



**Estimation of Potential Allowable
Cut using Modelling of Landowners'
Strategic Decision Making**

Mauno Pesonen

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Academic Dissertation in Forest Planning

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The study reviews three publications on modelling of non-industrial, private forest (NIPF) landowners' strategic decision making. The main study concerns the estimation of potential allowable cut while the others address the matter of testing machine-learning methods — genetic algorithms (GA) and artificial neural networks (ANN) — using modelling of landowners' strategic decision making.

A new cutting-budget method, based on NIPF landowners' choice of timber management strategy concerning their woodlots, is demonstrated in this dissertation. Compared to average commercial cuttings (1988-1995), landowners would annually cut 16% more timber in Pohjois-Savo, and 30% more in the Finland as a whole, assuming that they were to follow their choice of timber management strategy. During the economic boom of 1994-1995, cuttings increased close to the level of sustained allowable cut — in Pohjois-Savo slightly exceeding it in 1995.

Methodologically, the genetic algorithm proved applicable in predicting the short-term potential cut in NIPF landowners' woodlots. However, with respect to the comparison parameters used in this study, the performance of regression analysis proved to be slightly better. Compared to ANN, logistic regression produced better results in modelling the choice of forest taxation basis.

Keywords: analytic hierarchy process (AHP), artificial neural networks, decision making, genetic algorithms, MELA, potential allowable cut, potential cut, strategic planning, timber management strategy.

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List of articles

Estimation of Potential Allowable Cut using Modelling of Landowners' Strategic Decision Making

In addition to the present summary, this dissertation includes the following articles referred to by Roman numerals in the text:

- I Pesonen, M. 1995. Non-industrial private forest landowners' choices of timber management strategies and potential allowable cut: Case of Pohjois-Savo. *Acta Forestalia Fennica* 247. 31 p.
- II Pesonen, M., Kettunen, A. & Räsänen, P. 1995: Non-industrial private forest landowners' choices of timber management strategies — Genetic algorithm in predicting potential cut. *Acta Forestalia Fennica* 250. 28 p.
- III Pesonen, M., Räsänen, P. & Kettunen, A. 1995: Modelling non-industrial private forest landowners' strategic decision making by using logistic regression and neural networks: Case of predicting the choice of forest taxation basis. *Silva Fennica* 29(2):171-186.

Mauno Pesonen was responsible for planning, sampling and MELA calculations of Articles II and III. The examination of results, conclusions, and finishing of the article in Article II and III were carried out jointly by the authors. Arto Kettunen was mainly responsible for the GA calculations and writing of Article II, and Petri Räsänen for the ANN calculations and writing of Article III.

Preface

My mentor, one of Finland's greatest researchers in the field of forest sciences, the late professor Pekka Kilkki, was my scientific idol. Without knowing it, he inspired me to choose Forest management planning as my major and eventually encouraged me with great vigour to proceed to doctoral studies already at the close of my undergraduate studies. I take this opportunity to make known my appreciation for his contribution.

For my post-graduate period of employment in the banking sector I have then SKOP Bank's Forestry Sector manager Reijo Mattila to thank. It was then that I adopted result- and goal-oriented methods of work. These have stood me in good stead at the Finnish Forest Research Institute (METLA), where these methods are now being introduced.

Under the supervision of professor Jouko Hämäläinen, I commenced my career as researcher at METLA's Department of Forest Economics/Business Economics Research in 1989 in connection a thinning project. Many thanks to him for the excellent research facilities placed at my disposal at METLA's Pitäjänmäki premises. Likewise, thanks are due to that project's management team's chairman, professor Kari Mielikäinen and co-ordinator Tapio Hankala, M.Sc.(For.) and all the other project participants. Special thanks go to my good friend Dr. Olli Haltia, who is partly responsible for the subject of my doctoral thesis, and to my closest colleague Hannu Hirvelä, M.Sc.(For.). Those were the times...

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Centre Tapio, Pohjois-Savo Forest Centre, the National Board of Taxes, and the University of Joensuu. Funding for the project has been received from the Ministry of Agriculture and Forestry, Finnish Forester's Foundation, Finnish Forest Industries Federation, and METLA. Many thanks to my current superior, Research Director Matti Kärkkäinen, co-ordinator Harri Hänninen, and to METLA as a whole for the marvellous facilities I have had the pleasure of using. Thanks to my colleagues in the on-going PUUMA project for their patience with me and my thesis. Special thanks to my good friend Miika Kajanus, Lic.Sc., for many crazy and splendid ideas and discussions.

Without the support of my late father, it is highly unlikely that I would be involved in the field of forestry and forest research. I am grateful to my family, the people who have had to witness at close quarters the ups and downs of this *Via Dolorosa*. But, hey, in the end I managed to pull it off!

January, 1997, at the PUUMA premises,

Mauno Pesonen

1 Introduction

"In 1928 an Economic Council was appointed in Finland for studying the economic situation and planning the economic development of the country. The Council's recommendation was that the yield of the forests should be increased by all available means: by draining swamps, reforesting open forest areas, changing species of trees if they were unsuitable on the site, increasing improvement cuttings and thinnings and paying special attention to the regeneration of cutting areas. It should be possible to increase the yearly growth of 44 million m³ to 80 million m³." (Ilvessalo & Saari 1929).

And this is reality today, in 1996. The above changes have taken place.

1.1 Non-industrial private forest ownership in Finland

According to the official register of Finnish farm holdings, there are 437,000 private forest holdings (woodlots) in Finland, covering 62% of the country's forest area (Metsätalastollinen vuosikirja 1995). Non-industrial private forests (NIPF) represent 70% of the growing stock volume and 73% of the annual increment. Thus, private forestry has a very prominent role in the forest sector and in the Finland's national economy.

During the past few decades, the ownership structure of non-industrial private forestry (NIPF) in Finland has undergone changes. The average size of woodlots has diminished, while the number of non-farmer forest owners is constantly growing due to the inheritance mechanism (Ripatti & Reunala 1989, Ripatti

1994). Because the standard of living in Finland has risen, people are less dependent on their forest property as a source of income, and their attitudes toward the environmental aspects of forestry have become more positive. Also, the connection between agriculture and forestry has weakened. It has also been stated that the non-economic benefits of forestry, such as recreation and residing on the property, will gain increasing importance among NIPF landowners. According to Karppinen (1992), 15–35% of Finnish forest owners attach high priority to recreation and to residing on the property. An increase in the number of holdings used for recreation, and residence for other non-productive purposes may weaken the timber supply and decrease the use of the allowable cut in the long run (Järveläinen 1988). However, of the landowners who know the economic potential of their forest property, nearly 70% prefer the economic benefits compared to the non-economic ones (I, Pesonen et al. 1995).

Commercial cuttings from NIPF lands in Finland account for 50–70% of the total amount of timber used by the country's wood-based industries (Metsätalastollinen... 1995). Thus, the timber supply from NIPF woodlots is of vital important for industry. Following the economic recession in the early 1990s, new investments have been made by the wood-based industries. The total demand for roundwood has increased. In 1995, 45.3 mill. m³ of industrial roundwood were harvested from private forests (Metsätalastollinen... 1995). Under favourable trade conditions, the demand for roundwood from NIPF forests will be in the range of 51–52 mill. m³ in 1998 (Perusteollisuuden... 1995).

There is still room for new investments by wood-based forest industries, even though commercial cuttings will peak close to the level of the sustainable allowable cut. On the other hand, the supply of roundwood from NIPF landowners' woodlots depends on the cutting decisions made by individuals, and these are influenced by many other factors. These factors have not been sufficiently considered in the formulation of national forest policy. National cutting budgets are formulated without this information. Therefore, seeing it as a possible hindrance to future investments, Finnish forest industries have expressed concern over NIPF landowners' willingness to sell timber.

1.2 Determining allowable cut and NIPF planning in Finland

Generally, the allowable cut has been viewed from the perspective of many factors and sources of information. Cutting budgets utilising the forest inventory data provided by national forest inventories (NFI) and cutting budgets derived by combining private forestry plans are major sources of information when formulating the national allowable cut. The two major weaknesses related to cutting budgets based on NFI data are: 1) national cutting budgets have been calculated assuming that all the country's forests are treated as a single forestry unit, and 2) the variability of goals subscribed

to by NIPF landowners has been ignored. Due to differences between inventory data, and due to the calculation method, cutting budgets derived by combining private forestry plans can be more than 30% lower than those based on NFI data (Metsä 2000... 1985). Thus, considering the forest resources simply as one entity leads to overestimation of the allowable cut.

In 1993, 76% of the NIPF area was covered by forest management plans. (Tapion vuosikirja 1994). However, the degree of utilisation of forest management plans may be rather low, because many NIPF landowners do not understand the information contained in a forest management plan. On the other hand, these plans are compiled according to the principle of discretion. They often underestimate the sustainable allowable cut. Cutting budgets presented in private forestry plans are 22% smaller than the allowable cut based on sustainable forestry (Pesonen et al. 1995).

In Finland, present-day NIPF management planning is mostly of a tactical nature. Landowners lack information about the strategic decision alternatives and their long-term consequences. Furthermore, decision analysis is often separated from planning. The importance of defining preferences in planning to produce decision alternatives, and in defining landowners' preferences, is often ignored. Sometimes the straightforward presentation of a single timber production program based on silvicultural instructions has been called planning. A strategic component in NIPF management planning would greatly improve the usability of tactical plans by helping landowners to specify their management goals for their forests.

1.3 Modelling strategic decision making

A strategic decision is the choice between two or more decision alternatives with long-term effects. A rational decision maker maximises his/her utility in decision making (e.g. Hirschleifer 1984, von Winterfelt 1988). Strategic decision making is the process that begins with determining the problem and ends with choosing a strategic decision alternative.

Modelling decision making, like any other attempt to model human behaviour, is a complex and multi-dimensional task. The utility theory has been widely used in modelling decision making (see Chapter 3.1). One of the methods used in decision analysis is the Analytic Hierarchy Process (AHP) (Saaty 1977, 1980). Recently, AHP has been applied to many kinds of decision situations. Moreover, many studies of applications of AHP to forest management planning, forest planning and resource management planning have also been presented (Mendoza & Spruce 1989, Kangas 1992, Kangas 1991, Kangas et al. 1992, Kangas 1993, Kangas et al. 1993, Kangas & Kuusipalo 1993, Pukkala & Kangas 1993, Kangas 1994, Peterson et al. 1994, Schmoltdt et al. 1994, Pukkala & Kangas 1996). In this dissertation, AHP was used to determine NIPF landowners' choice of timber management strategy (I).

New approaches to retrieving knowledge from ill-defined, noisy domains are offered by methods in the field of machine learning. Many machine-learning techniques are capable of dealing with quantitative as well as qualitative variables with linear and nonlinear dependen-

cies. They are often noise-tolerant and insensitive to fixed hypotheses. Moreover, the results from machine learning analyses, particularly in the form of production rules, can be directly used to construct rule-based expert systems (Guan and Gertner 1991b). These methods have not been widely used in modelling decision making.

Genetic algorithms, the machine-learning approach of interest in this dissertation (II), have been suggested for various applications in forest science. These applications include maintenance and management of forestry-related, knowledge-based systems (Foster 1993), modelling of natural processes, and construction of rule-based expert systems (Guan and Gertner 1991b, Pesonen and Kettunen 1993), substituting and complementing the traditional tools for statistical analysis (Liepins et al. 1990), and the induction of rules from complex forestry databases (Jeffers 1991). The genetic algorithm used in this study has been applied to discrimination of *Populus* clones by measuring poplar leaves (Jeffers 1991) and to automated rule induction from a forest regeneration database (Saarenmaa 1992).

Artificial neural networks (ANN), the second machine-learning method used in this dissertation (III), were originally developed in an attempt to simulate and understand the process of the central nervous system. More generally, they are computation techniques that perform a mathematical mapping of input data to output values. In forest science, ANN have been used in estimating inoptimality losses in harvesting decisions (Lämås et al. 1991), in estimating forest-stand characteristics based on satellite remote sensing (Feychting, et al. 1991), and in modelling multi-objective land use planning (Yin and Xu 1991).

1.4 Aims of this dissertation

The main aim of this dissertation is to develop a new cutting-budget method incorporating the strategic decisions of landowners. This new regional cutting-budget method is based on landowners' strategic choices of timber management strategy. A secondary aim of this dissertation is to test the potential of machine learning in modelling strategic decision making. The framework of this dissertation is presented in Fig. 1. More specifically, the aims of this dissertation are:

- 1 to produce alternative timber management strategies for NIPF landowners, find out their choices, and clarify the factors affecting these choices (I)
- 2 based on landowners' choice of timber management strategy, to calculate the potential allowable cut from non-industrial private forests in the region of Pohjois-Savo (I)

- 3 to investigate the potential of machine learning in modelling strategic decision making by NIPF landowners (II and III)

Chapter 2 of this summary discusses studies conducted to date and the methods used concerning cutting budgets and strategic planning. The classification of cutting-budget methods is adapted from Pukkala (1994): 1) "No age-class" methods, 2) "Age-class" methods, 3) "Finnish age-class simulation" methods, and 4) operation research (OR) methods. Lihtonen (1959) and Poso (1990) have also dealt with cutting-budget methods. Because some sources are over 100 years old, the author was not able to trace all of them. These references are adapted according to Pukkala (1994). Chapter 3 discusses the decision making methods used in this dissertation, Chapter 4 deals with the results of articles, and Chapter 5 presents the conclusions of this dissertation.

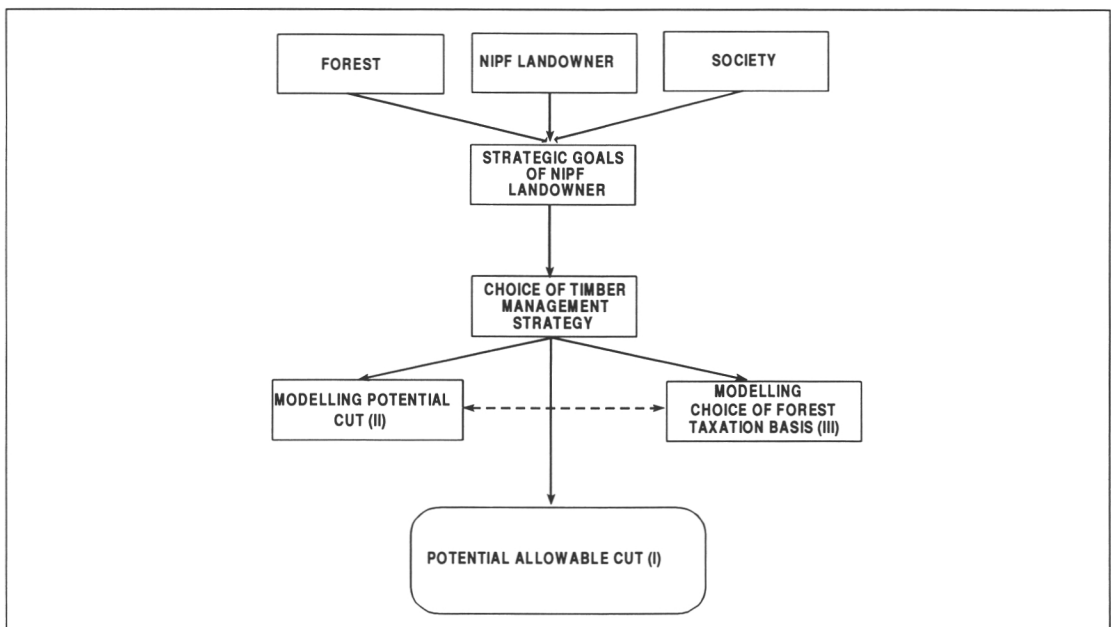


Figure 1. Frame of dissertation

2 Cutting-budget methods and strategic planning

2.1 History of cutting-budget methods

2.1.1 Fully regulated forest

There is no need for timber management planning, if there is an abundance of all forest products and forest utilities. The fear of running out of timber and other forest utilities has brought about a need for planning (Pukkala 1994). The first planning methods concerned the management areas of a forest (e.g. cutting areas). Lihtonen (1959) subdivided cutting-budget methods into deductive (calculations concerning the future) and inductive (calculations concerning the past) methods.

A single stand is seldom an independent economic unit (Kilkki 1985). The fully regulated forest is an idealistic model of a multi-stand forest consisting of even-aged stands and satisfying the following conditions (e.g. Lihtonen 1959):

- 1 The site quality of the entire forest area is uniform
- 2 No climatic variation occurs
- 3 Each age-class has an equal area
- 4 The oldest age-class is regenerated each year
- 5 Annual increment and drain are equal
- 6 Silvicultural measures remain unchanged
- 7 Prices and costs remain unchanged

2.1.2 "No age-class" methods

The first cutting budget methods were very simple. For example, these methods did not include information on the distribution of age classes and they are based on the cutting area, the volume of growing stock, and the volume of the growing stock of a fully regulated forest, increment and/or rotation. The simplest cutting-budget method is the annual cutting area method (e.g. Lihtonen 1959, Pukkala 1994) (1):

$$h = A/u \quad (1)$$

where

h	annual cutting area
A	forest area
u	rotation

Annual removals (R) can be calculated using formula (2)

$$R = h_c V_c + h_t V_t \quad (2)$$

where

V_c	volume of growing stock of clear-cutting age
V_t	volume of drain of thinnings
h_c	annual clear-cutting area
h_t	annual thinning area

In the Mantel-Masson formula, annual removal (R) is based on volume of growing stock and and rotation (3)

$$R = V/(0.5u) \quad (3)$$

where

V volume of growing stock

The oldest and the most well-known cutting budget formula is the Austrian formula (4) from the year 1788. This method is based on information on the volume, increment and volume of the growing stock of a fully regulated forest.

$$R = I + (V - V_n)/u \quad (4)$$

where

V_n average volume of growing stock of fully regulated forest
I increment

In the 1820s, Hundeshagen developed the cutting-budget method (5). When this method is used, the age class distribution should be rather even.

$$R = V * R_n / V_n \quad (5)$$

where

R_n removal (=increment) of fully regulated forest

In the Black Hills method, the growing stock consists of thinning and regeneration stands. Removals depend on the volume of the regeneration stands and the volume and increment of the thinning stands (6). All the stands are cut regularly.

$$R = (p_1 V_{rf} + p_2 (V_t + I_t)) / (100 * cr) \quad (6)$$

where

p_1 removals percentage in regeneration stands
 p_2 removals percentage in thinning stands

V_{rf} volume of growing stock in regeneration stands
 V_t volume of growing stock in thinning stands
 I_t increment in thinning stands
cr cutting rotation

The formula for the Baden-Württemberg method is (7)

$$R = (I + 2 * I_n) / 3 + (V - V_n) / a \quad (7)$$

where

I_n average increment during rotation
a equalizing time

"No age-class" methods were mainly developed during 17th and 18th centuries. All these methods are rather simple. Many of them are based on the theory of the fully regulated forest. These cutting-budget methods can be used in situations, where there is little inventory data on the forests.

2.1.3 "Age-class" methods

Compared to "No age-class methods", "Age-class" methods require more information on the forests: a more detailed forest inventory is necessary. These methods are based on the area covered by the various age-classes. In the Periodic Block method, the planning period is subdivided into periods in which the annual regeneration area is equal throughout the period. In the Breymann method, the main idea is the concept of area-weighted average age of the forest (8)

$$R = 2T_A I_n / u \quad (8)$$

where

T_A area-weighted average age of forest

Anuchin's formula gives the annual regeneration area for a forest area (9)

$$RA = (0.2A_1 + 0.6A_2 + 1.0A_3 + 1.4A_4 + 1.8A_5) / u \quad (9)$$

where

RA annual regeneration area
 $A_1 \dots A_5$ area of each age class

"Age-class" methods are more advanced applications of earlier cutting budget methods: more information is required. A forest inventory is a precondition for using these methods. Nevertheless, the calculation of the cutting budget is rather simple.

2.1.4 Finnish "Age-class simulation" methods

"Age-class simulation" methods simulate the development of the growing stock according to age classes. These methods differ from the previous methods in that the volume in each age class is known. In Finland, these methods were used in calculating cutting budgets from the 1940's to the 1980's. The rental cut method (Lihtonen 1943, 1959), and the cutting budget for a desirable growing stock (Kuusela & Nyysönen 1962) are the best-known of these methods.

The rental cut method (Lihtonen 1943, 1959) was the first widely used Finnish cutting-budget method. For example, Ilvessalo (1959) used it for determining cutting possibilities in Finland. The main idea of the method is that the initial age and the goal age-class distribu-

tions are known. The data requirements of the method are as follows:

- 1 Forest area
- 2 Tree species
- 3 Age-class distribution
- 4 Volume of growing stock in each age-class
- 5 Increment-% in each age-class
- 6 Cutting area of planning period (10 or 20 years)
- 7 Silvicultural condition

Using Martin's (1905) calculating methods, Lihtonen (1943, 1959) formulated the rental cut formula (10)

$$D = I - (GGS - IGS) \quad (10)$$

where

GGS goal growing stock
 IGS initial growing stock
 I increment
 D drain

Kuusela (1959) presented "the largest permanent allowable cut" method using the corrected Austrian formula (11)

$$H_S = (K_T + K_N) / 2 - (P_T - P_N) / u \quad (11)$$

where

H_S allowable cut
 K_T average increment of desirable stock
 K_N average increment of present stock
 P_T average volume of desirable stock
 P_N average volume of present stock
 u rotation of desirable stock

After presenting the aforementioned method, Kuusela & Nyysönen (1962) formulated the widely used Finnish cutting-budget method, i. e. the cutting budget for a desirable growing stock. According to Kuusela and Nyysönen (1962), the rental cut method was rather arduous and based partly on subjective analysis. The reason for using this method was "stock development forecast" (Kuusela 1958, 1959, Heikurainen et al. 1960).

The cutting budget for a desirable growing stock was of form (12)

$$S = kp^{t/2} - K/p^{t/2} \quad (12)$$

where

S	allowable cut
k	initial volume
K	final volume
p	increment per cent
t	number of years in the budget period

According to Kuusela and Nyysönen (1962), the allowable cut is a function of the current and desirable stock and increment during the cutting period. The budget is based on information about the forest area, site quality and growing stock and its structure obtained by way of inventory data.

2.1.5 OR-based methods

When computing equipment became available in the 1950s and 1960s, many applications were developed in forest management planning. The simplex procedure for solving linear programming problems signalled a significant change in production planning (Danzig 1963). A number of papers have been published on the subject of solving forest-level management problems using linear programming methods

(e.g. Curtis 1962, Wardle 1965, Navon and McConnen 1967). (Clutter et al. 1983).

Timber RAM (Resource Allocation Model) was a method developed at the US Forest Service (Navon 1971) for harvest scheduling in the national forests of western United States. MAX-MILLION was developed at the University of Georgia in collaboration with a number of industrial partners (Clutter 1968, Ware and Clutter 1971). (Clutter et al. 1983).

After the first applications, LP-based methods have found wide usage in forestry studies (e.g. Johnson & Scheurman 1977). The first studies employing these methods were rather theoretical, but the models presented by Johnson and Scheurman (1977), for instance, were practical and based on the FORPLAN and MUSYC systems (Johnson et al. 1986, Johnson & Jones 1986).

Kilkki (1968) presented the first Finnish cutting-budget method based on simulation and optimisation. Pökälä (1973), Kilkki and Siitonen (1976), and Siitonen (1983) developed a method which was subsequently given the name MELA System. Swedish forestry planning systems include GAYA (Eriksson 1983), Hugin (Bengtsson & Lundström 1987, Wilhelmsson 1989), and Indelningspaket (trans. Forest Management Planning Package) (Jacobson & Larsson 1987, Jonsson et al. 1993). AVVIRK (Eid 1990) is a planning system developed in Norway. Davis and Martell (1992), Jamnick (1990), and Weintraub (1991) have also used LP-based systems. TEAMS (Covington et al. 1988) is a decision-support system developed for multiresource management using GIS and LP. DTRAN is a forest management scheduling model designed to consider multiple market locations and the associated marketing alternatives (Hoganson & Rose 1984, 1987, Hoganson & Kapple 1991). FORXCEL is a software package designed to provide forest managers with a comprehensive forest management decision support (Rodriguez et al. 1993).

MELA is a widely used Finnish timber management planning system consisting of individual tree-level models and simulation of feasible management schedules for forest stands over a desired calculation period. The system simultaneously selects the production program for the forestry unit and stand management based on user-supplied goals at the forestry-unit level (Siitonen 1993). The MELA System was used in this dissertation (**I**), because national cutting budgets have been calculated using this system. Furthermore, it is possible to compare the potential allowable cut to other cutting budgets.

The LP model used in the MELA system presented by Kilkki (1985), has the following format (13)

$$\begin{aligned} \max & \\ (\min) & \sum_{i=1}^m \sum_{j=1}^{n_i} a_{ijl} w_{ij} = z \end{aligned} \quad (13)$$

where

(1) area constraints

$$\sum_{j=1}^{n_i} w_{ij} = b_i \quad i = 1, \dots, m$$

(2) other constraints

$$\sum_{i=1}^m \sum_{j=1}^{n_i} a_{ijk} w_{ij} \geq d_k \quad k = 2, \dots, p$$

(3) non-negativity constraints

$$w_{ij} \geq 0 \quad \text{for all } i, j$$

z	value of objective function
w_{ij}	proportion of calculation unit i (or absolute area) managed according to management schedule j
a_{ijl}	amount of item, if w_{ij} is area, then value/hectares
a_{ijk}	amount of item k produced or consumed if activity w_{ij} is employed for whole area of calculation unit i
d_k	constraint for item k
b_i^k	1, for all i values (or area of stand)
m	number of calculation units
n_i	number of management schedules for calculation unit i
p	number of items included in LP model

The MELA System has been widely used in many studies in Finland (e.g. Pesonen 1987, Pesonen & Hirvelä 1992, Pesonen & Hirvelä 1993, Pesonen et al. 1993, Pesonen & Räsänen 1993, Pesonen & Kajanus 1994, Pesonen & Räsänen 1994, Pesonen et al. 1994, Pesonen 1995, **I**, Pesonen et al. 1995, Pesonen & Kajanus 1995, **II**, **III**, Tokola & Pesonen 1995) and it has been applied on stand, forest holding, regional and national level. Compared to other LP-based systems, MELA's advantage is in that it includes a very detailed forest stand simulator including the simulation of many natural processes and activities in the forest (e.g. cuttings, and regeneration).

The only regional cutting-budget method applied to NIPF landowners' forests management strategies is the one introduced by Lönnstedt & Roos (1993). Lönnstedt & Roos (1993) calculated four scenarios for thirty-two "typical forest holdings": 1) a base scenario, 2) a structure-of-ownership scenario, 3) a timber price scenario, and 4) a changes-in-forestry-law scenario. Data for the model calculations were extracted from a random selection of 1,400 forest management plans. A comparison was made with material from the National Forest Survey and it showed a very high correspondence. Calculations were made for thirty-two type of forest holdings corresponding 11.5

mill. hectares owned by NIFP landowners. The main result obtained was that the condition of the forests and the private forest owners' potential cutting level enabled expansion by forest industries.

Compared to earlier cutting methods, OR-based are more complicated. These methods make possible the inclusion of a great number of data in calculations, determination of decision maker's goals and constraints, and presentation of the development of forest characteristics in dealing with different OR-problems.

2.2 Strategic planning

2.2.1 Definition of strategic planning

There is no commonly accepted definition of strategic planning, although it has been adopted into the business language from military terminology. One of the best definitions of strategic planning is to be found in Väinö Linna's novel "Unknown soldier" where Antti Rokka says: "Strategy is that you have to aim before firing!" (Linna 1954).

The essence of strategic planning is the long-term allocation of resource for the firm and forest holding. According to Naylor et al. (1983), strategic planning is forward-looking; accounting is by definition backward-looking. Furthermore, strategic planning consist of financial, marketing and production planning. The problem with decisions about the allocation of strategic resources can be formulated in three different ways: 1) optimisation, 2) system analysis, and 3) "what if?" analysis.

Another definition goes as follows: "The main purpose of strategic planning is to define the mission of an enterprise". The main questions for an enterprise are: Which strategic busi-

ness units (SBU) a enterprise wants to have? Who are its customers? What are its products, resources and competition strategies? (Ansoff 1965). The time frame in strategic planning varies from five to twenty years.

Ansoff's (1965) extensive work is important for the development of strategic planning. Long-range planning has traditionally assumed that the future would resemble the past. This assumption fell victim to the discontinuities of the business environment during the late 1960s and 1970s (energy crisis, etc.). The dominant features of strategic planning were experience curves, the grouping of related businesses and products into strategic business units (SBUs), and the use of the portfolio planning approach. A company has a collection, or portfolio, of businesses, products, or divisions, and must decide how to allocate its scarce financial resources across the portfolio (Naylor et al. 1983)

During the 1980s, competitive pressures and the slow growth of the economy forced companies to actively seek new opportunities. It became important to understand the changes influencing the main success factors. Competitive advantage became the cornerstone of planning. Porter (1987) argued for the importance of strategic planning and noted that the issues of good planning (i.e. that it is aimed at the future direction of competition, the needs of the customer, the likely behaviour of competitors, and how to gain competitive advantages) will never lose their relevance.

According to Kotler (1988), corporations consist of three levels: corporate level, business level, and product level. The corporate level mainly deals with decisions concerning matters such as the line of business the company should be in and how the available resources are to be divided among the different businesses. At the business level, the focus is on how one should compete in a particular industry or product/market segment. The product level is concerned with implementing the operational plans and achieving the objectives in a

given product market. Strategic planning is seen as a process that defines the purpose and the overall direction of the company, which are realised in the corporate mission and corporate objectives. Strategic planning also defines the means to achieving these objectives.

Niemelä (1993) classified definitions of the concepts of strategy as follows:

- 1 Strategy as a process of formal planning (Chandler 1962). This concept of strategy works well in a simple, stable, and predictable environment.
- 2 Strategy as a position (Ansoff 1965). The basic idea of this definition is to adjust the internal condition of the company to the external conditions of the environment.
- 3 Strategy as a pursuit of competitive advantage. The components of strategy here are competitive scope and competitive advantage (Porter 1985).
- 4 Strategy as a pattern of decisions and actions. The most significant contribution of this definition is in its idea of intended strategies being different from realised strategies (Mintzberg 1987).
- 5 Strategy as an atmosphere or a framework. Strategy understood in this way is a framework that guides important choices made in an organisation (Trogue and Zimmerman 1979).

Niemelä (1993) concludes that gaining competitive advantage is the ultimate objective of any strategy. Distinctive competences are sources of competitive advantage. A company can have distinctive competence in any of its functions.

In this dissertation, the framework of strategic planning may be defined as planning of production and management. In Niemelä's (1993)

classification, this study includes elements of concepts number 1 and 4. The main interest is on the level of timber management, especially in cuttings.

2.2.2 Strategic planning models

According to Naylor et al. (1983), there are three analytical tools for evaluating strategic decisions: 1) competitive-strategy models, 2) portfolio-optimisation models, and 3) corporate simulation models. Competitive strategic models are based on Porter's (1980) competitive advantage concept (number 3). It has been one of the most cited ideas in the business literature during the 1980s. The central concept in Porter's approach is the firm's profit. The generic competitive strategies model is then concerned with the means by which a firm can attain above-industry-average profits in the long run. Porter (1980) presents three different generic competitive strategies: cost leadership, differentiation, and focus. Cost leadership is gained by using the economies of large-scale production. Minimisation of production costs is the main objective, differentiation of products and customers is avoided, and the costs of product development and marketing are minimised. Differentiation of products and/or services can be based on customer service, product image, distribution and/or a reputation as an innovator in developing new products. By focusing on a certain customer group, market area or product group, the company can, thereby, achieve a cost or differentiation advantage within a chosen target group. The Boston Consulting Group (BCG) and the PIMS model are, according to Naylor et al. (1983) two of the best-known competitive strategy models.

The basic idea of Ansoff's (1965) strategy concept (number 2) is the strategic position of the company. The approach is called the "business portfolio approach". Portfolio optimisa-

tion models are based on this approach. The essence of this approach is in positioning a business within a matrix in accordance with its competitive strength (internal capabilities) and the attractiveness of its industry (external environment). Often a SWOT (Strengths/Weaknesses of the company and Opportunity/Threats of the environment) analysis is used as a basic analysis for defining this relationship. The result of this positioning is presented in a simple graphical matrix, which allows managers to visualize the contribution of each business to the corporate portfolio. These portfolio definitions have two basic levels of applicability: corporate and business. At the corporate level, they are used to evaluate the contribution of the different businesses of the company. The main question is the definition of different strategic business units (SBUs). Strategic planning is used to define each SBU's own strategy. At the business level, the focus of attention changes from the entire business to evaluating product-market segments. In Finland Kajanus (1992) has applied portfolio approach in decision making of forest regeneration.

Hämäläinen and Kuula (1992) have dealt with medium-term economic planning for a multi-branched enterprise in which agriculture and forestry plus associated livelihoods are practised. In the combined planning model, the management of the agricultural entrepreneur's economy and the problems of both real process and the financial process are solved simultaneously and optimally with regard to the goal function, taking into consideration the model's production factor, financing, taxation, and other such constraints (Hämäläinen & Kuula 1992).

Hyttinen (1992) used linear programming to determine the optimal combination of activities for farms. The objective was to maximise the total gross margin for the fixed resources of the entire farm. On most of the twenty-four farms studied, it was reasonable to increase forestry activities and to fully use the potential of forestry, but not to reduce agricultural activities (Hyttinen 1992).

In Article I of this dissertation, alternative timber management strategies were produced for strategic decision making. These strategies describe the recurrence and intensity of cuttings

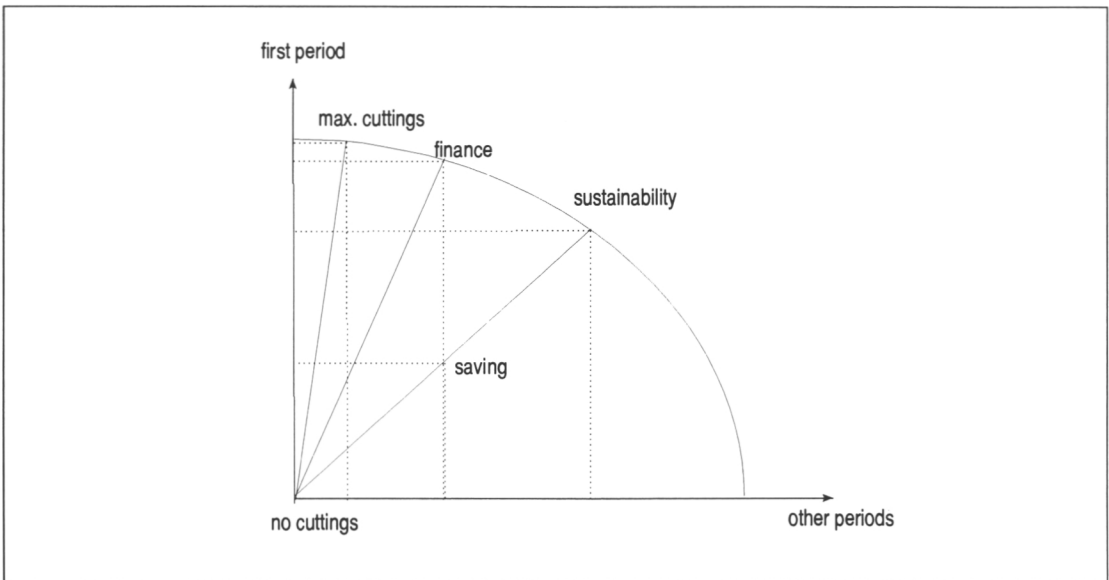


Figure 2. Removals in timber management strategies according to planning periods.

(Fig. 2). Each landowner was provided with five alternative timber management strategies covering a planning period of 20 years. In principle, the main differences between the strategies can be described in terms of intensity and the recurrence of removals. The objective variable used in optimisation was maximisation of the stumpage earnings for the first planning period (the constraints for each strategy are presented below).

The applied timber management strategies were as follows:

- S₁ "NO CUTTINGS"
- removals set to zero
- S₂ "SAVING"
- removals set to half of removals under condition "SUSTAINABILITY"

- S₃ "SUSTAINABILITY"
- even flow of removals over planning period
- even flow of stumpage earnings over planning period
- even amount of clearcut areas over planning period
- volume of sawtimber equal to, or greater, than at beginning of period
- market value of growing stock at end of planning period at least same as at beginning
- S₄ "FINANCE"
- even flow of removals during first two planning periods
- market value of the growing stock at end of planning period at least same as at beginning
- S₅ "MAX CUTTINGS"
- even flow of removals during last three planning periods

3 A review of methods used in modelling decision making

3.1 Decision making

The task of planning is to produce decision alternatives. Decision is defined as the choice between two or more decision alternatives. A rational decision maker maximises his/her utility in decision making (e.g. Hirschleifer 1984, von Winterfelt 1988). Decision making is the process that begins with determining the problem and ends with choosing the decision alternative. In strategic decision making, consideration of risk and uncertainty is very important. Risk and uncertainty, and the ways of dealing with attitudes towards them in the utility mode, have been widely discussed (e.g. von Neumann & Morgenstein 1947, Keeney & Raiffa 1976, Acs 1985). Pukkala and Kangas (1996) developed a method concerning both risk and the attitude toward risk into tactical planning.

According to Keeney (1982), decision analysis consists of four parts:

- 1 structuring the decision problem,
- 2 assessing possible impacts of each alternative,
- 3 determining preferences of decision makers, and
- 4 evaluating and comparing decision alternatives.

Pukkala (1994) connected the time horizon of planning and the characteristics of decision making. Political and principal decisions are normative and strategic decisions (Fig. 3). Furthermore, according to Pukkala (1994), planning and decision making are two parallel processes (Fig. 4).

Banfield (1973) lists three elements concerning the planning and decision process:

- 1 all alternative courses of action are listed,
- 2 all consequences of all possible courses of action are identified, and
- 3 course of action with preferred set of consequences is chosen.

According to Simon (1960), the premises of a decision consist of worth and matter sakes. Worth sakes are ethic and matter sakes are based on knowledge. According to Simon (1960), decision making consists of intelligence, planning and choice. Bradshaw and Boose (1990) subdivided decision making elements into three parts: alternatives, information, and preferences.

The principle of satisfying decision-making (e.g. Simon 1960) states that the decision maker does not strictly optimise when making decisions (e.g. Lilly 1994). This is due to human limitations in the optimisation process, the uncertainty of the decision environment, and the complexity of the decision situation. Instead, what may be called aspiration levels are used to evaluate the various outcomes of decisions. Aspiration levels represent those values of the objectives that can be accepted as reasonable or satisfactory by the decision maker (Lewandowski and Wierzbicki 1989).

Maximisation of utility is assumed to be the goal of rational decision makers. This assumption is taken as the point of departure in evaluating consequences and alternative plans (e.g. Mykkänen 1994). A utility function is a math-

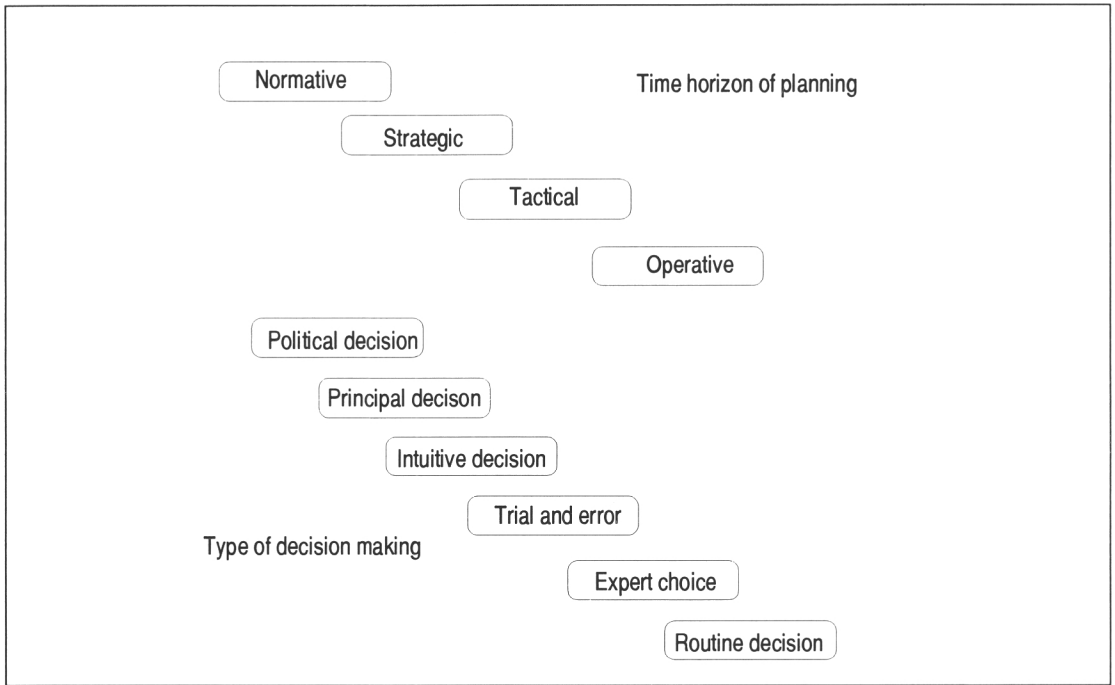


Figure 3. Type of decision making and time horizon of planning (Pukkala 1994).

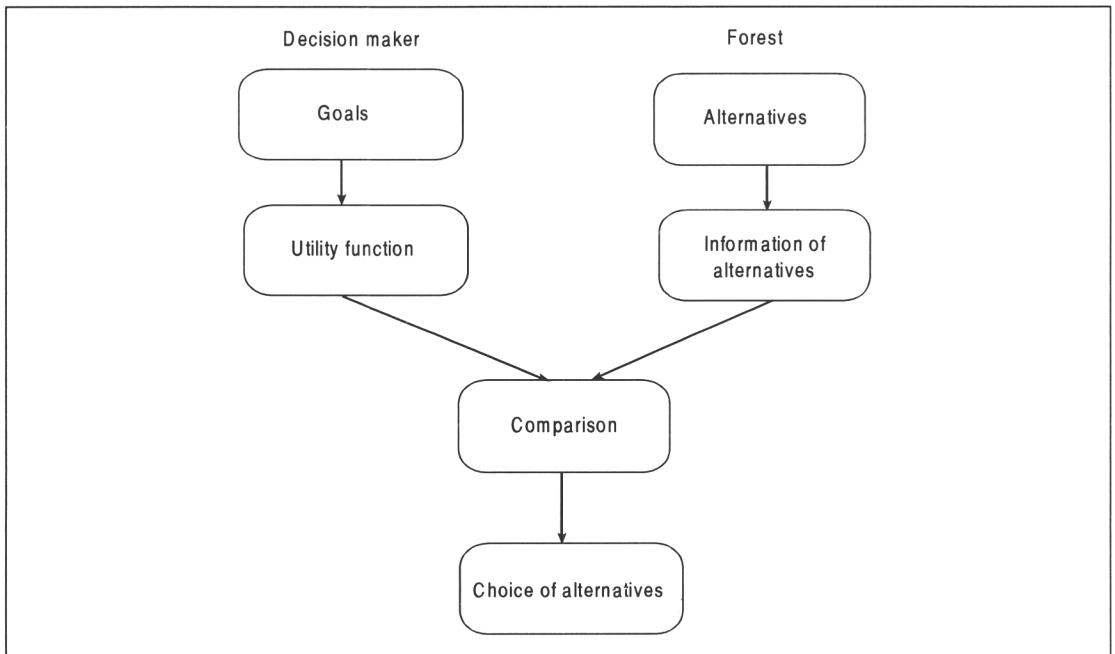


Figure 4. Planning and decision making according to Pukkala (1994).

emational transformation that associates a utility with each alternative so that all alternatives can be ranked (Cohon 1978). The multi-attribute utility theory (MAUT) is a theory that has been developed to solve decision problems with multiple objectives in complex decision situations.

3.2 Utility theory

3.2.1 History of utility theory

According to a generally accepted economic theory, rational decision makers are supposed to maximise their utility when making decisions (e.g. Hirshleifer 1984, Etzioni 1986). In the utility theoretical approach, the preferences of a decision maker are explicitly described via a utility function.

Modern utility-theory studies began with the works of Ramsay (1930) and von Neumann and Morgenstern (1947). The utility theory has been further developed to solve decision problems with multiple objectives in complex decision situations (e.g. von Winterfeldt & Edwards 1986, Kangas 1992, Mykkänen 1994). Initially, the analyses mainly concerned the risk factors in a choice situation (Kangas 1992).

According to Bentham (1823), utility consists of pain and pleasure. The behaviour of man is based on avoiding pain and seeking pleasure (Hirschleifer 1984). According to von Winterfeldt and Edwards (1986), MAUT consists of several parts:

- 1 determination of alternatives and goals,
- 2 valuation of alternatives concerning all individual goals
- 3 valuation of relative importances of goals,

- 4 holistic valuation of alternatives based on steps 2 and 3, and
- 5 conducting sensitivity analysis and producing decision recommendation.

3.2.2 Utility functions

A utility function is a model in which the decision maker can numerically evaluate all decision alternatives and choose the one which maximises his/her utility (Tell 1976). According to Nurmi (1978), a utility function includes expected values of all alternatives. A utility function, which does not include risk evaluation, is often called a value function (e.g. Keeney and Raiffa 1976).

According to Malinvaud (1985), a utility function has to possess several characteristics:

- 1 utility function has to be continuous and monotonically increasing
- 2 utility function has to be twice differentiable and the first derivative must not vanish

The linear and additive utility function applied in this study has been the one of most commonly used. It is also considered to be the easiest to interpret (Pukkala & Kangas 1993). The additive function may be written as follows (14):

$$U(x_1, x_2, \dots, x_n) = \sum_{i=1}^n a_i u_i(x_i) \quad (14)$$

where

- | | |
|---|------------------------------|
| U | total utility |
| x | decision variable |
| a | relative importance |
| n | number of decision variables |

Examples of other utility function forms are multiplicative and logarithmic utility functions.

In the specification of a utility function, all decision criteria, their relative importance, and possible interactions between them must be detailed. The methods of estimating utility functions may be divided into strictive and instrictive methods (Tell 1976). For instrictive methods, the parameters of a utility function are estimated according to a previous decision, e.g. using regression analysis. In strictive methods, the relative importances are asked strictly of decision makers.

According to Kangas (1992), regression analysis is widely used in the estimation of parameters. Other frequently used methods are variance and separation analysis. The dual solution of an LP model has been used in the estimation of parameters (Kilkki 1985). The analytic hierarchy process (Saaty 1977, 1980) has also been used in the estimation of parameters (e.g. Kangas 1992, I).

Utility models for determining economic goals have been produced, e.g. Lappi and Siitonen (1985), and Kilkki et al. (1986). Saastamoinen (1982), Mendoza et al. (1987) and Pukkala (1988) have formulated utility models concerning multiple-use forestry. Jacobsson (1986) and Kilkki et al. (1986) demonstrated multiplicative models of timber management planning. Other models have also been demonstrated, e.g. Hyberg (1987), Harrison and Rosenthal (1986), and Mendoza and Sprouse (1989).

Kangas (1992) formulated a utility model for choosing the forest regeneration program to be applied in a forest stand. The model was of the form (15)

$$U = a_1 u_{income} + a_2 u_{others} \quad (15)$$

where

u_{income} utility of net income of timber production

u_{others} utility of other benefits
 a_1, a_2 relative importances of decision criteria

Pukkala and Kangas (1993) developed a heuristic optimisation method for forest management planning based on the additive utility function (16)

$$U = \sum_{i=1}^m a_i u_i(q_i) \quad (16)$$

where

U total utility
 m number of objectives
 a_i relative importance of objective i
 $u_i(q_i)$ partial utility function of objective i
 q_i amount of objective variable i produced or consumed by plan

Mykkänen (1994) formulated a utility function in a planning model for timber flow management that consisted of net income, final capital, income trajectory index, and return on capital. The additive form was (17)

$$U = a_{NI} u_{NI}(NI) + a_{FC} u_{FC}(FC) + a_{ROC} u_{ROC}(ROC) + a_{ITI} u_{ITI}(ITI) \quad (17)$$

where

NI net income
 FC final capital
 ITI income trajectory index
 ROC return on capital

In this dissertation (II), the additive utility function was of form (18)

$$\max U(S_p) = a_1 u_{econ}(S_p) + a_2 u_{non}(S_p) \quad (18)$$

where

U	total utility obtained from use of forest property (i.e. utility from timber management strategy)
$u_{\text{econ}}(S_p)$	utility obtained from economic benefits of timber management strategy
$u_{\text{non}}(S_p)$	utility obtained from non-economic benefits of timber management strategy
S_p	timber management strategy, $1 \leq p \leq m$
m	number of timber management strategy
a_1, a_2	parameters describing importance of respective criterion

In Article I of this dissertation, the economic benefits consisted of the utility of timber production and the non-economic benefits consisted of other benefits. The parameters a_1 and a_2 of the utility function (1) were estimated using AHP, which is a mathematical method for analysing complex decision problems with multiple criteria (Saaty 1977, 1980). Basically, AHP is a general theory based on certain mathematical and psychological foundations. In AHP, a hierarchical decision schema is constructed by decomposing the decision problem in question into decision elements: goals, objectives, attributes and decision alternatives. The importances or preferences of the decision elements are compared in a pairwise manner with regard to the element preceding them in the hierarchy (Kangas 1992). In pairwise comparisons of Article I, landowners had to decide which one of the timber management strategies they preferred, both with respect to the economic and non-economic benefits of the use of their forest property.

3.3 Genetic algorithms

3.3.1 Background

Modelling human behaviour is a complex and multi-dimensional task. New approaches to retrieving knowledge from ill-defined, noisy domains are offered by methods in the field of machine learning. The third aim of this dissertation was to investigate the potential of machine learning in modelling strategic decision making by NIPF landowners. In this chapter, the main aim is to clarify the principle of genetic algorithms and how they fit into analysis of NIPF landowner's strategic decision making.

Genetic algorithms (GAs) are searching algorithms based on biological evolution and natural selection (Alander 1992). They combine mathematically simple operations and a robust basic structure into an effective searching system, which can be used to solve complicated problems (Goldberg 1989). The first actual genetic algorithms were presented in the 1960s and 1970s (Holland 1962, Bagley 1967, Holland 1975, De Jong 1975), but it was not until the 1980s that this method received more attention (Davis 1991). GAs have been applied to a variety of problem domains, including integer and combinatorial optimisation, heuristic search, rule induction, and biological simulation (Davis 1991).

Genetic algorithms belong to the group of Evolutionary Algorithms (EAs). EAs are part of a number of optimisation and searching methods resting on the theory of evolution that have potential for application in different sciences. They exploit the basic principles of evolution theory. An evolution algorithm usually contains the operations of reproduction, recombination, mutation, and "natural" choice. EAs have been proved to be capable of solving many different types of complex optimisation and adaptation problems (Nissen 1993).

Besides genetic algorithms, genetic programming (Haarala 1992, Nissen 1993), strategies of evolution (Voigt et al. 1991, Hoffmeister & Bäck 1991), evolutionary programming (Fogel 1992), and difference classification (Booker et al. 1989, Robertson 1987) are types of evolutionary algorithms (Holland 1975, Davis 1991).

According to Nissen (1993), evolutionary algorithms (EAs) differ from the usual searching algorithms in regard to the following characteristics:

- 1 EAs exploit genetic operators, which directly alter explicit choices of solution (members of population).
- 2 Instead of examining only one solution at the time, EAs investigate several points in the solution space simultaneously.
- 3 For goal-oriented searches, an EA needs information only about the fitness value of a solution. This can be calculated easily by the fitness function.
- 4 EAs include purposeful stochastic elements. This does not, however, mean just random search, but examination of the solution space using a given strategy. The search makes fast progress, because new solutions result from solutions found to be promising earlier.

The interest of biologists during this decade, using GA's, has focused especially on the pleat of protein (Vanhala & Kaski 1993) and research connected to the structural analysis of DNA (Lucasius et al. 1991). Furthermore, there have been some simulation tests, using GA's, and imitating the behaviour of animals (Sannier & Goodman 1987) and primitive artificial organisms (Dawkins 1989).

The number of research publications decreases when one moves from the field of biol-

ogy to that of forestry. Saarenmaa (1992) modelled factors affecting the success of forest cultivation using forestry accounting material provided by the Finnish Forest and Park Service. Rules for stand density were searched for by two machine-learning algorithms, one of which used a genetic algorithm.

Genetic algorithms have been suggested to adapt the maintenance of expert systems based on knowledge of forests (Foster 1993), to model natural processes, and to construct expert systems based on rules (Guan & Gertner 1991b), and also to replace traditional statistical analysis systems (Liepins et al. 1990). Jeffers (1991) has studied rule induction from a complex database by using genetic algorithms.

Genetic algorithms are suitable for carrying out complicated optimisation and searching functions in poorly known problem-areas (such as the so called NP-hard problems, Maniezzo 1991). Compared to the usual methods of optimisation and searching, they offer a mathematically simple, but robust and adjustable method of solving these problems (Goldberg 1989).

3.3.2 *Mathematical foundations*

The base operation of genetic algorithms is based on the essential paradigm of the theory of GAs called Schema Theorem (Goldberg 1989). The Schema Theorem may be described by considering the effect of reproduction, crossing-over (recombination), and mutation on the growth or decay of schemata from generation to generation. The Schema Theorem has been presented in article II.

In principle, the activity of a genetic algorithm is simply a matter of copying a string of symbols and changing parts of strings of symbols. A general condition is that the choice of solutions can be illustrated as a predefined

length of the files of symbols (Goldberg 1989). The most common coding used is the string-of-bits type of coding, although any other combination of symbols is possible in principle (Austin 1990). The string-of-bits type has, however, proved to be the most efficient manner of representation even in surprising problem fields (e.g. combinatorial optimisation) (Davis & Steenstrup 1987).

Classifier genetic algorithms were used in this dissertation (II) to produce rule sets. An applied genetic, rule-learning system called BEAGLE (Biologic Evolutionary Algorithm Generating Logical Expressions) was used to produce rules for predicting the potential cut described as the average annual removals of the first five-year planning period (m3/ha/a) of the landowner. The operation of BEAGLE is based on the presentation of alternative problem solutions as classification rules (Forsyth 1981, 1989). The genetic operators are analogous to the general presentation of a genetic algorithm, except that the population under genetic manipulation consists of rules and parts of rules (Forsyth 1981). The principle of the evolutionary learning is to save the best rules and generate new structures by recombining and mutating the surviving parts of rules.

3.4 Artificial neural networks (ANN)

3.4.1 Background

This chapter's main aim is to clarify the principle of ANN and how they fit into the analysis of NIPF landowners' strategic decision making. As yet, ANN have not been applied in dealing with these kinds of problems. Moreover,

there are only a few forestry applications using ANN.

The main principle of ANN is to create a model of information processing that resemble that in real knowledge (such as the human brain). The article titled "A Logical Calculus of Ideas Imminent in Nervous Activity" by Warren McCulloch and Walter Pitts (1943) is considered to have signalled the advent of ANN. Frank Rosenblatt published the first actual research on ANN in 1957. In 1959, Bernard developed Adaline (Adaptive Linear Neuron) and its double variant, Madaline (Multiple Adaline). These ANN were used, for example, to identify shapes and speech, and to make weather forecasts. The basic rules of the most common present-day ANN, the back-propagation-type of ANN, were published in 1986, with Rumelhart and McClelland as its main developers (Rumelhart et al. 1986, NeuralWare 1989, Aho 1990, Neural Computing 1990). The most remarkable example of Finnish research and applications in the field of ANN is Kohonen's Self-Organizing Map (SOM), which is used to find different kinds of structures and to classify material by structures already found (Kohonen et al. 1992).

3.4.2 ANN applications

ANN has been used in dealing with solving many kinds of problems. Applications for ANNs include identification of shapes, associative memory, expert systems, solving optimisation problems, controlling robots, recognizing speech, identifying faces, segmentation, recognising shapes and goals, finding optimal routes, and classifying stocks (Aho 1990). A few forestry applications of ANN's have appeared recently.

Guan and Gertner (1991a) examined several different back-propagation networks to model the survival of pine trees while Cook et al. (1991) used a back-propagation network for process control in chipboard manufacture. They found that regression and time-sequence analysis were not appropriate in dealing with this problem. ANN have also been used to estimate the losses caused by incorrect logging decisions (incorrect logging method and incorrect point of time) (Lämås et al. 1991). Feychting et al (1991) used ANN to decode satellite imagery by employing a back-propagation algorithm and two different ANN. Self-organizing characteristic maps (or Kohonen's network, SOM) have been used in estimating the accuracy of forest taxation in relation to the actualised selling prices of forest properties (Carlson 1992). Carlson (1990) has also used self-organizing maps in estimating the prices of real estate.

3.4.3 The operation of ANN

ANN consist of separate function units (processing elements, PEs), or neurons, resembling biological neural cells (Fig. 5). Each neuron gets external signals (input X_j), which the neuron then relays further on to the following neurons, and output information (Beale & Jackson 1991, Neural Computing 1990). Each incoming neuron signal has a given weight (w_j) and the weighted sum of the signals ($w_j X_j$) represents the total input of the neuron (total input j). The total input is further transformed by a transformation function (transformation function, $F(j)$) into a signal to be further transmitted along the ANN.

ANN consists of several layers of neurons. Information fed to ANN creates what may called an input layer while the information re-

turning to the environment outside ANN creates an output layer. There can be one or more hidden layers in between (Rumelhart et al. 1986, Beale & Jackson 1991).

The benefits ANN when compared to methods used in statistics are as follows (NeuralWare 1989):

- ANN tolerates incompleteness in data better than the methods used in statistics
- ANN is more robust and it does not require distribution suppositions of explanatory variables while predicting the final result better, especially if the initial materials have plenty of variation
- ANN can learn more when new observations are fed to the network; this is important in speech re-cognitions, for example. In statistical methods, for that matter (e. g. in regression analysis), it is often necessary to make a new model when adding new observations

and

- ANN can be fed many types of initial material (e.g. mixed numerical and classifying material)

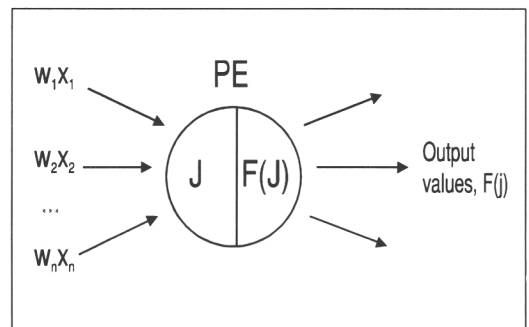


Figure 5. The basic unit in neural network ($w_1..w_n$ = weighting factors, $x_1..x_n$ = input values of the processing element (PE), $j = \sum w_j x_j$ and $F(j)$ = transformation function).

A model made using regression analysis is, however, more precise and particular; it is easier to construe than the results provided by ANN. It is difficult, at times even impossible, when using ANN, to explain the consequential relations of the cause of the facts supplied and facts output. When compared to traditional expert systems, 'knowledge' in ANN is included in the connection and connection weights between neurons (Cooke & Wolfe 1991, Cook et al. 1991). The weights between layers are essentially similar to statistical correlations. ANN are useful when compared to traditional rule induction rules in situations where the rules are not clearly known, or they are difficult to define. Likewise, ANN work better when the rules are not correct (i.e. they possess the ability to tolerate errors). Developing and teaching ANN, for that matter, takes time, and both the contents and outcome of ANN are difficult to construe (i.e. construing of the consequence relations of cause) (Foster 1993).

ANN are not suited to situations where precision or mathematical precision is required. In spite of this, cross validation techniques provide a valid estimates of the true accuracy of an ANN. Also, they allow the investigator to use all observations for training. If the initial material is temporary, or if the model requires deductive or stepwise rule induction, ANN are not useful (Bailey & Thompson 1990). ANN can be used in solving problems, which are complicated and have various phases, combined with, for example, handling signals and rule induction (Caudill 1991).

3.4.4 Back-propagation algorithm

The most commonly used type of ANN is the back-propagation ANN (e.g. Caudill 1991, Cook et al. 1991, Porter 1992). The reason for

this is the supervised-learning method of back-propagation ANN, which is also easy to carry out mathematically. The designer of a back-propagation ANN also knows in advance the result that ANN should produce (testing opportunity). The results provided by a back-propagation ANN (e.g. in the testing material) can be compared to real observed results (Caudill 1992).

Back-propagation ANN are named according to the way in which they handle errors as they appear in ANN and what the learning method of ANN is like. The Minsky and Peper multi-layered ANN (Multi-layered Perception) may be considered to be the forefather of back-propagation ANN (Rumelhart et al. 1986). ANN can also be given the appellation of generalized delta rule algorithm (Cooke & Wolfe 1991).

There is always a feeding layer, an output layer, and at least one hidden layer in a typical back-propagation ANN. The neurons in each layer are always connected to the neurons in the next layer. In theory, there is no limitation to the number of hidden layers, but when adding new neurons there is the risk of over-learning (Porter 1992).

The learning that takes place in a back-propagation ANN is based on what may be called 'supervised learning', where, based on the starting-out material, the correct 'weights' tend to be found for the connection between the neurons. Finding the correct weights is based on the result given by ANN and on minimizing the error between real observed values. Thereby, for example, the mean square error (MSE) is lowered (Porter 1992). This full-error term of the ANN is returned to separate neurons and the connection between neurons is converted so that the full-error term decreases. Teaching a network is continued until the desired error level is reached. The weights given after this are then attached.

The quality of ANN can be tested by entering new observations and by watching how

well ANN works. Usually, when testing ANN, the original initial material can be divided into two parts (teaching material and testing material). The network is taught and the weights of the connections are attached by the teaching material, and the quality of the network is tested by means of the testing material.

Another possibility is to use what may be called the cross-validation method, which means that a greater amount of material can be used for teaching. In such a case, the material is entered to the network several times, and each time one or more observations are left to be tested. Lämås et al. (1991) obtained more exact results using this method.

In this dissertation (III), ANN was used to predict NIPF landowners' choices of forest taxation basis. The back-propagation network used in this study was composed of three layers. The input layer consisted of independent variables scaled between 0 and 1. The hidden layer consisted of eleven nodes, which was the best number of nodes tested in this study, and the network had a single output node: the estimated probability of choosing site-productivity taxation. The way the network was constructed, the default value of selections of cases learnt was 500 000 unless the network converged before that. A software called NeuroShell was used in the calculations (NeuroShell 1989)

4 Summary of the articles

4.1 Potential allowable cut (I)

In the study, a new regional cutting budget method, potential allowable cut, was presented for the region of Pohjois-Savo. The method is based on (NIPF) landowners' choices of timber management strategies. Alternative timber management strategies were generated, and the choices and factors affecting the choices of timber management strategies by NIPF landowners were studied. Data were collected using a two-phase mail inquiry (Appendices 1 and 2). Timber management strategies were calculated for 213 forest holdings. The choices of timber management strategies were solved by maximizing the utility functions of the NIPF landowners. The parameters of the utility functions were estimated using the Analytic Hierarchy Process (AHP).

The most preferred strategy was "sustainability" (chosen by 62% of landowners). The second in order of preference was "finance" (17%) and the third was "saving" (11%). "No cuttings" and "maximum cuttings" were the least preferred. Non-farmers preferred the "no cuttings strategy" more than farmers did. The owners of the smallest forest holdings more frequently chose "no cuttings" and "saving" strategies than the rest.

An increase in the area of arable land (fields) led to landowners choosing strategies favouring intensive removals. In addition, recreation and residence as the primary uses of the property referred to the choices of "no cuttings" and "saving" strategies. The strategy most favoured by landowners practising agriculture and forestry was "sustainability". Landowners practising solely agriculture on their

farms preferred the "finance" strategy more than others.

In the analysis of the landowners' choices of strategies, the overall removals in the smallest holdings were smaller than in the rest of the area groups. This was due to the below-average removals and the preferred choices of "saving" and "no cuttings" strategies by the owners in the smallest area group. On the other hand, the heavier removals in the area group of large holdings were often followed by a preference for the "finance" strategy. The average harvest rate based on the landowners' choices of timber management strategies was 4.6 m³/ha/a. When weighted with the area group distribution of the Official Record of Finnish Farms, the average harvest rate obtained for both data sets was 4.5 m³/ha/a. The smallest holdings presented 13.7% of the weighted harvest rate.

The potential allowable cut was calculated using formula (19). Compared to the other presented methods, this cutting-budget method included the choices of timber management strategies by NIPF landowners. Thus, this method is based on landowners' predicted cutting intensity in the future.

$$PAC = FB \left(\sum_{i=1}^4 \left(\left(\sum_{j=1}^{k_i} \left(\sum_{l=1}^4 r_{k_i} / 20 \right) \right) / \sum_{j=1}^{k_i} a_j \right) \right) \text{taxarea} / 100 \quad (19)$$

where

PAC	potential allowable cut
FB	sum of forest land and scrub land area by forestry board
a	area (ha) of forest holding
i	size class of forest holding (1= 5 - 19,9 ha, 2= 20 - 49,9 ha, 3=50 - 99,9 ha, 4= 100-)
j	order number of forest holding

k	number of forest holdings
l	number of planning period
r	total removal over 5-year planning period (m ³) based on the landowners' choice of timber management strategy
taxarea	proportion of forest area according to Official register of Finnish Farms (%)

If there are no TASO data¹ available, the estimate for the potential allowable cut can be calculated using formula (20). Using this formula, the distribution of landowners' timber management strategy must be known.

$$PAC_{NFI} = FB \left(\sum_{l=1}^5 S_l * area_l \right) / 100 \quad (20)$$

where

PAC _{NFI}	potential allowable cut calculated using NFI data
S	average removal of 20-year planning period (m ³ /ha/a) using NFI data
l	timber management strategy (1= no cuttings ... 5= max cuttings)
area	proportion of forest land and scrub land area by timber management strategy (%)

Pesonen et al. (1995) used this formula in an area where TASO data were not available. In estimating PAC_{NFI}, the percentage of forest area in each timber management strategy was calculated using the average results for southern Finland.

As a generalisation of the results for the whole region of Pohjois-Savo, the average re-

movals of the 20-year planning period were 4.3 mill. m³/a. The potential allowable cut was 20% higher than the average realized cuttings in the Pohjois-Savo region during the years 1988-1993. Compared to the greatest allowable cut (based on sustained yield) of NFI8, the potential allowable cut for this study was 12% smaller. Furthermore, the cutting budget based on combining the forestry plans was 20% smaller than the one presented in this study.

4.2 Genetic algorithm in predicting potential cut (II)

The study addressed the factors affecting NIPP landowners' strategic decisions in management planning. A genetic algorithm is used to induce a set of rules predicting the potential cut of the landowners' choices of preferred timber management strategies. The rules are based on variables describing the characteristics of the landowners and their forest holdings. The predictive ability of a genetic algorithm is compared to linear regression analysis using identical data sets. The data were cross-validated seven times applying both genetic algorithm and regression analyses in order to examine the data-sensitivity and robustness of the generated models.

A total of seven sets of rules, with three rules in each set, was obtained after the execution of the genetic learning process. The generated rules were tested with the previously unseen test data. Thus, each of the seven sets of rules were tested with the respective sets of test data. The predictive abilities of the rules were examined by charting the estimated target values against the group average of the actual target values in each rule-combination category. In order to obtain a comparable measure for the fitness of the rules, the relative root mean square errors (rRMSE) and Pearson's correla-

¹ TASO is the Finnish forest planning system used in non-industrial private forestry.

tion coefficients were calculated for the predicted and observed target values of test data sets in the same way as with the regression analyses.

The cross-validated test data sets consisted of sixty cases each, of which, according to the measures provided by the genetic algorithm, an average of forty-one (i.e. 68% of the sample) were predicted correctly. The average target value for the category 'All rules true' (denoted by "111") was 6.53 m³/ha/a and for 'All rules false' (denoted by "000") it was 3.10 m³/ha/a. The average of the relative root mean square errors (rRMSE) of the test data sets was 0.42, and the Pearson correlation coefficient between the actual and estimated target values was 0.35.

In the regression analyses, all the independent variables of significance were entered into the models after four steps (forward stepping with alpha-to-enter of 0.15). The regression equations obtained from the analyses included seven different combinations of a total of nine independent variables with F-Ratios varying from 16.7 to 28.8. The average of the adjusted squared multiple R of the regression models was 0.37. When tested with the previously unseen data, the average for the rRMSE was 0.41 and the correlation coefficient between the estimated and the actual values of the dependent variable was 0.48.

The use of identical data sets and the principle of selecting the best predictive variables according to a specific strategy facilitated the comparison. The results of the predictive power and the accuracy of the two methods were compared in two phases: 1) by averaging, over the data sets, the rRMSEs and the correlation coefficients between the predicted and observed values of the planned removals, and 2) by selecting the optimal set of rules and the optimal regression equation, and then comparing their performance.

The predictive abilities of the optimal set of rules and regression equation were summarised

and the average figures of cross-validated data sets were presented. Furthermore, both the genetic algorithm and regression analyses were recalculated using the optimal models and the complete data set of 201 observations. In the genetic algorithm analysis, recalculation resulted in a fitness of 76.1% and an rRMSE value of 0.38, together with a Pearson correlation coefficient of 0.55. Respectively, the parameters derived from recalculation with the optimal regression model were: R² value of 0.34, rRMSE value of 0.38, and a Pearson correlation coefficient of 0.55.

When formulated into production rules, the effect of the variables on the potential cut may be interpreted as follows. The potential cut increases when 1) the mean initial volume increases, 2) the landowner is classified as farmer, 3) the landowner anticipates rising stumpage prices during the next eight years, and 4) the landowner's preference for recreational use of his forest property decreases.

In the regression analysis, an analogous interpretation of the regression equation results in the following conclusions (with the variables mean initial volume, proportion of forestry income, intention to cut extensively in future, and positive price expectations for the next two years).

The potential cut increases when 1) the mean initial volume increases, 2) the proportion of forestry income increases, 3) the landowner intends to cut intensively in the future, and 4) the landowner anticipates rising stumpage prices during the next two years.

For both methods, the mean initial volume was the most significant predictor of the potential cut. Furthermore, the parameters common to both methods included positive stumpage price expectations. This is consistent with, for example, the results obtained by Kuuluvainen (1989); analogous variables were discovered to be significant predictors of landowners' realised annual timber sales.

4.3 ANN in predicting choice of taxation basis (III)

In the study, logistic regression and ANN were used to predict non-industrial private forest (NIPF) landowners' choice of forest taxation basis. The main frame of reference of the study was the Finnish capital taxation reform of 1993. As a consequence of the reform, landowners were required to choose whether to be taxed according to site-productivity or realized-income during the coming transition period of thirteen years.

In the comparison between logistic regression and ANN, logistic regression produced better results in modelling both choices. On average, logistic regression predicted nearly 70% of the choices correctly, while ANN fared almost 10 percentage units worse. In all the mod-

els applied, the choice of site-productivity taxation was predicted more correctly than the choice of realized-income taxation. This can be interpreted in two ways: either landowners were more certain about their choice of SPT, or they intended to cut considerably more timber than in the level of cuttings where the profitability of the forest taxation basis changes.

The most significant variable in modelling the choices of the taxation basis was the forest taxation index (see III, p.179). In modelling the first choice, the other variables of the model were "intention to cut timber during next three years" and "age of landowner". In modelling the second choice, the significant variables included in the model, in addition to forest taxation index, were "marginal taxation rate" and "intention to cut timber in the near future". The occupational status of the landowner (farmer vs. non-farmer), the area of the forest holding, and the average cuttings of the past 5-year period did not significantly influence the choice.

5 Discussion and conclusions

5.1 Usability of results

5.1.1 *New cutting-budget method*

The main aim of this dissertation was to develop a new cutting-budget method applying landowners' strategic decisions. Machine learning was used in connection with landowners' strategic decision making modelling concerning the choice of timber management strategy and choice of taxation basis.

Regional and national cutting budgets of NIPF landowners' woodlots have usually been calculated without the decision makers' strategic goals in relation their woodlot. Lönnstedt & Roos (1993) estimated the potential cutting level of woodlots owned by Swedish NIPF landowners, but his method did not include individual strategic goals concerning the woodlots. The new cutting-budget method has been demonstrated in this dissertation (I) based on the NIPF landowners' choice of timber management strategy concerning their woodlots.

Compared to average commercial cuttings (1988-1995), landowners would annually cut 16% more in Pohjois-Savo and 30% more in the Finland as a whole, assuming that they were to follow their choice of timber management strategy. During the economic boom of the years 1994-1995, cuttings increased close to the level of sustained yield — in Pohjois-Savo in 1995 slightly exceeding it. The results concerning the whole of Finland (Pesonen et al. 1995) were of the same order (Figs. 6a and 6b).

Compared to the results obtained by Järveläinen and Torvelainen (1993), the potential allowable cut is clearly larger than the estimated timber supply from NIPF landowner's. The potential allowable cut may be considered as being the long-term planned cut from NIPF landowners' woodlots. In the short-term, matters such as timber prices and price expectations and the general "atmosphere" in the roundwood markets, influence the timber supply. Therefore, the potential allowable cut cannot be considered to predict the supply of timber.

The results of this study indicate that landowners' potential cut ensures the availability of wood raw material for consumption of roundwood by Finnish forest industry in this decade (Perusteollisuuden... 1995). Furthermore, the region's landowners could be activated to practise intensive management and timber harvesting by demonstrating to them the strategic alternatives in timber management. The results of this study may also help to direct the development of management planning in NIPF woodlots.

The most powerful application of the results of this dissertation is based on the use of preferred timber management strategies in calculating the potential allowable cut. The strategies can be generalised over a particular forest area. By taking into account the owners of "non-planned" woodlots and other landowners beyond the scope of this study, the potential allowable cut represented by NIPF woodlots can be derived from timber management strategies. This potential allowable cut, based on the landowners' objectives, can be taken into consideration in planning future investments by forest industries, for example.

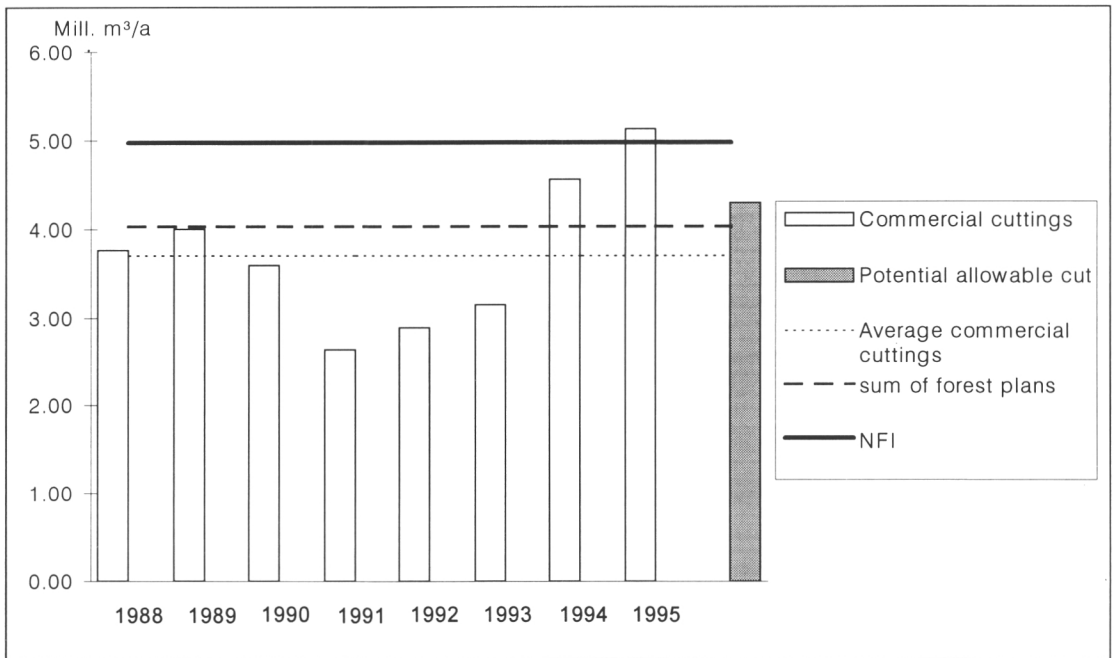


Figure 6a. Potential allowable cut in Pohjois-Savo. (NFI=sustained allowable cut calculated using National Forest Inventory data).

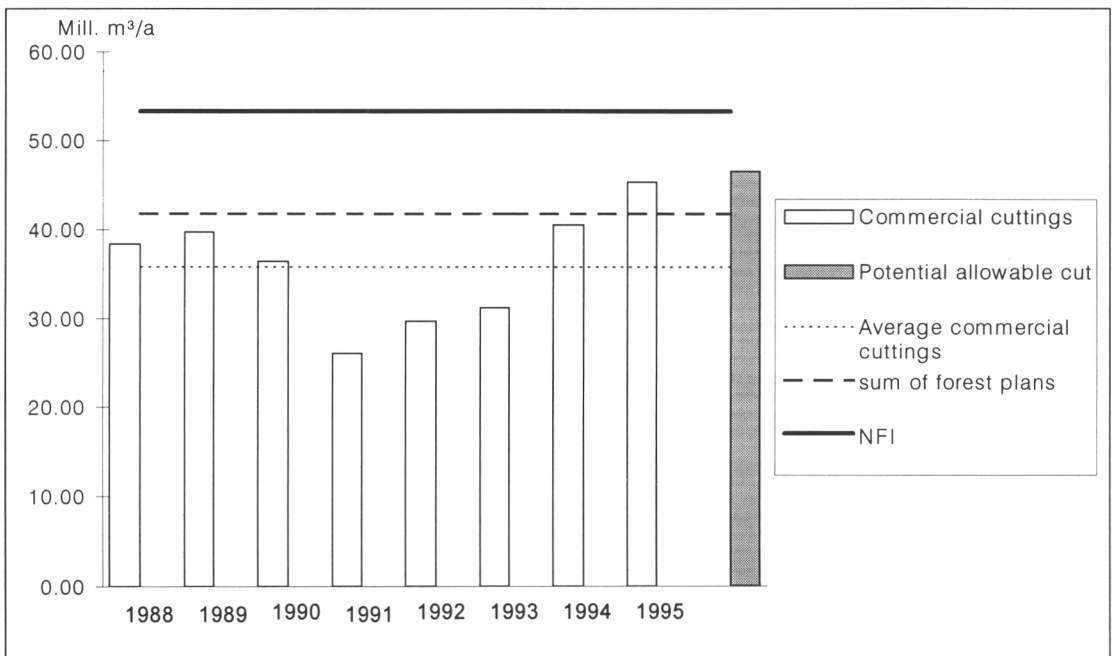


Figure 6b. Potential allowable cut in the whole Finland. (NFI=sustained allowable cut calculated using National Forest Inventory data).

5.1.2 Usability of machine-learning results

Although the genetic algorithm did not exceed the predictive ability of regression analysis, its major implications are based on the applicability of the generated set of rules. The rules classifying NIPF landowners into these strategy groups could be used to pre-compute the decision alternatives for the different landowner categories. Based on these results, it was possible to estimate the potential cut. The procedure was then used as part of an expert system in NIPF management planning as suggested by Pesonen and Kettunen (1993). Moreover, predictions of potential cut connected to the preferred strategies can be used to calculate the potential cut for landowner groups, whose characteristics are known in advance.

5.2 Applicability of methods used

5.2.1 AHP and potential allowable cut

In several studies, it has been noticed that the additive utility function produces a utility index which best describes the preferences of the decision maker (Tell 1976, Laskey & Fischer 1987). It has also been stated that landowners are utility-maximisers, who consider both the economic and the non-economic benefits of their woodlots (Boyd 1984, Hyberg 1987).

In this dissertation (I), the main point of the utility function was to determine out the choice of timber management strategy of landowner. The main question was cuttings in accordance with the chosen timber management strategy to

estimate potential allowable cut. The choice of timber management strategy was slightly sensitive to changes in the preferences of the economic and non-economic benefits of the use of forest property. If all the weight was placed on the economic benefits, the relative proportions of choices of "sustainability" and "finance" increased. On the contrary, if all the weight was placed on the non-economic benefits, the relative proportions of the choices of "no cuttings" and "saving" strategies increased.

Due to its simplicity, effectiveness, and ability to deal with qualitative as well as quantitative criteria (as was also indicated by the results obtained in this study), AHP is well-suited to dealing with forest management planning problems (e.g. Kangas 1992). When applied to mail questionnaires, the weakest point of the method is in dealing with the matter of whether all respondents are able to concentrate on the numerous comparisons as required when using AHP. Therefore, the results could be improved by the application of personal interviews in conjunction with data collecting.

AHP provides one approach to making different objectives — e.g. quantitative and qualitative — commensurable. However, AHP is not well suited to the statistical assessment of the uncertainty of the results. Alho et al. (1995) performed regression techniques in dealing with this problem. In this study, landowners made holistic decisions concerning their choice of timber management strategy and the results were very close to the results obtained when using AHP.

The objectives of landowners may also vary according to the point of time and/or region. Lönnstedt and Törnqvist (1990) stated that the choice of timber management strategy is affected by the needs and objectives of both short-term and long-term perspectives. The goal structure of landowners could have been clarified better. In this study, landowners were asked to compare only five precalculated timber management strategies. It would be possi-

ble to ask more specific questions about the objectives of the landowners in the first questionnaire, and then (with that information in mind) proceed to calculating the strategies individually.

An essential aspect to note is that the potential allowable cut, as defined in this study, is a far more sensitive and dynamic concept than completely forest-resource-oriented cutting budgets. The attitudes, values, and objectives of landowners vary far more and more frequently than forest growth does, for example. The allowable cut presented in this study is based on landowners' concepts and objectives in the spring of 1993.

It was not possible to determine the holistic statistical reliability of the potential allowable cut because there are so many error sources: 1) due to sampling, 2) due to the representativeness of the data, 3) due to the inconsistency of AHP comparisons, and 4) due to the models of the MELA system, for example.

5.2.2 Machine learning in strategic decision making modelling

One of the aims of this dissertation was to test the usability of machine-learning methods in modelling strategic decision making. Methodologically, the genetic algorithm proved applicable in predicting the short-term potential cut on NIPF landowners' woodlots. However, with respect to the comparison parameters used in this study, the performance of regression analysis proved to be slightly better. In spite of that, GAs are unique compared to other search and optimisation methods in that they generate new candidate solutions by merging portions of existing solutions.

It is also important to note that the genetic algorithm applied in this study has been proved to be better in dealing with logical problems, i.e. target expressions, which obtain only the values ' True' or 'False' (PC / BEAGLE 1987). In this sense, the reformulation of the problem into a logical one, and the inclusion of logistic regression analysis as a reference method, would be interesting topics for future research.

Despite the fact that the principles of genetic algorithms were developed more than twenty-five years ago, very few applications have been reported in the field of forest science so far. When adopting these methods, studies are needed in which different machine-learning approaches are compared in solving a variety of problems. An extension of this study would be to include a comparison of ANN and inductive-learning paradigms as supplementary prediction tools.

Compared to ANN, logistic regression produced better results in modelling the choice of forest taxation basis. On average, logistic regression predicted nearly 70% of the choices correctly, while ANN fared almost 10 percentage points worse. In all the models applied, the choice of site-productivity taxation was predicted more correctly than the choice of realised-income taxation. This can be interpreted in two ways: either landowners were more certain about their choice of SPT, or they intended to cut timber considerably in excess of the level of cuttings where the profitability of the forest taxation basis to change.

5.3 Conclusions

The following conclusions can be made on basis of this dissertation:

- 1 Using the developed method in this dissertation, regional cutting budgets based on strategic decisions of landowners' can be calculated more realistically than before. Potential allowable cut describe landowners' cutting intentions in the long run. Cutting budgets calculated without information on landowners describe the production possibility boundary of forests.
- 2 Timber management strategy calculations help to increase the timber supply in the long run. This is important because there are few tools at the disposal of Finnish forest policy.
- 3 Machine learning is suitable in modelling strategic decision making. An advantage of machine learning is its capability of producing rules to building knowledge based systems for resource management.

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Total of 176 references.

Appendix 1

I Questionnaire form



FINNISH FOREST RESEARCH INSTITUTE
 Department of Forest Resources
 KT 3136 / 1994

A) BACKGROUND INFORMATION CONCERNING THE WOODLOT AND THE LANDOWNER

1. If you wish to participate in the draw, please write your name and address below. By participating you get an alternative forest management plan for your woodlot.

Name: _____
 Street address _____ Town/City _____
 Zip code _____

This questionnaire concerns the space inside the frame. When answering, please use the forestry plan made for your woodlot.

<p>2. Information about farm size:</p> <p>The whole area _____ ha Forest area _____ ha Arable land _____ ha</p> <p>3. Changes in forest area since the year the forestry plan was made:</p> <p>The forest area has _____ ha a) increased _____ ha b) decreased _____ ha</p> <p>4. The annual amount of cuttings according to the forestry plan _____ m³</p>	<p>5. Do you own any other forests holdings besides the subject of this questionnaire?</p> <p>a) No _____ b) Yes, _____ ha</p> <p>6. What is the total area _____ ha forest area _____ ha arable area _____ ha of the holdings you own</p> <p>7. Your age? _____</p>
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8. Your sex? a) Male
 b) Female

9. Who is the owner of the woodlot?

- a) I own it by myself
- b) I own it together with my spouse and/or children
- c) The woodlot belongs to the estate of the deceased
- d) The woodlot is owned by a consortium of persons or really

10. The ownership of the woodlot was transferred to the present owner/owners in _____.

11. Does the owner or any of the owners live on the woodlot

- a) permanently
- b) part of the year
- c) not at all

12. What is your profession and status in your profession?

(one entry only, please)

Profession _____

Your status (what is your main source of income)

- a) salary earner
- b) entrepreneur in agriculture or forestry
- c) other entrepreneur
- d) retiree
- e) something else, what? _____

13. Your kind of educational background?

Basic education:

- a) Elementary school
- b) Secondary school
- c) Comprehensive school
- d) Senior secondary school graduate

Vocational education:

- a) No vocational education
- b) High school education
- c) College education
- d) Tertiary education

14. The average of the household incomes divided among different sources of income for the last five years:

(does not concern heirs or syndicates)

%

- a) Earned income _____
- b) Income from agriculture and other business _____
- c) Forestry income _____
- d) Other income _____

In total _____ 100%

15. The woodlot was transferred to its present owner

- a) Through inheritance _____
- b) Through purchasing at the free market _____
- c) Through purchasing from parents or relatives _____
- d) Through establishing of the heirs _____
- e) Some other way, how? _____

16. What is the main function of the farm?

- a) Agriculture _____
- b) Agriculture and forestry _____
- c) Forestry _____
- d) Holiday making and other recreation _____
- e) Something else, what? _____

B) INFORMATION CONCERNING OWNERSHIP AND CONSUMPTION OF THE FOREST USE.

17. Have you felled timber on this woodlot during the last five years? Estimate the annual amount of timber sales and cutting for your own needs

YES, year	timber sales	cutting for own needs	household timber	no sales
1993	m ³ _____	m ³ _____	m ³ _____	_____
1992	m ³ _____	m ³ _____	m ³ _____	_____
1991	m ³ _____	m ³ _____	m ³ _____	_____
1990	m ³ _____	m ³ _____	m ³ _____	_____
1989	m ³ _____	m ³ _____	m ³ _____	_____

18. What is the main purpose of use for your timber sales income for the last five years? How do you suppose you will dispose of your cutting incomes during the next five years?

Main purpose:	previous 5 years	next 5 years
a) saving	_____	_____
b) loan repayment	_____	_____
c) consumption	_____	_____
d) substantial purchases	_____	_____
e) tax payments	_____	_____
f) no specific purpose	_____	_____

19. Some goals for forest utilisation and forest ownership are presented below. Please, arrange the goals in order of priority using a sale of 1-6 considering your own forest. (most important goal=1, second most important=2,.....,6=least important).

- a) Recreation and leisure _____
- b) Wood production and income from selling wood _____
- c) Protection of forest nature and landscape _____
- d) Economic security brought by forest property _____
- e) Forest ownership as such _____
- f) Forest ownership as an object for investment _____

20. Which of the following statements describes best the future cutting to be carried out in your holdings? (one entry only, please)

- a) "No cutting will be done during my ownership"
- b) "I'll save the cutting possibilities for the future"
- c) "I constantly aim at regular cutting"
- d) "I will do much/a lot of cutting during the coming few years"
- e) "I will immediately do as much cutting as the Private Forest Act allows"

21. How do you suppose the ownership of your forest will change during the following ten years?

- a) No changes _____
- b) I will transfer the woodlot to one of my heirs _____
- c) The woodlot will be divided among the heirs _____
- d) I will sell the farm to an outsider _____
- e) I will purchase more forest _____
- f) some other changes, what? _____

22. What kind of estimates would you give for forestry as practiced on your woodlot during the following 10 years? (1994-2003) Please, mark with a tick below.

	Very good	Fairly good	Average	Fairly poor	Very poor
a) Possibilities for wood production provided by the woodlot	_____	_____	_____	_____	_____
b) Your status on the wood market in relation to the buyers	_____	_____	_____	_____	_____
c) Your status on the wood market in relation to other sellers	_____	_____	_____	_____	_____
d) Your knowledge about forestry	_____	_____	_____	_____	_____

23. What kind of estimates would you give concerning the development of stumpage prices in reality (in relation to other prices)? Please mark with a tick below.

increasing decreasing as before

- a) during the next two years _____
- b) during the following 8 years _____

C) ESTIMATION OF FORMS OF FOREST PROPERTY USE

Make an estimation concerning the alternative forms of use for your forest property. Each question has two choices you should compare: Considering your own forest holding, which alternative do you consider as more important, and how much more important?

Economic forms of forest use are compared with forms of use of forests use other than economic. **Economic forms of use** here refers to the benefits from regular incomes from selling wood, the role of forest property as a source of economic security, and the forest property as an object of investment. **Uses other than economic** are recreation use, care of forest nature and scenery, and intangible values of forest ownership, e.g. as maintenance of traditions and cherishing of the family woodland (see picture below).

ECONOMIC FORMS OF USE

- * Regular incomes from selling wood
- * Economic security brought about by the forest
- * Forest property as an object of investment

OTHER FORMS OF USE

- * Recreation usage of the forest
- * Care of forest nature and scenery
- * Intangible values of forest ownership

Which do you consider more important, considering your own forest holding, economic or other forms of use?

ECONOMIC FORMS OF USE
OTHER FORMS OF USE

_____ WHICH IS MORE IMPORTANT

Economic forms the more important
Other forms of use more important
Equally important

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more more
- 6)
- 5) Much more
- 4)
- 3) Fairly more
- 2)
- 1) Equally important

In the following, economic forms of forest property use are examined in more detail. Which alternative do you consider as more important economic use, **regular incomes from selling wood, or economic security provided by forest property?** (see picture below)

REGULAR INCOMES FROM SELLING WOOD WHICH IS MORE IMPORTANT
ECONOMIC SECURITY
FOREST PROPERTY AS AN OBJECT OF INVESTMENT

Regular incomes from selling wood is more important _____
Economic security is more important _____
Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) Equally important

Which do you consider more important - **regular incomes from selling wood, or forest property as an object of investment?** (see picture below)

REGULAR INCOMES FROM SELLING WOOD WHICH IS MORE IMPORTANT
ECONOMIC SECURITY
FOREST PROPERTY AS AN OBJECT OF INVESTMENT

Regular incomes from selling wood is more important _____
Forest property as an object of investment is more important _____
Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) Equally important

Which do you consider more important, the economic security provided by forest property or forest property as an object of investment?

REGULAR INCOMES FROM SELLING WOOD WHICH IS MORE IMPORTANT
 ECONOMIC SECURITY
 FOREST PROPERTY AS AN OBJECT OF INVESTMENT

Economic security more important _____
 Forest property as an object of investment is more important _____
 Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) Equally important

In the following we would like to know your evaluation of the other forms of use other than the financial ones, according to the same principles as above. Other forms of use, here refers to recreation use (berry picking, outdoor activities, hunting and similar use), care of forest nature and scenery (to preserve biodiversity and to pay attention to scenery factors) and intangible values connected to forest ownership (e.g. maintenance of traditions and cherishing of the family woodland).

Which one do you consider more important concerning forms of use other than recreation use or care of forest nature and scenery?

RECREATION USE WHICH IS MORE IMPORTANT
 CARE OF FOREST NATURE AND SCENERY
 INTANGIBLE VALUES CONNECTED TO FOREST OWNERSHIP

Recreation use more important _____
 Care of nature and scenery more important _____
 Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) equally important

Which do you consider more important - recreation use of the forest or intangible values connected to forest ownership?

RECREATION USE OF THE FOREST WHICH IS MORE IMPORTANT
 CARE OF FOREST NATURE AND SCENERY
 INTANGIBLE VALUES OF FOREST OWNERSHIP

Recreation use is more important _____
 Intangible values of forest ownership is more important _____
 Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) Equally important

Which one do you consider more important, care of forest nature and scenery or intangible values of forest ownership?

RECREATION USE OF THE FOREST WHICH IS MORE IMPORTANT
 CARE OF NATURE AND SCENERY
 INTANGIBLE VALUES OF FOREST OWNERSHIP

Care of nature and scenery is more important _____
 Intangible values of forest ownership is more important _____
 Equally important _____

How much more important?

- 9) Extremely so
- 8)
- 7) Very much more
- 6)
- 5) Much more
- 4)
- 3) Fairly much more
- 2)
- 1) Equally important

THANK YOU FOR YOUR CONTRIBUTIONS

Appendix 2 II Questionnaire form



FINNISH FOREST RESEARCH INSTITUTE
Department of Forest Resources
KT 3136 / 1994

PLEASE RETURN THIS FORM IN ENVELOPE ENCLOSED

A) QUESTIONS ABOUT MANAGEMENT PLANNING

- How, in your opinion, have you utilised the allowable cut of your forest, after obtaining the forest management plan?
 - according to forest management plan
 - more than the forest management plan suggests
 - less than the forest management plan suggests

- Some claims connected to the forest management plan following. Please fill up each section of this multiple choice exercise according to your own opinions.

I agree I do not I disagree know

- the forest management plan has influenced my decisions of cuttings a lot
- I think I influenced enough in the development of the forest management plan
- the information presented in the forest plan is correct
- the forest management plan has been worth its price

- What kind of information do you wish to receive more of from the forest management plan?

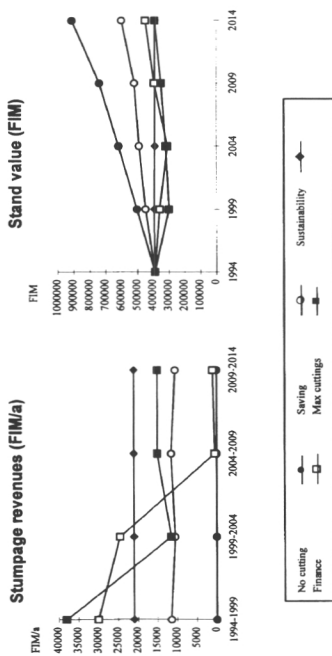
- information about economic planning
- information about game and tending landscape
- information about recreation activities
- other information about tending nature and multifunctionality of forests.
- other information, what? _____

B) ESTIMATION OF PLANS OF FOREST USE

A comparison of financial and other goals follows, and it is connected to the use of forest properties. On the next page there are short descriptions of five alternatives of the forest management plan is presented to you.

First by, different forest management plans are compared, based on economic goals, cutting income, financial security and investments

Five alternative forest management plans, calculated for your farm are presented below. The forest management plans and diagrams the development of the growing stock are attached. The area covered by calculations in the forest management plan is 1



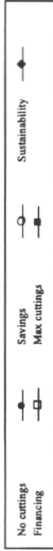
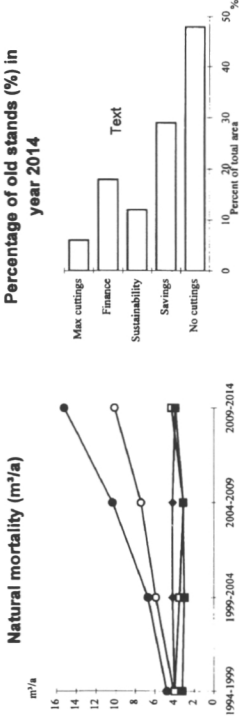
Please mark with a tick the plan you consider more satisfying from the financial-goal point of view.

Value 2014 FIM 526 534 Income 94-99 0 FIM/a	Very High	High	Fairly high	Equally satisfying	Fairly high	Fairly high	High	Very High	Value 2014 FIM 649 344 Income 94-99 0 FIM/a
Value 2014 FIM 526 534 Income 94-99 0 FIM/a	Very High	High	Fairly high	Equally satisfying	Fairly high	Fairly high	High	Very High	Value 2014 FIM 343 392 Income 94-99 0 FIM/a
Value 2014 FIM 526 534 Income 94-99 0 FIM/a	Very High	High	Fairly high	Equally satisfying	Fairly high	Fairly high	High	Very High	Value 2014 FIM 590 271 Income 94-99 0 FIM/a
Value 2014 FIM 526 534 Income 94-99 0 FIM/a	Very High	High	Fairly high	Equally satisfying	Fairly high	Fairly high	High	Very High	Value 2014 FIM 590 271 Income 94-99 0 FIM/a

Please mark with a tick the plan you consider more satisfying from the financial-goal point of view.

Value 2014 FIM 295 534 Income 94-99 0 FIM/a NO CUTTINGS	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 339 210 Income 94-99 0 FIM/a MAX CUTTINGS
Value 2014 FIM 649 344 Income 94-99 0 FIM/a SAVING	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 373 392 Income 94-99 0 FIM/a SUSTAINABILITY
Value 2014 FIM 649 344 Income 94-99 0 FIM/a SAVING	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 500 271 Income 94-99 0 FIM/a FINANCE
Value 2014 FIM 649 344 Income 94-99 0 FIM/a SAVING	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 339 210 Income 94-99 0 FIM/a MAX CUTTINGS
Value 2014 FIM 373 392 Income 94-99 0 FIM/a SUSTAINABILITY	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 500 271 Income 94-99 0 FIM/a FINANCE
Value 2014 FIM 373 392 Income 94-99 0 FIM/a SUSTAINABILITY	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 339 210 Income 94-99 0 FIM/a MAX CUTTINGS
Value 2014 FIM 500 271 Income 94-99 0 FIM/a FINANCE	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	Value 2014 FIM 339 210 Income 94-99 0 FIM/a MAX CUTTINGS

Next, we would like you to compare different forest management plans to (recreation consumption and forest nature- and scenery tending)
 The development of the natural drain in different forest management plans, and the share of old forests (more than 60 years of age) in the year 2014 in different forest management plans, are presented below.



Please mark with a tick the plan you consider more satisfying from the other-aims point of view

NO CUTTINGS	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	SAVING
NO CUTTINGS	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	SUSTAINABILITY
NO CUTTINGS	Very High High Fairly high Equally high Satisfying high Fairly high High Very High	FINANCE

4. Please place these five alternative forest management plans in order of superiority using the numbers 1-5 in accordance with your preference so that 1=best, 2=second, 3=third, 4=fourth and 5=fifth.

- NO CUTTINGS _____
- SAVING _____
- SUSTAINABILITY _____
- FINANCING _____
- MAX CUTTINGS _____

Please mark with a tick the plan you consider more satisfying from the other-sims point of view

NO CUTTINGS	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SAVING	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SAVING	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SAVING	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SUSTAINABILITY	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SUSTAINABILITY	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

FINANCE	Very High	High	Fairly high	Equally satisfying	Fairly high	High	Very High
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. Are you ready to change the utilisation of the allowable cut of your own forest holdings based on the forest management plans presented in this research?

- a) Yes, I shall increase cuttings _____
- b) Yes, I shall decrease cuttings _____
- c) The forest management plans presented in the research work will not change my intentions on cutting _____
- d) I do not know _____

6. Some statements follow concerning the development of forest planning. Please complete of the multiple choice exercise according to your own opinions.

- a) A forest plan should also present alternative calculations concerning utilisation of forest holdings _____
- b) The Forest plans should be kept updated based on actions taken at, for instance forestry association. _____
- c) The period of 10 years applied in forest planning is too long _____
- d) The Forest planning needs no developing _____

C) QUESTIONS CONCERNING DEVELOPMENTS IN TIMBER MARKETS

7. Which of the following might increase your desire to sell wood?

- a) Price recommendations _____
- b) Prices determined on the market _____
- c) Something else, what? _____
- d) None of the above _____
- e) I do not know _____

8. If you have neglected to sell wood during the last few years, what is the main reason?

- a) Inadequate price _____
- b) Unable to find a buyer for the item _____
- c) I have not had wood to sell _____
- d) Something else, what? _____
- e) I do not know _____

9. Would you be ready to make a long term shipment deal with the buyer, if it would guarantee regular annual purchase of wood?

- a) Yes
- b) No
- c) I do not know

10. To whom would you be ready to give information about your woodlot, if this would make the wood market function better?

- a) Local forestry association
- b) Companies of Forest industry
- c) Somewhere else, who? _____
- d) Nobody
- e) I do not know

Our research project continues, and our intentions is, among other things, to make forest management plans for some of the farms by using alternative calculations.

11. Would you like to have a forest management plan for your farm, made using alternative utilisation plans?

- a) Yes
- b) No
- c) I do not know

12. How much would you be ready to pay for this kind of a forest management plan?

- a) Less than for the present plan
- b) Same as for the present plan
- c) More than for the present plan
- d) FIM _____/ha
- e) Nothing
- f) I do not know

13. If you still have thoughts or opinions concerning this research project or forest planning, please let us know!

THANK YOU FOR YOUR CONTRIBUTION!

ACTA FORESTALIA FENNICA

247 · 1995

Mauno Pesonen

Non-Industrial Private Forest Landowners' Choices
of Timber Management Strategies and Potential
Allowable Cut: Case of Pohjois-Savo

The Finnish Society of Forest Science — The Finnish Forest Research Institute

Pesonen, M. 1995. Non-industrial private forest landowners' choices of timber management strategies and potential allowable cut: Case of Pohjois-Savo. *Acta Forestalia Fennica* 247. 31 p.

In the study, the potential allowable cut in the district of Pohjois-Savo – based on the non-industrial private forest landowners' (NIPF) landowners' choices of timber management strategies – was clarified. Alternative timber management strategies were generated, and the choices and factors affecting the choices of timber management strategies by NIPF landowners were studied. The choices of timber management strategies were solved by maximizing the utility functions of the NIPF landowners. The parameters of the utility functions were estimated using the Analytic Hierarchy Process (AHP).

The level of the potential allowable cut was compared to the cutting budgets based on the 7th and 8th National Forest Inventories (NFI7 and NFI8), to the combining of private forestry plans, and to the realized drain from non-industrial private forests. The potential allowable cut was calculated using the same MELA system as has been used in the calculation of the national cutting budget.

The data consisted of the NIPF holdings (from the TASO planning system) that had been inventoried compartmentwise and had forestry plans made during the years 1984–1992. The NIPF landowners' choices of timber management strategies were clarified by a two-phase mail inquiry.

The most preferred strategy obtained was “sustainability” (chosen by 62 % of landowners). The second in order of preference was “finance” (17 %) and the third was “saving” (11 %). “No cuttings”, and “maximum cuttings” were the least preferred (9 % and 1 %, resp.). The factors promoting the choices of strategies with intensive cuttings were a) “farmer as forest owner” and “owning fields”, b) “increase in the size of the forest holding”, c) agriculture and forestry orientation in production, d) “decreasing short term stumpage earning expectations”, e) “increasing intensity of future cuttings”, and f) “choice of forest taxation system based on site productivity”.

The potential allowable cut defined in the study was 20 % higher than the average of the realized drain during the years 1988–1993, which in turn, was at the same level as the cutting budget based on the combining of forestry plans in eastern Finland. Respectively, the potential allowable cut defined in the study was 12 % lower than the NFI8-based greatest sustained allowable cut for the 1990s. Using the method presented in this study, timber management strategies can be clarified for non-industrial private forest landowners in different parts of Finland. Based on the choices of timber management strategies, regular cutting budgets can be calculated more realistically than before.

Keywords Analytic Hierarchy Process, non-industrial private forest landowner, potential allowable cut, timber management strategy, utility function.

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Preface

This study is part of the project ‘Optimization of Regional Cutting Budgets’ in the Finnish Forest Research Institute. The main objective of the project is to develop a new system of calculation for determining regional cutting budgets. Special thanks are due to the following partners of the project for their help and advice during the research process: The Finnish Forest Industries Federation, The Central Union of Agricultural Producers and Forest Owners, The Forest Center Tapio, The Forestry District of Pohjois-Savo,

The University of Joensuu and The National Board of Taxation.

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1 Introduction

1.1 Sustained Allowable Cut in Finland

The commercial cuttings from non-industrial private forests (NIPF) in Finland have been 50–70 % of the total amount of timber used by the country's forest industries (Aarne 1993). Thus, the timber supply from NIPF lands is important for Finland's forest-based industries. Following the economic recession, new decisions for investments are again being considered by forest companies.

The sufficiency of the wood raw material does not limit plans for new mill investments – at the national level, the sustained allowable cut (Revised Forest... 1992) has been clearly higher than the realized cuttings during last few years. However, as a possible hindrance to future investments, forest industries have been concerned about NIPF landowners' willingness to sell timber.

Generally, the regional allowable cut has been viewed on the basis of the inventory data provided by National Forest Inventories (NFI) and the cutting budgets derived by combining private forestry plans. Two major weaknesses that relate to the cutting budgets based on NFI data, are:

- 1 Both regional and national cutting budgets have been calculated assuming that all the country's forests are treated as a single forestry unit.
- 2 The variability with goals of NIPF landowners has been ignored.

Thus, considering the forest resources simply as one entity leads to an overestimation of NFI-based cutting budgets. In fact, the cutting budgets derived by combining private forestry plans can be more than 30 % lower than those based on NFI data (FOREST 2000... 1985). On the other hand, forestry plans made for NIPF holdings are often deliberate underestimations of the actual cutting potential; the cutting budgets presented in private forestry plans can be nearly 20

% smaller than the actual allowable cut based on sustained forestry (Pesonen and Räsänen 1993).

1.2 Strategic Decisions in the Management of Non-Industrial Private Forests

Strategic planning operates on the future production possibilities; the starting point of which is the convertability of the factors of production and their allocation (e.g. Kast and Rosenzweig 1974). When applied to NIPF management planning, the strategic view includes the production of alternative, strategic-level programmes for timber production and silviculture. Timber management covers a range of strategies from no cuttings at all to maximum cuttings within the limits of timber production possibilities. For instance, timber management strategies can be described by the intensity and the recurrence of cuttings.

Non-industrial private forest landowners are a heterogenous group with different objectives and intentions. Due to the overall changes in society, the structure of non-industrial private forest (NIPF) ownership of Finland is constantly changing. The average size of forest holdings is decreasing, while the number of non-farmer forest owners is constantly growing due to the inheritance mechanism (Ripatti 1992). People are less dependent on their forest property as a source of income and their attitudes toward the environmental aspects of forestry have become more positive. It has also been stated that the non-economic benefits of forestry will gain increasing importance among NIPF landowners (Karppinen 1992).

Most NIPF landowners have long term perspectives and strategic views concerning forest management (Lönnstedt 1989). It is important to understand the strategic decisions of NIPF landowners for several reasons: e.g. 1) when predicting of the timber supply from private forests for future investments by forest industries (Lönnstedt and

Roos 1993), and 2) when planning the governmental forest policy in general.

In Finland, present-day NIPF management planning is basically tactical. Landowners lack information about the actual, strategic-level decision alternatives and their consequences. Furthermore, decision analysis; that is, giving recommendations about decisions and making decisions are often separated in planning. The importance of planning in the production of decision alternatives, and in defining landowners' preferences, is often ignored. Sometimes the presentation of even a single timber production program has been called planning (Kangas and Pukkala 1992). Due in part to the growing interest shown in the non-economic uses of forest property, there is an apparent need to include strategic aspects in NIPF management planning.

While strategic forest management planning is lacking in private forestry of Finland, landowners tend to underestimate their allowable cut. Furthermore, forestry plans are usually underestimates compared to the sustained allowable cut of forest holdings (Pesonen and Räsänen 1993). Moreover, 60 % of the landowners have actually harvested even less than the cutting budget presented in forestry plans (Pesonen et al. 1994a).

Many studies on strategic forest management planning (e.g. Wardle 1965, Kilkki 1968, Ware and Clutter 1971, Kangas and Pukkala 1992) have been done and several tools (Siitonen 1983, Johnson et al. 1986, Jonsson et al. 1993, Pukkala and Kangas 1993) have been developed for strategic forest management planning. However, few studies have been made concerning the regional cutting budgets derived from the strategic goals of NIPF landowners. Lönnstedt and Roos (1993) concluded that the cutting potential based on the objectives of NIPF landowners ensures an adequate supply of wood raw material for future investments by Sweden's forest-based industries.

1.3 Modelling the Strategic Decision Making of NIPF Landowners

Modelling the strategic decision making of NIPF landowners, like any other attempt at modelling human behaviour, is a complex and multidimensional task. Few studies have been made on the

strategic decisions of NIPF management (Lönnstedt and Törnqvist 1990, Hansson et al. 1990, Pukkala and Kangas 1993) and the factors affecting these decisions have received little attention.

One of the methods used in decision analysis is the Analytic Hierarchy Process (AHP). Recently, the AHP has been applied to several kinds of decision situations. Moreover, there have been studies on the applications of the AHP to forest management planning (Mendoza and Sprouse 1989, Kangas 1992, Kangas and Pukkala 1992).

The Analytic Hierarchy Process is a mathematical method for analysing complex decision problems with multiple criteria (Saaty 1977, 1980). Basically, the AHP is a general theory based on certain mathematical and psychological foundations. In the AHP, a hierarchial decision schema is constructed by decomposing the decision problem in question into decision elements: goals, objectives, attributes and decision alternatives. The importances or preferences of the decision elements are compared in a pairwise manner with regard to the element preceding them in the hierarchy (Kangas 1992). In this study, the AHP was used to determine the NIPF landowners' choices of preferred timber management strategies.

1.4 Aims of the Study

The aims of this study are to 1) produce alternative timber management strategies for the NIPF landowners, 2) find out their choices of alternative timber management strategies, 3) clarify the factors affecting these choices, and finally, 4) based on landowners' choices of timber management strategies, calculate the potential allowable cut from non-industrial private forests in the district of Pohjois-Savo. The potential allowable cut is calculated with TASO- and NFI-data to show, how reliable is to generate regional allowable cut with TASO-data.

In this study, *timber management strategy* is defined as an alternative for a NIPF landowner in the utilisation of his/her forest property and *potential allowable cut* means the regional cutting budget calculated for particular forestry area, and derived from the landowner's choices of timber management strategies.

The choices of timber management strategies

are solved by maximizing the utility functions of NIPF landowners. The parameters of the utility function are estimated with the AHP. The potential allowable cut is derived from the NIPF landowners' choices of timber management strategies, and it is compared a) to the cutting budgets based on NFI7 and NFI8, b) to the combining of NIPF

management plans, and c) to the realized cuttings from NIPF lands. The potential allowable cut is calculated using the same MELA system (Siitonen 1983) as has been used in the calculation of national cutting budgets. The frame of reference of this study is presented in Fig. 1.

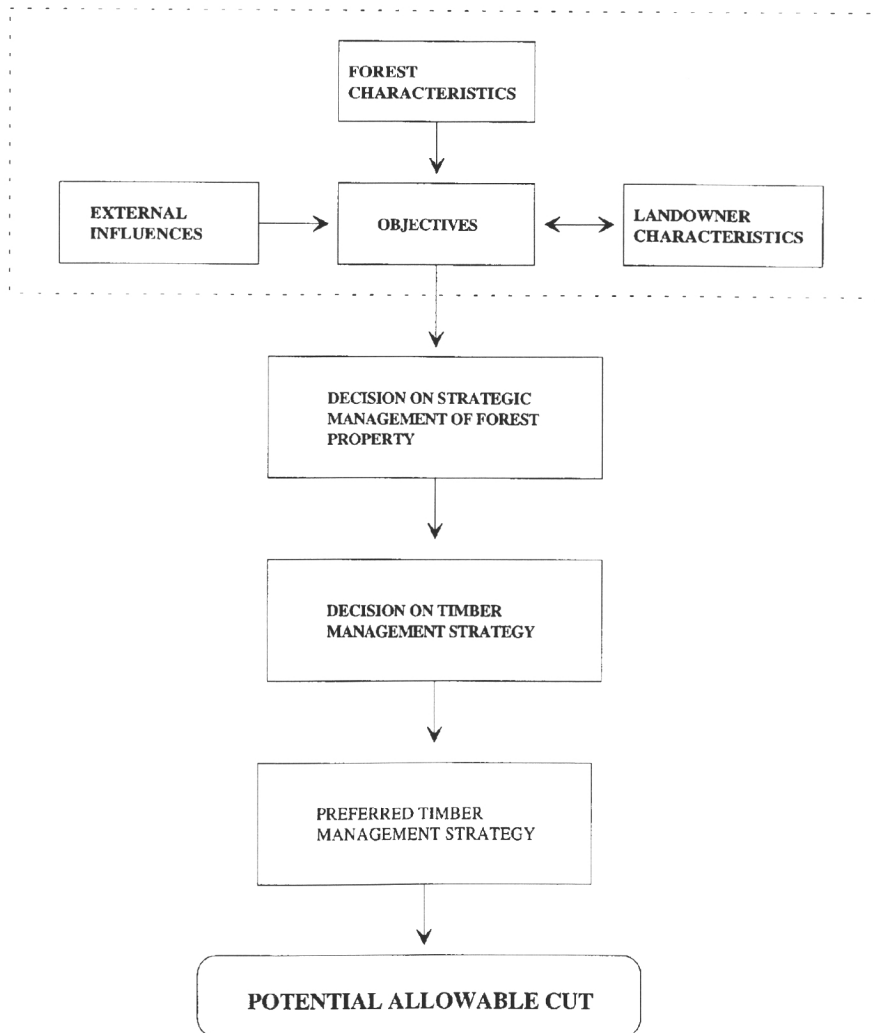


Fig. 1. Theoretical frame of the study.

2 Utility Function and Timber Management Strategies

2.1 Estimation of the Utility Function's Parameters Using the Analytic Hierarchy Process

According to a generally accepted economic theory, rational decision-makers (such as forest owners) are supposed to maximize their utility when they make decisions (eg. Hirshleifer 1984). In the theoretical utility approach, the preferences of a decision-maker are often modelled as a function called the utility function. Utility theory has been further developed to solve decision problems with multiple objectives in complex decision situations, i.e. the Multi-Attribute Utility Theory (e.g. von Winterfeldt and Edwards 1988, Kangas 1992, Mykkänen 1994).

The linear and additive utility function applied in this study, has been the one most commonly used. It is also considered to be the easiest to interpret (Pukkala and Kangas 1993). In the formulation of the utility function for determining the choice of timber management strategy, the overall utility obtained from the use of forest property consisted of the utility obtained from the economic and the non-economic benefits of the forest property. In this study, the *economic benefits* consisted of the utility of timber production and the *non-economic benefits* of other benefits. Therefore, the form of the additive utility function was (1)

$$\max U = a_1 u_{\text{econ}}(S_j) + a_2 u_{\text{non}}(S_j) \quad (1)$$

where

U is the total utility obtained from the use of the forest property (i.e. the utility from the preferred timber management strategy)

$u_{\text{econ}}(S_j)$ is the utility obtained from the economic benefits of the preferred timber management strategy

$u_{\text{non}}(S_j)$ is the utility obtained from the non-economic benefits of the preferred timber management strategy

S_j is the preferred timber management strategy

j is the number of timber management strategy

a_1, a_2 are parameters describing the importance of the respective criterion

The parameters a_1 , and a_2 of the utility function (1) were solved using the AHP. The use of the AHP to solve decision problems may be divided into four steps (Kangas 1992):

- 1 The decision hierarchy is constructed by decomposing the original decision problem into a hierarchy of interrelated decision elements (Zahedi 1986).
- 2 Pairwise comparisons are made at each level of the hierarchy. In making the comparisons, the question concerns, which of the two factors has the greater weight in decision-making, and how much greater, or which of the two decision alternatives is more preferred with regard to a certain decision attribute.
- 3 Using the pairwise comparisons as the input, the relative weights (importance/preference) of the elements at each level are computed by using the eigenvalue method. The resulting weights, or priorities, represent the decision-maker's perception of the relative importance or preference of the elements at each level of the hierarchy.
- 4 The ratings for the decision alternatives are calculated based on the priorities of the decision elements.

In pairwise comparisons, landowners had to decide which one of the two timber management strategies they preferred, both with respect to the economic and non-economic benefits of the use

of their forest property. Landowners had the option of expressing the priority ratio as (a) equal priority of both timber management strategies, (b) weak priority of one timber management strategy when compared to another, (c) strong priority of one timber management strategy when compared to another, (d) demonstrated priority of one timber management strategy over another, or (e) absolute priority of one timber management strategy over another. The respective priority ratios were translated into numerical values of 1:1, 3:1, 5:1, 7:1 and 9:1, or 2:1, 4:1, 6:1 and 8:1, as intermediate values.

Following the pairwise comparisons, a reciprocal matrix A (2) was constructed. In the matrix the element $a_{mn} = 1/a_{nm}$. Thus, when $i = j$, $a_{mn} = 1$.

$$A = (a_{mn}) = \begin{bmatrix} 1 & s_1/s_2 & \dots & s_1/s_j \\ s_2/s_1 & 1 & \dots & s_2/s_j \\ \vdots & \vdots & \dots & \vdots \\ s_j/s_1 & s_j/s_2 & \dots & 1 \end{bmatrix} \quad (2)$$

where

s_m/s_n is the priority ratio between the timber management strategies m and n

j is the number of timber management strategies compared

Using the matrix as the input, the relative priorities of the timber management strategies being compared, with respect to the economic and non-economic benefits of the use of the forest property, were computed using the eigenvalue technique. The right eigenvector of the largest eigenvalue of matrix A constituted the estimation of the relative priorities. The relative priorities were calculated by solving the eigenvector equation (3)

$$(A - \lambda_{\max}I)q = 0 \quad (3)$$

where

λ_{\max} is the largest eigenvalue of A

q is its right eigenvector

I is the unity matrix

Saaty (1977) has shown that λ_{\max} of a reciprocal matrix A is always greater or equal to j . If the pairwise comparisons do not include any inconsistencies, $\lambda_{\max} = j$. The more consistent the comparisons are, the closer the value of computed

λ_{\max} is to j . Based on this property, a consistency index, CI, was constructed (4).

$$CI = (\lambda_{\max} - j)/(j - 1) \quad (4)$$

CI estimates the level of consistency with respect to the entire comparison process. A consistency ratio, CR, also measures the coherence of the pairwise comparisons. To estimate the value of CR, the average consistency index of randomly generated comparisons, the value of ACI, has to be calculated (5). The ACI varies functionally according to the size of the matrix (e.g., Saaty 1980).

$$CR = 100(CI / ACI) \quad (5)$$

In human evaluation processes, some inconsistencies can be expected and also tolerated. As a rule of thumb, a CR value of 10 % or less is considered acceptable.

2.2 Definition of Timber Management Strategies

In order to solve the parameters of the utility function (1), five alternative timber management strategies were computed using the MELA system. MELA is a Finnish LP-based system for long-term timber management planning (Kilkki and Siitonen 1976, Siitonen 1983, 1993). The strategies were described for each landowner with the objective and constraint variables derived from the MELA parameters (Fig. 2). The planning period was 20 years, divided into four 5-year intervals. In the calculations, the forest-holding level development of several forest characteristics was described and illustrated for the landowners.

Each landowner was provided with five alternative timber management strategies covering a planning period of 20 years. In principle, the main differences between the strategies can be described in terms of intensity and the recurrence of removals. The objective variable used in optimisations was the maximisation of the stumpage earnings for the first planning period (the constraints for each strategy are presented below). The applied timber management strategies were as follows:

- S₁ "NO CUTTINGS"
 - removals set to zero
- S₂ "SAVING"
 - removals set to half of the removals under condition "SUSTAINABILITY"
- S₃ "SUSTAINABILITY"
 - even flow of removals over the planning period
 - even flow of stumpage earnings over the planning period
 - even amount of regeneration areas over the planning period
 - volume of sawtimber at the end of planning period equal to, or greater, than at the beginning of period
 - market value of growing stock at the end of planning period at least the same as at the beginning
- S₄ "FINANCE"
 - even flow of removals during the first two planning periods
 - market value of the growing stock at the end of planning period at least the same as at the beginning

- S₅ "MAX CUTTINGS"
 - even flow of removals during the last three planning periods

The NIPF landowners were asked to prioritise the timber management strategies according to their personal goals and preferences for forest use. First, the NIPF landowners were asked to compare the importance of the economic and non-economic benefits of the use of their forest holdings. Second, pairwise comparisons were made between the management strategies, considering the economic and the non-economic benefits separately (Fig. 3). The AHP process resulted in the relative priorities for each strategy being scaled 0–1. For each landowner, the strategy with the highest global priority (i.e., one that maximises the overall benefit) thus represented the most preferred alternative.

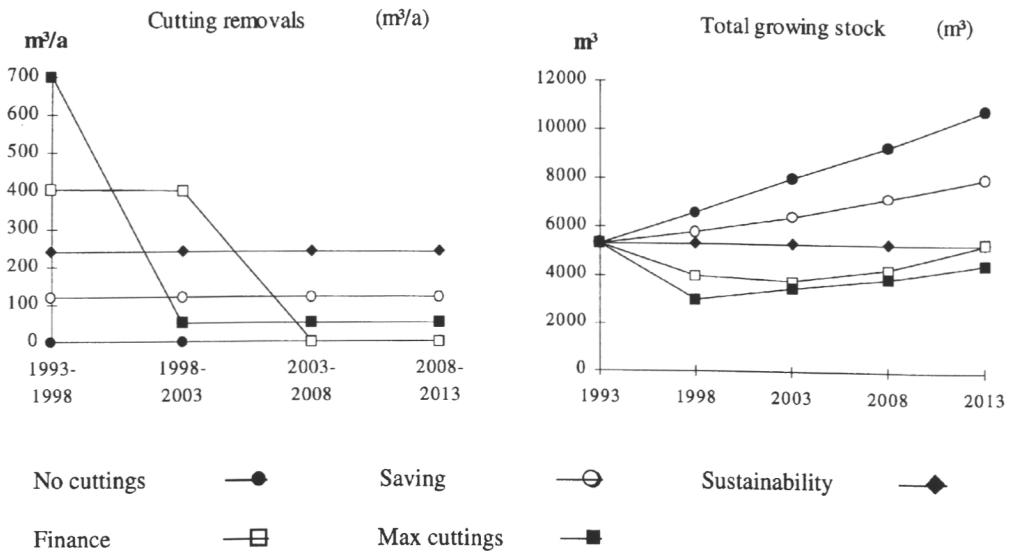


Fig. 2. Alternative timber management strategies described as the development of the removals and the total growing stock during the planning period (an example of calculations for each NIPF landowner, representing a sample case of the forest holdings).

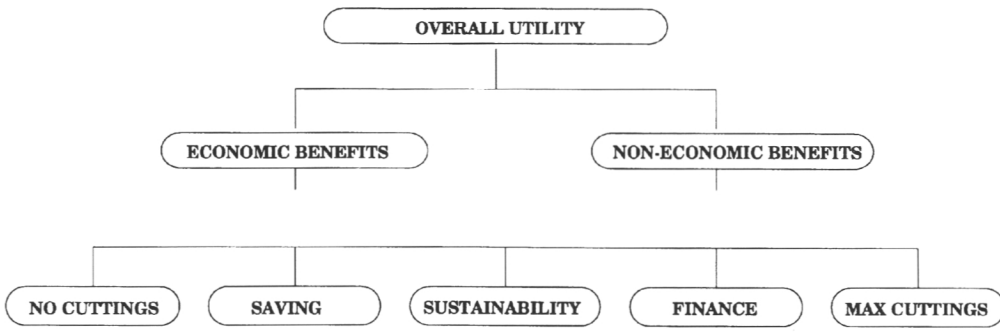


Fig. 3. Decision hierarchy for selecting the preferred timber management strategy.

3 Material

3.1 Data Sets Based on NFI and TASO

The basic data consisted of non-industrial private forest holdings in the Pohjois-Savo district that had a forestry plan made during the years 1984–1992. The data were collected from the TASO planning system, which has been the system of forest management planning for non-industrial private forestry since 1987 (Ranta 1991). The basic material consisted of 7365 forest holdings with a total forest area of 404 489 ha and an average holding size of 54.9 ha (Table 1). The coverage of the total forest area of Pohjois-Savo was 42.3 %. The difference when compared to the total coverage of the private forestry plans (73 % of total NIPF area in 1992) was due to the oldest plans not being in a usable form, and the fact that not all of the forest holdings had a forestry plan (Table 2).

Table 1. Distribution of the basic data according to the area of the forest holding.

Size of holding, ha	Forest area	%	Count	%	Average size
5–19.9	25058	6.2	1781	24.2	14.1
20–49.9	110322	27.3	3370	45.8	32.7
50–99.9	104942	25.9	1534	20.8	68.4
100–	164167	40.6	680	9.2	241.4
Total	404489	100.0	7365	100.0	54.9

Table 2. Forest area distribution of the official register on Finnish farm holdings.

Size of holding, ha	Forest area	%	Count	%	Average size
5–19.9	153502	16.8	9908	41.4	15.5
20–49.9	307742	33.8	9196	38.4	33.5
50–99.9	254132	27.9	3586	15.0	70.9
100–	196430	21.5	1252	5.2	156.9
Total	911806	100.0	23942	100.0	38.1

One of the aims of this study was to test the effect of the sampling method on the calculation of timber management strategies. Therefore, two sampling methods were used: 378 landowners were chosen by random sampling based on the NFI sample plot network and 379 landowners were chosen by systematic stratified sampling. Thus, the total sample consisted of 757 forest holdings (Table 3).

The forest holdings were divided into four groups according to their forest area: 5–19.9, 20–49.9, 50–99.9 and over 100 hectares. Stratified sampling was made according to the sizes of the forest holdings, so that the number of holdings in each sample group was determined by assigning a 4 % maximum standard error in the initial volume (m³/ha) within the groups. In the NFI-based sampling, a forest holding was included in the sample if an NFI sample plot was located on the holding and if a forestry plan had been made for the holding since 1984.

In order to obtain results as reliable as possible, the two samples were finally combined. This was done because comparison between the two samples revealed no significant differences in regard what comes to the average stand characteristics and the landowners' choices of timber management strategies.

After sampling, background information on NIPF landowners, their forest property and for-

Table 3. Distribution of the sampling according to the area of the forest holding.

Size of holding, ha	Forest area	%	Count	%	Average size
5–19.9	2388	5.1	169	22.3	14.1
20–49.9	8850	18.9	263	34.7	33.7
50–99.9	14423	30.8	205	27.1	70.4
100–	21122	45.1	120	15.9	176.0
Total	46783	100.0	757	100.0	61.8

Table 4. Distribution of the sampling after mail inquiries according to area of the forest holding.

Size of holding, ha	Forest area	%	Count	%	Average size
5–19.9	815	4.1	54	17.6	15.1
20–49.9	3442	17.2	104	34.0	33.1
50–99.9	6462	32.3	90	29.4	71.8
100–	9274	46.4	58	19.0	159.9
Total	19993	100.0	306	100.0	65.3

Table 5. Subsample of 213 records according to area of forest holding.

Size of holding, ha	Forest area	%	Count	%	Average size
5–19.9	629	4.6	41	19.2	15.3
20–49.9	2451	18.0	73	34.3	33.6
50–99.9	4038	29.6	57	26.8	70.8
100–	6532	47.9	42	19.7	155.5
Total	13650	100.0	213	100.0	64.1

estry goals were collected in a two-phase mail inquiry. The two-phase inquiry was necessary because the landowners had to be asked in advance for their permission to use the data from their forestry plans. In the first inquiry, the landowners were asked some questions about their ownership characteristics, economy and educational background. In addition, the inquiry asked about landowners' preferences for the economic vs. non-economic benefits of their forest property. The total number of accepted answers was 455 representing an average holding size of 59.1 ha. Furthermore, both inquiries included some questions about the landowners' conceptions as to the choice between two alternative forest taxation bases for the 13-year transition period*.

For the second inquiry, calculations were made and presented for each landowner about their timber management strategies and their choices of forest taxation basis. In the second inquiry, 306 acceptable answers were received representing an average holding size of 62.1 ha (Table 4).

The total area of the final sample was 13 650 ha, covering 1.4 % of the area of NIPF lands in the Pohjois-Savo district. The average size of the for-

est holdings presented was 64.1 ha, which was larger than the average of the entire population. The selection of material during the different phases of the study resulted in a situation where small holdings (under 20 ha and 20–50 ha) were under-represented and large holdings (over 100 ha) over-represented when compared to the corresponding proportions in the Official Register of Finnish Farms (Table 2, Pihljerta 1994). There are at least three reasons causing this bias: 1) the forest holdings with forestry plan were generally above-average in size, 2) NFI-sampling (one of the two sampling methods) favoured large holdings, and 3) presumably, landowners with large forest holdings were more interested in participating in the study. Due to this bias, all the results (distribution of choices of timber management strategies, potential allowable cut) were weighted with the area group distribution of the Official Record of Finnish Farms (Pihljerta 1994).

In order to calculate the regional cutting budgets, a subsample of 213 forest holdings (Table 5) was picked for further analyses (hereafter referred to as the TASO data). In order to obtain reliable and regionally representative results, the selection of these holdings was based on the date of the forest inventory. Thus, only holdings with inventory data not older than from 1988 were included in the subsample.

The reference material for the calculations consisted of the cutting budgets calculated on the basis of sample plot data provided by NFI8 (hereafter referred as the NFI data). The same timber management strategies were calculated for the NFI data, and the results were then compared to those of the TASO data. In the calculations of the potential allowable cut from NIPF lands, it was as-

* The Finnish forest taxation system was changed in 1993 when a site productivity taxation was replaced by a realized income taxation. Site productivity taxation has been based on estimated taxable income, i.e. mean annual increment according to the soil productivity. The realized income taxation is based on individual landowner's annual revenues from timber sales. In spring 1994, landowners had to choose the taxation basis according to which to be taxed for the next 13-year transition period. After the transition period, all landowners will be taxed by realized income from timber sales. By choosing the site productivity taxation for the transition period, the landowners with plenty of allowable cut are able to realize the cumulated increment which has already been taxed once. The choice between the alternative taxation bases is affected mainly by the amount of cuttings during the transition period, the estimated value of annual increment in site productivity taxation and landowner's marginal tax rate (Pesonen et al. 1994b).

Table 6. Main characteristics of the sample, based on owners' responds.

	Mean	SD
Owner, %		
Farmer	58.6	
Non-farmer	41.4	
Age, a	50.9	13.4
Forest area, ha	65.3	61.7
Arable land	10.4	11.0
Production orientation, %		
Agriculture	21.2	
Agriculture and forestry	24.2	
Forestry	38.4	
Recreation and residence	16.2	
Timber production possibilities, %		
Good	41.1	
Fairly good	45.4	
Poor	13.5	
Importance of recreation, %		
Important	23.1	
Neutral	41.4	
Not important	35.5	
Short term price expectation, %		
Increasing	11.1	
No change	58.2	
Decreasing	30.7	
Future cuttings, %		
Extensive cuttings	37.0	
Sustainability	50.7	
Intensive cuttings	12.3	
Choice of taxation, % (before tax calculations)		
Realized-income taxation	44.0	
Site-productivity taxation	25.8	
Cannot say	30.2	
Choice of taxation, % (after tax calculations)		
Realized-income taxation	48.1	
Site-productivity taxation	38.2	
Cannot say	13.7	
Mean volume, m ³ /ha	128.2	41.6

Table 7. Volume of growing stock (m³/ha) according to area of forest holding.

Size of holding, ha	Volume	SD	Min	Max
5–19.9	120.6	44.3	37.1	226.0
20–49.9	115.7	40.9	45.9	231.7
50–99.9	117.1	35.8	59.3	207.5
100–	125.6	32.2	44.7	184.3
Total	121.1	38.5	37.1	231.7

choices of, timber management strategies were studied according to twelve descriptive variables of the forest holdings and their owners (Table 6). The independent variables were selected on the basis of their statistical significance in the context of landowner behaviour, as demonstrated in earlier studies (e.g., Järveläinen 1988, Karppinen and Hänninen 1990, Kuuluvainen and Salo 1991).

3.2 Updating of the Data

The growth and removals of both TASSO- and NFI-data were updated to the beginning of the year 1993. Without updating the data sets, the comparison of information on the forest resources and timber management strategies would have been difficult because the TASSO data originated from the years 1988–1992 and the NFI data from 1990. In addition, updating the data enables the use of materials that are as recent as possible.

A statistical updating of the removals was required for the TASSO data because the landowners have stated their cuttings, on an average, 30 % below those found in the statistics on commercial cuttings. A random updating was completed so that the annual cuttings according to the statistics were removed from the data for each year; starting from the year of inventory and ending at the beginning of 1993. Updating was done using the MELA system. The constraints used in the optimisations were annual removals based on statistics according to timber assortments, and the harvest areas according to harvesting methods.

sumed that the timber management strategies based on the NFI data would represent the areal proportion of the choice of each strategy in the TASSO-data.

The NIPF landowners' preferences for, and their

3.3 Comparing the Data Sets

After updating growth and removals, the initial volume of the growing stock, (an average of the sample holdings) was 121.1 m³/ha (Table 7). The relative standard error of the mean initial volume varied between 4.0–5.7 % in the respective holding-size groups. The variance of the mean initial volume increased when the size of forest holding decreased. The mean initial volume of forest holdings varied within the range of 37.1–231.7 m³/ha.

The mean initial volumes of both the TASO and NFI data sets were very close to each other. The TASO data included more pine and spruce but, less birch than the NFI data (Table 8). Furthermore, there were more seedlings, and also more sawtimber trees, in the TASO data than in the NFI data.

Table 8. Volume of growing stock according to tree species and age class distribution in the TASO- and NFI-data.

	TASO	NFI
a) Volume (m ³ /ha)		
Average	121.1	123.0
Scots pine	37.7	31.6
Norway spruce	69.0	64.6
Hardwood	14.4	26.8
Sawtimber	58.8	53.2
b) Age-class distribution (%)		
–20	29.1	22.4
21–40	21.1	19.9
41–60	9.5	12.5
61–80	14.8	18.7
81–100	16.5	15.1
101–120	6.4	7.6
121–140	2.4	2.9
140–	0.2	0.9

4 Choices of Timber Management Strategies and the Factors Affecting Them

4.1 Economic and Non-Economic Benefits of Forest Property Use

The landowners' preferences in regard to the economic and non-economic benefits of forest property were asked before (first inquiry) and after (second inquiry) presentation of the calculations of the timber management strategies. After the presentation of the calculations, the average priority of economic benefits of forest property increased significantly. Prior to the presentation of the calculations, the average priority of the economic benefits of forest property was 0.64. After calculations, it was 0.71 (Figure 4).

The priorities of the economic and non-economic benefits were compared according to nine statistically significant (5 % significance level) descriptive variables (Table 9). Farmers felt the economic benefits to be more important than non-farmers. When the area of the forest holding increased, the importance of economic benefits increased. Moreover, an increase in the mean volume of the growing stock increased the importance of the economic benefits. Landowners that

owned fields felt that economic benefits were more important than those who did not own farming land.

Compared to the rest of the landowners, landowners that had set considerable preference on recreation and residence as the alternative uses of forest property felt that the non-economic benefits were more important than economic benefits. The greater the intensity of planned future removals, the more important were the economic benefits. Landowners who chose site-productivity based taxation considered economic benefits to be more important than those who chose realized-income based taxation. The differences between the taxation systems were slightly higher in the second than in the results of the first inquiry.

4.2 Choices of Timber Management Strategies

In the maximisation of the utility function (1), the most preferred strategy obtained was "sustainability" (chosen by 62 % of landowners).

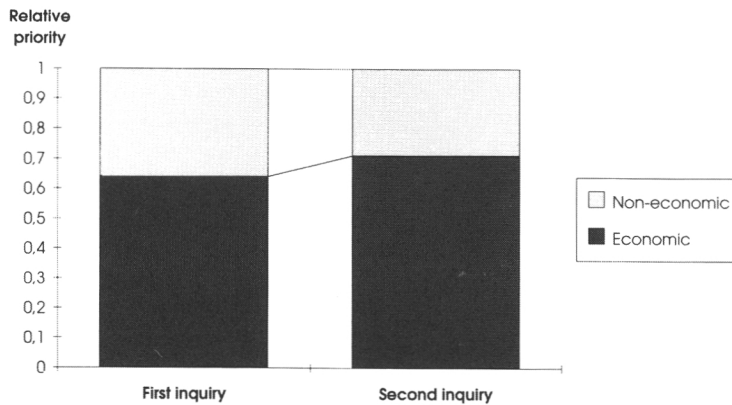


Fig. 4. Preferences for the economic vs. non-economic benefits of forest property use in the first and second inquiry.

Table 9. Priorities of the economic and non-economic importances of timber management strategies according to characteristics of the background information (priorities of first inquiry in parentheses).

	Economic	Non-economic	SE
Owner			
Farmer	0.733 (0.677)	0.267 (0.323)	0.011 (0.012)
Non-farmer	0.665 (0.579)	0.335 (0.421)	0.013 (0.013)
Forest area, ha			
5–20	0.667 (0.556)	0.333 (0.444)	0.021 (0.021)
20–50	0.685 (0.605)	0.315 (0.395)	0.015 (0.015)
50–100	0.714 (0.666)	0.286 (0.344)	0.016 (0.016)
over 100	0.760 (0.706)	0.240 (0.294)	0.020 (0.020)
Field (arable land)			
–5 ha	0.675 (0.575)	0.325 (0.325)	0.019 (0.011)
over 5 ha	0.730 (0.678)	0.270 (0.322)	0.010 (0.019)
Production orientation			
Agriculture	0.713 (0.657)	0.287 (0.343)	0.019 (0.014)
Agriculture and forestry	0.730 (0.653)	0.270 (0.347)	0.018 (0.014)
Forestry	0.719 (0.635)	0.281 (0.365)	0.014 (0.012)
Recreation and residence	0.622 (0.502)	0.378 (0.498)	0.022 (0.019)
Timber production possibilities			
Good	0.725 (0.668)	0.275 (0.332)	0.014 (0.012)
Fairly Good	0.709 (0.626)	0.291 (0.374)	0.013 (0.011)
Poor	0.624 (0.528)	0.376 (0.472)	0.024 (0.018)
Importance of recreation			
Important	0.598 (0.496)	0.402 (0.504)	0.019 (0.014)
Neutral	0.730 (0.647)	0.270 (0.353)	0.014 (0.011)
Not important	0.736 (0.687)	0.264 (0.313)	0.015 (0.012)
Short time price expectation			
Increasing	0.721 (0.660)	0.279 (0.340)	0.027 (0.024)
No change	0.705 (0.624)	0.295 (0.376)	0.012 (0.010)
Decreasing	0.696 (0.623)	0.304 (0.373)	0.016 (0.014)
Future cuttings			
Extensive cuttings	0.674 (0.610)	0.326 (0.390)	0.014 (0.016)
Sustainability	0.722 (0.656)	0.278 (0.344)	0.013 (0.013)
Intensive cuttings	0.727 (0.662)	0.273 (0.338)	0.018 (0.029)
Choice of taxation			
Realized-income taxation	0.685 (0.606)	0.315 (0.394)	0.014 (0.014)
Site-productivity taxation	0.736 (0.647)	0.264 (0.353)	0.018 (0.019)
Mean volume, m ³ /ha			
–100	0.676 (0.582)	0.324 (0.418)	0.018 (0.018)
100–150	0.714 (0.656)	0.286 (0.344)	0.013 (0.013)
150–	0.712 (0.650)	0.288 (0.350)	0.017 (0.018)

The second in preference was “finance” (17 %) and the third was “saving” (11 %). “No cuttings” and “maximum cuttings” were the least preferred (9 % and 1 %, resp.). When presented according to the number of landowners, the distributions of

the most preferred strategies were slightly different than when compared to the forest area represented by each strategy (Table 10, Fig. 5).

The non-farmers preferred the “no cuttings strategy” more than farmers did (Table 11). The own-

Table 10. Choices of timber management strategies according to area of the forest holding: proportion of number of landowners (a), and proportion of total forest area (b) (weighted mean was calculated according to area proportion of the official register on Finnish farm holdings).

Size of holding, ha	No cuttings	Saving	Sustainability	Finance	Max. cuttings
a) Proportion of number of landowners					
5–19.9	17.1%	14.6%	48.8%	17.1%	2.4%
20–49.9	4.1%	8.2%	69.9%	17.8%	0.0%
50–99.9	1.8%	7.0%	75.4%	14.0%	1.8%
100–	0.0%	4.8%	66.7%	26.2%	2.4%
Mean	5.2%	8.5%	66.7%	18.3%	1.4%
Weighted mean	8.9%	10.5%	61.8%	17.4%	1.4%
b) Proportion of total forest area					
5–19.9	18.0%	13.1%	49.9%	16.2%	2.8%
20–49.9	2.1%	7.9%	72.4%	17.6%	0.0%
50–99.9	2.3%	7.1%	75.9%	13.3%	1.4%
100–	0.0%	4.0%	68.6%	25.3%	2.0%
Mean	1.9%	6.0%	70.6%	19.9%	1.5%
Weighted mean	4.4%	7.7%	68.8%	17.8%	1.3%

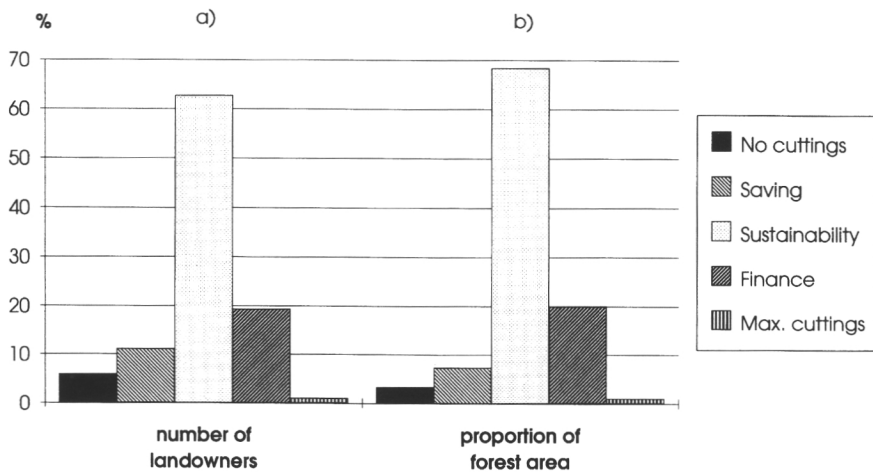


Fig. 5. The choices of timber management strategies according to a) the number of landowners, and b) the actual forest area represented by each strategy.

ers of the smallest forest holdings more frequently chose “no cuttings” and “saving” strategies than rest. On one hand, landowners with large forest holdings (forest areas between 50 and 100 hectares) preferred “sustainability” more than the average landowners. On the other hand, the owners of holdings of over 100 forest hectares chose the “finance” strategy more frequently than owners of smaller holdings.

Increase in the area of arable land (fields) led to choices of strategies favouring intensive removals. In addition, recreation and residence as the primary uses of the property referred to the choices of “no cuttings” and “saving” strategies. The strategy most favoured by landowners practising agriculture and forestry was “sustainability”. Landowners practising solely agriculture on their farms preferred the “finance” strategy more than others.

Table 11. The choices of timber management strategies according to the characteristics of the background information.

	No cuttings	Savings	Sustainability	Finance	Max cuttings
Owner					
Farmer	3.4	10.7	64.6	20.2	1.1
Non-farmer	9.5	11.1	61.1	17.5	0.8
Forest area, ha					
5–20	13.0	22.2	50.0	13.0	1.8
20–50	6.7	10.6	59.6	23.1	0.0
50–100	3.3	7.8	74.5	13.3	1.1
over 100	1.7	6.9	62.1	27.6	1.7
Field (arable land)					
–5 ha	11.9	12.7	59.3	15.2	0.9
over 5 ha	1.8	9.7	67.3	20.0	1.2
Production orientation					
Agriculture	3.1	14.1	51.6	31.2	0.0
Agriculture and forestry	0.0	9.6	75.4	12.3	2.7
Forestry	4.3	8.6	37.2	19.8	0.0
Recreation and residence	22.5	14.3	46.9	14.3	2.0
Timber production possibilities					
Good	2.4	6.5	67.7	21.8	1.6
Fairly good	5.8	14.6	65.0	14.6	0.0
Poor	17.1	14.6	43.9	24.4	0.0
Importance of recreation					
Important	11.0	17.0	52.0	20.0	0.0
Neutral	4.5	4.5	69.4	19.8	1.8
Not important	2.1	12.6	66.3	17.9	1.1
Short time price expectation					
Increasing	6.1	21.2	48.5	21.2	3.0
Same	5.8	8.1	71.7	14.4	0.0
Decreasing	4.4	12.1	54.9	27.5	1.1
Future cuttings					
Extensive cuttings	13.0	19.0	56.0	11.0	1.0
Sustainability	2.2	6.6	69.3	21.2	0.7
Intensive cuttings	0.0	3.0	51.5	42.5	3.0
Choice of taxation					
Realized-income taxation	10.9	13.9	57.6	16.1	1.5
Site-productivity taxation	1.9	5.8	67.3	25.0	0.0
Cannot say	2.2	15.2	65.2	17.4	0.0

The landowners' opinions regarding timber production possibilities were asked before the presentation of the strategy calculations. The strategies with extensive cuttings were the most favoured among landowners who felt their timber production possibilities to be poor. Short term positive stumpage price expectations led to choices of extensive strategies. The most favoured strate-

gy was "sustainability" among landowners who felt that future stumpage prices would remain stable. Landowners with expectations of falling stumpage prices preferred the "finance" strategy more than others.

When the landowners were asked for their opinions on future cuttings before presenting the calculations of the strategies, the landowners who

preferred extensive cuttings chose the “no cuttings” and “saving” strategies more frequently than the rest of the landowners. The “finance” strategy viewed with favor among landowners who preferred intensive cuttings. These choices coincided in both inquiries.

Landowners who chose forest taxation based on site productivity preferred the “finance” strat-

egy more than those who chose forest taxation based on realized income. The “no cuttings” and the “saving” strategies were favoured by landowners who chose realized-income based forest taxation. In analysing the choices of strategies, the differences between the taxation systems were slightly bigger in the first than in the second inquiry.

5 Potential Allowable Cut in Pohjois-Savo

5.1 Comparison of Timber Management Strategies at the Regional Level

Timber management strategies were compared at regional level assuming that all landowners would follow the same strategy. Comparison were made for both the TASO and the NFI data sets in order to verify the reliability of the TASO data. The average removals in both data sets were compared over the entire 20-year planning period. Furthermore, the development of the removals, mean volume and growth was compared every five years period (1993–1998, 1998–2003, 2003–2008 and 2008–2013).

In the “sustainability” strategy, the average harvest rate in the NFI data was 3.9 % higher compared to the TASO data (Table 12a). In the “saving” strategy, the average harvest was, by definition, approximately half of the removals of the “sustainability” strategy. In the “finance” strategy, the average removals were smaller than in the “sustainability” strategy. With the “finance” strat-

egy, the removals in the TASO data were 6.5 % greater than those in the NFI data. This difference may be due to the larger proportion of sawtimber in the TASO data.

When assuming that all landowners would choose the “max cuttings” strategy, the average removals were considerably greater in the TASO data than in the NFI data. This difference may be caused by the same reason as the difference observed when examining the “finance” strategy. However, the difference had only a small effect on the potential allowable cut, since only 1.0 % of the landowners had chosen the “max cuttings” strategy. The greatest cumulative removals were obtained in the TASO data with the “max cuttings” choice, and in the NFI data when choosing “sustainability”. By generalising the results over the whole study area, the following average regional removals were obtained: 5.3 mill. m³ in the TASO data, and 4.9 mill. m³ in the NFI data (Table 12b).

In the smallest area group, the average harvest rates were also lowest for every strategy (Table 13), although the mean initial volume in this group did not differ significantly from the other forest

Table 12. Average removals over 20 years, according to strategies, m³/ha (a), and cumulative removals, mill. m³ (b), assuming that all landowners would follow the same strategy

	TASO	NFI
a) Average removals (m ³ /ha)		
No cuttings	0.00	0.00
Saving	2.47	2.56
Sustainability	4.93	5.12
Finance	4.64	4.35
Max. cuttings	5.53	4.73
b) Cumulative removals (mill. m ³)		
No cuttings	0.00	0.00
Saving	2.36	2.45
Sustainability	4.71	4.90
Finance	4.44	4.16
Max. cuttings	5.29	4.53

Table 13. Average removals (m³/ha/a) according to area of the forest holdings.

Size of holding, ha		Saving	Sustain-ability	Finance	Max. cuttings
5–19.9	Mean	2.35	4.61	4.78	4.85
	SD	0.99	1.98	1.74	2.41
20–49.9	Mean	2.49	4.97	4.75	5.18
	SD	0.84	1.67	1.44	2.25
50–99.9	Mean	2.42	4.82	4.59	5.26
	SD	0.68	1.36	1.06	2.02
100–	Mean	2.49	4.98	4.58	5.66
	SD	0.68	1.36	1.10	1.85
Total	Mean	2.45	4.86	4.68	5.23
	SD	0.80	1.60	1.35	2.15

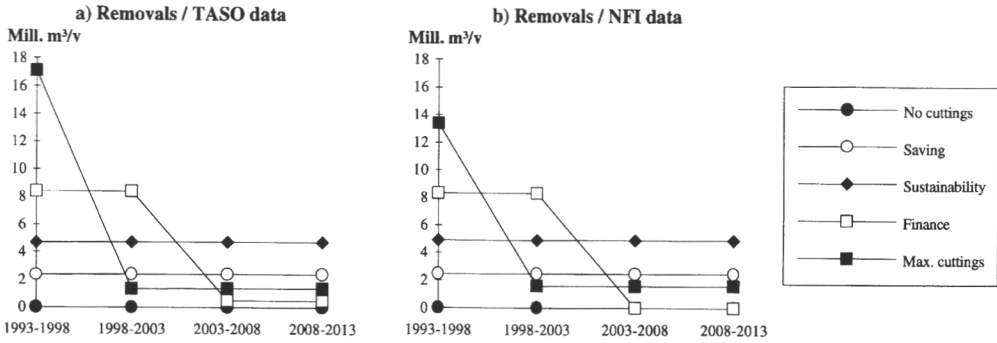


Fig. 6. The average removals (mill. m³/a) under the assumption that all landowners would follow the same strategy.

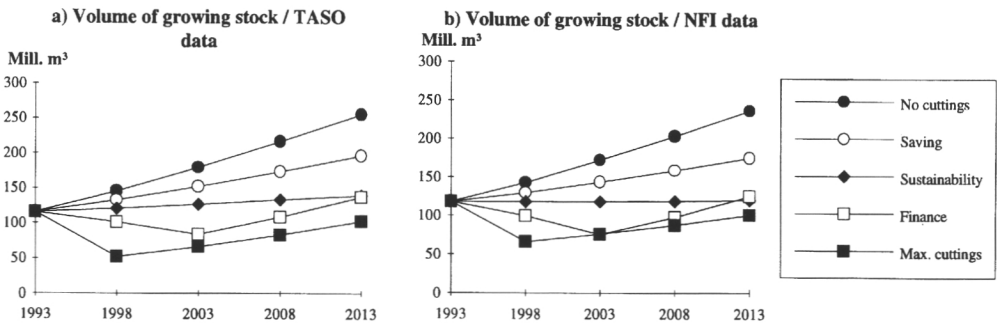


Fig. 7. The development of the volume of the growing stock (mill. m³) under the assumption that all landowners would follow the same strategy.

area groups. However, the overall differences in cuttings between the area groups were not statistically significant. For all strategies, the relative standard error for the whole data varied between 2.0–2.8 % for the different strategies. In the different area groups, the relative standard errors varied between 3.0–7.8 % with the greatest errors being observed in the group consisting of the smallest holdings.

In the periodical analysis, the removals of the first period (1993–1998) of the “max cuttings” strategy were tripled, and those of the “finance” strategy doubled when compared to the removals of the “sustainability” strategy (Fig. 6). The differences between the data sets were relatively small, with the exception of the “max cuttings” strategy, in which the average removals of the first planning period were 3.7 mill. m³/a higher in the TASO data. In the both “sustainability” and

“saving” strategy, the average removals were almost the same in the both data sets. In the finance strategy, slightly higher removals were observed in the TASO data than in the NFI data during the first half of the planning period.

In all choices of timber management strategies, the mean volume of the growing stock attained at the end of planning period was higher in the TASO data than in the NFI data (Fig. 7). The lowest mean volume attained was 107.0 m³/ha in the TASO data and 105.5 m³/ha in the NFI data. The highest mean volumes were reached in the “no cuttings” strategy: 266.7 m³/ha and 247.0 m³/ha, respectively. The higher mean volume in the TASO data was due to the higher growth rate when compared to the NFI data (Fig. 8). For example, the average growth in the sustainability strategy for the whole planning period was 11.3 % greater in the TASO data than in the NFI data.

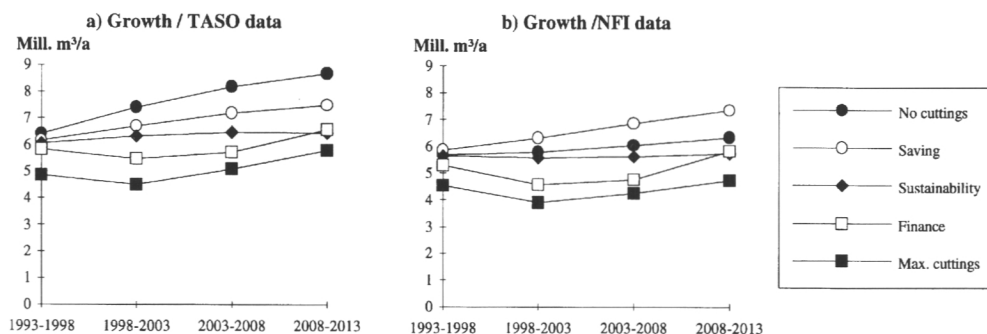


Fig. 8. The development of forest growth (mill. m³/a) under the assumption that all landowners would follow the same strategy.

Table 14. The average removals (m³/ha/a) according to choices of timber management strategies, and cumulative removals over the whole area

Size of holding, ha	No cutt.	Saving	Sust. m ³ /ha	Finance	Max. cutt.	Average	Cumulative milj.m ³
5–19.9	0.00	1.89	4.98	4.26	4.93	3.57	0.59
20–49.9	0.00	2.78	4.98	4.69	0.00	4.57	1.48
50–99.9	0.00	2.20	4.85	4.73	8.11	4.58	1.23
100–	0.00	2.57	4.99	4.59	5.10	4.79	0.99
Average	0.00	2.42	4.94	4.62	5.91	4.63	4.29

5.2 Potential Allowable Cut

In the analysis of the landowners' choices of strategies, the overall removals in the smallest holdings were smaller than in the rest of the area groups (Table 14). This was due to the below-average removals and the preferred choices of "saving" and "no cuttings" strategies by the owners in the smallest area group. On the other hand, the heavier removals in the area group of large holdings were often followed by a preference for the "finance" strategy. The average harvest rate based on the landowners' choices of timber management strategies was 4.6 m³/ha/a. When weighted with the area group distribution of the Official Record of Finnish Farms (Pihljerta 1994), the average harvest rate obtained for both data sets was 4.5 m³/ha/a. The smallest holdings presented 13.7 % of the weighted harvest rate.

As a generalisation of the results for the whole

district of Pohjois-Savo, the average removals of the 20-year planning period were 4.3 mill. m³/a for the TASSO data and 4.4 mill. m³/a for the NFI data (Fig. 9). During the first half of the planning period, the removals were heavier due to the accumulation of removals in the "max cuttings" and "finance" strategies. The proportion of sawtimber in the removals was somewhat higher in the TASSO data than in the NFI data.

In both data sets, the mean volume increased towards the end of the planning period (Fig. 10). In addition, the mean volume in the TASSO data was a little higher, particularly concerning the proportion of sawtimber. This was due to the higher level of growth observed in the TASSO data when compared to that in the NFI data (Fig. 11). The average growth for the planning period was 6.3 mill. m³/a in the TASSO data and 5.7 mill. m³/a in the NFI data.

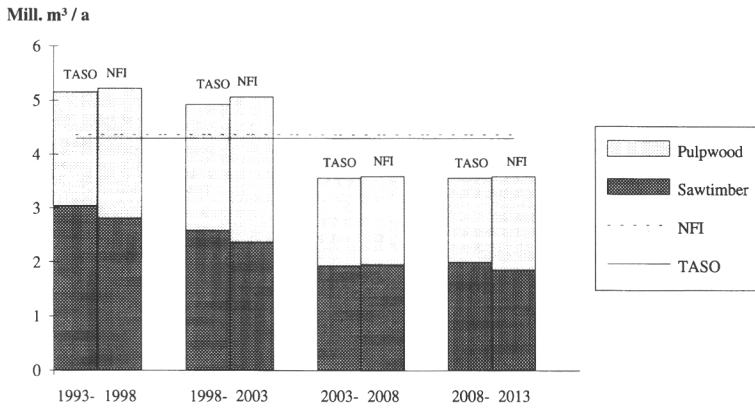


Fig. 9. The removals (mill. m³) according to the choices of preferred strategies during each five-year period, and average removals.

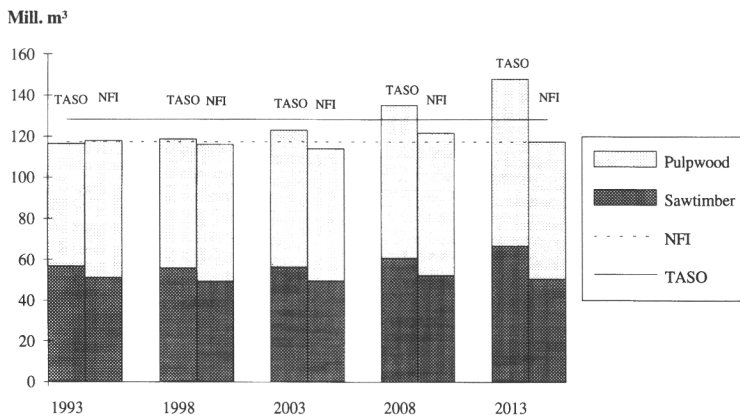


Fig. 10. The total volume (mill. m³) according to planning periods, and the average volume during 20 years.

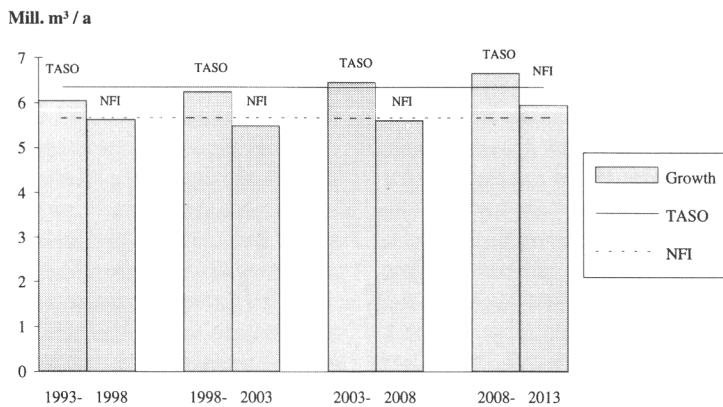


Fig. 11. The growth (mill. m³/a) according to the time periods, and the average growth.

6 Discussion and Conclusions

6.1 Comparing the Cutting Budgets

The potential allowable cut determined in this study was 20 % higher than the average realized cuttings in the Pohjois-Savo district during the years 1988–1993 (Fig. 12). However, during the years of economic boom, 1989–1990, the potential allowable cut almost reached the level of removals as well as the greatest sustained cut according to NFI7. Compared to the greatest allowable cut (based on sustained yield) of NFI8, the potential allowable cut of this study was 12 % smaller. Furthermore, the cutting budget based on combining the forestry plans was 20 % smaller than the one presented in this study.

The differences between the cutting budgets based on combining forestry plans and the potential allowable cut as defined in this study are due to two reasons: the principle of discretion in NIPF planning and the older, NFI7-based growth models used in the TASO planning system. The underestimation of the actual cutting possibilities

on sustained yield basis in the TASO forestry plans can be almost 20 % (Pesonen and Räsänen 1993). Forest planning of non-industrial private forests is still based on standwise propositions of treatments made by professional planners. The planners seldom have full knowledge of the sustained cutting possibilities at the forest holding level.

In comparing the NFI8-based, forest-resources oriented cutting budget and the potential allowable cut of this study, two main reasons for the difference can be outlined: ignorance of landowner-specific forestry goals in the former and the constraints caused by the requirement of forest-holding level sustainability in the latter. The fact that the owners of small forest holdings preferred the choices of “no cuttings” and “saving” strategies reduces the potential allowable cut from NIPF lands. The requirement of sustained yield at the forest holding level has been reported to decrease regional cutting possibilities by over 10 % (Pesonen and Soimasuo 1994).

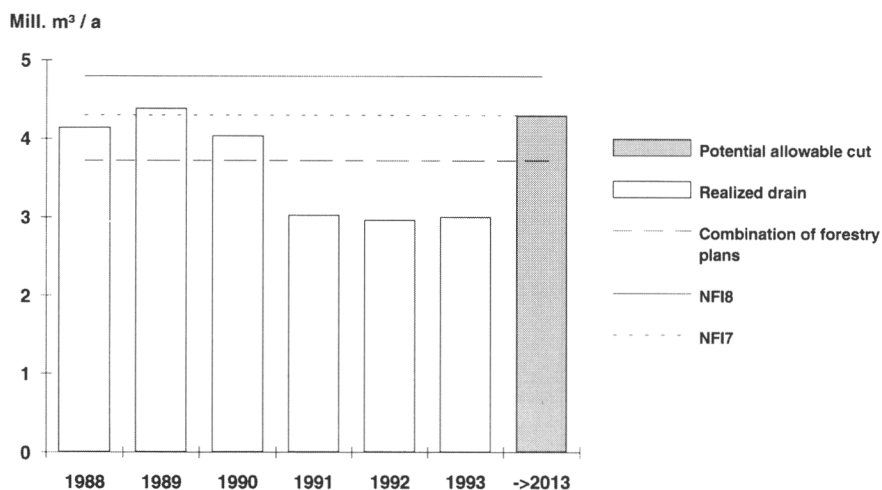


Fig. 12. The realized drain (mill. m³/a) in Pohjois-Savo, and cutting budgets calculated applying the alternative methods.

6.2 Timber Management Strategies

In this study, the utility functions were formulated in order to find out the landowners' choices of timber management strategies. After strategy calculations, the importance of the economic benefits of forest property increased. Thus, the importance of non-economic factors – such as recreational use of the forest – decreased when the landowners realised the increasing possibilities of removals and regular stumpage earnings.

The factors that increased the importance of the economic benefits of forest property were as follows:

- 1 Farmer as landowner and possession of arable land (fields),
- 2 Increase in the area of the forest holding,
- 3 Agriculture and forestry as the main activities on the property,
- 4 Good or fairly good timber production possibilities,
- 5 Neutral or weak importance of recreation as an alternative forest use,
- 6 Positive short term price expectations,
- 7 Increase in the intensity of future removals,
- 8 Choice of forest taxation system based on site productivity,
- 9 Increase in the mean volume of the growing stock.

“Sustainability” was the preferred choice of strategy for nearly 70 % of the landowners. It is likely that at least some of the landowners did not realize how much heavier removals were included in this strategy compared to realized drain and the removals proposed in their forestry plan. However, 23 % of the landowners were willing to increase their removals after seeing the alternative timber management strategies.

The choice of timber management strategy was slightly sensitive to changes of preferences of the economic and non-economic benefits of the use of forest property (Fig. 13). If all the weight was placed on the economic benefits, the relative proportions of choices of “sustainability” and “finance” increased. On the contrary, if all the weight was placed on the non-economic benefits, the relative proportions of the choices of “no cuttings” and “saving” strategies increased (Fig. 13).

The size of forest holding had a significant effect on the choice of timber management strategy. Owners with forest holdings less than 20 ha in forest area preferred the choices of “no cuttings” and “saving” strategies, while owners of large holdings of more than 100 ha preferred the “finance” strategy. In addition to this, the following facts resulted in the area-based choices of timber management strategies: forestry plans were made for above-average sized holdings, one of the sam-

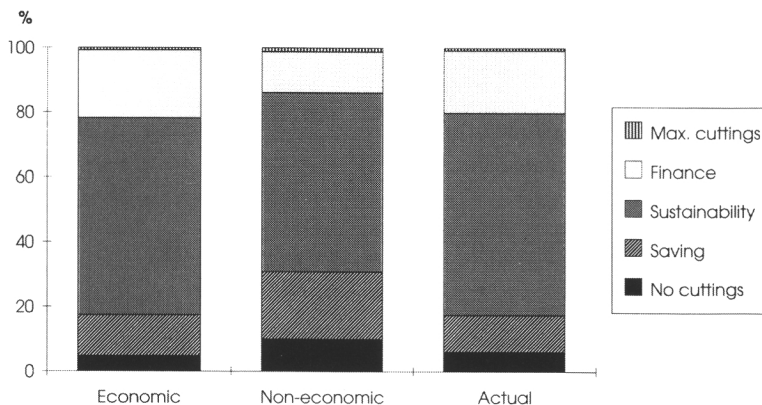


Fig. 13. The relative frequencies of the choices of timber management strategies when using a) total weight on economic benefits, b) total weight on non-economic benefits, and c) actual weights obtained from pairwise comparisons.

pling methods favoured large holdings, and evidently the owners of forest holdings above-average in size were more interested in participating in the study.

The following factors led to the choices of strategies with intensive cuttings:

- 1 Farmer as landowner and ownership of arable land (fields),
- 2 Increase in the area of the forest holding,
- 3 Agriculture and forestry as the main activities on the property,
- 4 Negative short term price expectations,
- 5 Increase in the intensity of future removals,
- 6 Choice of taxation system based on site productivity.

The results of the choices and the factors affecting these choices of timber management strategies may be summarised as follows:

“No cuttings”

This group consisted of small forest holdings (less than 20 ha in area), which were usually owned by non-farmers. They owned only little arable land or not at all. Furthermore, the landowners in this group preferred residence and recreation as alternative uses of the forest holding. The realized-income taxation was the choice of forest taxation system for these landowners.

“Saving”

This group also consisted of relatively small forest holdings (less than 20 ha in area), and the owners considered their timber production possibilities poor, or at the best, normal. They preferred recreation as the alternative use of forest property, and, like their fellows in the “no cuttings” group, their choice of forest taxation basis was realized-income taxation. Moreover, these landowners anticipated a rise in timber prices in the near future.

“Sustainability”

“Sustainability” was chosen by the landowners with forest holding sizes between 50 and 100 ha in area. For these landowners, the main activities on their holdings were agriculture and forestry. In addition, the landowners in this group considered their timber production possibilities to be good.

They did not prefer recreation as an alternative use of forest property, and they thought that the timber prices would remain stable in the near future.

“Finance”

This group consisted of the largest forest holdings (over 100 hectares in area), and the owners practised mainly agriculture on their holdings. The short-term timber price expectations of this group were that they would decrease.

“Max cuttings”

Only three landowners (1.0 % of the sample) chose this strategy; thus, conclusions could not be drawn regarding it.

6.3 Reliability of the Data and Methods

The additive utility function, the function form used in this study, is the easiest to interpret (Pukkala and Kangas 1993). In several studies, it has been noticed that the additive utility function produces a utility index which best describes the preferences of the decision-maker (Tell 1976, Laskey and Fischer 1987). It has also been stated that landowners are utility-maximizers who consider both the economic and the non-economic benefits of their forests (Boyd 1984, Hyberg 1987).

Due to its simplicity, effectiveness and ability to deal with qualitative as well as quantitative criteria (this is also indicated by the results of this study) the AHP is well-suited to dealing with problems with forest management planning (e.g. Kangas 1992). When applied to the mail inquiries, the weakest point of the method is the question of whether all respondents are able to concentrate on the numerous comparisons required by the AHP. Therefore, the results would be improved by the application of personal interviews in conjunction with data collection.

The consistency ratios (CR) were slightly higher than was acceptable: 18.5 % in economic and 17.2 % in non-economic comparisons. This may be partly due to the fact that the inquiries used in the study were made by mail, and all kinds of landowners did tens of AHP comparisons. How-

ever, there is no unequivocal upper limit for the level of inconsistency in pairwise comparisons, and moreover, the inconsistency in comparisons can also be due to a conscious choice, and must therefore be accepted (e.g., Wedley 1993, Apostolou and Hassell 1993). It can thus be concluded, after all, that the majority of landowners did understand the differences between the strategies, and they were also consistent with their comparisons.

The AHP method and the use of mail inquiry in data collection limited the alternative choices of strategies to five. In spite of this, the alternative strategies and choices made by the landowners were based on the actual, forest-holding level development of cuttings, income from timber sales and other forest characteristics. Although few landowners chose the extreme alternatives – “no cuttings” or “max cuttings” strategies – these strategies were included in the comparisons in order to describe the whole range of timber production possibilities.

The applied sampling methods did not significantly affect the definition of the potential allowable cut. The results of the data obtained from systematic stratified sampling did not differ from those obtained with data from random sampling. Thus, after being compared, the two samples were combined.

The objectives of the landowners may also vary according to the point of time, and/or region. Lönnstedt and Törnqvist (1990) stated that the choice of timber management strategy is affected by the needs and objectives of both short- and long term perspective. The goal structure of the landowners could have been clarified better. In this study, the landowners were able to compare only five precalculated timber management strategies. It would be possible to ask more specific questions about the objectives of the landowners in the first inquiry, and with that information in mind, calculate the strategies more individually.

The removals corresponding to the timber management strategies calculated using the TASO data were slightly overestimated. This was demonstrated by combining the forest holdings into a single, large forestry unit, and then recalculating the strategies; with the single unit, the removals corresponding to sustainability were 5.5 m³/ha/a which is 5.5 % more than those given by the NFI data. In

spite of this, the overall differences between the results from the two data sets (TASO and NFI) were small. Based on this study, the material from the standwise inventory is reliable enough to enable the definition of regional cutting possibilities, although considerable measurement errors have been reported in standwise inventories due to personal characteristics of the planners (Laasasenaho and Päivinen 1986).

The study material (the TASO data) was representative in comparison with the reference material (the NFI data) in regard to the forest resource information. No major differences between the data sets were found concerning the mean volumes, proportions of sawtimber and tree species, and age class distributions. The only substantial difference was caused by the greater growth given by the TASO data, which was partly due to the greater proportion of seedling stands in the TASO data compared to the NFI data. In “sustainability”, for example, the growth in the TASO data for the first five-year period was 6.9 % greater and 11.3 % greater during the whole planning period than in the NFI data.

Due to requirement of sustainability at the forest holding level, the removals resulting from the TASO data were smaller and led to the faster volume increase and higher growth rate. One reason for the difference could have been in the fact that in the NFI data, the diameter distribution was constructed using the measured sample trees, while in the TASO data, the diameter distribution was formulated using the theoretical, Weibull-distribution (Kilikki et al. 1989). The reliability of the results could have been further increased by selecting diameter distribution from the NFI data by using the standwise information of the TASO data.

The effects of no-response observations were examined by comparing the average planned removals of landowners included in the first inquiry to those of landowners who were included in the second inquiry. In the comparison, it was assumed that all landowners would have chosen the “sustainability” strategy. The average removals did not differ significantly between the first and the second inquiry. Furthermore, the data of the 213 landowners used to calculate the potential allowable cut did not differ from the data of the first inquiry. Moreover, in regard to the distributions of the choices of timber management strategies

and forest area, there were no significant differences between the data used to calculate the potential allowable cut ($n = 213$) and the data of the second inquiry ($n = 306$).

The representativeness of the data was also tested by a no-response mail inquiry addressed to 51 landowners. The variables that had significant effects on the choices of timber management strategies were examined in the no-response survey. Generally, the characteristics of the no-response data were well in line with the actual study material. Thus, the no-response observations had little effect on the external reliability of results.

The landowners that had not responded to the mail inquiry were asked for their reasons for not answering the inquiry. Half of the no-response landowners could not give any particular reason for not responding. Lack of time and being busy with work were reported as the reasons by 25 % of the landowners. About 15 % of landowners were fed up with continuous inquiries. Other reported reasons for no-response included serious illness or death of the landowner, and problems with mailing. In this study, the preferred timber management strategy could not be clarified for the non-response landowners, and for landowners that did not have an up-to-date forestry plan.

An essential aspect to note is that the potential allowable cut, as defined in this study, is a far more sensitive and dynamic concept than the completely forest-resource-oriented cutting budgets. The attitudes, values and objectives of the landowners vary much more and more frequently than forest growth, for example. The allowable cut presented in this study is based on the landowners' concepts and objectives in the spring of 1993.

6.4 Conclusions

The potential allowable cut presented in this study appeared to settle in the middle of the realized drain and the greatest allowable cut based on the National Forest Inventory. When compared to the realized drain, landowners would have cut 20 % more annually, assuming that they were to follow their choices of timber management strategies.

The results of this study indicate that the landowners' future harvesting intentions in Pohjois-Savo will ensure the availability of wood raw material for future investments by forest companies. Furthermore, the region's landowners could be activated to practise intensive management and harvesting by demonstrating to them the strategic alternatives in timber management. The results of this study may also help to direct the development of management planning on NIPF lands.

An interesting issue for future research would be to monitor the sample forest holdings – will strategic calculations affect the future harvesting behaviour of the owners? In addition, forestry plans based on the choices of timber management strategies could be made for the sample holdings and then proceed to monitor owner's harvesting behaviour. Comparisons of harvesting behaviour could then be made between the owners of sample holdings, those of forest holdings without forestry plans, and those forest holdings with up-to-date plans, made by state-funded forestry organisations.

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ACTA FORESTALIA FENNICA

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Mauno Pesonen, Arto Kettunen and Petri Räsänen

Non-Industrial Private Forest Landowners' Choices of Timber Management Strategies: Genetic Algorithm in Predicting Potential Cut

The Finnish Society of Forest Science — The Finnish Forest Research Institute

Pesonen, M., Kettunen, A. & Räsänen, P. 1995. Non-industrial private forest landowners' choices of timber management strategies: Genetic algorithm in predicting potential cut. *Acta Forestalia Fennica* 250. 28 p.

The factors affecting the non-industrial, private forest landowners' (hereafter referred to using the acronym NIPF) strategic decisions in management planning are studied. A genetic algorithm is used to induce a set of rules predicting potential cut of the landowners' choices of preferred timber management strategies. The rules are based on variables describing the characteristics of the landowners and their forest holdings. The predictive ability of a genetic algorithm is compared to linear regression analysis using identical data sets. The data are cross-validated seven times applying both genetic algorithm and regression analyses in order to examine the data-sensitivity and robustness of the generated models.

The optimal rule set derived from genetic algorithm analyses included the following variables: mean initial volume, landowner's positive price expectations for the next eight years, landowner being classified as farmer, and preference for the recreational use of forest property. When tested with previously unseen test data, the optimal rule set resulted in a relative root mean square error of 0.40.

In the regression analyses, the optimal regression equation consisted of the following variables: mean initial volume, proportion of forestry income, intention to cut extensively in future, and positive price expectations for the next two years. The R^2 of the optimal regression equation was 0.34 and the relative root mean square error obtained from the test data was 0.38.

In both models, mean initial volume and positive stumpage price expectations were entered as significant predictors of potential cut of preferred timber management strategy. When tested with the complete data set of 201 observations, both the optimal rule set and the optimal regression model achieved the same level of accuracy.

Keywords genetic algorithms, strategic decision making, timber management strategies.

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Preface

This study is part of the project ‘Optimisation of Regional Cutting Budgets’ conducted at The Finnish Forest Research Institute. The main objective of the project is to develop a new calculation system for determining regional cutting budgets. Special thanks are due to the following project partners for their help and advice during the research process: The Finnish Forest Industries Federation, The Central Union of Agricultural Producers and Forest Owners, The Forest Centre Tapio, The Regional Forestry Board of Pohjois-

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1 Introduction

1.1 Strategic Decisions in Management of Non-Industrial Private Forests

The behaviour of non-industrial private forest (NIPF) landowners has been studied widely in many industrialised countries where forests in private ownership amount to significant proportions. In these countries, forest industry receives a great amount of timber from NIPF lands, and there is also a growing demand for recreational and other non-timber uses of non-industrial private forests. Many landowner studies have focused on relating the landowners' characteristics to specific aspects of past and future behaviour, e.g. harvesting (Kuuluvainen and Salo 1991), forestry investments (Romm et al. 1987), management intentions (Greene and Blatner 1986), and objectives and motivations of NIPF landowners (Kurtz and Lewis 1981, Bliss and Martin 1989).

It has been generally accepted that, by knowing the factors affecting the behaviour of landowners, it is possible to guide public measures to activate NIPF management (e.g. Gramann et al. 1985). It is also known that NIPF landowners form a diverse group with a variety of objectives and intentions. Moreover, most NIPF landowners have long-time perspectives and strategic views concerning management (Lönstedt 1989). However, few studies have been made on the strategic decisions made in NIPF management (Lönstedt and Törnqvist 1990, Hansson et al. 1990, Pukkala and Kangas 1993) and the factors that affect these decisions have been, more or less, neglected.

Understanding the strategic decisions of NIPF landowners is important for several reasons. First, it helps in the planning of public measures to promote timber management on NIPF lands. Second, predictions concerning the supply of timber from private forests for the future development of forest industry can be based on knowledge of these decisions (Lönstedt and Roos 1993). Third, a

strategic view is needed in the development of day-to-day NIPF management planning.

At the strategic level of decision making, NIPF landowners lack information about the decision alternatives and their consequences (Kangas et al. 1992). So far, NIPF management planning in Finland has been basically tactical. Forestry plans are usually based on the presentation of a single cutting budget with no real decision alternatives. Thus, the various goals of Finland's over 400 000 NIPF landowners are almost totally ignored in State-funded forest management planning. This being the case, it is important to bring landowners into the planning process by offering them alternatives for the strategic use of their forest property.

1.2 Machine Learning

Modelling the strategic decision making of NIPF landowners, like any other attempt to model human behaviour, is a complex and multidimensional task. New approaches to retrieving knowledge from complex problem domains are offered by *machine learning* methods. Many machine learning techniques are capable of dealing with quantitative as well as qualitative variables with linear and non-linear dependencies. They are often non-parametric in character, noise-tolerant, and non-sensitive to fixed hypotheses. Moreover, the results obtained from machine learning analyses, particularly in the form of production rules, can be directly used to construct rule-based expert systems (Guan and Gertner 1991).

Genetic algorithms, the machine learning approach addressed in this study, have been suggested for various applications in forest science, including the maintenance and management of forestry-related, knowledge-based systems (Foster 1993), modelling of natural processes and con-

struction of rule-based expert systems (Guan and Gertner 1991), substituting for and complementing the traditional tools of statistical analysis (Liepins et al. 1990), and for inducing rules from complex forestry databases (Jeffers 1991). The genetic algorithm used in this study (BEAGLE) has been applied to discrimination of *Populus* clones by measurement of poplar leaves (Jeffers 1991) and to automated rule induction from forest regeneration database (Saarenmaa 1992).

In this study, a rule-learning genetic algorithm is applied to analysing NIPF landowners' strategic decisions. This kind of an approach has not been reported in any earlier studies of landowner behaviour. Neither have genetic algorithms, as yet, been applied in the same sense.

1.3 Aim of the Study

The aim of this study is to predict non-industrial, private forest landowners' potential cut using a genetic algorithm and linear regression. Furthermore, the factors affecting the landowners' strategic decisions in NIPF management planning are studied. A genetic algorithm is used to induce a set of production rules predicting NIPF landowners' preferred timber management strategies. The rules are based on the landowners' objectives and characteristics of the landowners and their forest holdings. The dependent variable is the preferred timber management strategy, potential cut, described as *average annual removals of the first five-year planning period (m³/ha/a)*. The performance of genetic-based machine learning is compared to more traditional statistical analysis. The theoretical framework of the study is presented in Fig. 1.

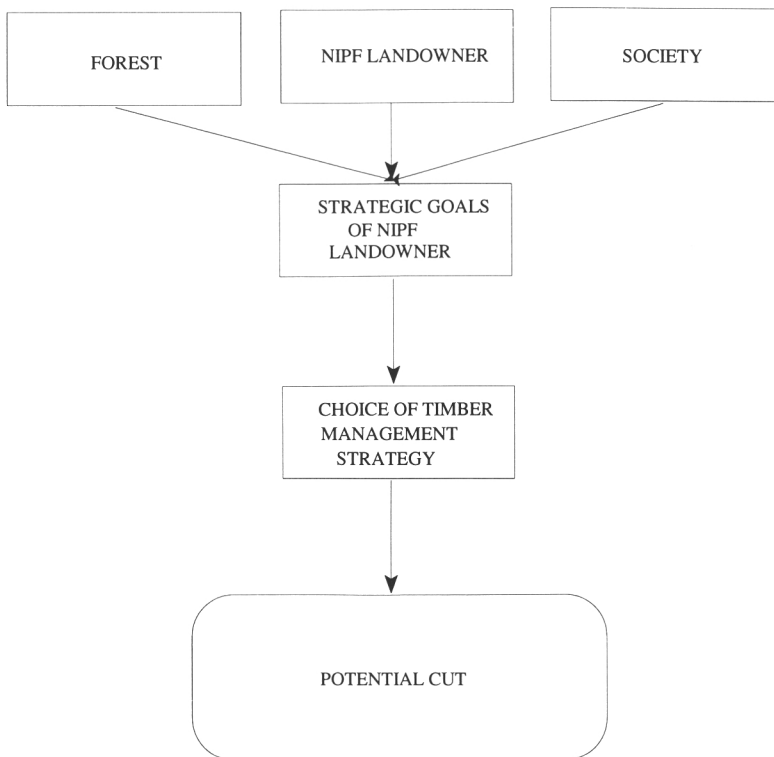


Figure 1. Frame of reference applied in this study.

2 Genetic Algorithms

2.1 Introduction to Genetic Algorithms

Genetic algorithms (GA) can be defined as inductive, problem-solving methods applying the principles of biological evolution and natural selection (Alander 1992). The basic idea in genetic algorithms is that of developing a mathematically simple, yet robust, basic structure and make it into an effective search method appropriate for solving various types of complex problems (Goldberg 1989). Genetic algorithms have been applied to a variety of problem domains, including integer and combinatorial optimisation, heuristic search, rule induction and biological simulation (Davis 1991).

Genetic algorithms differ from traditional optimisation and search procedures in four ways (Goldberg 1989):

- 1 GAs work based on encoding of the parameter set, not the parameters themselves.
- 2 GAs conduct searches within a population of points, not a single point.
- 3 GAs use payoff (objective function) information, not derivatives or other auxiliary knowledge.
- 4 GAs use probabilistic transition rules, not deterministic rules.

A standard genetic algorithm usually operates on a population of bit strings. In principle, the operation of a genetic algorithm includes copying of bit strings and mutual changes between string parts. The only assumption in applying genetic algorithms is that the alternative solutions to the problem at hand can be represented as character strings of definite length. The bit-string encoding of alternative solutions is merely to facilitate the operation of genetic algorithms – the actual information included in bit-strings can be, for example, classification or production rules (Goldberg 1989).

Genetic algorithms produce variation in the

populations of candidate solutions through genetic operators. The basic genetic operators include *reproduction*, *recombination* (i.e. crossover) and *mutation* (Goldberg 1989). Reproduction creates new information structures, starting from the initial population, so that the surviving descendants relate to the above average candidate solutions. In recombination, bit-strings exchange a random part of their information structures. Mutation creates new individuals by randomly altering the value of one or more bits with pre-specified probability. With a population of classification rules, the above operations are basically the same except that the information structures under manipulation consist of parts of rules (Forsyth 1989). An example of recombination is presented below (Goldberg 1989).

Let A_1 and A_2 represent bit-strings of length $l = 5$

$A_1 = 01101$
 $A_2 = 11010$

Assuming that, in choosing the crossover site, we obtain a random number $k = 2$ (indicated by the separator symbol $|$), the resulting crossover leads to new strings A'_1 and A'_2 where the specified parts of the information structures have been exchanged:

$$\begin{array}{lcl} A_1 = 01|101 & & A'_1 = 01010 \\ & \Rightarrow & \\ A_2 = 11|010 & & A'_2 = 11101 \end{array}$$

A fitness function is needed to make the selection between the alternative problem solutions. The best individuals of the population of alternative solutions are cross-bred and the most compatible solutions are selected in terms of the fitness function. The procedure is iterated until the desired outcome has been achieved (Alander 1992).

Adopted from Davis (1991), a top-level description of a rule-manipulating genetic algorithm in action can be outlined as follows:

- 1 Initialise a population of rules at random.
- 2 Evaluate each rule in the population.
- 3 Create new rules by mating current rules; apply genetic operators as the parent rules mate.
- 4 Delete inferior members of the population to make room for the new rules.
- 5 Evaluate the new rules and insert them into the new population.
- 6 If time is up, or a desired outcome is reached, stop and return the best rules; if not, go to 3.

2.2 Schema Theorem

The basic functions of genetic algorithms are primarily based on an essential paradigm of the theory of GAs called *Schema Theorem* (Goldberg 1989). Schema Theorem may be described by considering the effect of reproduction, crossover (recombination), and mutation on the growth or decay of schemata from generation to generation. Prior to any mathematical formulation of the functions of a genetic algorithm, some important concepts have to be defined.

A *bit-string* is a binary-coded set of characters of finite length, e.g. the seven-bit string $A = 0011010$ can be represented as $A = a_1, a_2, a_3, a_4, a_5, a_6, a_7$. In order to describe the ideas of the schemata, a *, which stands for a wild-card symbol, (i.e., a * can be either 0 or 1), is added to form a character set $\{0, 1, *\}$.

A *population* of individual strings is defined A_j , $j = 1, 2, \dots, n$, and it is contained in the population $A(t)$ at time t (boldface denotes a population).

A *schema* (Holland 1975) is a similarity template describing a subset of strings with similarities at certain string positions. For example, a schema $H = *11*0**$ is represented by string $A = 0111000$ because of the matching positions at certain string positions.

Order of a schema H , denoted by $o(H)$, is the number of fixed positions (the number of 1's and 0's) in the template, e.g. $o(*11*0**) = 3$.

Defining length of a schema H , denoted by $\delta(H)$, is the distance between the first and the last specific string position, e.g. $\delta(*11*0**) = 3$, because

the distance between the first (2) and the last (5) fixed position is $(5 - 2) = 3$.

In analysing the function of a genetic algorithm, effects of genetic operators on manipulation of the schemata must be considered first. As a result of reproduction on a particular schema, an ever increasing number of samples are given to the more fit strings. However, reproduction alone introduces no new points in the search space. Crossover leaves a schema non-manipulated unless it cuts the schema, but it may disrupt the schema in doing so. Mutation at normal, low rates does not disrupt a particular schema very frequently. Thus, it can be concluded that the more fit, short-defining-length schemata (*building blocks*) survive from generation to generation by having exponentially increasing probabilities to survive and reproduce (Goldberg 1989).

During reproduction, a string is copied according to its fitness. After picking a non-overlapping population of size n , with replacement from population $A(t)$, it is expected to have $m(H, t + 1)$ representatives of the schema H in the population at time $t + 1$. Thus, the reproductive schema growth equation (1) may be written as follows:

$$m(H, t + 1) = m(H, t) \frac{f(H)}{\bar{f}} \quad (1)$$

where

$m(H, t + 1)$	= number of representatives of schema H at time $t + 1$
$m(H, t)$	= initial number of representatives of schema H at time t
$f(H)$	= average fitness of strings representing schema H at time t
\bar{f}	= average fitness of the entire population of strings

Schemata with fitness values above the population average will receive an increasing number of trials in the next generation, while schemata with fitness values below the population average will receive a decreasing number of trials. This procedure is carried out with every schema H in population A in parallel (Goldberg 1989).

The mathematical form of growth (or decay) of schemata can be reduced to the general form of *compound interest equation* by assuming that a particular schema H remains above-average by an amount cf , where c stands for a constant. Un-

der this assumption, the schema difference equation (2) may be written as follows (starting at $t = 0$ and assuming a stationary value of c):

$$m(H,t) = m(H,0) \cdot (1 + c)^t \quad (2)$$

Crossover is a structured, yet randomised, information exchange between strings. Crossover creates new structures with a minimum of disruption to the allocation strategy dictated by reproduction. This results in exponentially increasing (or decreasing) proportions of schemata in the population.

A lower boundary to crossover survival probability p_s can be calculated for any schema. Because a schema survives when the crossover site falls outside the defining length, the survival probability under simple crossover is $p_s = 1 - \delta(H) / (l-1)$. If crossover itself is performed by random choice, e.g. with probability p_c for a particular mating, the survival probability may be given by expression (3).

$$p_s \geq 1 - p_c \cdot \frac{\delta(H)}{l-1} \quad (3)$$

where

$(l-1)$ = number of possible crossover sites in a schema of length l

which reduces to the earlier expression when $p_c = 1.0$.

The combined effect of reproduction and crossover can be defined by calculating the number of a particular schema H expected in the next generation. Assuming independence of the reproduction and crossover operations, the estimate (4) is obtained:

$$m(H,t+1) \geq m(H,t) \cdot \frac{f(H)}{\bar{f}} [1 - p_c \cdot \delta(H) / (l-1)] \quad (4)$$

The combined effect of crossover and reproduction is obtained by multiplying the expected number of schemata for reproduction alone by the survival probability under crossover p_s . Schema H grows or decays depending on the multiplication factor. With both crossover and reproduction, this factor depends on whether the schema is above or below the population average, and whether the schema is of relatively short or long in terms of defining length (Goldberg 1989).

Mutation is the random alteration of a single bit position with probability p_m . In order that a schema H would survive, all the specified positions must themselves survive. Therefore, since a single allele survives with probability $(1 - p_m)$, and since each of the mutations is statistically independent, a particular schema survives when each of the $o(H)$ fixed positions within the schema survives. The probability of a surviving mutation is obtained by multiplying the survival probability $(1 - p_m)$ by itself $o(H)$ times, $(1 - p_m)^{o(H)}$. For small values of p_m ($p_m \ll 1$), the schema survival probability may be approximated by the expression $1 - o(H) \cdot p_m$. Thus, ignoring small cross-product terms, the combined effect of reproduction, crossover, and mutation can be given by expression (5) (Goldberg 1989):

$$m(H,t+1) \geq m(H,t) \cdot \frac{f(H)}{\bar{f}} [1 - p_c \cdot \delta(H) / (l-1) - o(H)p_m] \quad (5)$$

Expression (5) can be explained so that the number of representatives of schema H at time $t+1$ is equal to, or greater than the product of reproductive schema growth (1), survival probability in crossover (3), and probability of a surviving mutation (with small terms ignored).

2.3 BEAGLE

The applied genetic, rule-learning system called BEAGLE (**B**iotic **E**volutionary **A**lgorithm **G**enerating **L**ogical **E**xpressions) displays the essential ideas of the genetic algorithm in the form of evolutionary rule induction. The operation of BEAGLE is based on the presentation of alternative problem solutions as classification rules. The genetic operators are analogous to the general presentation of a genetic algorithm, except that the population under genetic manipulation consists of rules and parts of rules (Forsyth 1981). The principle of the evolutionary learning is to save the best rules and generate new structures by recombining and mutating the rule parts that survive. In that way, the process gradually creates rules that predict the target better and better.

The BEAGLE system consists of six main

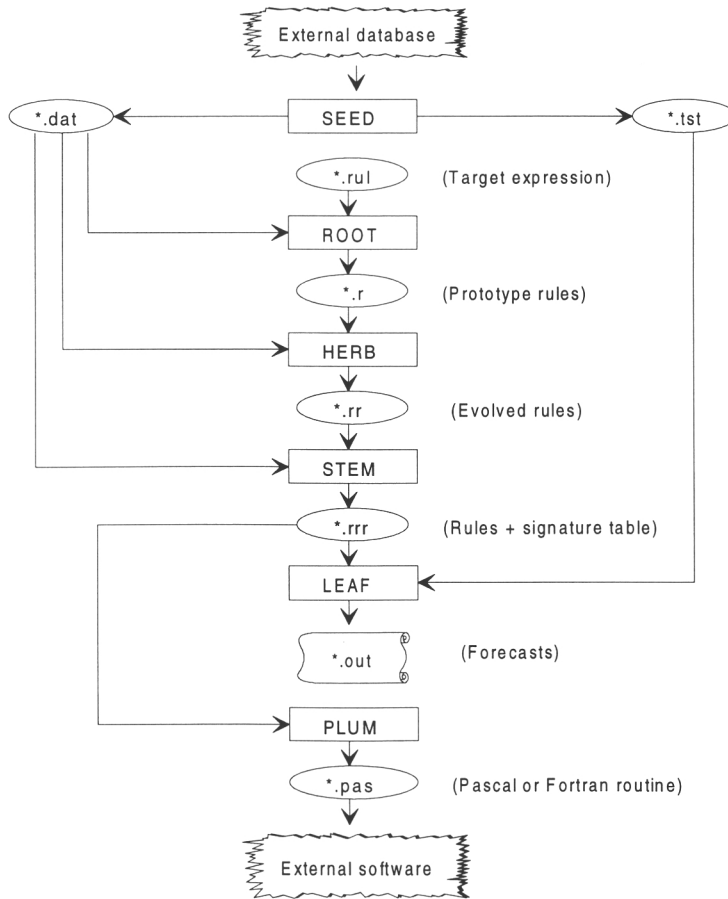


Figure 2. Main functions, output files and components of the applied genetic algorithm (Forsyth 1989).

modules performing the following tasks (Fig. 2): importing of external data files and randomly splitting data into subsets for learning and testing (SEED), creating the initial rule set at random and testing the user-suggested rules (ROOT), generating of new rules by applying genetic operators (HERB), testing and ranking the generated rules (STEM), and applying rules to the test data (LEAF). Furthermore, there is a subroutine (PLUM) which can be used to convert rules into other computer languages.

The rule-language BEAGLE operates on consists of variables from the initial data and numeric constants linked by logical, comparison and arithmetic operators (Forsyth 1989). The applied operators are:

LOGIC

- ! Logical negation (NOT)
- & Logical conjunction (AND)
- | Logical disjunction (OR)

COMPARISON

- = Equality (EQ)
- <> Inequality (NE)
- > Superiority (GT)
- <= Non-superiority (LE)
- >= Non-inferiority (GE)

ARITHMETIC

- + Addition
- Subtraction
- * Multiplication

An example of the rule language and the scoring of rules:

((MEANVOL > 122.2730) >
(TAXREAL > (MEANVOL > 146.5312)))

Rule	Target expression	
	true	false
true	80	18
false	33	71
score	57.08	

According to the rule language, the following interpretation of the example rule is obtained: the rule is true IF *mean initial volume* is between 122.3 and 146.5 m³/ha AND *choice of the forest taxation basis* is site productivity OR *mean initial volume* is greater than 146.5 m³/ha. After the rule, there is a score table which can be interpreted as follows:

80	true positives (rule true – target true)
18	false positives (rule true – target false)
33	false negatives (rule false – target true)
71	true negatives (rule false – target false)
57.08	rule-quality score (depends on predicting power and length of rule)

The BEAGLE decides upon survival of the rules according to the rule-quality score, which can be seen as a fitness value of an individual rule. The rule-quality score is obtained by calculating the proportion of variance accounted for the actual and predicted target values (Table 2) and by

scaling the value to the range 0–100. Furthermore, a penalty of $0.25 * L$, where L is the number of variables, constants and operators in the rule, is deducted. Thus, the scoring slightly favors shorter rules. The rule-quality score can be described as the percentage of the maximum departure from expectation due to pure chance. As a rule of thumb, a score of 50 is good and any score over 60 excellent (Forsyth 1981).

When the target expression deals with numeric variables, the truth values of individual rule-target combinations indicate whether the rule predicts the target value to be over or under the actual mean target value of the training data. In the example rule, the first of the above rule scores implies that 80 cases out of 202 fell in the category where both the predicted and the actual target values were above the mean target value of the training data. Respectively, in 18 cases the target value predicted by the rule was above the mean, but the actual target value fell under the mean. In statistics, the corresponding figures would form a contingency table.

In the following, all rules are presented as verbally interpreted expressions in order to facilitate the review of the results. Furthermore, it should be noted that conclusions concerning the prediction accuracy of an individual rule are not valid; rules must always be seen as complete sets denoting a certain target value (see chapter 4.1).

3 Material

3.1 Description of Data

The data were collected from within the jurisdiction of the Regional Forestry Board of Pohjois-Savo. The basic information on the forest holdings consisted of forestry plans made according to the TASO planning system for NIPFs (Ranta 1991). The descriptive information on NIPF landowners, their forestry goals, and characteristics of their forest holdings were collected by means of a two-phase mail inquiry (Pesonen 1994). The two-phase survey was necessary because the landowners had to be asked in advance for their permission to use the data from their forestry plans. In this study, the final sample included 201 NIPF landowners with forest holdings in Pohjois-Savo, comprising at least 5 ha of forest land and an up-to-date forestry plan.

In the first phase, the landowners were asked some questions about the characteristics of their ownership, economic situation and educational background. In addition, the questionnaire enquired about the landowners' preferences for alternative uses for their forest property.

In the second phase, NIPF landowners were asked to prioritise a group of alternative timber management strategies for their forest holdings, computed and presented individually for each landowner (Fig 3). Furthermore, both questionnaires included some questions about the landowners' conceptions of the choice between two alternative forest taxation bases for the next 13-year transition period¹.

3.2 Choice of Timber Management Strategy

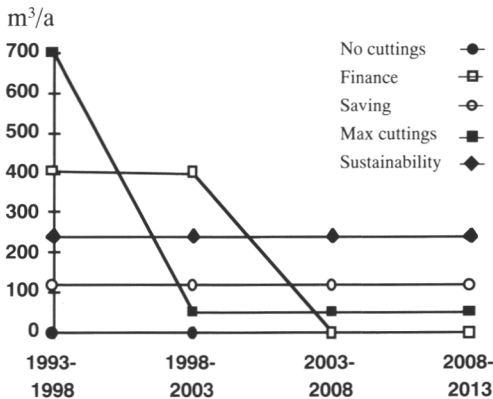
Each NIPF landowner was provided with five alternative timber management strategies covering a period of 20 years. The strategies were computed using the MELA system, an LP-based system developed in Finland for long-term timber management planning (Kilkki and Siitonen 1976, Siitonen 1983). The MELA system is based on the tree-level simulation of feasible management schedules for forest stands and the simultaneous selection of the production programme for the forestry unit (Siitonen 1993). The strategies were described for each landowner with the objective and constraint variables derived from the MELA parameters (Fig. 3). The total planning period was 20 years, divided into four 5-year intervals. In the calculations, the forest-holding-level development of several forest characteristics was described and illustrated for the landowners (Pesonen 1994).

In principle, the main differences between the strategies can be described in terms of intensity and the recurrence of removals. The objective variable used in the optimisations was maximisation of the income from timber sales for the first planning period (the constraints for each strategy are presented below). With potential cut of the first five-year planning period, $m^3/ha/a$, calculated from the initial data, the applied strategies were as follows:

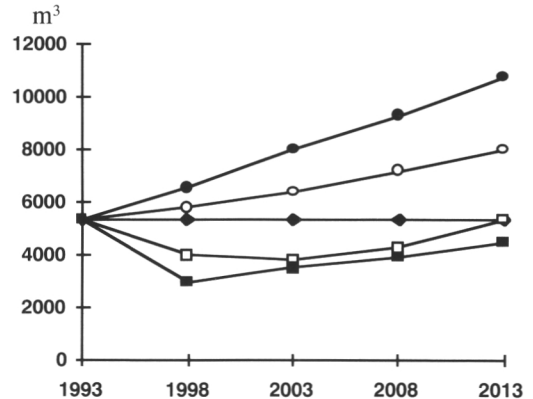
¹) The Finnish forest taxation system was changed in 1993 when the former site-productivity system of taxation was replaced by a system based on realized income. In the spring of 1994, landowners had to choose between the two taxation systems to be applied during the coming 13-year transition period. With the transition period over, all landowners will be taxed according to their realized income from timber sales. By choosing site-productivity based taxation for the

transition period, landowners with an abundance of timber ripe for cutting are in a position to realize the accumulated increment which has already been taxed once. The choice between the two alternatives is affected mainly by potential cut during the transition period, the estimated value of annual increment under site-productivity taxation, and the individual landowner's marginal tax rate (Pesonen et al. 1995).

a) Cutting removals



b) Total growing stock



Figures 3a and 3b. Alternative timber management strategies described in terms of development of removals (3a) and total growing stock (3b) during the planning period (an example of calculations made for each NIPF landowner, representing a sample case of the forest holdings). *Characteristics of the holding: forest area = 50.8 ha, initial growing stock = 5332 m³, mean initial volume = 105 m³/ha and average of the realized commercial cuttings during 1988–1992 = 347 m³/a.*

- 1 NO CUTTINGS *Total abstinence from cuttings (0.00 m³/ha/a)*
– removals set to zero
- 2 SAVING *Utilisation of approx. half of the sustained allowable cut (2.46 m³/ha/a)*
– removals set to half of the removals of SUSTAINABILITY
- 3 SUSTAINABILITY *Practising forestry on a sustained yield basis (4.91 m³/ha/a)*
– even flow of removals over time
– even flow of stumpage earnings over time
– even amount of clear-cut areas over time
– volume of sawtimber at the end of period equal to, or greater, than in the beginning
– market value of growing stock at the end of period at least the same as in the beginning
- 4 FINANCE *Utilisation of most of the allowable cut during first 10-year period (8.78 m³/ha/a)*
– even flow of removals during the first and the last two planning periods
– market value of the growing

- stock at the end of planning period at least the same as in the beginning
- 5 MAX CUTTINGS *Immediate utilisation of the total allowable cut (17.87 m³/ha/a)*
– even flow of removals during the last three planning periods

The NIPF landowners were asked to prioritise the timber management strategies according to their personal goals and preferences for forest use. In prioritisation, the strategies were compared pairwise and preferences were derived by means of the Analytic Hierarchy Process (Saaty 1980).

The Analytic Hierarchy Process (AHP) is a mathematical method for analysing complex decision problems with multiple criteria. The method is based on the hierarchical presentation of the decision problem as interrelated decision elements (Fig. 4). On each level of the hierarchy, pairwise comparisons are made between the decision elements. As a result, the weights are computed to represent the decision maker’s preferences concerning each decision element. The decision alternatives on the lowest level of the hierarchy are

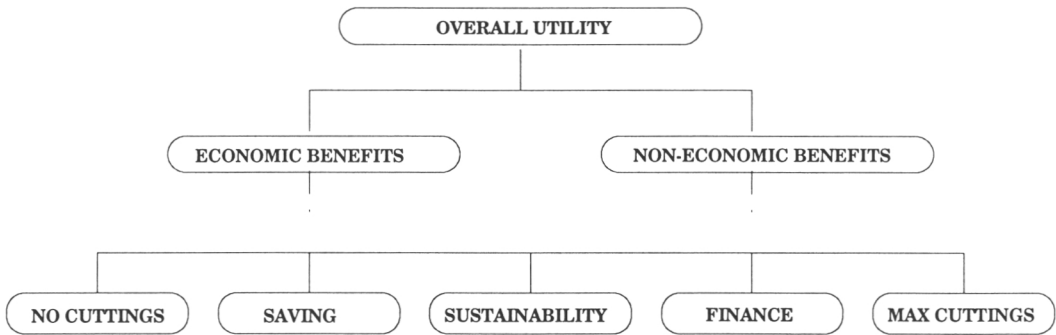


Figure 4. Decision hierarchy in selecting the preferred timber management strategy.

ranked according to the relative weights of the corresponding decision elements (Saaty 1980). Recent applications of the AHP to forest management planning include those by Mendoza and Sprouse (1989), Kangas (1992), Pukkala and Kangas (1993), and Pesonen (1994).

When applied to the present problem (Fig. 4), the overall benefit from forest property was placed at the highest hierarchy level. The NIPF landowners were first asked to compare the benefits from the economic and non-economic uses of their forest holdings. Second, pairwise comparisons were made between the management strategies, considering economic and non-economic benefits separately. The AHP process resulted in the relative priorities for each strategy being scaled 0–1. For each landowner, the strategy with the highest global priority (i.e. one that maximises the overall benefit) thus represented the preferred alternative (Pesonen 1994).

3.3 Problem Definition

A total of twenty-three variables were used to predict the NIPF landowners' choices of timber management strategies (Table 1). The main criterion for the selection of independent variables was significance in the context of landowner behaviour, as demonstrated in earlier studies (e.g. Järveläinen 1988, Karpainen & Hänninen 1990, Kuuluvainen & Salo 1991).

The dependent variable defined for the analyses was derived from the landowners' choices of timber management strategies and it was described

as *potential cut of the first five-year planning period of the preferred strategy* ($m^3/ha/a$). Thus, the dependent variable represented potential cut of the timber management strategy chosen by the NIPF landowner. Potential cut of the first planning period was used because it was considered to best reflect the differences between the strategies as regards the intensity and recurrence of cuttings. However, despite the differences between potential cut, the overall removals during the 20-year planning period came very close to each other in the cases of the strategies SUSTAINABILITY, FINANCE, and MAX CUTTINGS.

The data were cross-validated in both the genetic algorithm and regression analyses in order to examine the data-sensitivity and robustness of the generated models. A total of seven cross-validated data sets were produced with a random split of 70% (i.e. 141 observations) in the data sets for learning and modelling, and 30% (i.e. 60 observations) in the data sets for testing. The same randomly formed data sets were used in both methods. Thus, from the model point of view, the test data used in the genetic algorithm and regression analyses consisted of previously unseen cases.

A logarithmic transformation was required for the dependent variable in order to linearise the effects of independent variables. Prior to testing, the dependent variable was back-transformed and the bias caused by logarithmic transformation was rectified.

The model defined for the analyses was of the form

Table 1. Summary of the initial variables for the genetic algorithm and linear regression analyses.

Variable	Measurement	Mean	Min-Max	SD
RESPERM	Binary, permanent residence on farm	0.63	0.1	0.48
RESNOT	Binary, no residence on farm	0.26	0.1	0.44
FARMER	Binary, farmer	0.58	0.1	0.49
EINCOME	Proportion of gross earned income of household's gross total income, %	24.4	0–100	31.8
AINCOME	Proportion of gross agricultural income, %	42.3	0–100	32.6
FINCOME	Proportion of gross forestry income, %	17.6	0–80	16.6
FOLAND	Area of forest land, ha	69.0	8.9–609	67.5
FALAND	Area of farm land	10.0	0–49.6	11.3
EXCUT	Binary, intention to cut extensively in future	0.30	0.1	0.46
INCUT	Binary, intention to cut intensively in future	0.11	0.1	0.31
TIMBERG	Binary, landowner's view of timber production possibilities of his forest holding is 'good'	0.43	0.1	0.50
TIMBERP	Binary, view of timber production possibilities is 'poor'	0.12	0.1	0.33
ECONOMIC	Binary, preference of economic benefits of forest property	0.70	0.1	0.46
AVECUT	Average commercial cuttings of last 5-year period, m ³ /ha/a	2.34	0–10.3	2.27
MEANVOL	Mean initial volume, m ³ /ha	117.6	37.1–231.7	38.3
AHPCUT ¹	Preference of regular income from timber sales	0.27	0.02–0.70	0.16
AHPREC ¹	Preference of recreational use of forest property	0.14	0.01–0.52	0.08
TAXPROD	Binary, choice of site productivity based forest taxation	0.22	0.1	0.42
TAXREAL	Binary, choice of realized income based forest taxation	0.40	0.1	0.49
PRICE2HI	Binary, positive stumpage price expectations for next two years	0.10	0.1	0.30
PRICE2LO	Binary, negative stumpage price expectations for next two years	0.30	0.1	0.46
PRICE8HI	Binary, positive stumpage price expectations for next eight years	0.61	0.1	0.49
PRICE8LO	Binary, negative stumpage price expectations for next eight years	0.11	0.1	0.31
STRATEGY ²	Dependent var., harvest rate of preferred timber management strategy, m ³ /ha/a	5.44	0.65–18.0	2.70

¹) Preferences of alternative uses of forest property (scaled to 0–1) expressed in the first inquiry and calculated with AHP-method

²) The NIPF landowners that chose the 'NO CUTTINGS' strategy were excluded from the final analyses, see discussion section

$$\log(y) = a + bx_1 + cx_2 + \dots + lx_m \quad (6)$$

where

$\log(y)$ = dependent variable, logarithm of the average removals of first five-year planning period

a, b, c, \dots, l = constant and regression coefficients

x_1, x_2, \dots, x_m = independent variables

and the formula for rectifying the bias of estimated values of dependent variable caused by the transformation was

$$y = \exp\left(a + bx_1 + cx_2 + \dots + lx_m + \frac{\delta^2}{2}\right) \quad (7)$$

where

y = dependent variable, back-transformed

δ^2 = variance of residuals

The internal operations of the genetic algorithm required that the target values cross the zero line. Therefore, the average value of the logarithmic dependent variable was subtracted from each observation. Thus, the task of the genetic algorithm was to generate rules predicting the average removals of the preferred timber management strategy of each landowner.

Seven cross-validated data sets were used in the genetic algorithm analysis. Starting from randomly created initial populations of rules, with ten rules per population, the genetic algorithm performed the evolutionary learning process and resulted in seven independent sets of four rules.

Compared to the initial sets of rule created at random, the fitness of the rules improved considerably during the evolution process and rules also became more concise and easier to interpret. A total of 200 learning generations was obtained for each data set.

After obtaining the improved sets of rules from the genetic learning procedure, the sets of rules were evaluated in terms of their prediction accuracy. One rule was then excluded from each set of rules on the basis of not improving the overall predictive ability within the context of the remaining three rules (Forsyth 1981).

4 Results

4.1 Rules Induced by Genetic Algorithm

A total of seven sets of rules, with three rules in each set, was obtained after the execution of the genetic learning process (Appendix). The resulting final sets of rules were evaluated according to the truth-value combinations of the respective rules (Table 2). The truth values (0, 1) indicate whether an individual rule is considered true (1) or false (0). Thus, the combination “100” indi-

cates that rule number 1 is true and rules 2 and 3 are false.

On being interpreted, the rules must always be viewed as complete sets denoting a certain truth-value combination and a value of the target expression of that particular set of rules. For example, the first set of rules with the truth value combination “000” (meaning all three rules are false), predicts the average annual removals of $2.52 \text{ m}^3/\text{ha/a}$ for the landowners that fall into the “000”

Table 2. Summary of estimated / observed target values of the rule truth value combinations derived from the seven cross-validated data sets. All values are in $\text{m}^3/\text{ha/a}$, describing the average removals of the first five-year planning period. The observed target values are given in parentheses.

Truth values / Rule set	1	2	3	4	5	6	7	Mean	TMS ¹
000	2.52 (3.01)	3.41 (3.02)	2.68 (4.71)	3.50 (3.84)	2.85 (4.20)	2.99 (3.67)	3.75 (3.69)	3.10 (3.73)	2.46 (SAVING)
001	3.22 (4.71)	4.40 (3.69)	3.85 (3.62)	4.67 (4.38)	3.96 (4.21)	4.31 (4.85)	3.94 (4.18)	4.05 (4.23)	
010	4.00 (3.93)	2.97 (4.55)	4.34 (4.69)	2.89 (5.20)	4.35 (4.20)	4.49 (4.56)	4.12 (4.39)	3.88 (4.50)	
100	4.81 (5.56)	5.98 (4.44)	4.75 (6.69)	5.08 (6.31)	5.24 (4.42)	5.52 (5.50)	4.48 (6.47)	5.12 (5.63)	4.91 (SUST.)
011	5.88 (5.31)	5.23 (4.30)	4.16 (6.38)	5.09 (4.86)	5.53 (4.44)	5.72 (4.29)	5.43 (5.86)	5.29 (5.06)	
110	5.93 (6.61)	5.98 (5.91)	6.23 (6.18)	7.08 (7.16)	5.90 (6.53)	6.45 (7.46)	6.22 (6.26)	6.26 (6.59)	
101	6.59 (6.16)	4.97 (5.57)	5.63 (6.79)	4.76 (6.12)	6.76 (6.44)	6.77 (4.88)	6.18 (5.90)	5.95 (5.98)	
111	6.27 (6.27)	6.74 (6.31)	6.72 (5.24)	6.69 (6.30)	6.24 (5.99)	6.20 (6.75)	6.86 (6.55)	6.53 (6.20)	8.78 (FINAN.)
Average	4.90 (5.20)	4.96 (4.72)	4.80 (5.54)	4.97 (5.52)	5.10 (5.05)	5.31 (5.25)	5.12 (5.41)	5.02 (5.24)	

¹ Refers to the timber management strategy that best corresponds the particular truth value combination.

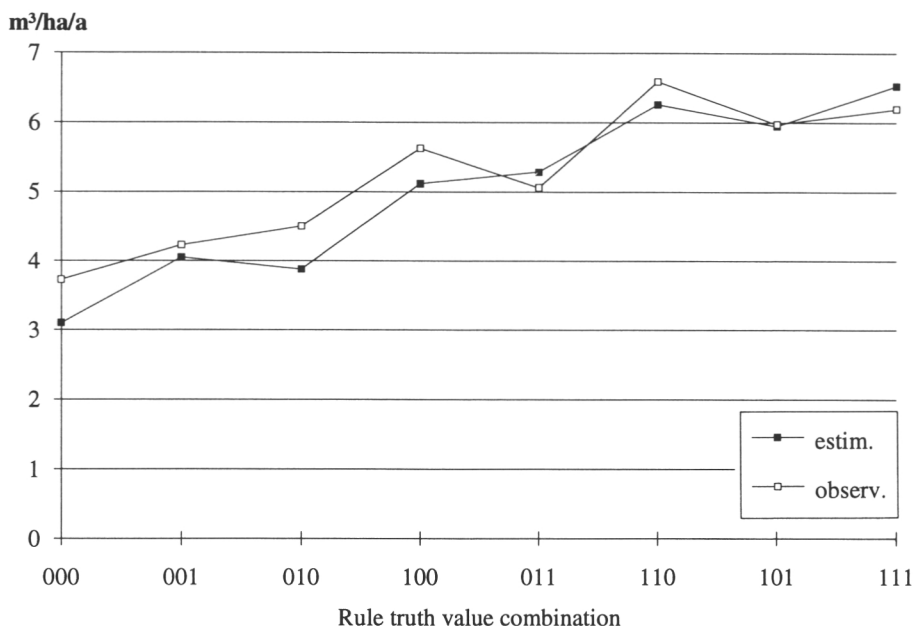


Figure 5. Average of estimated and observed target values in cross-validated data sets according to the rule truth value combination. (Observed values are presented as group averages of individual sets of rules)

category (Table 2).

The complete matrix of eight different truth value combinations times seven sets of rules can be viewed in the same fashion, together with the estimated and observed values of target expression (Table 2).

Finally, the generated rules were tested with the previously unseen test data. Thus, each of the seven sets of rules were tested with the respective sets of test data. The predictive abilities of the rules were examined by charting the estimated target values against the group average of the actual target values in each rule-combination category (Fig. 5). In order to obtain a comparable measure for the fitness of the rules, the relative root mean square errors (RMSE) and correlation coefficients were calculated for the predicted and observed target values of test data sets in the same way as in the regression analyses. Furthermore, the appearance of the independent variables in each set of rules was summarised (Table 3).

The cross-validated test data sets consisted of 60 cases each, of which, according to the measures provided by the genetic algorithm, an aver-

age of 41 (i.e. 68% of the sample, Table 3) were predicted correctly. The average target value for the category 'All rules true' (denoted by "111") was $6.53 \text{ m}^3/\text{ha/a}$ and for 'All rules false' (denoted by "000") it was $3.10 \text{ m}^3/\text{ha/a}$. The average of the relative root mean square errors (rRMSE) of the test data sets was 0.42 and the Pearson correlation coefficient between the actual and estimated target values was 0.35 (Table 3).

The seven final sets of rules had to be applied as such because they originated from separate data sets; i.e. mixing the rules from different sets would have led to misinterpretation of the actual predictive abilities. Thus, the performance of the rule sets must be compared quantitatively to find out the optimal set of rules. In comparison, a balance should be reached between the complexity of a set of rules vs. the fitness (predictive power) and robustness of rules. Therefore, the sets of rules were examined by considering the parameters as a number of variables in the rule set, relative RMSE, and the correlation coefficient between the predicted and observed target values in each set (Fig. 6). Judged by RMSEs, the rule sets per-

Table 3. Appearance of independent variables in rule sets derived from seven cross-validated data sets and summary of test results. (Appearance of a variable in resp. rule set is denoted by '1').

Variable / Rule set	1	2	3	4	5	6	7	Total
MEANVOL	1	1	1	1	1	1	1	7
RESPERM			1					1
RESNOT						1		1
FARMER	1		1	1	1			4
EINCOME		1		1	1			3
AINCOME				1			1	2
FINCOME		1	1	1	1			4
EXCUT					1			1
INCUT							1	1
TIMBERP		1			1	1		3
ECONOMIC			1					1
AHPCUT						1		1
AHPREC	1						1	2
TAXREAL		1	1			1		3
PRICE2LO			1	1				2
PRICE8HI	1		1					2
Test results								
'FITNESS'	70.00	60.42	69.77	69.77	65.91	72.73	67.92	68.07
RMSE	0.395	0.408	0.486	0.401	0.386	0.429	0.415	0.417
Pearson correl. coeff. between estimated and observed dep. var.	0.412	0.396	0.138	0.372	0.371	0.335	0.436	0.352

formed in a stable manner in the prediction stage, although the number of variables varied considerably between sets of rules. The correlation coefficients varied more than did the relative RMSEs since, compared to RMSE, the Pearson correlation coefficient is more sensitive to variance in the dependent variable to be tested.

4.2 Regression Analysis

Stepwise linear regression analyses were carried out to compare the performance of the genetic learning procedure to more conventional data analysis. Stepwise analyses were applied because the method of selecting the independent variables from the group of initial variables is somewhat analogous to that of the genetic algorithm. In regression analysis, the same, previously formed data sets were used so that the model was built using the cross-validated training data sets of the genetic process and tested using simi-

lar sets of the test data. The initial variables were also analogous to those of the genetic learning process, including the logarithmic transformation of the dependent variable.

In the regression analyses, all the independent variables of significance were entered into the models after four steps (forward stepping with alpha-to-enter of 0.15). The regression equations obtained from the analyses included seven different combinations of a total of nine independent variables with F-Ratios varying from 16.7 to 28.8 (Table 4). The average of the adjusted squared multiple R of the regression models was 0.37. When tested with the previously unseen data, the average for the relative RMSE was 0.41 and the correlation coefficient between estimated and the actual values of the dependent variable was 0.48 (Table 4).

As with genetic algorithm analyses, the seven independent regression equations were compared to determine the optimal model with respect to robustness, fitness and predictive ability. Thus,

Table 4. Regression models and test results of the cross-validated data sets. (T-values are given in parenthesis and significance is denoted by asterisk, so that * = 0.05, ** = 0.01 and *** = 0.001 -significance level).

Variable/Model	1	2	3	4	5	6	7
CONSTANT	0.577*** (5.98)	0.726*** (5.98)	0.639*** (5.59)	0.607*** (5.34)	0.897*** (6.35)	0.633*** (4.87)	0.706*** (6.48)
MEANVOL	0.007*** (7.94)	0.007*** (7.47)	0.007*** (8.61)	0.007*** (8.09)	0.008*** (8.19)	0.008*** (8.01)	0.006*** (7.52)
EINCOME	–	–	–	–	–0.002 (–1.57)	–	–
FINCOME	0.005* (2.35)	–	0.005* (2.37)	0.009*** (3.29)	–	0.004 (1.46)	0.004* (2.30)
FOLAND	–	–	–	–0.001* (–1.96)	–	–	–
EXCUT	–	–0.132 (–1.65)	–0.141 (–1.83)	–	–0.231** (–2.96)	–0.129 (–1.58)	–
INCUT	0.247* (2.22)	0.227 (1.85)	–	0.392*** (3.31)	–	–	0.241** (2.52)
AHPREC	–	–	–	–	–1.012* (–2.32)	–	–
PRICE2HI	0.379** (3.21)	0.279* (2.34)	–	0.374** (2.99)	0.311** (2.53)	0.289* (2.07)	0.338** (3.03)
PRICE8LO	–	–	–	–	–	–	0.195 (1.92)
Test results							
R ²	0.373	0.329	0.373	0.384	0.408	0.338	0.359
F-Ratio	21.86	18.13	28.76	18.46	20.32	18.90	16.70
P(tail)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RMSE	0.395	0.378	0.426	0.486	0.409	0.380	0.417
Pearson correl. coeff. between estimated and observed dependent var.	0.447	0.555	0.487	0.375	0.488	0.556	0.448

the regression equations were examined by charting the R² and the number of variables in the different models together with the RMSEs calculated from the test data sets (Fig. 7). Similarly to

genetic algorithm analyses, the regression models were stable in terms of R² and RMSE, although there was substantial variance in the number of variables included in the models.

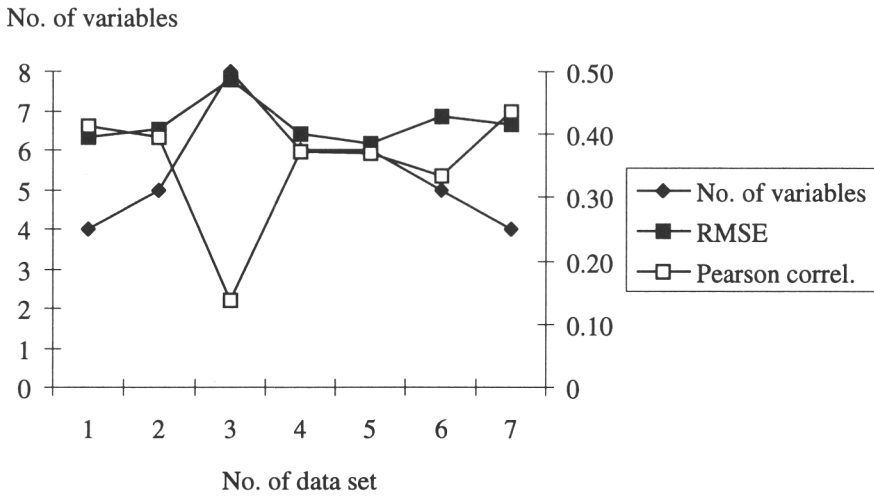


Figure 6. Number of variables, RMSE, and Pearson correlation coefficient between observed and the estimated target values in the seven cross-validated test data sets.

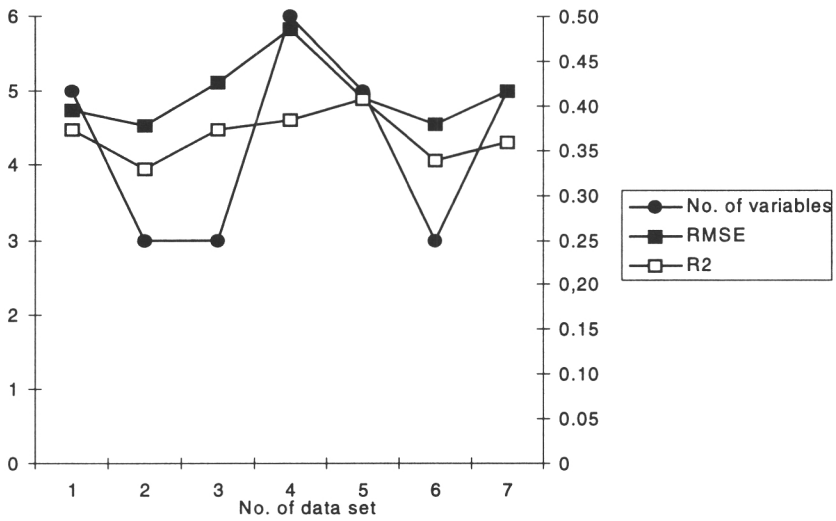


Figure 7. Number of variables, R², and relative RMSE according to the regression models derived from the seven cross-validated data sets.

5 Discussion

5.1 Comparison of Methods

One of the aims of this study was to compare the two modelling approaches. The use of identical data sets and the principle of selecting the best predictive variables according to a specific strategy facilitated the comparison. The results of the predictive power and the accuracy of the two methods were compared in two phases: 1) by averaging, over the data sets, the RMSEs and the correlation coefficients between the predicted and observed values of the planned removals, and 2) by selecting the optimal set of rules and the regression equation, and then comparing their performance.

In the genetic algorithm approach, the highest correlation and the lowest RMSE were obtained from rule sets 1 and 7 with the least number of variables used in the rules. Furthermore, there seemed to be obvious problems with rule set 3 with its many variables and weak predictive power. Of the leading sets, rule set number 1 was selected on the basis of its slightly better RMSE (0.395 vs. 0.415) which is indicative of higher prediction accuracy (Table 3).

In comparing the regression analyses, equations 5 and 6 can both be introduced as candidates for the optimal model. On the one hand, equation 5 has more variables, but gives a better fitness than does equation 6. On the other hand, equation 6 returns the lowest RMSE and shows the highest correlation with the least number of variables (Table 4). On the basis of predictive ability and simplicity of the model, equation number 6 was chosen to be the optimal model for the purposes of this study.

The predictive abilities of the optimal set of rules and regression equation were summarised and the average figures of cross-validated data sets were presented (Table 5). Furthermore, both the genetic algorithm and regression analyses were recalculated using the optimal models and the com-

Table 5. Summary of predictive abilities of the optimal rule set (number one) and regression equation (number six). Averages of resp. parameters in cross-validated data sets are given in parenthesis.

	RMSE	Corr. coeff.
Rule set one from genetic algorithm (Average of the seven sets)	0.395 (0.417)	0.412 (0.352)
Regression equation no. six (Average of the seven models)	0.380 (0.413)	0.556 (0.479)

plete data set of 201 observations. In the genetic algorithm analysis, recalculation resulted in a fitness of 76.1% and an RMSE value of 0.38, together with a Pearson correlation coefficient of 0.55. Respectively, the parameters derived from recalculation with the optimal regression model were: R^2 value of 0.34, RMSE value of 0.38, and Pearson correlation coefficient of 0.55. Thus, when tested with the complete data set, the optimal set of rules (1) and the optimal regression equation (6) performed equally well.

In the genetic algorithm analysis, the variables used as predictors of potential cut of NIPF landowners included the following variables: mean initial volume (MEANVOL), landowner's positive price expectations for the next eight years (PRICE8HI), landowner being classified as a farmer (FARMER), and preference for the recreational use of one's forest property (AHPREC).

When formulated into production rules, the effect of the variables on potential cut may be interpreted as follows:

Potential cut increases when

- 1) the mean initial volume increases,
- 2) the landowner is classified as farmer,
- 3) the landowner anticipates rising stumpage prices during the next eight years, and
- 4) the landowner's preference for recreational use of his forest property decreases.

In the regression analysis, an analogous interpretation of the regression equation results in the following conclusions (with variables mean initial volume (MEANVOL), proportion of forestry income (FINCOME), intention to cut extensively in future (EXCUT), and positive price expectations for the next two years (PRICE2HI)):

Potential cut increases when

- 1) the mean initial volume increases,
- 2) the proportion of forestry income increases,
- 3) the landowner intends to cut intensively in the future, and
- 4) the landowner anticipates rising stumpage prices during the next two years.

For both methods, mean initial volume was the most significant predictor of potential cut of the preferred timber management strategy. Furthermore, the parameters common to both methods included positive stumpage price expectations. This is consistent with, for example, the results obtained by Kuuluvainen (1989); analogous variables were discovered to be significant predictors of landowners' realized annual timber sales.

5.2 Reliability of Results

The central role of mean initial volume as a predictor in both analyses is partly due to the factors related to the original definition of the timber management strategies. On the one hand, by strongly referring to the actual potential cut of each forest holding, the mean initial volume "sets the level" around which potential cut varies. On the other hand, the fact that the landowners were consistent in their choices of timber management strategies as regards the actual timber production possibilities of their forest holdings, implies the landowners' rationale of decision making – at least in regard to the benefits to be gained from timber production. In more a

general context, this has also been stated by Romm et al. (1987) and Hyberg (1987), among others.

The proportions of the alternative sources of total income for households indicate the decision makers' economic dependency on agriculture and forestry. The analyses showed that NIPF landowners, who obtained a considerable proportion of their gross annual income from forestry, and particularly from agriculture, were willing to cut intensively in the future. Furthermore, the subdivision of landowners into farmers and non-farmers influenced significantly the future potential cut. In the case of Finland, this may be interpreted as indicating that there is still a link between traditional farming and forestry, with forestry representing a supplementary source of income (e.g. Järveläinen 1988, Hyttinen 1992).

The average level of potential cut was increased by leaving the strategy group 'NO CUTTINGS' out of the analysis. Preliminary inspections of the data showed that landowners who had chosen the strategy of 'NO CUTTINGS' formed a heterogeneous group, whose behaviour could not be modelled along with the others. The strategy group 'NO CUTTINGS' could have been included in the analyses by using a tobit/logit formulation of the regression model as was done by Kuuluvainen & Salo (1991), Gramman et al. (1985), and Royer (1987). In that case, the genetic approach would have required two separate models: one for identifying the 'NO CUTTINGS' group from among the others, and the other for predicting potential cut of the rest of the landowners. This is due to the dualistic character of the genetic algorithm; numeric models must be analysed separate from logistic models.

When generalising the results of this study, it must be noted that the results suffer from the bias caused by the auto-selection of the data during the study phases. First, the initial population was formed on the basis of the landowner having a forestry plan for the property; it is possible that owners of forest holdings with forestry plans are more oriented towards timber production than owners of 'non-planned' forest holdings. Second, the two-phase survey could also have further selected the active, timber-production-oriented landowners. Third, the final data were small in number, consisting of only 201 landowners, and the strat-

egy group that favoured the non-timber uses of forest (NO CUTTINGS) had to be excluded from the analyses.

5.3 Applicability of Genetic Algorithm

Methodologically, the genetic algorithm proved applicable in predicting the planned removals of preferred timber management strategies. However, with respect to the comparison parameters used in this study, the performance of the regression analysis proved to be slightly better. This may be due to the linear response surface of the independent variables. Despite small differences between the predictive abilities of the applied methods, the results from the cross-validated data sets imply the robustness and reliability of both methods in the sense of data-dependency. Moreover, when tested with the complete data set of 201 observations, both the optimal rule set and the optimal regression model reached the same level of accuracy.

The fact that the number of variables as well as selection of variables varied substantially between the BEAGLE runs is related to the small number of cases in the final analyses and random effect of the cross-validation. The analyses showed that besides the mean initial volume (MEANVOL) being the most powerful predictor, there were several independent variables with approximately equal explanatory power. Thus, the number of cases being small and the random division of them into test and learning data may have affected the variables that were picked up during each run. The same random character of cross-validated data sets had an influence on the regression analyses as well.

The genetic algorithm could have been more effective in bringing out the possible effects of the qualitative variables and of the non-linear dependency. It is also important to note that the genetic algorithm applied to this study has been proved to be better in dealing with logical problems, i.e. target expressions which obtain only the values 'true' or 'false' (PC / BEAGLE 1987). In that sense, reformulation of the problem into a logical one and the inclusion of logistic regression analysis as a reference method would be an interesting topic for future research.

Although the genetic algorithm did not exceed

the predictive ability of regression analysis, its major implications are based on the applicability of the generated set of rules. The results from the genetic algorithm analysis may be interpreted as suggesting the grouping of the landowners, as homogeneously as possible, according to planned removals. The rules classifying NIPF landowners into these strategy groups could be used to precompute the decision alternatives for the different landowner categories. The preferred strategy could then be defined by specifying the individual goal structure of each NIPF landowner. This procedure could then be used as a part of an expert system in NIPF forest management planning as suggested by Pesonen and Kettunen (1993).

5.4 Conclusions

According to results obtained from both the genetic algorithm and the regression analyses, mean initial volume and stumpage price expectations were the most significant predictors of potential cut of NIPF landowners with properties in eastern Finland. Thus, it may be concluded that landowners are more or less aware of the possibilities of their forest holdings for timber production, and that landowners with plenty of timber are also willing to make use of their possibilities to cut. Furthermore, in making their choices on strategic management, the landowners follow, and also react to, anticipated changes in timber prices.

The most powerful application of the results of this study is based on the use of the preferred timber management strategies in calculating the regional allowable cut. The strategies can be generalised over a particular forestry area. By taking into notice the owners of non-planned forest holdings and other landowners beyond the scope of this study, the potential allowable cut represented by NIPF land can be derived from the timber management strategies (Pesonen 1994). This allowable cut, based on the landowners' objectives, can be taken into consideration in the planning of future investments by forest industry, for example. Moreover, the predictions of potential cut connected to the preferred strategies can be used to calculate potential cut for landowner groups, whose characteristics are known in advance.

Despite the fact that the principles of genetic algorithms were developed more than 25 years ago, very few applications have been reported in the field of forest science so far. However, genetic algorithms, along with other machine-learning methods, have great potential in solving complex problems in forestry-related domains. When adopting these methods, studies are needed in which different machine-learning approaches are compared in the solving of a variety of problems. An extension of this study would be to include a comparison of the neural network- and inductive-learning paradigms as supplementary prediction tools.

According to the results obtained by Pesonen (1994), when he used the same data as in this study,

it was shown that the presentation of timber production possibilities for the landowners had a positive effect on their orientation towards timber production; 23% of the landowners were prepared to increase their cuttings after having seen the alternative timber management strategies. An important conclusion, and one that concerns this study as well, is that by increasing the availability of information on the strategic alternatives in forest management, and landowners' awareness of their timber production potential, it is possible to activate landowners into practising more intensive management on their forest holdings. This is crucial for the development of forest management planning on NIPF lands.

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Total of 40 references

Appendix. Verbal interpretation of target expression and rule sets induced from seven cross-validated data sets.

Target expression: Logarithm of the removals of preferred strategy subtracted by average value of removals within respective data set.

DATA SET 1.

Rule 1: The rule is true IF *mean initial volume* is greater than $112.5 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *price expectations of next eight years* are positive (rise in prices) AND *landowner is classified as farmer*.

Rule 3: The rule is true IF *preference of recreational use of forest property* is smaller than 0.12

DATA SET 2.

Rule 1: The rule is true IF *mean initial volume* is greater than $105.2 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *landowner's view of the timber production possibilities of his forest holding* is 'moderate' or 'good' AND *share of gross earned income* of household's total annual income is less than 20 % AND his *residence on the farm* is 'permanent' or 'temporary'.

Rule 3: The rule is true IF *landowner has at least some forestry income* OR *choice of forest taxation basis* is site productivity taxation.

DATA SET 3.

Rule 1: The rule is true IF *mean initial volume* is greater than $105.1 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *price expectations of next eight years* are positive (rise in prices) AND *landowner is classified as farmer*.

Rule 3: The rule is true IF *landowner prefers non-economic uses of forest* AND his *price expectations of next two years* are negative (fall in prices) OR *landowner prefers economic uses of forest* AND his *price expectations of next two years* are not negative (stable prices or rise in prices).

DATA SET 4.

Rule 1: The rule is true IF *mean initial volume* is greater than $117.3 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *landowner has at least some agricultural income* AND *he does not have gross earned income at all*.

Rule 3: The rule is true IF *landowner has at least some forestry income* AND his *price expectations of next two years* are not negative (stable prices or rise in prices) AND *landowner is classified as farmer*.

DATA SET 5.

Rule 1: The rule is true IF *mean initial volume* is greater than $113.7 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *landowner has at least some forestry income* AND *he is classified as farmer* AND *landowner's view of the timber production possibilities of his forest holding* is 'moderate' or 'good'.

Rule 3: The rule is true IF *landowner's intention to cut* is 'sustainable cuttings' or 'heavy cuttings' OR *share of gross earned income* of household's total annual income is less than 25 %.

DATA SET 6.

Rule 1: The rule is true IF *mean initial volume* is greater than $117.3 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *landowner's preference of regular income from timber sales* is greater than 0.24

Rule 3: The rule is true IF *landowner's choice of forest taxation basis* is site productivity taxation AND his *residence on the farm* is 'permanent' or 'temporary' AND *landowner's view of the timber production possibilities of his forest holding* is 'moderate' or 'good'.

DATA SET 7.

Rule 1: The rule is true IF *mean initial volume* is greater than $119.9 \text{ m}^3/\text{ha}$.

Rule 2: The rule is true IF *landowner has at least some agricultural income* AND *he does not have gross earned income at all*.

Rule 3: The rule is true IF *landowner's intention to cut* is 'heavy cuttings' AND his *preference of recreational use of forest property* is 0.00

Modelling Non-Industrial Private Forest Landowners' Strategic Decision Making by Using Logistic Regression and Neural Networks: Case of Predicting the Choice of Forest Taxation Basis

Mauno Pesonen, Petri Räsänen and Arto Kettunen

Pesonen, M., Räsänen, P. & Kettunen, A. 1995. Modelling non-industrial private forest landowners' strategic decision making by using logistic regression and neural networks: Case of predicting the choice of forest taxation basis. *Silva Fennica* 29(2): 171–186.

In this study, logistic regression and neural networks were used to predict non-industrial private forest (NIPF) landowners' choice of forest taxation basis. The main frame of reference of the study was the Finnish capital taxation reform of 1993. As a consequence of the reform, landowners were required to choose whether to be taxed according to site-productivity or realized-income during the coming transition period of thirteen years.

The most important factor affecting the landowners' choice of taxation basis was the harvest rate during the transition period, i.e. the chosen timber management strategy. Furthermore, the estimated personal marginal tax rate and the intention to cut timber during next three years affected the choice. The descriptive landowner variables did not have any marked effect on the choice of forest taxation basis.

On average, logistic regression predicted 71 % of the choices correctly; the corresponding figure for neural networks was 63 %. In both methods, the choice of site-productivity taxation was predicted more accurately than the choice of realized-income taxation. An increase in the number of model variables did not significantly improve the results of neural networks and logistic regression.

Keywords forest taxation, logistic regression, neural networks, non-industrial private forest landowner, timber management strategies.

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1 Introduction

1.1 Strategic Decision Making

Most non-industrial private forest (NIPF) landowners have long-term perspectives in regard to their strategic view of forest management (Lönnstedt 1989). It is important to understand the strategic decisions of NIPF landowners for several reasons: e.g. predictions of the timber supply from private forests for investment plans by forest industries (Lönnstedt and Roos 1993).

Strategic planning operates on future production possibilities; the starting point in planning is in the variability of the factors of production and their allocation (e.g. Kast and Rosenzweig 1974). When applied to NIPF management planning, the strategic view includes the production of alternative, strategic-level programmes for timber production and silviculture. Timber management covers a range of strategies from “no cuttings at all” to “maximum cuttings within the limits of timber production possibilities”. Timber management strategies can be described in terms of intensity and recurrence of cuttings, for instance.

Many studies (e.g. Wardle 1965, Kilkki 1968, Ware and Clutter 1971, Kangas and Pukkala 1992, Siitonen 1983, Johnson et al. 1986, Jonsen et al. 1993, Pukkala and Kangas 1993) have been done on the subject of strategic forest management planning. Strategic-level decision making and decision processes have been studied by Lönnstedt and Törnqvist (1990), Kajanus (1992), Pukkala and Kangas (1993). Forest taxation, as part of forest management planning, has received little attention.

1.2 Forest Taxation Reform

In 1993, the Finnish forest taxation system underwent a reform, when site-productivity taxation (SPT) was replaced by realized-income taxation (RIT). The Finnish forest taxation reform includes a 13-year transition period for non-industrial private forest (NIPF) landowners.

The choice of forest taxation basis is part of the strategic decision making of landowners, as is also the choice of timber management strategy (Pesonen 1995). In the spring of 1994, landowners were

required to choose whether to be taxed according to SPT or RIT for the next 13 years. During this transition period of 13 years (1993–2005), landowners choosing SPT will be able to realize their accumulated timber growth which has already been taxed once prior to the taxation reform.

SPT is based on the estimated taxable income, i.e. the estimated value of the mean annual increment according to the site’s soil productivity (Laki maatilatalouden ... 1990). Under this system, the estimated taxable income from forestry is added to the NIPF landowner’s non-forestry income, and the final and actual tax to be paid annually depends on the landowner’s personal marginal tax rate. The new RIT system is based on the individual landowner’s annual timber sales revenues. The net timber income is taxed applying a uniform and constant tax rate, which in 1993 was 25 % (Tuolverolaki 1992).

The most important factor affecting the individual NIPF landowner’s optimal choice of taxation basis is the harvest rate during the transition period, i.e. the chosen timber management strategy. The estimated value of annual increment under SPT, the landowner’s personal marginal tax rate, and the uniform capital tax rate were also significant factors influencing the optimal forest taxation basis (Ovaskainen et al. 1992, Pesonen and Räsänen 1993). In order to assist NIPF landowners in making their choice, Pesonen and Räsänen (1993) formulated a model for the optimal forest taxation basis. In the model, the optimal choice depends on the landowner’s marginal tax rate and the relation between the chosen timber management strategy and the volume of taxable increment ($m^3/ha/a$), i.e. the estimated growth under SPT.

1.3 Logistic Regression and Neural Networks

Logistic regression has been rarely used in modelling strategic decision-making problems. Instead, logistic regression models have been widely used in solving other kinds of problems. Royer (1987), for example, has modelled the reforestation behaviour of NIPF landowners, Heliövaara et al. (1991) have predicted the distribution of bark beetles using climatic variables, and

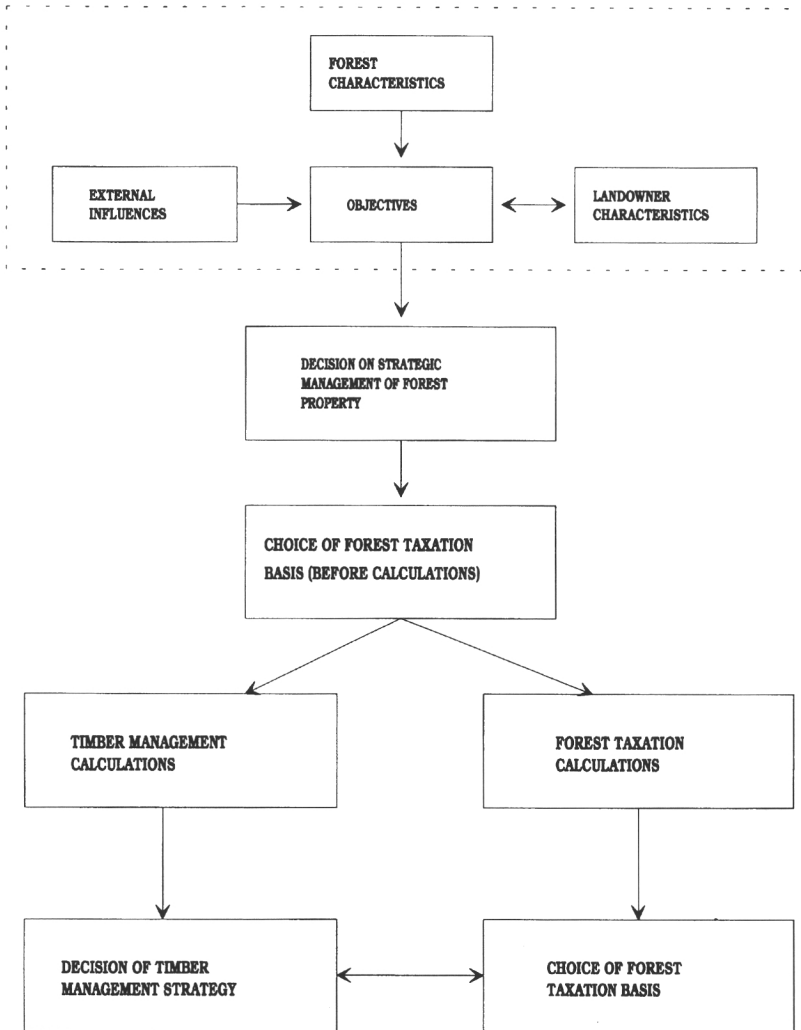


Fig. 1. Frame of reference applied in this study.

Uusitalo (1993) has predicted the timber quality of Scots pine.

Methods in the field of machine learning offer new approaches to retrieving knowledge from ill-defined, noisy domains. Many machine learning techniques are non-parametric in character and capable of dealing with quantitative as well as qualitative variables with linear and nonlinear dependencies. Often they are noise-tolerant and nonsensitive to fixed hypotheses (Guan and Gertner 1991).

The basic idea in neural networks is to simu-

late and understand the processes of a nervous system. In forest science, neural networks have been used, for example, in estimating non-optimality losses resulting from harvesting decisions (Lämås et al. 1991) and in estimating forest stand characteristics based on satellite-based remote sensing (Feycting et al. 1991). Nikula and Väkevä (1991) have modelled the risk of moose-browsing in forest plantations and Guan and Gertner (1991) have modelled red pine survival. Furthermore, neural networks have been applied to forecasting recreation in wilderness areas (Pattie

1992) and to predicting processing parameters in particleboard manufacturing (Cook et al. 1991). As yet, neural networks have not been applied in modelling strategic decision-making problems.

1.4 Aim of the Study

The aim of this study is to 1) predict NIPF landowners' choices using logistic regression and neural networks, 2) compare the performance of the two methods in predicting NIPF landowners' choices of forest taxation basis, and 3) clarify the factors affecting landowners' actual choices between site-productivity taxation and realized-income taxation.

In modelling the choice of forest taxation basis, logistic regression is used because of the binary outcome of the choices. The frame of references of the study is presented in Fig. 1.

2 Methods

2.1 Logistic Regression

The form of the logistic regression model (1) was

$$\text{Log}\left(\frac{\pi}{1-\pi}\right) = \text{Log}(O) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_n x_n \quad (1)$$

where

π	conditional probability of choosing site-productivity taxation
$1 - \pi$	conditional probability of choosing realized-income taxation
$\alpha, \beta_1, \dots, \beta_n$	parameters of logistic regression
x_1, x_2, \dots, x_n	independent variables
O	conditional odds of choosing site-productivity taxation
n	number of independent variables.

The betas (β_1, \dots, β_n) represented the change in the log-odds due to unit increments in the value of the dependent variables. Moreover, the exponential coefficient $\exp(\beta_i)$ was the coefficient of the odds ($\pi / (1 - \pi)$) for a one-unit increase in the i th predictor, and $100 [\exp(\beta_i) - 1]$ was the estimated percentage change in the odds for a

one-unit increase in the i th predictor. The method of maximum likelihood was used to compute estimates of the parameters $\alpha, \beta_1, \dots, \beta_n$ (Demaris 1992, BMDP ... 1992).

2.2 Neural Networks

2.2.1 Principle of Neural Networks

A neural network, or a parallel distributed processing model, is a system consisting of a number of simple, highly interconnected processing elements. Neural network models are non-parametric in character and make inferior assumptions than classical statistical methods about independent variables (Cook et al. 1991). There are several types of neural networks: e.g. back-propagation networks, self-organizing maps, and hopfield networks. The networks differ from one another in, for example, network size, input or output type, and the training method applied (Bailey and Thompson 1990).

The basic unit in neural networks is the processing element (PE), analogous to the biological neuron (Fig. 2) (Rumelhart and McClelland 1986). A PE receives inputs from its neighbours and, as a function of the inputs it receives and through the transition function, the PE produces an output value, which it then sends to its neighbours (Fig. 2). The transition function can be either a threshold or a stochastic function. The network stores knowledge implicitly in a set of connection weights; e.g. if the weight between units u_i and u_j is a positive number, unit u_i excites unit u_j and if the weight is negative, unit u_i inhibits unit u_j . The absolute value of w_{ij} specifies the strength of the connection (Rumelhart and McClelland 1986).

Neural networks usually include three kinds of processing elements (or nodes): input, output and hidden nodes. Input and output nodes connect the network to the outside world, e.g. to the process parameters being measured (Cook et al. 1991). A series of input nodes comprises an input layer while output nodes make up the output layer. Between these layers of nodes there may be one or more hidden layers, which, in turn, are connected to the other layers. The way the neural network changes the weights between

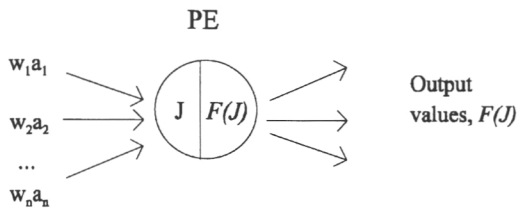


Fig. 2. The basic unit in a neural network ($w_1..w_n$ = weighting factors, $a_1..a_n$ = input values of the processing element (PE), $J = \sum w_i a_i$ and $F(J)$ = transformation function).

the processing elements is referred to as the learning method. An example of learning methods applied to neural networks is the generalized delta rule method used in back-propagation networks (Rumelhart and McClelland 1986).

2.2.2 Back-Propagation Algorithm

A back-propagation-type of neural network was used in this study. This kind of a network first uses input data sets to produce a random output, and then compares this with the observed output. The differences between the output predicted by the network and the observed output are called error signals. Thus, the back-propagation method belongs to the group of supervised learning methods, because the correct result of each input data set is required to control the learning process (Bailey and Thomson 1990).

The main idea in a back-propagation network is to minimize the sum of errors by manufacturing the weights of the connections. The weight changes are first made for all connections feeding into the final layer, and once this has been done, the error signals for all units in the previous layer are computed. This propagates the errors back one layer, and the same process is repeated for every layer. The learning process continues until the network finds a single set of weights satisfying the input/output pairs presented to the network (Rumelhart and McClelland 1986, Cook and Wolfe 1991).

The neural network system is inherently parallel in that many units can execute their computations concurrently (Rumelhart and McClelland

1986). Usually, the primary data are divided into two parts: a training set, which is used in teaching the neural network, and a test set, which is used in evaluating the results of the network. In testing, each observation of the test data is fed in the network and the error between the predicted and the original value is then calculated.

The back-propagation network used in this study was composed of three layers. The input layer consisted of independent variables scaled between 0 and 1. The hidden layer consisted of 11 nodes, which was the best number of nodes tested in this study, and the network had a single output node: the estimated probability of choosing site-productivity taxation. The way the network was constructed, the default value of selections of cases learnt was 500 000 unless the network converged before that. In the calculations, software called NeuroShell (NeuroShell 1989) was used.

3 Material

3.1 Data and Choices of Timber Management Strategy and Forest Taxation Basis

The data were collected from the area under the jurisdiction of the Pohjois-Savo forestry board, in eastern Finland. The basic information about the forest holdings consisted of the forestry plans made according to the TASO planning system managed by the Forestry Centre Tapio (Ranta 1991). Descriptive information about landowners, their forestry property and forestry goals were collected by means of a two-phase mail inquiry (Pesonen 1995). The total sample consisted of 757 forest holdings.

NIPF landowners were asked as to their intended choice of forest taxation basis in two phases (Fig. 3). In addition to the intended choice of forest taxation basis, they were presented with the arguments for a particular choice, detailed information about NIPF landowners' holdings (e.g. the number of taxation cubic meters under SPT) and asked about landowner's taxable income in the first inquiry. The number of acceptable answers received was 413.

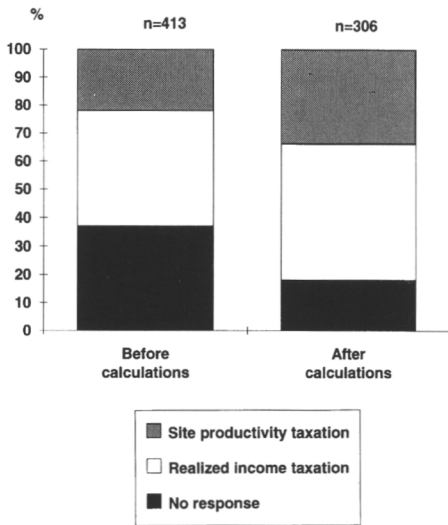


Fig. 3. The choices of forest taxation basis made by the forest owners in the two mail questionnaires.

Following the first inquiry, five timber management strategies were calculated using the MELA system (Kilkki and Siitonen 1976, Siitonen 1983, Siitonen 1993) for each NIPF landowner for a planning period of 20 years. The applied strategies were (Pesonen 1995):

- 1 NO CUTTINGS (Total abstaining from cuttings)
- 2 SAVING (Utilizing approx. half of the sustained allowable cut)
- 3 SUSTAINABILITY (Practising forestry on sustained yield basis)
- 4 FINANCE (Utilizing majority of the allowable cut during the first 10-year period)
- 5 MAX CUTTINGS (Instantly utilizing the total allowable cut).

The forest-holding-level development of, for example, removals, growth and total volume of growing stock were presented to the landowners

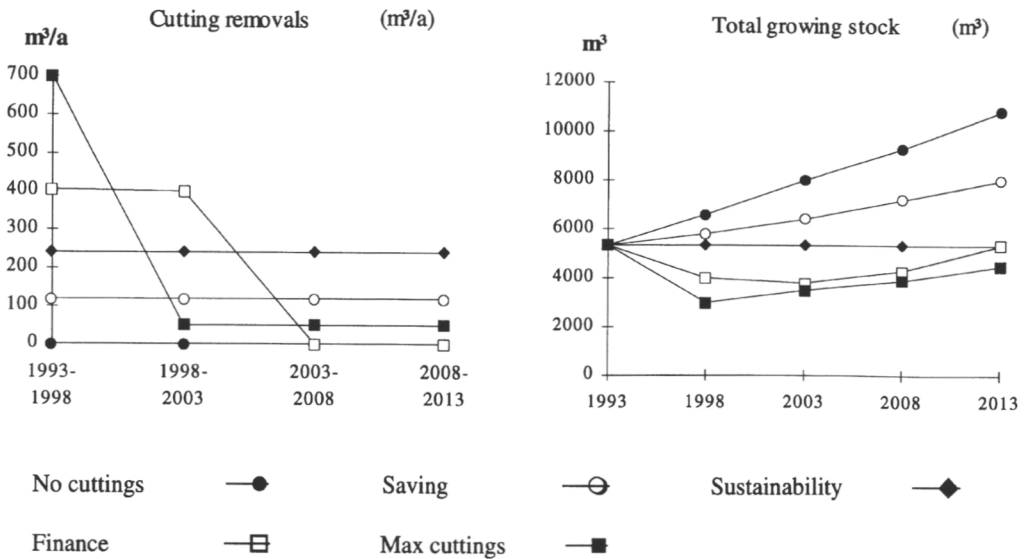


Fig. 4. Alternative timber management strategies (Pesonen 1995) described as the development of the removals and the total growing stock during the planning period (an example of calculations for each forest owner, representing a sample case of the forest holdings).

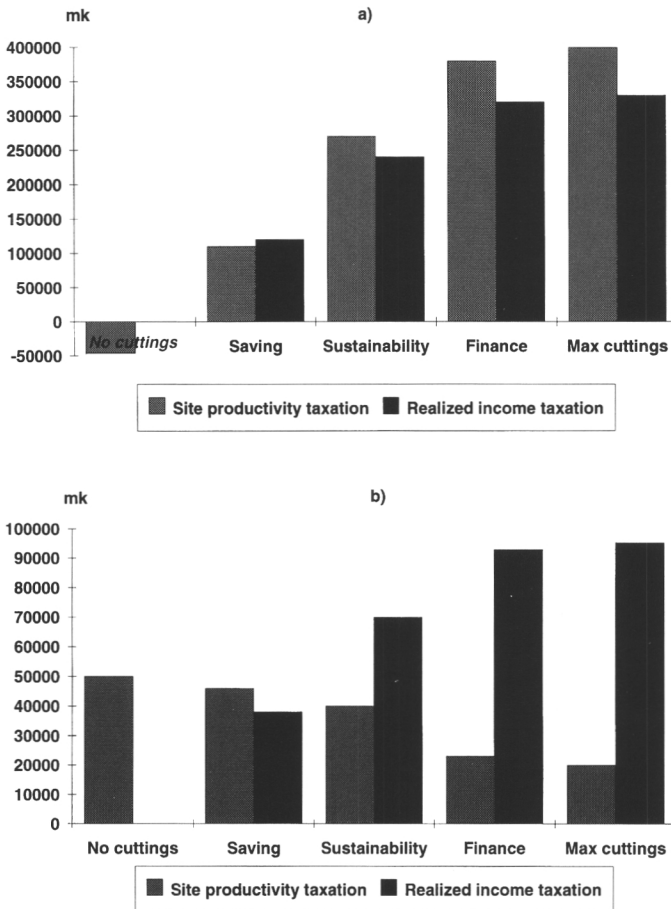


Fig. 5. Profit (a) and payable taxes (b) for the transition period (an example of calculations for each forest owner, representing a sample case of the forest holdings).

(Fig. 4). The landowners were then asked to prioritize alternative timber management strategies by using the Analytic Hierarchy Process (AHP) (Saaty 1977, 1980). The highest priority obtained from AHP represented the preferred timber management strategy (Pesonen 1995).

The profits and the amount of payable taxes for the transition period in each timber management strategy were illustrated for the NIPF landowners (Fig. 5). According to the example presented below, if the landowner intended to cut less than the SAVING strategy, RIT would have been the optimal choice, but if he intended to cut according to sustainability or more, the optimal choice would have been SPT (Fig. 5). Based on these

illustrations of comparison, the landowners were asked to re-assess the question of forest taxation basis (Fig. 3). After the two inquiries, the final sample consisted of 306 NIPF landowners.

3.2 Variables Used in the Study

In the analyses, the dependent variable was the choice of forest taxation basis both before and after the profitability calculations. In the first inquiry (before landowners were shown the comparison pictures), the landowners had to make the choice without the benefit of information about the economic consequences of their choice

of forest taxation basis in alternative timber management strategies. It can be assumed that these choices were more or less based on personal conceptions of the alternative forest taxation bases. In the second phase (after the profitability calculations were shown to the landowners), the NIPF owners were able to use the comparison pictures of the two forest taxation bases when making the choice between the two taxation systems. In the second phase, it can be assumed that these choices were based more on economic and rational facts than the choices made before being shown the calculations.

Timber management strategy has been found to be a significant variable in modelling the optimal choice of forest taxation basis (Pesonen and Räsänen 1993). Therefore, only those NIPF landowners with information on the preferred timber management strategy ($n = 306$), were included in the analyses. The analyses were completed only for non-industrial private forest landowners; corporate ownership was not included, because the taxation system and the decision making process in corporately-owned holdings are somewhat different to those applied in privately owned forests. Furthermore, the “no-response” observations were ignored because of the heterogeneity of the group. The number of “no-response” observations decreased in the second inquiry (Fig. 3). As a result, the number of landowners in modelling the first choice was 147, and in modelling the second choice (after the profitability calculations) it was 193 (Table 1).

Seven independent variables were used to describe both choices of forest taxation basis (Table 1). In earlier studies, it has been found that the future cuttings during the transition period divided by the volume of taxable increment in SPT (here referred as forest taxation index) is the most important factor affecting the optimal forest taxation basis (Ovaskainen et al. 1992, Pesonen and Räsänen 1993). The forest taxation index describes the “harshness” of SPT at varying harvest rates. Furthermore, the landowner’s estimated marginal tax rate and his/her intention to cut timber in the near future (an expressed intention to cut or not to cut timber during 1993–1995) influenced the optimal choice (Pesonen and Räsänen 1993). The landowners’ personal marginal tax rate under SPT depicted the harsh-

ness of their personal taxation level and their intention to cut timber depicted the short-term cutting of timber while the timber management strategy depicted the average cutting of timber during the transition period. In addition, the average commercial cuttings of timber of the past 5-year period were assumed to affect the future cuttings of timber and, thereby, also the choices of the forest taxation basis.

The age of the landowner has been found to be a significant variable describing the forestry behaviour of NIPF landowners, e.g. the life cycle harvest of NIPF landowners (Kuuluvainen and Salo 1991). One of the variables discovered to affect the timber management strategy choice was the area of forest land owned by the person (Pesonen 1995). Ovaskainen et al. (1992) assumed also that the forest area owned could affect the choice. Therefore, according to Ovaskainen et al. (1992), if the forest area is smaller than 15 ha, the landowner is assumed to always choose RIT. Furthermore, in that study, farmers were supposed to choose SPT more frequently than non-farmers, because of the debt burden of farmers and the poor profitability of agriculture (Ovaskainen et al. 1992).

3.3 Cross-Validation and Classification

In the comparison between logistic regression and neural networks, both of the data sets (choices of taxation basis before and after the profitability calculations) were randomly cross-validated into seven training sets and seven test sets. Thus, a total of 14 ($= 7 \times 2$) logistic regression equations and neural networks were obtained from the training sets. Cross-validation was applied in order to increase the reliability of the results. With a single division of the material into training and testing sets, the results obtained depend more on the random effect of the division (e.g. Lämäs et al. 1991). In modelling the first choice, the training sets included 100 landowners and, in modelling the second choice, there were 135 landowners.

After cross-validation, the estimated values of the observations in each test set were calculated using the regression equation constructed by using the respective training set. After calculating

Table 1. Summary of the variables used in this study.

	Before calculations	After calculations
Number of observations ¹⁾	147	193
Choice of the site productivity taxation	49 (33 %)	84 (44 %)
Choice of the the realized net income taxation	98 (67 %)	109 (56 %)
The age of the landowners (AGE)	51	51
Minimum-Maximum	22–87	22–87
Standard deviation	13	14
Farmer/Non-farmer, Dummy (FARMER)		
Number of farmers (1)	92 (63 %)	121 (63 %)
Number of non-farmers	55 (37 %)	72 (37 %)
Area of forest land, ha (AREA)	65	67
Minimum-Maximum	8–605	8–605
Standard deviation	69	66
Average commercial cuttings of the past 5-year period, m ³ /ha/a (CUTTINGS)	2.4	2.3
Minimum-Maximum	0–13.7	0–13.7
Standard deviation	2.5	2.5
Intention to cut during 1993–95, Dummy (CU9395)		
Intends to cut (1)	125 (85 %)	164 (85 %)
No cuttings	22 (15 %)	29 (15 %)
The estimated marginal tax rate in 1991, % (RATE)	41	39
Minimum-Maximum	0–56	0–56
Standard deviation	13	15
Forest taxation index ²⁾ (INDEX)	1.6	1.7
Minimum-Maximum	0–5.5	0–5.5
Standard deviation	0.9	0.9

¹⁾ No-response cases were ignored.

²⁾ Forest taxation index = the timber management strategy of the landowners (m³/ha/a) divided by the volume of taxable increment in site productivity taxation (m³/ha/a). The forest taxation index describes how much the landowner intends to cut in relation to the mean annual increment during the transition period.

the probabilities, the test observations were classified according to the actual distribution of the choices obtained from the respective training set (the cut-off point). For instance, if the number of actual choices of RIT was 34 in the training set and the number of choices of SPT was 24, the cut-off point used would be 0.41 (= 24 / (34 + 24)). If the estimated probability of an observation was greater than 0.41, the predicted choice of forest taxation basis was SPT (1), and if the estimated probability was lower than 0.41, the predicted choice was RIT (0). This classification is generally done by using a cut-off point value

of 0.5, but if the sample is relatively unbalanced, the cut-off point of 0.5 may never predict a case to category 1 (or zero) (Greene 1993).

4 Results

4.1 Factors Affecting the Choice of Forest Taxation Basis

In order to clarify the factors which affected the landowners' choice of forest taxation basis, two

Table 2a. Logistic models for the choices of the forest taxation basis before calculations.

Variable	Coefficient	Coeff./SE
Intercept	-3.385	1.45
Age	-0.025	-1.53
Cu9395	1.930	1.79
Index	1.237	4.26
χ^2 ¹⁾	7.333	
Df	8	
N	147	

Table 2b. Logistic models for the choices of the forest taxation basis after calculations.

Variable	Coefficient	Coeff./SE
Intercept	-1.769	-2.47
Cu9395	1.337	2.34
Rate	-0.030	-2.55
Index	0.862	3.93
χ^2 ¹⁾	18.193	
Df	8	
N	193	

¹⁾ The test is the Hosmer-Lemeshow test because of the use of the real-valued variables. The Hosmer-Lemeshow goodness of fit chi-square test divides the data into 10 cells and compares the observed and predicted frequencies for these cells. The cells are defined using the predicted frequencies (DeMaris1992, BMDP ... 1992).

logistic regression equations were constructed with seven independent variables (Appendix). Because the results of these analyses were poorer than those of analyses using significant variables, the results are reported using only models with significant variables. The final model consisted of significant variables with P-values lower than 0.20 (BMDP... 1992).

The most significant variable in modelling the choices of the taxation basis was the forest taxation index (Index) and it was the included in both models (Tables 2a and 2b). In modelling the first choice, the other variables of the model were “intention to cut timber during next three years” (Cu9395) and “age of landowner” (Age) (Table 2a). In modelling the second choice, the

significant variables included in the model, in addition to forest taxation index, were “marginal taxation rate” (Rate) and “intention to cut timber in the near future” (Cu9395) (Table 2b). The occupational status of the landowner (farmer vs. non-farmer), the area of the forest holding, and the average cuttings of the past 5-year period did not significantly influence the choice (Appendix).

Were the landowner to double the cutting of timber during the transition period, i.e. forest taxation index increases from 1 to 2, the odds of choosing SPT ($\pi / (1 - \pi)$) would increase by more than 200 % in the first-choice model, and over 130 % in the second-choice model. A one-unit increase in the tax rate would decrease the odds by 3.0 % in modelling the second choice. Furthermore, the log-odds were observed, in both models, to be very sensitive to the intention to cut timber during the next three years.

4.2 Comparison between Logistic Regression and Neural Networks

The performance of logistic regression and neural networks was compared by using seven cross-validated data sets. Moreover, comparisons were made between models with seven independent variables (Appendix 1) and with three significant variables (Tables 3 and 4). Because the results of the models with three variables were better both in logistic regression and in neural networks, only these results are reported.

In the first choice (before calculations), logistic regression predicted 72 % of the cases correctly (Table 3), while neural networks predicted only 64 % of landowners' choices correctly. Both methods gave better results in predicting the choices favouring SPT. The proportions of the correctly predicted choices were 75 % in logistic regression, and 69 % in neural networks.

In modelling the second choice (after calculations), the proportion of correctly predicted choices was 7 percentage units higher for logistic regression than for neural networks (Table 4). As was the case with models for the first choice, both methods gave better results in predicting the choice of SPT than the choice of RIT: of the predictions of choices favouring RIT as the sec-

Table 3. Summary of the modelling of the choice before calculations. SPT = Site-productivity taxation, RIT = realized-income taxation, N = the average number of the landowners in seven different models, Stdev. = the standard deviation of the number of landowners in different models and % = the average percentage of the correctly modelled choice.

	Logistic regression				Neural networks			
	Modelled / actual	N	Stdev.	%	Modelled / actual	N	Stdev.	%
SPT / SPT ¹⁾	12	2.27	75		SPT / SPT ¹⁾	11	5.08	69
RIT / SPT	4	1.95			RIT / SPT	5	5.46	
SPT / RIT	9	2.75			SPT / RIT	12	6.87	
RIT / RIT	22	2.52	71		RIT / RIT	19	6.26	61
Total	47		72			47		64

¹⁾ E.g., the modelled choice was site-productivity taxation and the actual choice was site-productivity taxation.

Table 4. Summary of the modelling of the choice after calculations. SPT = Site productivity taxation, RIT = realized income taxation, N = the average number of the landowners in seven different models, Stdev. = the standard deviation of the number of landowners in different models and % = the average percentage of the correctly modelled choice.

	Logistic regression				Neural networks			
	Modelled / actual	N	Stdev.	%	Modelled / actual	N	Stdev.	%
SPT / SPT ¹⁾	21	2.06	87		SPT / SPT ¹⁾	16	5.82	66
RIT / SPT	3	1.57			RIT / SPT	8	5.87	
SPT / RIT	15	3.95			SPT / RIT	14	10.58	
RIT / RIT	19	3.69	57		RIT / RIT	20	10.39	60
Total	58		69			58		62

¹⁾ E.g., the modelled choice was site-productivity taxation and the actual choice was site-productivity taxation.

ond choice, 66 % were correct for neural networks, and as many as 87 % were correct for logistic regression.

In the modelling the two choices, the standard deviations of the numbers of landowners in different classified groups were higher in modelling with neural networks than with logistic regression. Moreover, the standard deviations were higher in modelling the second choice than the first choice. The standard deviations were also higher in estimating the choice of RIT than of SPT (Tables 3 and 4).

The analysis of the classifications of logistic

regression and neural networks was done using t-tests. In the analyses, the difference between the numbers of landowners in each class was tested between the two methods (e.g. for the first choice, both the actual and predicted choices were SPT in both methods). Differences at 5 % significance level were observed between the classes with the second choice being SPT (Table 4).

5 Discussion

5.1 Predicting the Choice of Forest Taxation Basis

In this study, in the comparison between logistic regression and neural networks, logistic regression produced better results in modelling both choices. On average, logistic regression predicted nearly 70 % of the choices correctly, while neural networks fared almost 10 percentage units worse. In all the models applied, the choice of site-productivity taxation was predicted more correctly than the choice of realized-income taxation. This can be interpreted in two ways: either the landowners were more certain about their choice of SPT, or they intended to cut timber considerably more than the level of cuttings where the profitability of the forest taxation basis changes.

Cross-validation was used to increase the reliability of the results obtained. In modelling, both data sets were randomly divided into seven training sets and seven test sets. The standard deviations of the correctly and incorrectly estimated choices for neural networks were higher than for logistic regression equations. Thus, compared to logistic regression, neural networks are more sensitive to the division of data into training and testing sets. Had the data set been divided only once, the results for neural networks would have varied markedly with a relatively small number of observations. The reliability of the results provided by neural networks could be improved by increasing the number of observations in the analyses.

According to the χ^2 values obtained, the logistic regression model performed better in modelling the first choice than the second choice. It can be assumed that landowners with a strong opinion on the preferred, but not always the optimal, forest taxation basis in the first inquiry did not change their opinion in the second inquiry – regardless of what seemed to be the optimal taxation system. Landowners with no opinion on the preferred forest taxation basis in the first inquiry were divided equally between the choices of optimal and non-optimal forest taxation bases in the second inquiry.

In analysing the log-odds of the independent variables in modelling the first choice, the prob-

ability of choosing SPT increased when the cuttings during the transition period increased. Young landowners, intent on harvesting in the near future, chose SPT more frequently than RIT. Furthermore, in modelling the second choice, the probability of choosing SPT increased when the planned harvest rates increased during the transition period. Increase in the marginal tax rate of the landowners decreased the probability of choices favouring SPT. The results are consistent with, for example, Pesonen and Räsänen (1993).

In modelling the first choices (before calculations), the factors affecting the choice of taxation basis were:

- 1) forest taxation index,
- 2) age of landowner, and
- 3) intention to cut timber during the next three years

Respectively, the significant factors in modelling the second choice (after calculations) were:

- 1) forest taxation index,
- 2) estimated personal marginal tax rate in 1991, and
- 3) intention to cut timber during the next three years.

The most important variable affecting the choice of forest taxation basis was the forest taxation index. The connection between timber management strategies and the choice of forest taxation basis has been reported by Pesonen (1995) and Pesonen et al. (1995). The choice of forest taxation basis is part of the strategic decision making of NIPF landowners. According to the results, most landowners were aware of the most important factor affecting the optimal choice, i.e. first they chose the preferred timber management strategy, and after that, the suitable forest taxation basis. Also, the connection between intention to cut during the next three years and the choice of the forest taxation basis was apparent, i.e. for landowners with no intention to cut during 1993–1995, the probable choice was RIT.

In general, the characteristics of landowners did not demonstrate any marked connection with the choice of forest taxation basis. The landowner's age was proven to be slightly significant in modelling the choices before any information was produced about the economic consequences

of alternative taxation bases for the transition period. It is inevitable that during the life cycle of NIPF landowners, the strategic goals will vary. Furthermore, Kuuluvainen and Salo (1991) have reported that age is a significant variable when analysing the timber supply and life cycle harvest of NIPF landowners.

The intention to cut timber during the years 1993–1995, the estimated personal marginal rate in 1991, and the forest taxation index, all of which affected the optimal choice of the forest taxation basis, were more significant in the modelling of the second choices, i.e. after NIPF landowners had been shown information about the economic consequences of their choices. In the modelling of the second choice, the landowner's marginal tax rate was more significant than in the models for the first choice. In addition, the non-economical factors lost their significance in modelling the second choice. In that sense, the calculations increased the economic consciousness of the landowners.

The material used in this study was somewhat limited in terms of the point in time when the inquiry was conducted. At the time as the material was collected, the summer of 1993, the final decisions of concerning the forest taxation basis for NIPF landowners were not known. In addition, the final data sets used were quite small, consisting of only 147 and 193 NIPF landowners respectively. The accuracy of the models could have been improved with the use of final and actual choices and larger sample sizes.

5.2 Conclusions

In this study, logistic regression predicted the choice of forest taxation basis more accurately than did neural networks. Logistic regression gives good possibilities for quantifying independent variables and their influence on the dependent variable. In general, the modelling of NIPF landowners' behaviour is considered to be a multi-dimensional problem with few possibilities for developing accurate models (e.g. Pesonen et al. 1995).

In further studies, it is important to study landowners' behaviour during the transition period. There are numerous possibilities for comparing

landowners who chose site-productivity taxation with those who chose realized-income taxation. Furthermore, other interesting issues for study would be the possible differences in the future timber cutting behaviour of landowners, and the effects that the Finnish forest taxation reform has on the future supply of timber from NIPF landowners. Moreover, an essential matter to find out is the division of potential, allowable cut between landowners differentiated by their choice of forest taxation basis.

After obtaining the actual choices of forest taxation basis, the possible differences in the distribution of the choices in different parts of Finland could be clarified. If the choices vary, the crucial subject to study would then be the reasons for this variation.

In the future, it will be possible to test other machine learning techniques, e.g. genetic algorithms, in modelling the choice of forest taxation basis. As an example of alternative machine learning approaches, Pesonen et al. (1995) modelled the NIPF landowners' choices of timber management strategies using a genetic algorithm.

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Total of 43 references

Appendix. Logistic models for the choices of forest taxation basis before and after calculations with seven independent variables.

Variable	Before calculations		After calculations	
	Beta	Coeff./SE	Beta	Coeff./SE
Intercept	-2.6360	-1.67	-1.0930	-0.98
Age	-0.0233*	-1.41	-0.0169	-0.86
Farmer	0.2655	0.58	0.1287	0.363
Area	-0.0019	-0.58	-0.0001	-0.02
Cuttings	-0.0972	-0.94	-0.0308	-0.40
Cu9395	1.9520**	1.80	1.2380***	2.11
Rate	-0.0126	0.81	-0.0293***	-2.48
Index	1.1420***	3.87	0.8242***	3.70
χ^2 ¹⁾	6.047		14.621	
Df	8		8	
N	147		193	

*** denotes significance at 0.05 level

** denotes significance at 0.10 level

* denotes significance at 0.20 level

1) The test is Hosmer-Lemeshow test because some of the variables are continuous. The Hosmer-Lemeshow goodness of fit chi-square test divides the data into 10 cells and compares the observed and predicted frequencies for these cells. The cells are defined using the predicted frequencies (DeMaris 1992, BMDP... 1992).

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