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Methods to incorporate the amenity of landscape into forest management planning

Timo Pukkala

TIIVISTELMÄ: MENETELMIÄ MAISEMANHOIDON LIITTÄMISEKSI METSÄTALOUDEN SUUNNITTELUUN

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The study presents methods that incorporate the amenity of a forest area into the management planning. The management plan is based on treatment schedules simulated for each compartment over the 20-year planning period. The best combination of treatment schedules is selected by multiobjective optimization. The amenity is divided into two parts: (1) within-stand amenity and (2) the amenity of landscape when viewed afar (distant scene). The within-stand amenity is expressed in terms of adjective sum which is estimated from stand characteristics. The adjective sum is calculated at three time points for each treatment schedule. The mean adjective sum of the whole area in a selected year can be taken as an objective or constraining variable of optimization. The assessment of the distant scene is based on computer illustrations which show the predicted temporal change of landscape according to a particular management plan.

Tutkimuksessa esitellään tapoja ottaa metsän maisema-arvo huomioon metsänhoitotoimenpiteiden suunnittelussa. Metsänhoitosuunnitelma perustuu kuvioille simuloituihin käsittelyohjelmiin, joista valitaan sopivin yhdistelmä monitavoiteoptimoinnilla. Suunnittelu kattaa 20-vuotiskauden. Metsän maisema-arvo koostuu (1) metsiköiden sisäisestä viihtyisyydestä ja (2) metsäalueen esteettisestä arvosta kaukaa katsottaessa. Sisäistä viihtyisyyttä kuvataan adjektiivisummalla, joka estimoidaan metsikkötunnusten avulla. Jokaiselle simuloidulle käsittelyohjelmalle lasketaan ajdektiivisumma kolmena ajankohtana. Tietyn vuoden keskimääräistä adjektiivisummaa voidaan käyttää optimoinnin tavoite- tai rajoitemuuttujana. Kaukomaiseman arvottaminen perustuu tietokonepiirroksiin, jotka havainnollistavat, kuinka metsämaisema muuttuu eri suunnitelmavaihtoehdoissa.

Keywords: multipurpose forestry, multiobjective planning, computer simulation, mathematical optimization
ODC 624 + 627.3 + 916

Author's address: University of Joensuu, Faculty of Forestry, P.O.Box 111, SF-80101 Joensuu, Finland.

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1. Introduction

The forest produces raw material for sawlog timber, pulpwood and fuel, as well as working possibilities, recreation, berries, mushrooms, etc. In Finland wood production has been traditionally the dominating way of using forest resources, but the importance of outputs connected with the amenity of environment is increasing constantly, especially near urban areas.

There is much knowledge about the wood production of different stands and the inputs needed for the production. Wood production and labour can easily be assessed in terms of money, which makes it possible to evaluate different outputs and inputs at the same time. On the other hand, no exact methods exist so far for evaluating inputs and outputs not connected with wood production.

Lack of models and methods for predicting and evaluating amenity values has led to management planning systems designed for wood production only. Consequently, the management of forest resources is based exclusively on wood production, although the importance of other outputs is widely acknowledged. This means that there are no methodologies available for preparing management plans for the areas whose main function is to produce recreation possibilities or aesthetic values.

Lack of methods is also reflected in forestry education; management for other products than wood is often neglected because there are only non-operational methodologies available. The consequence is that foresters do not always acknowledge the importance of the multiple outputs of a forest ecosystem; there may be a gap between the values of a forester and other consumers of forest resources. However, the decision maker, whose values should be decisive in management planning, is not usually a forester but someone else belonging to the group of 'other consumers'.

The aim of this work is to present methodologies that take amenity values into account in ordinary forest management planning. The methods do not presuppose additional measurements in the forest inventory nor additional work in the planning stage.

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2. Concepts, methods and material

2.1 The applied planning system

2.1.1 General aspects

Forest management planning is based on existing forest and monetary resources, on one hand, and the objectives set for the forestry, on the other hand. The planning should not rely on silvicultural rules only, but it should rather produce such a set of rules that the different targets of forestry will be met (Kilkki 1986, Pukkala and Pohjonen 1987).

In management planning the different management alternatives are evaluated by studying their consequences; the aim is to find as good consequences of decision as possible. The consequences are assessed with the help of some critical variables which correlate with the utility of the decision maker (objectives). In forest management planning typical objectives are the costs, income, labour and harvests during a certain period of time and the volume, value and productivity of the growing stock at certain point of time.

The simplest way to prepare a management plan is to experiment with different combinations of treatment schedules of individual stands using the method of trial and error. This is the most common method in practical forestry in Finland today. There are, however, more effective methods available which are based on mathematical optimization (Siitonen 1983, Pukkala and Pohjonen 1987). These methods require the decision situation to be modelled to describe how the variables used for evaluating the decision depend on management.

The optimization phase of the management planning can be carried out e.g. by using linear programming (Kilkki 1986) or multiobjective planning (Korhonen 1987a, 1987b). Typical of both these methods is that the management plan always uses the forest resources in an effective way, i.e. the solutions for the planning problem lie on the production possibility boundary (production frontier) of the forest area. This means that it is impossible to improve an objective without impairing the value of some other objective (Kilkki 1986).

The model that gives the dependence of objectives on treatments is usually based on simulated treatment schedules, of which the treatments and the values of objectives are known (Siitonen 1983, Pukkala and Pohjonen 1987). Thus a simulation model is an essential part of a forest management planning system besides the optimization procedure.

In this work the management alternatives of the case study area were studied by simulating treatment schedules for each compartment, after which mathematical optimization was applied to evaluate the consequences of decisions and to find out the optimal combination of treatment schedules.

2.1.2 Simulations

The management planning of this study covers 20 years divided into two 10-year periods. In the first phase of planning, a number of treatment regimes was simulated for each compartment by using the program of Pukkala (1985), in which the simulation of growth is based on single-tree growth-models of Nyyssönen and Mielikäinen (1978). The simulation of one treatment schedule included the following stages:

(1) Calculate the present stand characteristics (present status).
(2) Let the stand grow by 5 years.
(3) Simulate the treatments of the first 10-year period.
(4) Let the stand grow by 5 years.
(5) Calculate the status at the end of the first 10-year period.
(6) Let the stand grow by 5 years.
(7) Simulate the treatments of the second 10-year period.
(8) Let the stand grow by 5 years.
(9) Calculate the status at the end of the second 10-year period.

The status of the stand was described by stand characteristics, which included stand volume, volumes of different tree species, sawlog volume, pulpwood volume, value of growing stock, volume and value increment, etc. The harvested volume and the costs and income associated with the treatments were also calculated for each 10-year period.

Besides treatment schedules encountered in practical forestry, a few additional schedules were simulated for some compartments where a few parent trees were left in the area under natural regeneration to prevent the scene from becoming too open.

2.1.3 Optimization

The optimal treatments according to different objectives were sought by using the program of Korhonen (1987a, 1987b) designed to solve multiple objective decision problems. The program allows 10 objectives at the same time and a great number of constraints. The planner always sees the values of all objectives, i.e. he always knows the consequences of his decision if he chooses one point of the production frontier. He can freely move along the production frontier so that the effect of improving an objective on other objectives can be seen immediately. This feature renders the studying and mapping of the production frontier very easy.

Any of the variables that describe the status of the stand at the end of the first or second 10-year period, as well as the costs, income and removal, can be used as objectives or constraints. In this study only the following parameters were used for evaluating alternative management plans:

– net income during the first 10-year period (1987–1996)
– net income during the second 10-year period (1997–2006)
– total stemwood volume at the end of the second 10-year period (at the beginning of 2007)
– mean amenity at the end of the second 10-year period (described in the next Section)

2.2 Incorporation of amenity values

2.2.1 Within-stand amenity

As an additional state variable the adjective sum proposed by Savolainen and Kellomäki (1981) was estimated by (Pukkala and Kellomäki 1987)

$$AS=49.04+0.3344H+1.398SP+0.03370V_{hw} \quad (1)$$

where AS = adjective sum
H = mean height (m)
SP = number of tree species
V_{hw} = volume of hardwood (m^3/ha)

The adjective sum usually varies between 50 (low amenity) and 67 (high amenity). For making the range of variation more understandable the adjective sums estimated for different compartments were scaled between 0 (very poor) and 50 (very good). The adjective sum was calculated for the same points of time as the rest of the state variables, i.e. at the beginning and at the end of the 1st 10-year period and at the end of the 2nd 10-year period.

The adjective sum is the sum of the assessments of several stand parameters which describe the amenity of the stand (Savolainen and Kellomäki 1981). Because the adjective sum mainly depends on a particular stand and not on its surroundings, it can be used for describing the within-stand amenity.

The mean adjective sum calculated over the whole case study area (later referred to as the mean amenity) was used as an objective variable in the management planning examples. It was calculated by multiplying the estimated adjective sum by the area of the compartment, and dividing the sum of these products by the total area of compartments. Thus, the mean amenity can be supposed to describe the average enjoyment of people who are distributed evenly over the whole forest area.

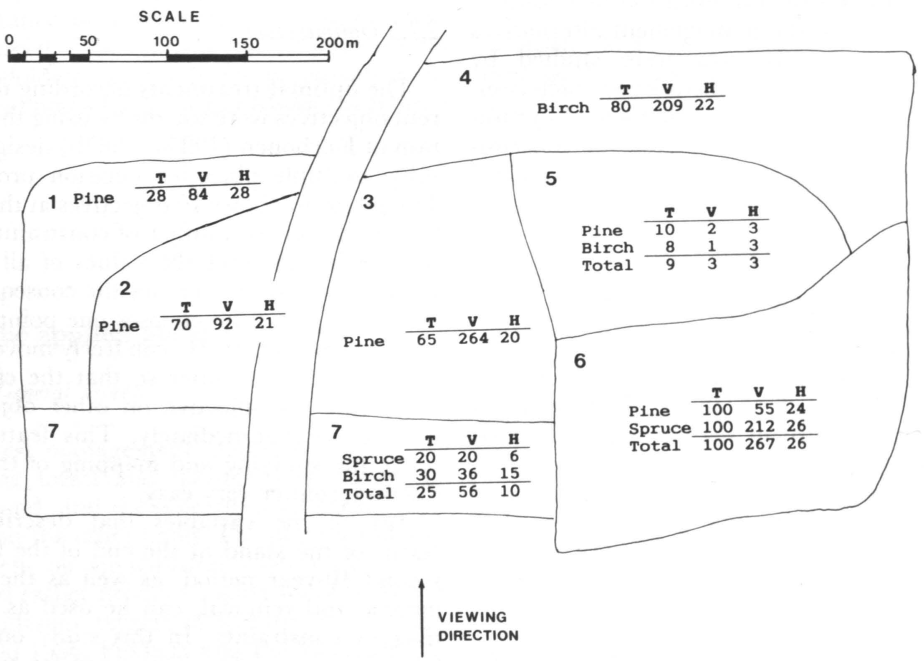

Fig. 1. Map of the case study area. T = age (a), V = volume (m^3/ha), H = mean height (m).

2.2.2 Far-view amenity

No numerical parameters were estimated from stand characteristics for the amenity of forest area viewed afar. Instead, computer drawings which were assessed subjectively by a number of persons were created (Fig. 6). The scale was from 0 (very poor) to 50 (very good). Each person was told to imagine the landscape in nature and assess that image. The mean score was used as a measure of the amenity of landscape.

The drawings were made by the program of Kellomäki and Pukkala (1987). The program allows the drawing of landscape at 5-year intervals. At each point of time it is possible to treat the stands and calculate stand parameters.

In the program each stand is described by a few trees whose species, diameter, height, age and number of stems are known. The simulation of growth is done by increasing the diameter and height of these trees by using models of Nyyssönen and Mielikäinen (1978). The treatments are simulated by harvesting part of the trees or by adding new seedlings.

The drawing of landscape is based on a set of points, the x, y and z-coordinates of which are known, as well as the compartment on which the point lay. When producing landscape the program draws different tree symbols on these points so that the size and species distribution correspond to the situation in nature.

2.3 Description of the case study area

The results of this study concern a case study area of 13.5 ha consisting of 7 compartments (Fig. 1). This area is surrounded by arable land and other treeless areas. The forested area lies on two small hills of an undulating terrain. The forest stands are therefore strikingly visible from the road that goes through the region (Figs. 1 and 6).

The age and species composition of the stands of the compartments vary considerably. The present status of the stands allows many different management strategies which renders the area very suitable for the case study (Fig. 1). Several stands are mature for regeneration, which means that the change in landscape will be considerable in the near future.

3. Results from case study

3.1 Production frontier

The cuttings of the case study area allow net income ranging from 50 000 FIM to 300 000 FIM during both 10-year periods, depending on the objectives and constraints set for forestry. It is possible to cut up to 270 000 FIM during the first 10-year period with practically no decrease in the mean amenity in 2007 (Curve 1 in Fig. 2). After this income the final amenity begins to decrease rapidly. The obvious reason for the sharp bending in production frontier is that it is possible to get the 270 000 FIM income from thinnings and cuttings aimed at natural regeneration, after which clearcuttings become a necessity to further increase the income.

The constraint that the final volume (in 2007) must be at least the same as in 1987 assures high final amenity, but restricts the income of the first 10-year period to a level lower than 250 000 FIM (Curve 2 in Fig. 2). With a constraint of net incomes during the second 10-year period being at least 150 000 FIM, all the thinnings of the first period decrease the final amenity (Curve 3 in Fig. 2).

The cuttings during the second 10-year period begin to decrease the final amenity after 200 000 FIM income (Curve 1 in Fig. 3). If the income is less than the 200 000 FIM, the mean amenity in 2007 would be less than with the 200 000 FIM income. This means that some cuttings have to be done during 1997–2006 to reach the maximum

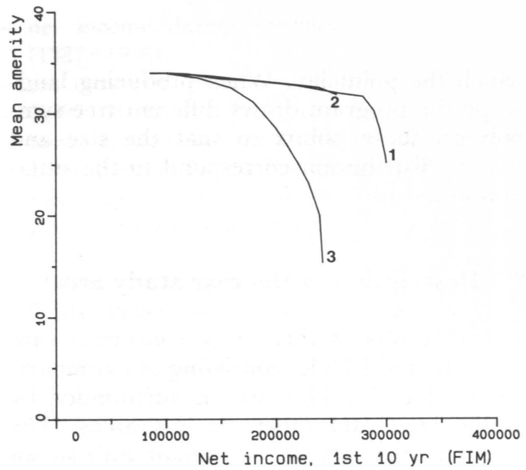

Fig. 2. Production frontiers of the case study area. 1 = production possibility boundary of mean amenity after 20 years and net income during first 10-year period. 2 = the boundary with the constraint that the total volume after 20 years is the same as at the beginning. 3 = the boundary with the constraint that the net income is at least 150 000 FIM during the second 10-year period.

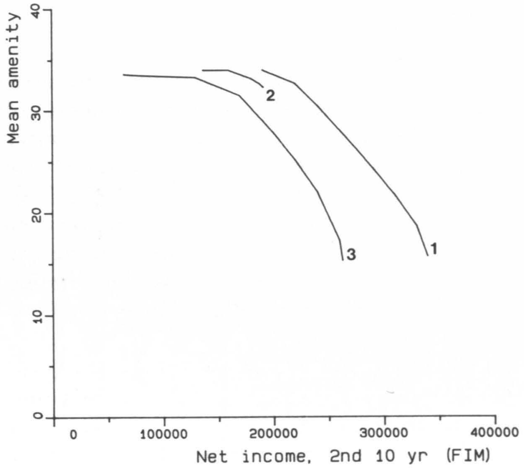

Fig. 3. Production frontiers of the case study area. 1 = production possibility boundary of mean amenity after 20 years and net income during second 10-year period. 2 = the boundary with the constraint that the total volume after 20 years is the same as at the beginning. 3 = the boundary with the constraint that the net income is at least 150 000 FIM during the first 10-year period.

amenity in 2007. The cuttings are obviously thinnings from below or cuttings for natural regeneration, which according to Eqn (1) can increase the amenity of the stand.

The constraint that the total volume in 2007 must be at least the same as in 1987 restricts the variation of the income in the 2nd period to a very narrow range; if the income is less than 135 000 FIM, the final amenity decreases, and if the income is more that 195 000 FIM, the final volume is less than in 1987 (Curve 2 in Fig. 3). The requirement of 150 000 net income during the first period increases the effect of income in the 2nd period on the final amenity, but it is again noteworthy that it is possible to get 150 000 FIM during the 1st period and 120 000 FIM during the 2nd period without decreasing the final amenity (Curve 3 in Fig. 3).

The income of the first 10-year period decreases the income of the second period almost linearly (Curve 1 in Fig. 4). The constraint that the mean amenity in 2007 shall be equal to that in 1987 causes a considerable decline in income (Curve 2 in Fig. 4). The

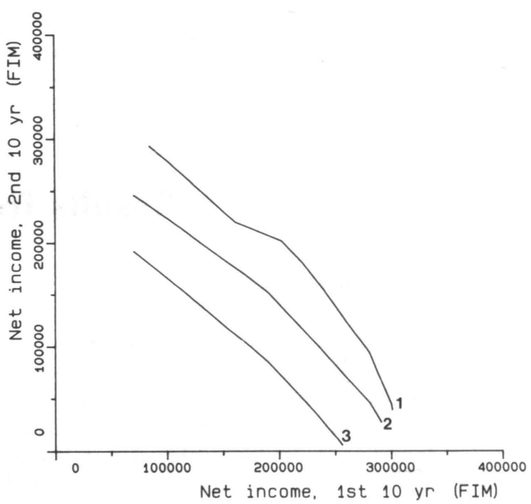

Fig. 4. Production frontiers of the case study area. 1 = production possibility boundary of net incomes during first and second 10-year period. 2 = the boundary with the constraint that the mean amenity after 20 years is the same as at the beginning. 3 = the boundary with the constraint that the total volume after 20 years is the same as at the beginning.

requirement of the final volume being at least the same as in 1987 has, however, much stronger influence on cuttings (Curve 3 in Fig. 4).

3.2 Management plans

Three different management plans were prepared for the case study area to illustrate more clearly the consequences of stating different objectives for forestry, or selecting different points from the production possibility boundary. The alternative plans were based on the following objectives and constraints.

Plan	Maximized	Constraints
1	Mean amenity in 2007	–
2	Net income during 1987–1996	(1) Net income during 1997–2006 ≥ 150 000 FIM
3	Net income during 1987–1996	(1) Net income during 1997–2006 ≥ 150 000 FIM (2) Mean amenity in 2007 same as in 1987

Maximizing mean amenity in alternative 1 leads to a management plan where the cuttings consist mainly of thinnings and natural regeneration (Table 1, Fig. 6). There are no clearcuttings nor such treatments where all parent trees of the regeneration area are removed. In the thinnings of mixed stands the birches are always left to grow on (Table 1).

In the second alternative, where the only objective was to get income, the amount of cuttings is greatest (Tables 2, 4 and 5). The regeneration is not always by planting, presumably because of the high costs, but in all cases where the natural regeneration has been selected for the first 10-year period, all parent trees should be removed during the second period. In the thinning of mixed stands all birches are cropped because they are bigger and more valuable than pines and spruces and, therefore, give more income.

In alternative 3 some treatments have been postponed from the first 10-year period to the second one compared to alternative 2 (Table 3). Some parent trees have been left in regenerated areas. The requirement of reasonably

Table 1. Optimal treatments if the mean adjective sum at the end of the 2nd 10-year period is maximized without constraints.

Compart/ Schedule	Area (ha)	Treatments during 1st 10-year period	Treatments during 2nd 10-year period
1/2	1.2	– No treatments	– Thin
2/2	1.2	– Remove most parent trees	– No treatments
3/4	2.0	– No treatments	– Natural regeneration for Scots pine – Scalping
4/4	2.4	– Natural regeneration for birch – Disc ploughing	– Tend young stand (leave parent trees)
5/4	2.0	– No treatments	– Thin (leave birches)
6/7	3.2	– No treatments	– Natural regeneration for spruce
7/4	1.5	– No treatments	– Thin (leave birches)

Table 2. Optimal treatments if the net income during the first 10-year period is maximized with the constraint that the net income during the 2nd 10-year period must be at least 150 000 FIM.

Compart/ Schedule	Area (ha)	Treatments during 1st 10-year period	Treatments during 2nd 10-year period
1/2	1.2	– No treatments	– Thin
2/1	1.2	– Remove all parent trees – Tend young stand	– No treatments
3/5	2.0	– Natural regeneration for Scots pine – Scalping	– Remove all parent trees – Tend young stand
4/3	2.4	– Natural regeneration for birch – Disc ploughing	– Remove all parent trees – Tend young stand
5/3	2.0	– No treatments	– Thin (remove birches)
6/2	0.2	– Clearcut – Disc ploughing – Plant birches – Tend young stand	– No treatments
6/5	3.0	– Natural regeneration for spruce	– Remove all parent trees – Tend young stand
6/7	3.2	– No treatments	– Natural regeneration for spruce
7/3	1.5	– No treatments	– Thin (remove birches)

Table 3. Optimal treatments if the net income during first 10-year period is maximized with constraints that the mean adjective sum must not decrease during 20-year period and the net income during second 10-year period must be at least 150 000 FIM.

Compart/ Schedule	Area (ha)	Treatments during 1st 10-year period	Treatments during 2nd 10-year period
1/2	1.2	– No treatments	– Thin
2/3	1.2	– No treatment	– Remove all parent trees – Tend young stand
3/4	1.9	– No treatments	– Natural regeneration for Scots pine – Scalping
3/6	0.1	– Natural regeneration for Scots pine – Scalping	– Remove most parent trees – Tend young stand
4/3	1.2	– Natural regeneration for birch – Disc ploughing	– Remove parent trees – Tend young stand
4/4	1.2	– Natural regeneration for birch – Disc ploughing	– Tend young stand (leave birches)
5/4	2.0	– No treatments	– Thin (leave birches)
6/2	3.2	– Clearcut – Disc ploughing – Plant birches – Tend young stand	– No treatments
7/4	1.5	– No treatments	– Thin (leave birches)

Table 4. The net income and removal in different management plans (see Tables 1-3 and text for the description of the alternatives).

Parameter	Alternative 1	2	3
	First 10-year period (1987–1996)		
Net income, FIM	86747	242836	191252
Total removal, m³	561	1545	1408
Sawlog removal, m³	432	1316	1217
Pulpwood removal, m³	125	218	184
	Second 10-year period (1997–2006)		
Net income, FIM	190873	150000	150000
Total removal, m³	1261	1243	996
Sawlog removal, m³	1027	862	752
Pulpwood removal, m³	202	271	186

Table 5. The predicted change of some parameters during the 20-year planning period in different management plans (see Tables 1–3 and text for the description of alternatives).

Parameter	Year 1987	Year 2007 Alternative 1	2	3
Total volume, m³	2175	1949	677	1580
Sawlog volume, m³	1716	1188	139	496
Pulpwood volume, m³	408	482	448	836
Volume of birch, m³	548	683	144	964
Volume growth, m³/a	87	96	60	117
Mean amenity	30	34	15	30
Score of distant scene	40	36	21	36

high within-stand amenity in 2007 has caused the leaving of birches in mixed stands.

Because of the rather large proportion of old stands in 1987, the total volume decreases in all management alternatives, even when the final mean amenity is maximized without any restrictions (Fig. 5, Table 5). The decrease in volume is very striking in alternative 2 where the only objective was to get income. The reasonably high final amenity in alternatives 1 and 3 is based on totally different strategies: in alternative 1 there are big old trees on almost every compartment, whereas in alternative 3 the main reason for good within-stand amenity in 2007 is the large proportion of birches (Figs. 5 and 6).

The far-view-scene points given to the drawings of the final landscape indicate a correlation between vista amenity and within-stand amenity (Table 5, Fig. 6). Alternative 2 has clearly the poorest score. The rest of the drawings are near to each other.

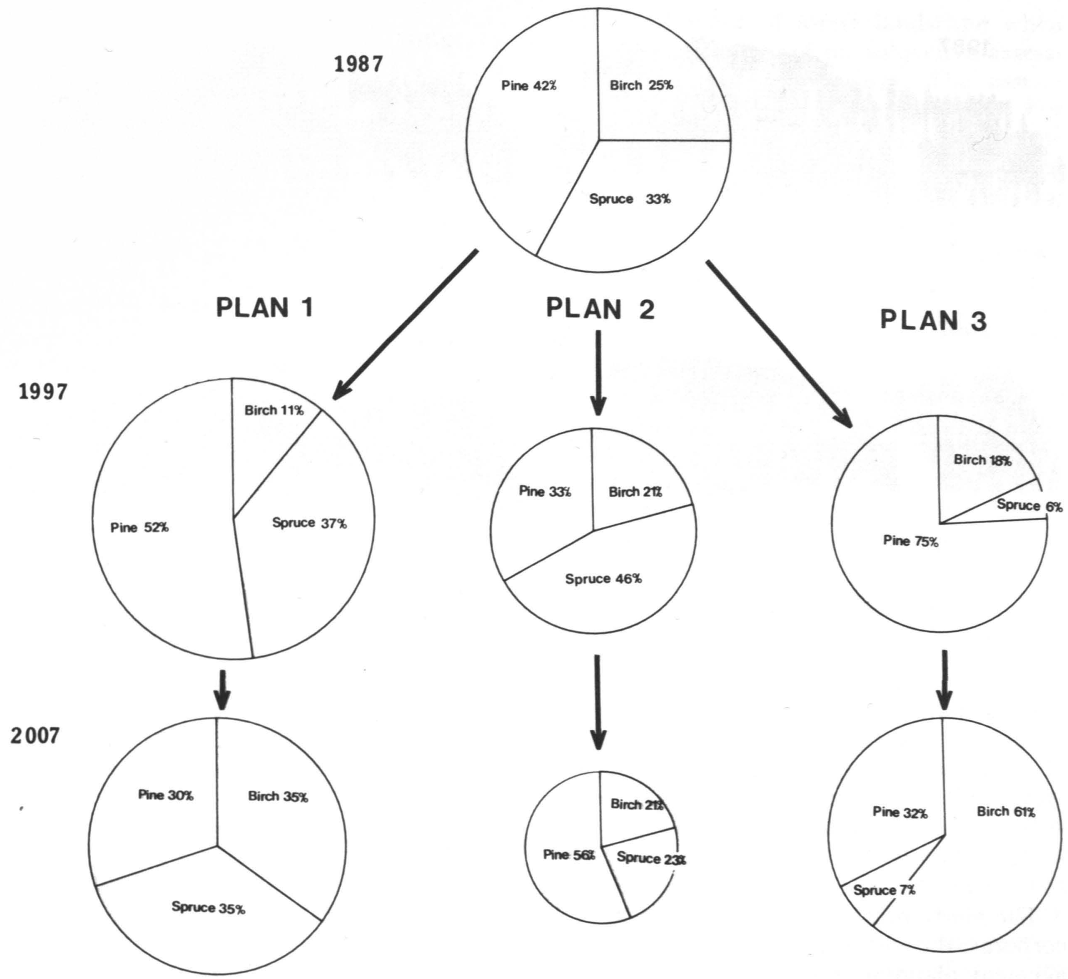

Fig. 5. Development of total volume and the contribution of tree species to the total volume in different management alternatives. The area of circle is proportional to the total volume. In plan 1 the mean amenity in 2007 is maximized without constraints. In plan 2 the net income of the 1st 10-year period is maximized with the constraint that the income of 2nd 10-year period must be at least 150 000 FIM. In plan 3 the net income during the first 10-year period is maximized with constraints that the net income during the 2nd period must be at least 150 000 FIM and the mean amenity in 2007 must be the same as in 1987.

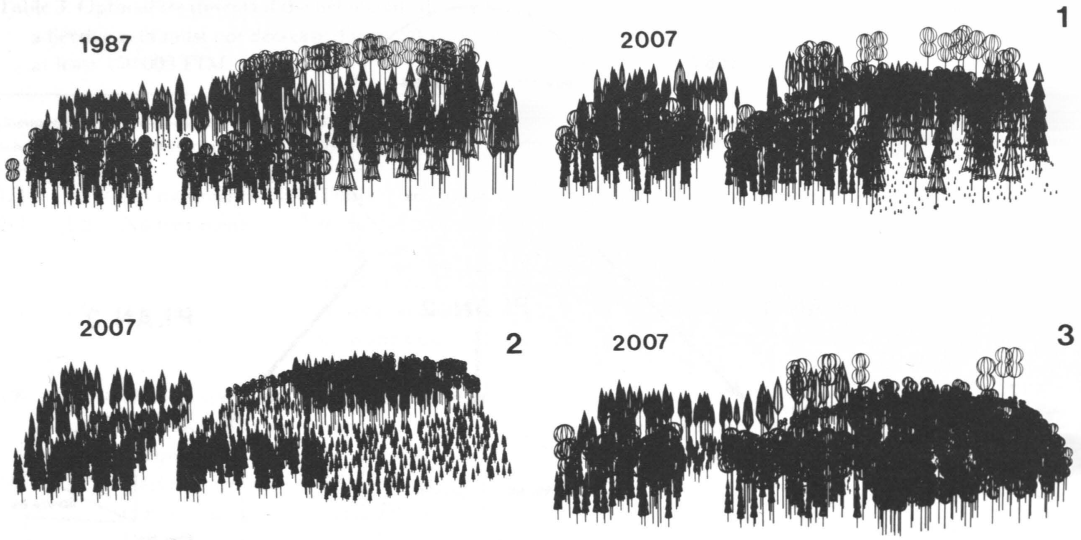

Fig. 6. The actual landscape and the predicted landscape in 2007 in three different management plans (see Fig. 5 for the explanation of alternative plans). The assessments of distant scenes were based on these drawings (in a larger scale).

4. Discussion

The study presents an explicit way to incorporate the within-stand amenity into management planning and a much less explicit way to evaluate far-view amenity. The methodology can be used for deriving treatment orders for forest areas whose important function is recreation or aesthetic beauty.

An important feature of the applied method is that the treatment recommendations are deducted from the objectives of the decision maker and are not based on standard rules. This increases the flexibility of the method considerably. The fact that all management plans are composed of simulated treatment schedules, ensures the fulfillment of legislation, provided that only legal treatments are simulated.

The illustration of landscape by computer graphics is an additional tool to assess different management alternatives. The drawings may also increase the reliance of the decision maker on the management plan. In addition, the management plan can be visualized by a series of drawings showing the development of the stands.

The management planning method used in this study can be utilized to examine how the amenity of the forest area depends on characteristics describing non-amenity variables. In theory, when these relationships are known well enough, no special estimates on amenity are needed anymore. If we know, for example, that birches and big old trees increase amenity, we can use constraints concerning the total volume of birch or the area of old stands to ensure high amenity (Kilkki 1986). However, it is easier to the planner to state directly that the amenity must have some value in some year.

In this study the within-stand amenity was assessed with the help of the mean adjective sum. The use of this measure is based on the assumption that the movements of people in the forest do not depend on the properties of the stands, and that moving from one type of stand to another type does not have any special effect on the enjoyment of the recreationist. These assumptions simplify the real situation considerably (Zivnuska 1961). More probably people gather to the best places of the forest and also the variation as such increases amenity. In addition, different people enjoy different types of forest, which means that the creation of a good recreation environment for as many people as possible requires many types of stands.

One way of further developing the description of within-stand amenity of a forest area is to combine the measure of amenity of two components: (1) mean amenity (2) variation in stand characteristics between compartments. On the other hand, the requirement for continuous and even yields and the site variation usually lead to a mosaic where the age and species composition of stands vary. Therefore, the omission of variation when describing amenity is not necessarily a serious shortcoming.

The presented methodologies to handle amenity are aimed at assisting the management of forestry, the main product of which is still wood, and it is important to produce wood on every compartment. One could also ask whether it would be more profitable to concentrate on wood production on some compartments and on amenity on the rest of compartments (Zivnuska 1978). These kinds of questions could be studied by the same method as used in this study, except that additional treatment schedules should be simulated to some or all compartments where the main emphasis is on amenity.

The judgment of forest landscape when viewed afar was based on subjective assessments of computer drawings. The assessments concerned the year 2007 only. For getting a better estimate of the distant scene associated with management plan, several landscapes drawn e.g. at intervals of five years should have been evaluated.

To identify quantitative variables which correlate with the perception of distant scene, a method related to that of Shafer et al. (1969) could be used. In this method the photograph of landscape is divided into different zones (sky, distant vegetation, etc.), after which the areas and the configuration of zones are used to predict the landscape preferences of people. It is clear that the search for quantitative variables describing the distant scene is much more difficult than at within-stand level.

Although the results of this study only concern a small area and are based on rather preliminary models on amenity, some conclusions can be made. It seems that the incorporation of amenity values into management does not necessarily decrease income if the cuttings are made in a proper way. In some cases cuttings even increase the within-stand amenity. For example, the removal of small trees from a dense stand and a shelter tree thinning may increase amenity. Also leaving some parent trees on naturally regenerated areas and the increase in the proportion of birch have a beneficial effect on the amenity.

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