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Strategic Forestry Planning
Evaluation of variable spatial aggregations and forest landscapes

Torgny Lind

Swedish University of Agricultural Sciences

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Abstract

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As a base for a forest management programme in the Hugin system, results from a questionnaire study of the public preferences concerning the forest environment in a northern Swedish county were used. The results were translated into forest data useful in the Hugin system for selection of appropriate NFI sample plots. A forest scenario with high consideration given to peoples' preferences regarding different forest attributes was compared with a scenario with 1990s levels of cutting and use of silviculture methods. The management programmes differed substantially, with much more single tree selection, natural regeneration and higher shares of broad-leaved trees in the first scenario. In this scenario, which considered the people's preferences, calculations indicated an approximately 20% reduction in logged timber volumes, which corresponds to a 10% loss of profit.

Generally, the basic unit in tactical and operational planning is predefined stands. With small homogeneous stands the opportunities to apply optimal management at the local level are better than with large heterogeneous stands, but the costs for inventories, planning, and harvesting single stands will be higher. The economic consequences of different stand delineation strategies were analysed on an area of 5900 ha having a continuous description of forest variables in raster elements estimated using field and satellite data combined by the k nearest neighbour (kNN) method. The results indicate that differences in net present values (NPVs) are small: 0.8 % and 2.0 % higher NPV for small stands than for medium and large stands (3.6, 7.8, and 21.2 ha), respectively. When including entry costs, that is, the cost of moving machines between treatment units, large stands have 2.1% and 3.2 % higher NPV than medium and small stands, respectively.

In the final study, the formation of treatment units was included as a part of the planning process. Dynamic treatment units were formed and selected for harvest such that NPVs were maximised for a forest area of 558 ha in Northern Sweden. The forest variables were described in raster elements (30 m x 30 m) estimated by the kNN method. The degree of clustering was controlled by an entry cost for logging. Simulated annealing was used as solution technique. The results show that the net present values are at least as high as forestry with predefined stands even if entry costs are included. The NPV from felling decreases by about 4% when the degree of clustering is increased to about the same level as with predefined stands.

Key words: forest landscape, forest management, forest recreation, planning, simulated annealing, stands, strategic planning.

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Torgny Lind
Department of Forest Resource Management and Geomatics
Umeå

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Author's address: Torgny Lind, Department of Forest Resource Management and Geomatics, SLU, S-901 83 Umeå, Sweden.

Contents

Appendix

Papers I – IV

This thesis is based on the following papers, referred to by their Roman numerals in the text:

I. Lind, T. & Söderberg, U. 1994. Considering costs and revenues in long-term forecasts of timber yields. *Scand. J. For. Res. 9:397-404*

II. Holgén, P. & Lind, T. 1995. How do Adjustments in the Forest Landscape Resulting from Environmental Demands Affect the Costs and Revenues to Forestry? *Journal of Environmental Management 45, 177-187*

III. Lind, T. Economic consequences of different stand delineation strategies. (Manuscript)

IV. Lind, T. Spatial and temporal delineation of forest in dynamic treatment units using simulated annealing. (Manuscript)

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Introduction

Background

The forest resource has been used for a long time and has contributed to the welfare of humans through the production of such commodities as industrial wood, fuelwood, food, and shelter (Stridsberg, 1984; Fritzböger and Söndergaard, 1995). In the industrial era in western countries timber production has been, and still is, the dominant use of the forest resource in many countries. Industries demand timber and pulpwood for refinement, resulting in large incomes and employment to society. The planning of timber production is, therefore, important for economic reasons. Today, the use of forests differs between regions depending on, for example, population density, technological development, socio-economic factors, the political system, and the importance of the forest sector to the economy.

In Sweden, more than half of the land surface is covered with productive forest—(Anon, 1999) an indication that the forest sector, which provides a high export surplus, job opportunities, recreation and hunting facilities, and the possibility of living in sparsely populated areas, is important for society. Today, Sweden is the second largest exporter of wooden goods, third on pulp, and fourth on paper (Skogsindustrierna, 1997). The efficiency and intensity of timber production has been increased by means of large clear-cuts, mechanisation, artificial regeneration, cultivation of exotic tree species, and so on.

Besides the obvious values coming from timber, there are also non-market-priced values such as on- and off-site recreational, forest environmental, and existence values (e.g., Walsh, 1990; Mattsson et al., 1993; Bostedt, 1995; Fredman, 1995; Wibe, 1995; Boman, 1997; Bengston et al., 1999). These values were not considered much before the 1960s (Hultman, 1984). At that time, the standard of living was raised and the public's demand for and willingness to pay for outdoor recreation, and the preservation of biodiversity and the environment increased.

Forest planning

Legislation, and information and advisory services to users and owners of forests are important tools used to regulate conflicts and overexploitation of forests. As a basis for decisions and planning of forestry issues some kind of forecasts of forest development must be available. Provision of such forecasts is not an easy task because of the many stakeholders, multiple objectives (see e.g., Iverson and Alston, 1986; Hof and Joyce, 1993; Hytönen, 1995; Kangas et al., 1998), and a long-term horizon. Furthermore, contradictory requirements from interest groups can give rise to conflicts (e.g. Hellström and Reunala, 1995; Hellström, 1998; Maier, 1998; Proctor, 1998; Mann, 1999).

In Sweden, planning of the forest resource is nothing new (af Ström, 1829). Several long-term forecasts of timber yield and potential cut have been made during the twentieth century (Nilsson, 1985). In the beginning, the methods for forecasting the forest resource were simple and aimed at attaining a sustained yield of wood. The possibilities for making long-term forecasts were also limited without computers and good input data. The development of computers has increased the potential for creating more sophisticated forest planning systems. The approach to strategic planning has also been developed from single to multiple objective planning (e.g. Iverson and Alston, 1986; Fries, et al., 1998; Krcmar Nozic et al., 1998). The provision of guidelines to decision-makers, where values other than timber production are considered, increases the complexity of the planning process (Naesset, 1997).

A frequently used procedure to make planning easier, and sometimes even possible, is to organise it in a hierarchical structure (e.g., Nelson et al., 1991; Weintraub and Cholaky, 1991; Davis and Matrell, 1993) commonly, with three levels: strategic (allocation of resources), tactical (scheduling of operations), and operational (implementation of the goals set at higher levels). The planning horizon for strategic planning is normally extended over 30 to 150 years; for tactical, 3 to 10 years; and down to months in operational planning. The strategic level incorporates objectives with respect to such concerns as timber production, environmental values, and composition of tree species. The tactical level is used to allocate and schedule actions for specific areas of the forest over the following few years. The operational level implements the objectives set at higher planning levels. The objectives and demand on input data are different depending on planning level. Whereas strategic planning is often non-spatial and covers large areas, the tactical and operational levels are, by definition, directed towards finding suitable spatial patterns for activities such as thinning and final harvesting (e.g., Jamnick, 1990; Bare and Mendoza, 1991; Dahlin and Sallnäs, 1993; Lockwood and Moore, 1993; Yoshimoto, 1996; Murray, 1999).

Planning systems

Many systems deal with strategic planning and all of them have their strengths and weaknesses. Usually, the driving force behind the development of these systems has been prediction of timber production, and many systems still concentrate on this problem area. Non-timber and environmental values are often considered as restrictions to timber production (Päivinen, 1996). Examples of systems are, for instance, FORPLAN (Iverson and Alston, 1986; Hoekstra et al., 1987), Spectrum (Camenson et al., 1996), DTRAN (Hoganson, 1996), the MELA system (Siitonen, 1993; Siitonen, 1995; Siitonen and Nuutinen, 1996), the GAYJA-JLP system (Hoen, 1996), the Forest Management Planning Package (FMPP) (Jonsson, et al., 1993), and the Hugin system (Lundström and Söderberg, 1996).

These systems can be classified in two main types: those using simulation methods and those using optimisation approaches (cf. Päivinen, 1996). The systems using simulation methods describe the probable development of the forests under specified assumptions regarding felling, silviculture, cleaning, etc. The optimisation approach, using for instance linear programming (LP), chooses the best combination of large sets of management alternatives created by simulation. Generally, adjacency constraints are not considered in strategic planning contradictory to the planning at the tactical and operational levels, partly because of problems in including adjacency constraints for large forest areas when using LP (Murray and Snyder, 2000). The outcomes from strategic planning should provide ready guidelines for planners and managers and also set the confines for tactical and operational planning. Typical results show potential harvest volumes, increment, growing stock distributed on tree species, areas cut, net revenues, etc.

When using the multi-level planning approach the translation of results from strategic planning into tactical and operational planning (Davis and Martell, 1993) is important. If management restrictions (which only occur in tactical and/or operational planning and not in strategic planning), negatively influence for example, net incomes from timber production, it will not be possible to reach the target levels set within strategic planning. In operational planning, restrictions often originate from spatial considerations that not have been included in strategic planning. These include concentration aspects of logging, buffers around objects because of environmental reasons, and recreation considerations (Naesset, 1997). Daust and Nelson (1993) showed that the sustained yields estimated by spatial formulations were in all cases lower than those estimated by aspatial formulations. One way to improve links between the planning levels is to include spatial considerations at all planning levels (Covington, 1988; Lau et al., 1996; Naesset et al., 1997; Murray and Snyder, 2000).

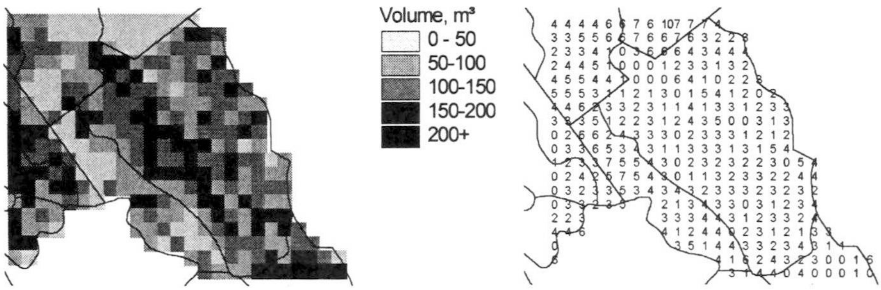
Forest data

A fundamental requirement for all forest management planning is the existence of data that describe the forest in an adequate way (e.g., Larsson, 1994; Ståhl et al., 1994). How to get the information needed to conduct planning varies depending on objectives, planning horizon, level of planning, etc. The planning base is often collected by field inventories and other auxiliary information sources such as aerial photos (Holmgren et al., 1997), satellite images (Jaakkola et al., 1988, Holmgren and Thuresson, 1998), and radar (Leckie and Ranson, 1998; Fransson and Israelsson, 1999). Generally, the data used in strategic planning come from large-scale inventories such as National Forest Inventories (NFI) with no or weak spatial connection to stands and in operational planning from inventories with predefined stands.

To get adequate data that quantify the non-timber values arising from on- and off-site use of the forests, such as berry and mushroom picking, hiking, camping, etc., can be difficult. Two commonly used methods that estimate these values are the contingent valuation method and the travel cost method (e.g. Hoen and Winther, 1993; Mattsson et al., 1993; Schröder, 1997; Golos, 1998). Furthermore, to include the results of such valuation methods in forest planning systems can be an intricate task because of weak connections between non-timber values and forest attributes and management (Kangas and Kristiansen, 1995).

Normally, forest management planning, at least at the levels of tactical and operational planning, is based on predefined spatial units (stands). As a simplification, these are assumed to be internally homogeneous and spatially stable over time. In fact, there is often large within-stand variation in old stands (Ståhl, 1992) and it is unlikely that young stands will preserve their spatial homogeneity over time. Applied treatments seldom follow the predefined stand borders and can cause errors in updating the stand description register. The internal variation leads to implementation of non-optimal treatments on those parts of the forest stands that deviate greatly from the mean value of variables such as volume, age, tree species distribution, etc., on which management decisions are made. Murray (1999) concludes that there is little or no research to date that has examined scale and aggregation effects associated with spatial unit definition in harvest scheduling. A description of the forest where information is available for every point or for small area units as raster elements would be preferable (Holmgren and Thuresson, 1997).

Until recently, assessment of such a database has not been realistic, but new techniques (Dykstra, 1997), incorporating Geographic Information Systems (GIS), Global Positioning Systems (GPS), satellite images, radar sensors, etc. have made it possible to create such databases. Figure 1a shows an example of a forest area described in raster elements with predefined stands having large within-stand variation of volume. Figure 1b shows the optimal time for final felling without any consideration to entry costs for cutting, adjacency restrictions of cuttings, etc. To utilise such a forest database in forest planning it is necessary to have methods that can form treatment units over time and space as a part of the planning process (Holmgren and Thuresson, 1997; Lu and Eriksson, 2000).



(a) (b)

Figure 1. Distribution of volume within older stands (a) and the optimal time for final felling, ten-year periods (b).

Objectives

The main objectives of this thesis were to develop methods within strategic forestry planning able to aggregate treatment units and evaluate forest landscapes. Data from the Swedish NFI (Paper I and II) and a continuous forest database obtained by combining field inventory data and satellite data using the kNN estimation method (Paper III and IV) were used.

The specific objectives of the Papers included were to:

- Describe methods that can be used for calculating costs and revenues in a system for long-term forecasting of timber yields and possible cut (Paper I)

- Estimate the adaptation costs associated with a change of forest management programme from current practices to one with a high level of consideration for people's preferences (Paper II)

- Analyse the economic consequences of different strategies for stand delineation regarding size, i.e., degree of homogeneity (Paper III)

- Develop a method capable of forming economic optimal treatment units both in time and space in long-term planning based on a raster element description of forests (Paper IV).

Material and Methods

Paper I

At the former Faculty of Forestry, at the Swedish University of Agricultural Sciences, a system called Hugin (Lundström and Söderberg, 1996) was developed. The system primarily aims at regional long-term forecasts of timber yields and potential cut to analyse different forest management programmes. The system is used for strategic planning on the regional/national level or by large companies. The forecasts are based on data from the Swedish National Forest Inventory temporary and permanent sample plots.

The present general Swedish NFI design is an annual stratified sample plot design with plots clustered into tracts using sampling with partial replacement (Ranneby et al., 1987). Up to two hundred variables describing the state of the forest and the site conditions in detail are collected for these sample plots.

The basic feature of Hugin is a deterministic simulation model with some stochastic components built in. The results from a forecast describe the state of the forest, its growth, and the potential cut for every ten-year period, with specific assumptions about the future silviculture and cutting (Figure 2). The planning period is normally one hundred years divided into 10-year periods. The individual plots are used as the unit for decisions regarding different measures, and individual trees on each plot as units for the growth prognosis (Söderberg, 1986). In 1985 the Hugin system was used for long-term forecasts of timber yields for the whole of Sweden, (Bengtsson et al., 1989), and again in 1992 (SOU, 1992) and in 1999 (National Board of Forestry, 2000).

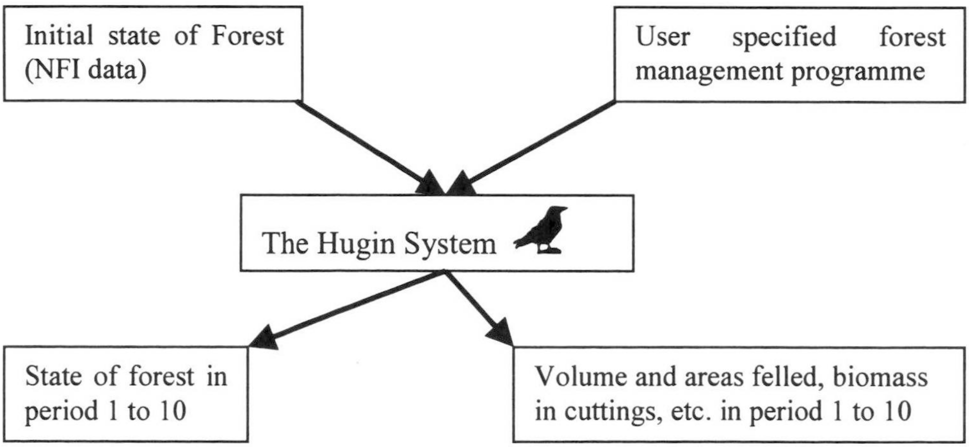


Figure 2. Input and output from the Hugin system.

Hugin calculates the saw timber quality of single trees cut and the distribution on assortments by using regression functions based on NFI sample tree data collected in 1974–75 for Scots pine (*Pinus sylvestris L.*) and Norway spruce (*Picea abies (L.) Karst.*). All broad-leaved trees are assumed to be pulpwood. First, the probability for single trees to become saw timber is calculated. Second, if saw timber is received, the probabilities for the saw timber part of the single tree to become of better quality (i.e., unsorted timber (U/S)) is calculated. Other functions are then used to calculate the height of the quality limits (Figure 3). Important variables in these functions are tree age, diameter, site index (SI) and the geographic location of the sample plots. In addition, the individual trees' taper curve (Edgren and Nylinder, 1950), tree height (Söderberg, 1992), form factor (Näslund, 1940, 1947), and form quotient (Petterson, 1955) are predicted. Having obtained all the data needed, the division into assortments is optimised against a price list for each single tree.

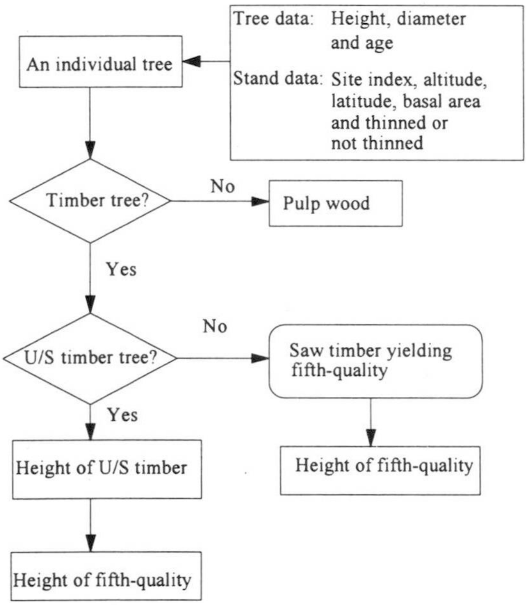


Figure 3. Flow chart showing the way to calculate the individual tree quality and the heights of the quality limits.

Functions predicting costs for logging and off-road extraction, adapted to NFI sample plots with the intention that they should describe the variation in time needed for felling and off-road extraction for geographical zones of Sweden, were made. They were based on a study (unpublished) that recapitulated the costs, the distribution of the methods used, and their efficiency for felling and silviculture measures. The felling costs depend on zone, the methods selected for felling, the felling form, volume, and the number of trees on the sample plot. The off-road extraction costs with forwarders depend on geographical zone, the felled volume and the distance from the sample plot to the nearest road.

Paper II

As a base for a forest management programme in the Hugin system (see previous section and Figure 2) results from a study made by Mattsson and Li (1994) were used. Their study included questions about people's preferences regarding different forest attributes in the county of Västerbotten in northern Sweden. Photographs showing various types of forest landscapes, representing different silvicultural systems, were presented to the respondents. The photographs were translated into forest data useful in the Hugin system.

Initially, about 7900 NFI sample plots inventoried between 1983 and 1992 were used. From these plots, 378 plots were selected subjectively, in correspondence to the forest stands in the photographs and preferences to represent the forest in the county of Västerbotten in northern Sweden. Preferences concerning the composition of tree species were also taken into account in choosing plots with broad-leaved trees whenever possible.

A forest scenario with maximum consideration given to peoples' preferences regarding different forest attributes based on selected sample plots was called the "alternative". The silviculture measures in Hugin were applied on this hypothetical initial forest state based on the selected sample plots. This imaginary state had the attributes and characteristics requested by the public in the county of Västerbotten.

In the calculations, the "alternative" is compared with a reference scenario, from now on named the "reference". The "reference" calculations were based on sample plots inventoried during the 1992 survey season. The management programme is based on results from an inquiry made by the National Board of Forestry into the future levels of cutting and use of methods in the 1990s. The results imply that artificial regeneration after final felling on two thirds and natural regeneration using seed trees on one third of the final felled area should be the approach adopted. The management programme for the "alternative" differs substantially from the programme employed in the "reference". In the former scenario, single tree selection is utilised on about 30 % of the forest land and about 60 % is managed using natural regeneration. Artificial regeneration after final felling is practised on about 10 % of the forest land area. Further, in the "alternative", the silviculture employed is aimed at raising the share of broad-leaved trees over a 100-year period, and at retaining all other initial attributes of the forests.

The time span studied was 100 years, divided into ten periods. To make a useful comparison between the two scenarios possible, the timber harvests have been held as close as possible to a maximum sustainable yield level.

The approximate divergence in contribution profits between today's methods and objectives and the "alternative" were calculated in Hugin. Figure 4 shows the flow of forest data for the two scenarios to arrive at an estimation of adaptation costs.

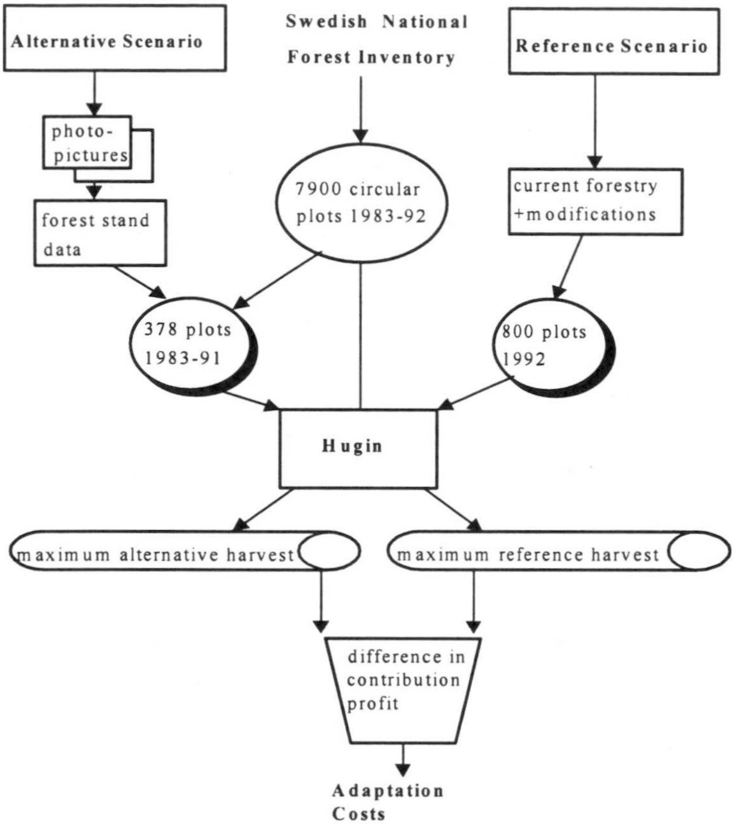


Figure 4. Data-flow in cost estimations.

The estimations in Hugin of the difference in contribution profits did not take the present value into account. Consideration of rate of interest will, however, affect the annual cost considerably. This is especially true since the large discrepancies in contribution profits arise in the latter half of the 100-year period. Accordingly, the net present value has been calculated with a discount rate of 3.0 %.

Paper III

A forest area of about 5900 ha located in northern Sweden was surveyed using the Forest Management Planning Package (FMPP) inventory method with some additional variables (Jonsson et al., 1993; Christoffersson and Jonsson, 1997). The field survey was a stratified and systematic sample plot inventory, designed to be suitable for forestry without predefined stand boundaries (Wallerman, 1998). A Landsat TM-scene with seven spectral bands and a ground resolution of approximately 30 m x 30 m was also available.

The field data were combined with satellite image data by using the kNN estimation method (Tokola et al., 1996; Nilsson, 1997; Tomppo et al., 1999) to create a spatially continuous forest database covering the whole study area, independent of the existing stand delineation. The satellite image used was a Landsat TM-scene from 950613 with seven spectral bands available (band 6 was not used) and a ground resolution of approximately 30 m x 30 m.

Two methods were used to delineate stands in the study area: A manual aerial photo interpretation method according to the Holmen Company's guidelines and the automatic t-ratio segmentation method (Hagner, 1990). The t-ratio segmentation method is a type of region-growing algorithm. The basic idea is that spatially adjacent regions should be merged if they cannot be separated with a given certainty. The t-ratio segmentation was tuned to provide delineations with different average sizes and degrees of homogeneity. The results were transformed to layers in a GIS and assigned data from the kNN estimations by an overlaying procedure. Three delineations using the segmentation method resulting in mean area of stands of 3.6, 7.8, and 21.2 hectare were made. A delineation based on manual aerial photo interpretation having a mean area of 8.0 ha was also used.

The Forest Management Planning Package (FMPP) was used to evaluate the economic outcomes of the different stand delineations (Jonsson et al. 1993). The FMPP calculates the maximum net present value (NPV) at the stand level by an algorithm that tests a large set of management alternatives (Jacobsson, 1986). The sample plots were assigned to pixels with the kNN technique and to stands with an overlay procedure. All stands were then included in the FMPP calculations opposite to the normal case where field plot data from sample stands constitute the basis.

Normally, the FMPP does not consider any effects of costs associated with spreading or concentration of logging. In the calculations with the FMPP the four delineation strategies were analysed with and without entry costs, that is, the costs for moving machines between treatment units. Thus, a restriction that controlled the size of allowed treatment units was tested, implying that small stands would always be treated together with stands in the vicinity, thus lowering the entry costs. Functions for calculating costs for final felling depended on volume, stems per hectare, and size of treatment units.

Paper IV

A study area of 558 ha was selected manually in the middle of the larger inventoried area described above in the section on Paper III. The field data were combined with satellite image data by using the kNN (k = 5) estimation method (Tokola et al., 1996; Nilsson 1997; Tomppo et al., 1999). The description unit was raster elements of 30 m x 30 m independent of the existing predefined stands.

Simulated annealing (SA) was used as a solution technique (Connolly, 1990) to form dynamic treatment units (DTUs) economically optimal both in time and space (Holmgren and Thuresson, 1997). Using SA, more management options increase the number of iterations exponentially. Therefore, the management schedules were limited to point of time for final felling. Treatments were assumed to take place in the beginning of each period. The planning horizon was 100 years divided into ten ten-year periods. The minimum accepted final-felling age was 70 years. Depending on the management schedule, the raster elements were treated between zero and two times.

A version of the Chapman-Richards model was used to predict growth for each management schedule on all raster elements (Nilsson, 1978). Initial volume, age, species composition (pine, spruce, and broad-leaved trees), and SI were used as independent variables. Tables predicting natural mortality as annual natural mortality (percent of total growing stock) were used (Bengtsson, 1994). The amount of timber and pulpwood from felling (Ollas, 1980) and the distribution of saw timber on quality classes were calculated using statistics of normal distribution in the area (National Board of Forestry, 1999). The timber price list of the Forest Owners Association 1998/1999 for the Västerbotten-Örnsköldsvik area was used to value the harvested timber and pulpwood. The mean height, one of the independent variables used by Ollas (1980), was predicted by a function derived from regression technique based on the inventory data. As input to the growth predictions (Nilsson, 1978) after final felling, the raster elements were assigned new tree volumes depending on SI class based on inventoried sample plots in strata of young forest.

The harvests and silviculture costs used in this study were the averages reported for large-scale forestry in Sweden in 1997 (National Board of Forestry, 1999). The cost for final felling was set at 70 Swedish crowns (SEK)/m^3, thinning at 120 SEK/m^3, and regeneration at 6000 SEK·ha^{-1}. Soil expectation values (SEVs) were calculated for the same SI classes by choosing the optimal management schedule. One thinning was allowed when calculating the highest possible SEV.

The raster elements are selected for harvest such that the net present value (NPV) is maximised, that is, controlled by the entry costs associated with the harvests in all periods. The entry costs for a single raster element were estimated depending on occurrences of simultaneous treatments around 5 x 5 raster elements around a centre single raster element. The same algorithm for calculating entry costs with DTUs (Holmgren and Thuresson, 1997) was applied to forestry with predefined stands to compare the economic results. No other costs associated with size of harvest areas, such as costs for road building and maintenance, and administration, were considered.

Results and discussion

Considering costs and revenues in long-term forecasts of timber yields (I)

The methods for calculating costs and revenues in the Hugin system are developed and analysed. The system can calculate costs associated with logging, off-road extraction, silviculture, and "other work".

Functions estimating the division into assortments for tree zones of Sweden have been implemented in the system to make it possible to calculate revenues from timber and pulpwood. The results from the tests of functions distributing the single tree into high and low quality of saw timber were compared with statistics from the Wood Measurement Society (National Board of Forestry, 1992). The comparison indicates that division into assortments was in agreement for most parts of the country. For Norway spruce there were large discrepancies in the middle part of Sweden. One possible explanation could be that these counties are located close to the border where a shift of functions valid for the north zone to the middle zone of Sweden occur.

Several grading systems have been developed for Swedish conditions and after this study was carried out a new grading system has come into use (Virkesmätningsrådet, 1997). The new grading system makes it difficult to use the functions included in the Hugin. Nevertheless, the method for deciding the division into assortments in steps could be useful. If necessary, the price lists valid for the new grading system could be converted to the old price lists.

Lately, new functions predicting important variables associated with quality of timber, such as crown height (Petersson, 1997), diameter of the thickest living branch (Petersson, 1998), branchiness (Petersson, 1998) and knot diameter (Björklund and Petersson, 1999) have been developed. Hopefully, these functions can be included in systems for long-term forecasts, such as the Hugin system and the FMPP.

How do Adjustments in the Forest Landscape Resulting from Environmental Demands Affect the Costs and Revenues to Forestry? (II)

The study focuses on the adaptation costs associated with a change from a scenario with today's silvicultural systems and tree species' composition ("reference") to a scenario where maximum consideration is given to the public's preferences concerning the forest landscape ("alternative") in a Northern Sweden county. The important results show the relation between the two alternatives and not the absolute numbers of costs and revenues.

The annual maximum sustainable logged volume within each ten-year period, with a total planning period of one hundred years, was on average 8.6 and 6.9 million m^3 for the "reference" and "alternative", respectively. This implies a reduction of approximately 20 % in the volume of logged timber in the "alternative". The mean annual contribution profit was also calculated. The difference between the two scenarios is about 20% of the total net gain, implying an annual adaptation cost of 166 million SEK corresponding to a 10 % loss of NPV in the "alternative".

The proposed changes in silvicultural methods in the "alternative" reduce both revenues and logged volumes. The lower volumes harvested and higher cost for logging were not significantly counteracted by less expensive regeneration methods. The main reason for higher logging costs is that an increasing share of the logged volumes is extracted from expensive thinnings.

It is important to note that the silviculture measures in the Hugin system were applied on a hypothetical initial forest state that differs to some extent from the current state of forest. The "alternative" has a comparatively high proportion of spruce because of the public preferences for forest being treated with selective cutting. This is somewhat contradictory to the preferences for more broad leaves and less spruce. However, the proportion of broad-leaved trees is almost 30% of the standing volume in forests not treated with selective cuttings. The implication of this is that almost three-quarters of the forest land area has a large proportion of broad-leaved trees.

There are, however, reasons why an "ideal" forest landscape, as defined in this paper, would not have as large a share of forest being treated with selective cutting as a quarter of the total forested area. There are reasons to believe that it is the mature state of the forest that attracts people most, and not the fact that the trees are spruce instead of, for example, pine. In this respect, a decrease in the current level of the selection system in favour of a system with more regeneration felling having only a short phase in which there is no mature forest present, would be of interest.

Economic consequences of different stand delineation strategies (III)

Generally, in forest management planning the stand is the basic unit when deciding on activities aimed at specified goals, such as highest economic yield. Normally, stand delineation follows certain guidelines, resulting in minimum, maximum, and mean sizes. With small homogeneous stands, the opportunities to apply optimal management at the local level are good in contrast with the case with large heterogeneous stands, but the costs for inventories, planning, and harvesting will be comparably high.

The results indicate that the highest NPVs are obtained with delineation of a lot of small stands when no entry costs for logging are included. However, the differences are rather small: 0.8 % and 2.0 % higher NPV for small stands than for medium and large stands, respectively. When including entry costs large stands have 2.1% and 3.2 % higher NPV than medium and small stands, respectively.

Spatial and temporal delineation of forest in dynamic treatment units using simulated annealing (IV)

The SA worked well for the test area and formed dynamic treatment units both over time and space. The results show that the NPV is higher or as high as forestry with treatments applied on predefined stands, in the same forest area, delineated with guidelines of the forest owner, the Holmen Company. The NPV decreases by about 4% when the degree of clustering increases from none to comparable to predefined stands in the study area (Table 3). The degree of clustering was controlled by a constant in an equation that calculates the entry costs for felling depending on concurrent treatments on a 5 x 5 grid.

Table 3. Comparison of NPVs for solutions with different values on C controlling entry costs and related to NPV when C = 0

C (SEK)	NPV(1000 SEK)	Per cent (%)
0	8779	100.0
500	8765	99.8
1000	8735	99.5
1500	8696	99.1
2500	8608	98.1
5000	8435	96.1

Figure 5 shows that the spatial pattern of logging clearly changes with different entry costs. When the constant controlling the entry costs and consequently the clustering of logging is low more raster elements are felled without any other neighbouring elements being felled at the same time.

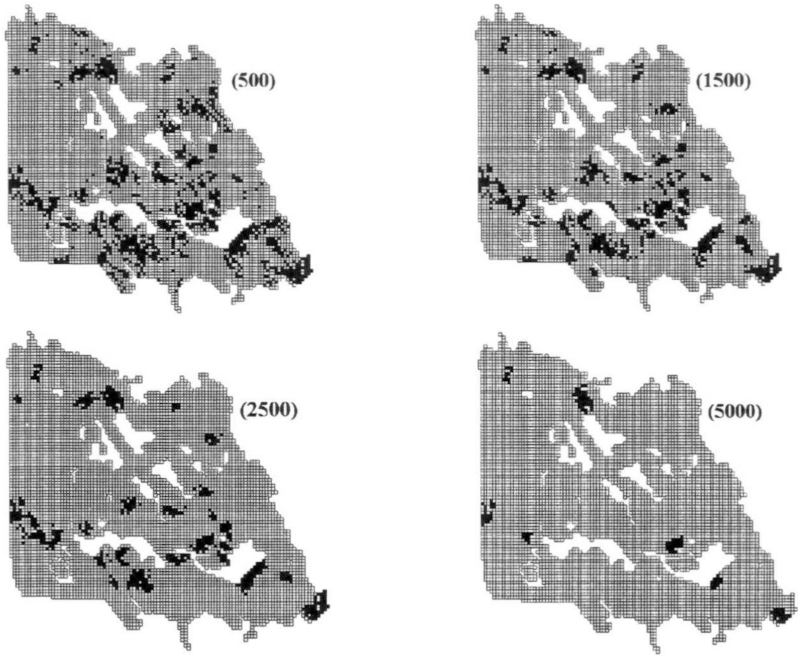


Figure 5. Location of final fellings for the first ten-year period when entry costs ranged from low to high (500 equals low and 5000 equals high). Black elements indicate felling and grey, no felling.

Conclusions and recommendations

All results presented in this thesis deal with strategic forestry planning. The method of estimating the timber quality of single trees seems to work rather well together with the algorithm optimising the distribution on assortments economically (Paper I). The approach of using functions to estimate the probabilities of single trees becoming saw timber and of different saw timber qualities should be possible to use with new grading systems.

The results in Paper II show a reduction in both harvested volumes and NPVs by about 20 and 10 %, respectively, if a change of predominant silviculture regimes to silviculture regimes that correspond to people's preferences is applied in a county in northern Sweden. Note that the silviculture measures in the Hugin system were applied on a hypothetical initial forest state that differs to some extent from the current state of forest. The method of estimating the adaptation cost includes some subjective elements, such as translation of people's preferences to forest data, specification of management programme, etc. This is not an easy task to avoid and perhaps not the most important part to develop. More important is further development of growth predictions for silviculture practices not commonly used before 1990s for single tree selection felling and a shelterwood system (Anon., 1998). Also important to develop are planning systems and methods that are able to consider varying demands on recreation-friendly forests depending on their geographical location, such as nearness to urban areas.

In Paper III, the economic consequences of different strategies of stand delineation according to size (i.e., degree of homogeneity) were tested. It can be concluded that if the treatment units are small and homogeneous the NPVs will be higher because there are better opportunities to apply optimal management. When a simple algorithm that calculates entry costs associated with size of felling areas was included, the increased NPVs that resulted from more optimal management applied to small stands could not compensate for increased entry costs.

The results imply that much work should be focused on harvest scheduling to decrease costs for logging. However, the improved opportunities to apply optimal management when having small description units of forest, such as in raster elements, should still be used, thus including the formation of treatment units as a part of the planning process.

In Paper IV, DTUs are delineated during the planning process to consider variations in the forest more effectively. The solution technique, simulated annealing, seems to be able to form treatments units both in time and space in an appropriate manner. One problem is that the solution time becomes high for larger areas normally considered in strategic planning. This problem will be reduced if the current development of computers continues.

A change from the traditional way of describing forest with predefined stands to raster elements with no predefined stands requires much development of planning systems, education, new ways of thinking etc. Nevertheless, the reasons for a change from traditional forest management planning with predefined stands as units for calculations and decisions will probably be stronger in future, especially, if further development of methods for assessment of forest data make it possible and practical to describe forest in a continuous manner. Then it will be important to have methods and planning systems that utilise such a description effectively. Furthermore, the development of a combined harvester/forwarder may also decrease the entry costs (Hallonborg, 1999) and make it less expensive to move around when felling.

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