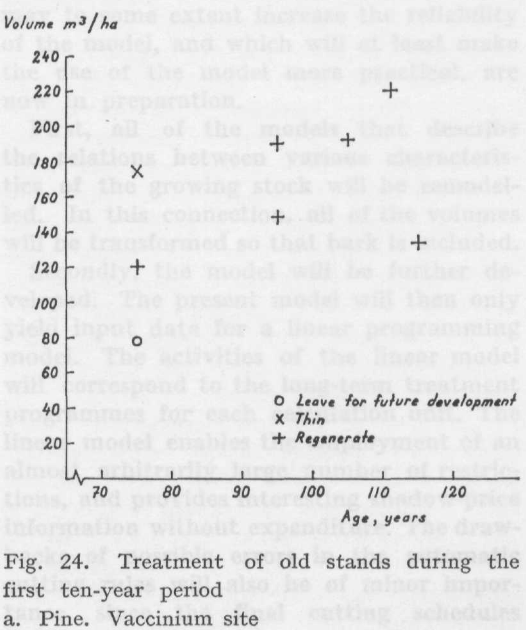


Fig. 24. Treatment of old stands during the first ten-year period

a. Pine. Vaccinium site

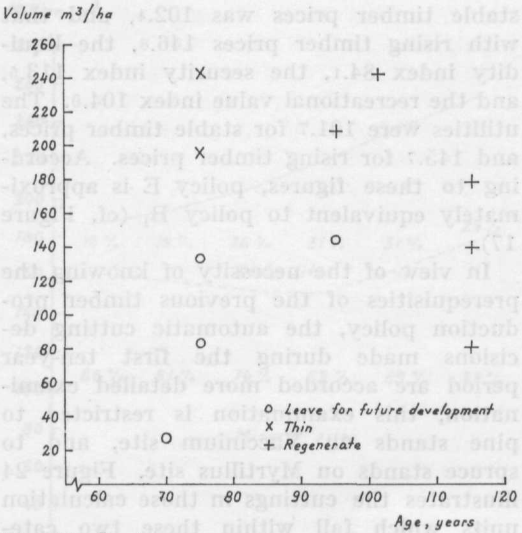


Fig. 24. Cont.
b. Spruce. Myrtillus site

equal characteristics other than that of the volume, the stand with the higher volume is generally regenerated first. The same features have been observed in pure profitability calculations (cf. Kilkki and Väisänen 1969; Kilkki 1972). The necessity to grow a stand with a relatively low volume is further stressed if it forms a part of a forest area in which the growing stock is a resource that is scarcer than the land. Nonetheless, it needs to be emphasized that the treatment rules are not permanent and unchangeable, but will be amended as dictated by the condition of the forest and the needs of the community. A stand treatment policy which favoured regeneration was appropriate a quarter century ago throughout the whole of Finland. It is extremely probable that a similar situation will be a fact in the early years of the 21st century.

Timber production policy E is feasible only if the decisions which form its basis are fully implemented, and if the data employed in the timber production model are reliable. Policy E is relatively close to the optimum if the utility function is approximately that assumed, the opponent's strategy lies at some point between the two opponent's strategies under examination, and the automatic decision rules are appropriate. As it is within the bounds of possibility that, despite the general acceptance of policy E, not all the necessary measures would be taken, it may be quite appropriate to start from a lower volume drain during the first ten-year period. Currently, relatively young and sparse forests enable the pursuit of this policy without any losses being incurred in profitability (cf. policy B_1 as against policy E).

8. DISCUSSION

The purpose of this study has been that of providing a better means for long-term planning in timber production, and to shed light upon the opportunities available for the utilization of the results in decision-making on the national level. The experience obtained indicates that the planning model developed here may be employed for provision of the necessary information for decision-making. Nevertheless, the real value of the anticipations offered by timber production model is dependent upon a number of factors.

First of all, a consensus should be obtained of the utility function on a national level. Although this might be accomplished, implementation of the decisions needed for the adoption of an accepted policy is difficult by reason of the current forest law and forest ownership in Finland. Of course, these factors reduce the importance of any plan made on the national level. Moreover, uncertainty as to the future introduces major problems into decisions. Notwithstanding this, it seems possible to overcome some of the difficulties arising from uncertainty by the agency of an adequate number of alternative timber production policy calculations, and correct treatment of the decision problem.

The most critical question in application of the timber production model is concerned with the reliability of the growth and yield data. No special tests were made to assess the sensitivity of the results to errors in these data. Nersten and Delbeck (1965) have estimated that a 10-per-cent change in the volume growth induces a change between three and five per cent, and a 10-per-cent change in the production capacity of the site, a change between two and four per cent in the sustained yield. The recurrent national forest inventories in Finland markedly reduce the risk that erroneous data might lead to a critical situation.

Applications of the timber production model have clearly demonstrated the need for extension of the calculations to cover a relatively long period of time, and to provide detailed information on development of the forests in accordance with a stated policy. Errors which might occur in evaluation of the forest after a fifty-year period are of far less importance than those occurring after a ten-year period. The analysis of the results has also demonstrated the need for research concerning the utility models of the community as a whole. In development of the timber production model, it must always be borne in mind that the output of the model should comprise only that information which provides the decision-maker with a value at least as large as a given minimum value. Today, unfortunately, the only one to decide on the variables to be included in the model is the model constructor himself.

At the moment, a number of ways already exist for improvement of the timber production model. The best means of augmenting the reliability of the model lies in the acquisition of more reliable growth and yield data. This, however, constitutes a long-term problem, impossible of solution in the near future. Some measures which may to some extent increase the reliability of the model, and which will at least make the use of the model more practical, are now in preparation.

First, all of the models that describe the relations between various characteristics of the growing stock will be remodelled. In this connection, all of the volumes will be transformed so that bark is included.

Secondly, the model will be further developed. The present model will then only yield input data for a linear programming model. The activities of the linear model will correspond to the long-term treatment programmes for each calculation unit. The linear model enables the employment of an almost arbitrarily large number of restrictions, and provides interesting shadow-price information without expenditure. The drawbacks of possible errors in the automatic cutting rules will also be of minor importance, since the final cutting schedules emerge from the solution of the linear model. Cutting decisions, which are currently aimed solely at maximization of the profitability, will then take into account all of the goals defined both by the object function and by the restrictions of the linear model. The new model will also save data processing costs, as the same set of activities may be used in a large number of calculations, and the present process of trial and error in the search for the desired policy can be avoided.

Thirdly, the link between the data processing system of the national forest inventory, and the timber production model, should be made automatic.

Furthermore, benefit would be derived by deviation from the present deterministic model and, say, allowing the automatic cutting rules include some random variation.

Under present circumstances, reduction in the present drain is one of the most effective means of increasing long-term forest production. Naturally, this presupposes that the savings are made in the stands with the highest thinning and regeneration criteria. The overall rejection of thinnings, for instance, would completely wreck the production policy. Special emphasis should also be laid upon individual treatment of the stands.

The new allowable cut estimate, 88.7 million cu.m. per ten years, presented by Kuusela and Salovaara (1974), also seems feasible, although it may lead to a fall in the drain of merchantable timber at the turn of the century.

9. SUMMARY

The aim of this study was the development of a long-term timber production model which would be applicable both to single forest lots and to large forest areas. The model is based upon numerical simulation, and has been programmed for a computer. The major part of the input data are obtained from forest measurements. The output data of the model comprise predictions of the necessary measures to be taken, and of the development of the forest area concerned during a stated planning period.

The forest area is divided into calculation units, each of which comprises either one subcompartment, or a group of subcompartments. Cuttings, natural and artificial regeneration, the tending of seedling stands, fertilization, and drainage, are the measures that can be adopted in each calculation unit. The measures in, and the development of each calculation unit, can be followed from year to year through the planning period.

The measures are based upon either genuine or automatic decisions. The genuine decisions, the most important of which are the annual drain and regeneration area, are generally applied to the whole forest area. The automatic decisions, such as those relating to cutting and regeneration, apply to the calculation units. Consequently, the user of the model does not need to formulate in advance a detailed treatment programme for each calculation unit. Special attention has been paid here to automatic cutting decisions; these are based upon classic investment criteria.

The sixth section is devoted to a theoretical discussion of the factors that determine the choice of a timber production policy. The timber production model is viewed only as a means of providing the decision-maker with values of the predicting variables in his utility function. In the final decision process, conservative decision criteria are regarded as appropriate if the decisions concern the whole community.

The timber production model was applied to the area of two forest board districts in Central Finland; the forest area was divided into 226 calculation units, 134 of which were on mineral sites, and 92 on peaty sites. The measurement data were extracted from the sixth national forest inventory, which was made in 1973.

First, a search was made for a set of feasible policy alternatives. The examination was limited to the first decade, 1973—83. The volume drain and regeneration area were used for characterization of the production policies. The examination indicated that a volume drain similar to that of the first ten-year period is achievable by widely different regeneration areas. With this result as a starting point, four timber production policies for a fifty-year period were selected for more detailed examination. Policies A_1 and A_2 represented relatively high and even volume drains, and policies B_1 and B_2 rising volume drains. The regeneration area of the first ten-year period was as low as possible in policies A_1 and B_1, and as high as possible in policies A_2 and B_2.

The utility of each production policy was derived from a utility function, in which the utility was calculated as a product of (1) the present net value of future income, (2) the volume of merchantable drain during the first ten-year period, (3) the lowest volume of growing stock after the first ten-year period, and (4) the lowest percentage proportion of the area of stands exceeding 20 years in age during the planning period. It was assumed that these variables, in the order given, measured the profitability, liquidity, security, and recreational value of the production policy. The present net value of the future income was calculated under two assumptions. First, the assumption was made that the timber prices would remain stable, and secondly, that they would double during a fifty-year period. It was assumed that in each case the costs would remain unchanged.

It became apparent from the calculations that, with the given hypothetical utility function, policies A_1 and B_1 were clearly superior to policies A_2 and B_2. Policy B_1 was the best choice, and its volume drain, 81 million cubic metres excluding bark during the first ten-year period, was found to be well in accordance with the actual drain of recent years.

The planned cut of the recent years was chosen as a basis for detailed calculation in regard to policy E for a fifty-year period. The volume drains of the successive ten-year periods were 84.9, 92.5, 100.4, 107.8, and 115.9 million cubic metres, excluding bark. The gross value of the drain was shown to increase rapidly, but with a temporary decline after the turn of the century by reason of the abundance of thinnings in young stands. The total development of the growing stock during the fifty-year period concerned was quite satisfactory. For example, the volume of the growing stock increased continuously, and exceeded the original volume by 36 per cent at the end of the planning period. Policy E was approximately as desirable as policy B_1, according to the preceding utility function.

The bringing to accomplishment of policy E, and also of the other four policies, presupposes afforestation of all open areas on forest land at the beginning of the calculation period, the following of a given drainage programme, and a relatively intensive fertilization programme during the following twenty years. Furthermore, it is assumed that the whole forest area is used for timber production. Policy E favours selection cuttings during the first part of the fifty-year period. The volume of the growing stock after increment cuttings, thus, is assumed to be 30 per cent lower at the beginning of the fifty-year period than at the end of the period.

The results need to be accepted with a number of reservations. The greatest uncertainties are associated with the growth and yield data. Nevertheless, it may be said that the present planned cut for the area under examination seems feasible as far as the forest resources are concerned, although no conclusions in regard to the desirability of this or any other drain, as viewed from the standpoint of the community, can be drawn from this presentation.

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Seloste:

PITKÄN AJAN PUUNTUOTANTOMALLI JA SEN SOVELLUTUS KESKI-SUOMEN JA POHJOIS-SAVON PIIRIMETSÄLAUTAKUNTIEN ALUEELLE

Tutkimuksessa on kehitetty sekä metsälölle että suurmetsäalueelle tehtäviin pitkän ajan ennusteisiin soveltuva hakkuulaskelmamalli. Mallia kutsutaan kuitenkin puuntuotantomalliksi, sillä kuutiometreissä ilmaistu hakkuusuunnite muodostaa päinvastoin kuin hakkuulaskelmamalleissa vain vähäisen osan mallin tuottamasta informaatiosta. Malli perustuu numeeriseen simulointiin ja se on ohjelmoitu tietokoneelle. Pääosa puuntuotantomallin syöttötiedoista saadaan metsästä tehtävillä mittauksilla. Mallista saadaan tuloksena ennusteita suunnittelun kohteena olevan metsäalueen kehityksestä sekä sillä tapahtuvista toimenpiteistä halutun pituisen suunnitelmakauden aikana. Saatujen ennusteiden pohjalta voi päätöksentekijä valita parhaaksi katsomansa vaihtoehdon toimintansa perustaksi.

Suunnittelun kohteena oleva metsäalue jaetaan laskentayksikköihin. Laskentayksikkö muodostuu joko yhdestä tai useammasta metsiköstä. Kunkin laskentayksikön maa ja puusto kuvataan tavanomaisin kuvioittaisessa arvioinnissa määritettävin metsikkötiedoin. Laskentayksikköihin kohdistuvia toimenpiteitä ovat hakkuut, luontainen ja keinollinen uudistaminen, taimiston hoito, lannoitus sekä ojitus. Toimenpiteitä sekä metsän kehitystä seurataan laskentayksikön tarkkuudella koko ennustejakson ajan.

Metsässä tapahtuvat toimenpiteet perustuvat joko aitoihin tai automaattisiin päätöksiin. Aidot päätökset, joista tärkeimpiä ovat esimerkiksi vuotuinen hakkuupoistuma ja uudistuspinta-ala, kohdistuvat yleensä koko metsäalueeseen. Automaattiset päätökset, joista tyypillisiä ovat hakkuu- ja metsänhoitopäätökset, kohdistuvat laskentayksiköihin. Mallin käyttäjän ei täten tarvitse määrittää etukäteen yksityiskohtaista käsittelyohjelmaa kullekin laskentayksikölle, vaan hän voi jättää sen aitoina päätöksinä annettujen automaattisten päätössääntöjen varaan. Erityistä huomiota on kiinnitetty hakkuupäätöksiin, joiden perustana ovat pääosaksi klassiset investointikriteerit.

Kuudennessa luvussa tarkastellaan puuntuotanto-ohjelman valintaan vaikuttavia tekijöitä. Puuntuotantomallia soveltamalla voidaan määrittää arvot osalle päätöksentekijän hyötyfunktiossa esiintyvistä ennustemuuttujista. Lopullinen päätös tietyn puuntuotanto-ohjelman hyväksymisestä syntyy arvottamalla hyötyfunktion tulokset erilaisten tulevaisuuden odotusten vallitessa haluttua päätöskriteeriä käyttäen. Koska kansantalouden tasolla ei ole varaa suuriin riskeihin, on ilmeistä, että ainoastaan konservatiiviset päätöskriteerit tulevat kysymykseen tehtäessä metsätalouden tuotantopäätöksiä suuralueilla.

Puuntuotantomallia sovellettiin Keski-Suomen ja Pohjois-Savon piirimetsälautakuntien yhteiselle alueelle. Metsäalue jaettiin 226 laskentayksikköön, joista 134 oli kivennäismaalla ja 92 turvemaalla. Laskentayksiköiden maa- ja puustotiedot saatiin valtakunnan metsien kuudennesta inventoinnista, jonka kenttätyöt kyseisellä alueella tehtiin kesällä 1973.

Aluksi pyrittiin rajaamaan toteutettavissa olevien puuntuotanto-ohjelmien joukko kymmenvuotiskaudella 1973—83. Puuntuotanto-ohjelmia kuvaavina tunnuksina käytettiin kuutiopoistumaa ja uudistuspinta-alaa. Tarkastelu osoitti, että samansuuruinen hakkuupoistuma voidaan saavuttaa varsin paljon toisistaan poikkeavilla uudistuspinta-aloilla. Tulosten perusteella valittiin neljä viidellekymmenelle vuodelle laadittua puuntuotanto-ohjelmaa lähempään tarkasteluun. Ohjelmat A$_1$ ja A$_2$ merkitsivät jo lähtötasoltaan korkeita ja suunnitelmakauden aikana muuttumattomina pysyviä hakkuumääriä ja ohjelmat B$_1$ ja B$_2$ lähtötasoltaan huomattavasti alhaisempia mutta voimakkaasti kohoavia hakkuumääriä. Ohjelmissa A$_1$ ja B$_1$ pyrittiin mahdollisimman pieniin uudistuspinta-aloihin ensimmäisen kymmenvuotiskauden aikana ja ohjelmissa A$_2$ ja B$_2$ mahdollisimman suuriin uudistuspinta-aloihin.

Tutkittujen ohjelmien haluttavuutta päätöksentekijän kannalta mitattiin hypoteettisella hyötyfunktiolla. Funktiossa olivat muuttujina (1) nykyhetkeen diskontatut nettotulot, (2) hakkuissa saatava käyttöpuun määrä ensimmäisen kymmenvuotiskauden aikana, (3) alhaisin puuston kuutiomäärä ensimmäisen kymmenvuotiskauden jälkeen sekä (4) alhaisin yli 20 vuotiaiden metsiköiden osuus pinta-alasta suunnitelmakauden aikana. Näiden muuttujien oletettiin mittaavan puuntuotanto-ohjelman antamaa kannattavuutta, maksuvalmiutta, varmuutta ja virkistysarvoa luetellussa järjestyksessä. Muuttujien tulon oletettiin ilmaisevan kokonaishyödyn. Nykyhetkeen diskontattuja nettotuloja laskettaessa käytettiin kahta vaihtoehtoista olettamusta puutavaran hintakehityksestä. Ensimmäisessä vaihtoehdossa oletettiin puutavaran hintojen pysyvän muuttumattomina ja toisessa niiden oletettiin kaksinkertaistuvan tulevan 50 vuoden aikana. Kustannustason oletettiin pysyvän molemmissa vaihtoehdoissa muuttumattomana. Hyötyfunktion mukaisesti arvosteltuna ohjelmat A_1 ja B_1 osoittautuivat selvästi edullisemmiksi kuin ohjelmat A_2 ja B_2. Näin tapahtui käytettiinpä mitä tahansa rationaalista päätöskriteeriä. Parhaaksi vaihtoehdoksi osoittautui ohjelma B_1, jossa hakkuupoistuma ensimmäisen kymmenvuotiskauden aikana oli 81 miljoonaa kuoretonta kiintokuutiometriä, mikä vastaa likimain viime vuosien poistumaa.

Laskenta-alueen tähänastinen hakkuusuunnite valittiin lähtökohdaksi yksityiskohtaisesti tarkastelulle puuntuotanto-ohjelmalle E. Peräkkäisten kymmenvuotiskausien keskellä saatavat hakkuupoistumat olivat tässä ohjelmassa 84.9, 92.5, 100.4, 107.8 ja 115.9 miljoonaa kuoretonta kiintokuutiometriä. Poistuman bruttoarvo kasvoi aluksi voimakkaasti, mutta laski tilapäisesti jonkin verran vuosituhannen vaihteen tienoilla hakkuiden keskittyessä nuoriin harvennusmetsiköihin. Puuston kokonaiskehitys oli laskentakauden aikana tyydyttävä, sillä esimerkiksi kokonaiskuutiomäärä kohosi jatkuvasti ja ylitti 50 vuoden kuluttua nykyisen kuutiomäärän 36 prosentilla. Ohjelma E osoittautui likimain yhtä edulliseksi kuin ohjelma B_1 edellä esitetyn hyötyfunktion perusteella arvostellen.

Ohjelman E, samoin kuin muidenkin edellä esitettyjen ohjelmien toteutuminen edellyttää koko aukean metsäalan metsittämistä lähivuosina, meneillään olevan ojitusohjelman loppuunsaattamista sekä kohtalaisen voimakkaita lannoituksia lähimpien kahden vuosikymmenen aikana. Lisäksi on oletettu, että koko metsäala käytetään puuntuotantoon. Ohjelma E merkitsee myös kasvatushakkuiden suosimista suunnitelmakauden alkupuolella. Esimerkiksi väljennysmetsiköissä hakkuun jälkeisen puuston oletetaan olevan kahden ensimmäisen vuosikymmenen aikana 30 prosenttia lopullisen tavoitteen alapuolella.

Saatuihin tuloksiin on suhtauduttava monin varauksin. Erityisesti kasvu- ja tuotostietoihin liittyy monia epävarmuustekijöitä. Pelkästään metsien tilan mukaan arvosteltuna tähänastinen hakkuusuunnite vaikuttaa realistiselta, mikäli tavoitteena ovat tasaiset tai lievästi kohoavat hakkuumäärät. Tämän tutkimuksen perusteella ei kuitenkaan voida ratkaista sen paremmin tämän kuin minkään muunkaan hakkuusuunnitteen haluttavuutta yhteiskunnan kannalta.

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