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Composing landscape level forest plans for forest areas under multiple private ownership

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This study illustrates planning approaches available for forest planning concerning multiple private ownership, referred to here as regional planning. These approaches are necessary because of ecological reasons: evaluating the habitat quality of several species requires examining the forest landscape within areas larger than a single forest holding. Forest holdings are administratively delineated and do not coincide with habitat patches, which leads to interdependencies between forest holdings. The basic planning approaches applied in this study were the top-down, bottom-up and integrated approaches. In the top-down approach, the landscape-level plan was prepared according to landscape-level objectives, ignoring the holding-level objectives. In the bottom-up approach, the landscape-level plan was created by selecting the best combination among already accepted forest plan alternatives first created for each holding. In the integrated approach, landscape-level and forest-holding-level objectives were considered simultaneously in the same optimization model. It was concluded that a general ranking of the approaches is impossible because different planning situations emphasize different requirements. The ranking of approaches depends on the comparison criteria and the planning situation. It is also possible to use several approaches in one planning situation.

Introduction

Stand compartments and forest holdings are the most commonly used operational units in the management planning of Finnish nonindustrial private forestry. Typically, stand-level alternatives are produced and combined to yield an optimal forest plan at the forest-holding level with respect to stated objectives. Forest owners set their objectives, which may, for example, concern timber production, game management, recreation, or the scenic beauty of the landscape. At present, biodiversity maintenance, by preserving the populations of existing species viable in the planning area, is gaining importance. Stand-level management practices are being altered to better correspond to biodiversity demands, and small, ecologically important areas are being set aside. In addition, biodiversity indices (e.g. Pukkala *et al.* 1997) or indices measuring habitat suitability for certain species (e.g. Bettinger *et al.* 1999) can be used as decision-making objectives in tactical forest planning.

When seeking to improve the viability of species, a stand and a forest holding are large enough planning areas for some of them. However, for many other species, the habitat requirements and the indirect ecological effects to be considered require examination of the whole forest landscape (e.g. Andrén 1994, Mönkkönen *et al.* 1997, Kurki 1997, Kurki *et al.* 1999). Landscape ecological plans for large contiguous forest areas (e.g. 50 000 ha tracts of land) have been created for state owned forests in Finland, especially in the northern and eastern part of the country. In southern Finland and Ostrobotnia, the need for forest protection was recently analyzed (Forest protection…, 2000), and some of the recommended operations are expected to affect private forests. Flexible, goal-oriented and ecologically sound forest planning could support forest protection in regions where the area of protected forest is small and the proportion of state-owned forest land is low. However, a meaningful area for such planning does not often correspond to the area of one privately owned forest holding. This is due to the small average size of privately owned holdings (about 30 hectares) and the fact that these holdings are administratively delineated and do not coincide with habitat patches. Thus, a meaningful area for landscape ecological planning consists of several forest holdings. The eventual decision makers within this area are the individual forest landowners each having their own forest management objectives.

In the management planning of private forestry, a new planning approach is therefore needed. This approach is termed "regional planning" (Pukkala *et al.* 1997), where several holdings are considered simultaneously. Some of the stated objectives are related to individual forest holdings while others concern the whole planning area, ignoring the borders of the holding. The maximum size of the planning area and the realistic number of participating forest owners are situation-specific questions. One solution would be to adhere to the current Finnish practices and expand the planning area according to the forest planning system of Forestry Centers, where plans for the forest holdings within continuous areas of 2000–6000 ha are prepared during the same season (Oksanen-Peltola and Paananen 1995).

Regional planning belongs to the category of hierarchical planning. Hierarchical planning is, by definition, "the organization of information for making decisions at different levels when the quality of the decision made at one level is dependent upon decisions or information at other levels. Levels may be defined temporally or spatially where the scope of the higher level fully encompasses the scope of the lower level" (Connelly 1996). Examples of decision levels are an enterprise's organizational structure, strategic, tactical and operational levels of planning and spatially hierarchical levels of planning. One aim of hierarchical planning is to preserve consistency between levels of decision (Weintraub and Cholaky 1991). In addition, the production of information that supports negotiations between or inside the levels of hierarchy is important (Davis and Liu 1991). Weintraub and Cholaky (1991) and Martell *et al.* (1996) offer additional information and references concerning hierarchical planning.

The strength of regional planning is the maintenance of consistency inside the decision levels. In regional planning, the plans are prepared simultaneously for all forest holdings within the target area in a synchronized way to enhance acceptability at the forest-holding level. Ecologically important characteristics of the planning area and the interdependencies between forest holdings are considered and a good combination of plans over the whole planning area is created. By enlarging the planning area to cover several forest holdings, regional planning can result in a positive sum game at the landscape level, whereas both winners and losers can exist at the level of forest holdings (e.g. Davis and

Liu 1991). It might, however, be possible to eliminate the losers in some cases. Acceptance of the created plans is a precondition for this approach since the owners will not implement plans that they can not accept and which do not contribute to their welfare. If the plans are not accepted and followed, the potential benefits to be gained from regional planning will not be realized. Therefore, collaborative and interactive planning that involves all forest owners, and possibly other instruments are also needed in the planning process.

Suitable planning models for regional planning in the private forestry of Finland already exist. However, these planning models are not being used. Nor have alternative planning approaches and models been tested and compared. Davis and Liu (1991) presented and discussed a two-stage planning approach for integrated multiple-ownership planning where, in the first stage, feasible alternative plans for each planning unit are produced. An aggregation of these plans follows, e.g. via integer programming (IP), across all planning units. Different goal programming (GP) formulations, such as minimizing the relative weighted deviations from the desired levels of outputs or classical MAXMIN formulation concerning all desired goals can be used in the aggregation of the plans.

Navon and Weintraub (1986) presented an operational model to assist the strategic planning of large wildland enterprises. In the model, among other features, the alternative plans of the enterprise's sub-units are combined into one enterprise plan by means of IP. The model also includes the creation of alternative plans for sub-units and facilitates a broad investigation of the enterprise's production possibilities.

Fries *et al.* (1998) presented a landscape ecological planning approach and its practical application in a private forest area in Sweden. The approach was called "the Stream Model". A key component of the model is protected stream corridors, which affect a large proportion of forest estates and are used to connect other protected areas. The model includes an inventory of ecologically valuable areas, protection or specific management of stands containing conservation values or considered important for the biodiversity of the landscape, as well as discussions and interviews with forest owners. In the application presented, in 28 of the 41 forest estates some areas were set aside; the protected proportion was 3.4% of the 2440 ha forest area (Fries *et al.* 1998). While the practical viewpoint of the model was good, it was not directly connected to the creation of forest plans for individual forest owners.

The aim of the present study is to illustrate and compare alternative planning approaches and corresponding models in regional planning situations. The models maintain the consistency of decisions at different hierarchical levels. Acceptability of the plans at the holding level was a crucial criterion when comparing the models.

The following sections describe three basic approaches for composing landscape-level forest plans in a multiple-ownership planning situation. These approaches are then illustrated by a case study, in which 39 individually managed forest holdings form the landscape. Finally, we draw some conclusions on the applicability of the presented approaches and emphasize that more than just optimization is needed for successful regional planning.

Alternative planning approaches

Top-down approach

In the top-down approach, planning is carried out according to the objectives set at the landscape level. The achieved solution can be split into holding level plans. The plan represents the most efficient allocation of resources included in the model at the landscape level but it disregards holding-level preferences. Therefore, it can result in a very uneven attainment of holding-specific objectives. With respect to the objectives employed, the information gathered is valuable, for example, in identifying the promising allocations of resources. It also provides an important point of reference for negotiations with and between forest owners. Subsequent phases can include agreement concerning forest-holding-level objectives or possible constraints added to the model when seeking increased acceptability of the plans at the forest-holding-level.

Bottom-up approach

In the bottom-up approach, the landscape level plan is composed as an aggregate of forest-holding-level plans. A number of efficient and feasible forest plans are created for every forest holding by varying the objective variables, their weights or levels of constraints, depending on the optimization method used in the first phase. In the second phase, the optimal combination of these alternatives, with respect to landscape-level objectives, is selected by applying suitable optimization techniques. If the alternative plans are indivisible, i.e. the alternative space is discrete, IP techniques must be used. Since forest owners have already accepted the alternative plans, the selected combination of the plans that form the landscape-level plan is therefore also accepted.

Integrated approach

In the integrated approach, landscape and forest-holding-level objectives are considered simultaneously. In the optimization model, some objectives concern individual holdings while others concern the whole planning area. Depending on the optimization technique, the objectives can be strict (e.g. the constraints of LP) or flexible (e.g. the goal variables in GP). In addition, the relative importance or weights may be determined for objective variables. As a result, the objectives related to different forest holdings can have equal weights or they differ: they can be determined according to the surface area of the forest holdings, for instance. Depending on the problem formulation, weights set for different objectives, and the absoluteness of the constraints, the landscape level or forest-holding level can be emphasized.

Case study

Study area

The case study area is situated in North Karelia, Finland, and consists of 39 nonindustrial private forest holdings, ranging in size from 9.1 ha to 395.1 ha. The total forest area is 1884.4 ha. The area was divided into 1486 stands in a forest inventory carried out by the Forestry Center of North Karelia. At the outset of the planning period the mean growing stock volume averaged 153.2 m^3 ha^{-1} (from 65.9 to 250.8 m^3 ha^{-1} in individual holdings), of which the proportions of pine (*Pinus sylvestris*), spruce (*Picea abies*) and broadleaved trees were 64.2%, 23.4% and 12.4% respectively. The initial age class distribution was as follows: younger than 20 years 19.0%; 20–39 years 25.0%; 40–59 years 15.9%; 60–79 years 16.8% and more than 80 years 23.3%. The current annual increment was estimated at 5.9 m^3 ha^{-1}.

The landscape-level ecological objective used throughout the case study was to increase the area of old forests, determined according to the age criterion. The minimum age of an "old forest" was 120 years for pine, 100 years for spruce, and 80 years for deciduous trees. For mixed stands, the minimum age was computed as a weighted mean of the age limits for pine, spruce and deciduous trees. The initial old forest area was 242.2 ha. Old forest was selected as an objective because the loss of habitats with old-forest characteristics has deleterious effects on many forest-dwelling species in different taxa in Fennoscandia (Helle and Järvinen 1986, Virkkala 1987, 1991, Siitonen and Martikainen 1994, Edenius and Elmberg 1996). However, in addition to natural old forests, also managed old forests can provide some important resources, i.e. combinations of structural elements, microhabitats and community structures, for individuals and populations of many forest-dwelling species. The limiting ages of 80 to 120 years represent typical rotation lengths of different tree species. Therefore, the objective variable describes the area of forests left to continue growing after the economic maturity has been reached.

The length of the planning period was 30 years, divided into three 10-year sub-periods. One to twelve alternative treatment schedules, differing mainly with respect to timings and types of fellings, were simulated for each compartment by using the growth and stand management models included in the Monsu forest planning software (Pukkala 2000). The total number of treatment schedules was 5499. For most compartments, one of the simulated treatment schedules was the "No treatments" option. The other treatment schedules were simulated in compliance with the current Finnish forest treatment recommendations (Luonnonläheinen... 1994).

In order to improve the comparability of the presented approaches to the combination of independently prepared forest-holding-level plans, the old forest area goal is used also when the forest-holding-level plans are produced. Therefore, the achieved results better illustrate the effects caused by increased size of the planning area and the allowed flexibility in the forest-holding-level goals that is incorporated in the planning models through three different ways.

Producing alternative plans for forest holdings

Five alternative forest plans were composed for each forest holding on the basis of simulated schedules using Monsu forest planning software (Pukkala 2000), and LP and GP optimization techniques. First, an LP model for each holding was constructed in which net incomes during the whole planning period were maximized with the stipulation that the growing stock volume at the end of the planning period had to be at least equal to the initial volume. These volume constraints and the volume objectives used in the forthcoming models represent the continuity of several forest related utilities, not only the continuity of income. The net income level that was achieved by solving the LP model was used as a reference level (referred to as NI^{ref}) when alternative plans were produced.

After determining the NI^{ref}, alternative forest plans for each holding were produced by solving the following GP model:

$$\text{Min } z = w_V dV^- / V^{max} + w_{Old} d\text{Old}^- / \text{Old}^{max} \quad (1)$$

subject to

$$\sum_{j=1}^{n}\sum_{i=1}^{n_j} a_{ij}x_{ij} + dV^- \geq V^{max} \quad (2)$$

$$\sum_{j=1}^{n}\sum_{i=1}^{n_j} b_{ij}x_{ij} + d\text{Old}^- \geq \text{Old}^{max} \quad (3)$$

$$\sum_{j=1}^{n}\sum_{i=1}^{n_j} c_{ij}x_{ij} \geq \text{NI} \quad (4)$$

$$\sum_{i=1}^{n_j} x_{ij} = e_j,\ j = 1,\ldots,n \quad (5)$$

$$x_{ij} \geq 0,\ i = 1,\ldots,n_j,\ j = 1,\ldots,n \quad (6)$$

The applied model included (1) the objective function, where the weighted sum of the relative negative deviations from the greatest possible levels of growing stock volume and old forest area at the end of the planning period was minimized; (2) a goal constraint for growing stock volume at the end of the planning period; (3) a goal constraint for old forest area at the end of the planning period; (4) a constraint for net incomes during the whole planning period; (5) area constraints for each compartment; and (6) non-negativity constraints. dV^- is the shortfall in the growing stock volume goal at the end of the planning period, $d(\text{Old}^-)$is the shortfall in the old forest area goal at the end of the planning period, w_V and w_{Old} the weights given to each unit of negative deviation of goal variables, V^{max} and Old^{max} the maximum values of growing stock volume and old forest area that can be attained by the end of the planning period, NI the demanded net income level, n the number of stands, n_j the number of treatment alternatives for stand j, e_j the area of stand j, x_{ij} the area of stand j that is treated according to schedule i, a_{ij} the growing stock volume per hectare that treatment i of stand j yields at the end of the planning period, b_{ij} is one if stand j in schedule i is classified as old forest at the end of the planning period (otherwise b_{ij} is equal to zero), and c_{ij} is the net income per hectare that treatment i of stand j produces.

In order to produce alternative plans, a varying level of demanded net income (NI) was employed. First, the NI^{ref} level was used. Then, 10% and 20% changes upwards and downwards from NI^{ref} level were used as constraints. In some forest holdings, the 10% or 20% upward change in net incomes could not be attained, indicating that their forests were relatively young and a cutting level lower than volume growth was justifiable. In this case, an additional downward change was used (30% and 40% lower than NI^{ref}). In all cases, the weights (w_V and w_{Old}) given to each unit of underachievement deviation were equal.

Solving the formulated GP models resulted in five different plans for each forest holding. In the absence of true preference information from the owners, the middle plan (that containing the middle income level) was taken to represent the plan preferred by the forest owner (referred to as the optimal plan). It was assumed that forest owners would also accept the net income levels of the other plans and the consequent changes in other variables. These plans are located at the efficient production frontier between total net income, residual growing stock volume and area of old forest. Thus, they are not plans that include only the maximization of economic variables such as NPVs of cutting income and value of ending inventory. They represent plans that could be adopted by forest owners who value not only economic, but also ecological and other utilities from their forests, and who are participating in a regional planning project. The selected net income level in each plan is unconditional, but tradeoffs between old-forest-area objective and growing stock volume objective can be made.

The tested approaches (explained below) are compared to the combination of optimal forest-holding-level plans, which is assumed to represent the outcome of the current Finnish forest planning practices. The sums of the objective variables (net income, growing stock volume and old forest area) over all holdings were used when comparing the approaches. Standard deviation calculated from the proportional deviations of net incomes from the optimal holding level plans was used to describe how equally the different approaches treated forest owners.

Composing regional plans

Top-down approach

In the top-down approach, the holding-specific goals and constraints were ignored. In the GP model corresponding to the top-down approach, the sum of relative deviations from the maximum possible old forest area and growing stock volume of the planning area was minimized (Eq. 7). The net income constraint was obtained by summing the incomes of "optimal" forest-holding-level plans (Eq. 10). The model was as follows:

$$\text{Min} z = w_V dV^{-}/V^{max} + w_{Old} d(\text{Old}^{-})/(\text{Old}^{max}) \quad (7)$$

subject to

$$\sum_{k=1}^{l}\sum_{j=1}^{n_k}\sum_{i=1}^{n_{ijk}} a_{ijk}x_{ijk} + dV^{-} \geq V^{max} \quad (8)$$

$$\sum_{k=1}^{l}\sum_{j=1}^{n_k}\sum_{i=1}^{n_{ijk}} b_{ijk}x_{ijk} + d\text{Old}^{-} \geq \text{Old}^{max} \quad (9)$$

$$\sum_{k=1}^{l}\sum_{j=1}^{n_k}\sum_{i=1}^{n_{ijk}} c_{ijk}x_{ijk} \geq \sum_{k=1}^{l} \text{NI}_k^{opt} \quad (10)$$

$$\sum_{i=1}^{n_{ijk}} x_{ijk} = e_{jk},\ j = 1,\ldots,n_k,\ k = 1,\ldots,l \quad (11)$$

$$x_{ijk} \geq 0,\ i = 1,\ldots,n_{jk} j = 1,\ldots,n_k\ k = 1,\ldots,l \quad (12)$$

where l is the total number of forest holdings, n_k is the number of compartments in holding k, n_{jk} is the number of treatment alternatives in compartment j of holding k, V^{max} and Old^{max} represent the maximum values of growing stock volume and old forest area at the end of the planning period in the planning area, and $\sum_{k=1}^{l} \text{NI}_k^{opt}$ is the sum of net incomes of the optimal plans.

Bottom-up approach

The five alternative forest plans produced for each holding were activities in a mixed integer programming (MIP) model. This model was solved to find the optimal combination of forest-holding-level plans with respect to landscape-level objectives. The alternative plans were integer variables and it was assumed that forest owners were ready to accept any of the five plans, but combinations of two or more forest plans were not acceptable (such a plan would be difficult to implement). The MIP model was formulated as a GP model in such a way that the sum of relative deviations from the desired levels of old forest area and growing stock volume was minimized in the objective function (Eq. 13). The model was as follows:

$$\text{Min}\, z = w_V dV^- \Big/ \sum_{k=1}^{l} V_k^{\max} + w_{\text{Old}} d\text{Old}^- \Big/ \sum_{k=1}^{l} \text{Old}_k^{\max} \qquad (13)$$

subject to

$$\sum_{k=1}^{l}\sum_{m=1}^{5} a_{km} y_{km} + dV^- \geq \sum_{k=1}^{l} V_k^{\max} \qquad (14)$$

$$\sum_{k=1}^{l}\sum_{m=1}^{5} b_{km} y_{km} + d\text{Old}^- \geq \sum_{k=1}^{l} \text{Old}_k^{\max} \qquad (15)$$

$$\sum_{k=1}^{l}\sum_{m=1}^{5} c_{km} y_{km} \geq \sum_{k=1}^{l} \text{NI}_k^{\text{opt}} \qquad (16)$$

$$\sum_{m=1}^{5} y_{km} = 1,\ k = 1,\ldots,l \qquad (17)$$

$$y_{km} = 0, 1,\ k = 1,\ldots,l,\ m = 1,\ldots,5 \qquad (18)$$

where l is the number of holdings, $V_k^{\max}$ and $\text{Old}_k^{\max}$ are the largest value of growing stock volume and old forest, respectively, at the end of the planning period resulting from one of the plans produced earlier for holding k, y_{km} is equal to 1 if plan m for holding k is selected (otherwise y_{km} is equal to zero), a_{km} is the growing stock volume that plan m of holding k yields at the end of the planning period, b_{km} is the area of old forest that plan m of holding k yields at the end of the planning period, c_{km} is the total net income that plan m of holding k produces during the planning period, and NI_k^{opt} is the net income of the optimal plan in holding k. Equations 17 and 18 ensure that only one whole plan is selected for each holding.

Integrated approach

In the integrated approach, forest-holding and landscape-level objectives were included in the same model. The forest-holding-level objectives used were net income and growing stock volume. The landscape-level objective was the old forest area. Deviation from its maximum level was minimized in the GP model simultaneously with forest-holding-level objectives (Eq. 19). The model was as follows:

$$\text{Min}\, z = \sum_{k=1}^{l} w_{V_k} dV_k^- / V_k^{\max} + \sum_{k=1}^{l} w_{\text{NI}_k} d\text{NI}_k^- / \text{NI}_k^{\max} + w_{\text{Old}} d\text{Old}^- / \text{Old}^{\max} \qquad (19)$$

subject to

$$\sum_{j=1}^{n_k}\sum_{i=1}^{n_{jk}} a_{ijk} x_{ijk} + dV_k^- \geq V_k^{\max},\ k=1,\ldots,l \qquad (20)$$

$$\sum_{j=1}^{n_k}\sum_{i=1}^{n_{jk}} c_{ijk} x_{ijk} + d\text{NI}_k^- \geq \text{NI}_k^{\max},\ k=1,\ldots,l \qquad (21)$$

$$\sum_{k=1}^{l}\sum_{j=1}^{n_k}\sum_{i=1}^{n_{jk}} b_{ijk} x_{ijk} + d\text{Old}^- \geq \text{Old}^{\max} \qquad (22)$$

$$\sum_{i=1}^{n_{jk}} x_{ijk} = e_{jk},\ j = 1,\ldots,n_k,\ k = 1,\ldots,l \qquad (23)$$

$$x_{ijk} \geq 0,\ i = 1,\ldots,n_{jk},\ j = 1,\ldots,n_k\ \text{k} = 1,\ldots,l \qquad (24)$$

where $V_k^{\max}$ is the maximum value of growing stock volume of holding k at the end of the planning period, $\text{NI}_k^{\max}$ the highest value of net incomes of holding k resulting from one of the alternative plans produced earlier, and $\text{Old}^{\max}$ the maximum old forest area in the planning area at the end of the planning period. The weights (w_{V_k} and w_{NI_k}) given to objective variables related to individual forest holdings were equal (all one), meaning that the relative deviation in forest-holding-level objectives was considered to be equally important in small and large forest holdings. This formulation can be interpreted as “minimization of the social unfairness” of the combination of the forest-holding-level plans. The weight given to the landscape-level objective (w_{Old}) was equal to the number of forest holdings (39). This model was named Integrated 1. In the Integrated 2 model, a constraint specifying that the total net income level must be at least the same as the sum of net incomes achieved in optimal holding-level plans was added to the formulation:

$$\sum_{k=1}^{K}\sum_{j=1}^{n_k}\sum_{i=1}^{n_{jk}} c_{ijk}x_{ijk} \geq \sum_{k=1}^{K} \mathrm{NI}_k^{\mathrm{opt}} \qquad (25)$$

Results

The differences between the sum of optimal holding-level plans and the presented approaches were logical (Table 1). The reason that differences in old forest area were not large is that old forest area was also used as an objective variable when creating optimal holding-level plans. Common to all approaches was the fact that allowing some deviation at the forest-holding-level resulted in a positive net gain at the landscape level. This was indicated by greater values in the old forest area compared to the sum of optimal holding-level plans (Table 1). Growing stock volume decreased in all approaches except Integrated 1, the reason being the permitted substitutability of goal variables, and perhaps the decreased efficiency in wood production as well.

The net income deviations from the optimal holding-level income were largest in the top-down approach, where holding-specific goals and constraints were ignored. Deviations from the optimal net income level were strikingly large in small forest holdings (Fig 1). On the other hand, the “cost” of seeking equal treatment for forest owners with respect to growing stock volume and net incomes can be observed from the differences between the top-down model and the Integrated 2 model (Table 1). In these approaches, the problem formulation and the levels of constraints and goal variables were basically similar, except that in the latter approach the target levels were determined and minimized at the forest-holding level.

The differences between the bottom-up and the Integrated 2 models were mainly caused by the fact that in the latter model all forest holdings had the same weight in objective function. As a result, a decrease of one percentage point in a small forest holding reduced the objective function value as much as the corresponding reduction in a large forest holding. Therefore, achieving the desired levels of objective variables was in this case easier in small holdings than in large ones with respect to changes in

Table 1. Values of some landscape-level variables in alternative approaches and their relative differences (%, in parenthesis) compared to the sum of optimal forest-holding-level plans.

Planning model	Net income (mil. FIM)	Old forest area (ha)	Growing stock volume (m^3)	Net income deviation[1] (%)
Sum of optimal holding-level plans	47.32	400.7	331 040	0.0
Top-down	47.32 (0.0%)	432.8 (8.0%)	323 662 (–2.2)	27.2
Bottom-up	47.32 (0.0%)	426.5 (6.4%)	325 074 (–1.8%)	16.6
Integrated 1	43.65 (–7.8%)	468.8 (17.0%)	338 328 (2.2%)	21.8
Integrated 2	47.32 (0.0%)	418.9 (4.5%)	317 377 (–4.1%)	16.6

[1] Net income deviation (%) is the standard deviation calculated from the proportional deviations of the net incomes compared to the optimal holding-level plans.

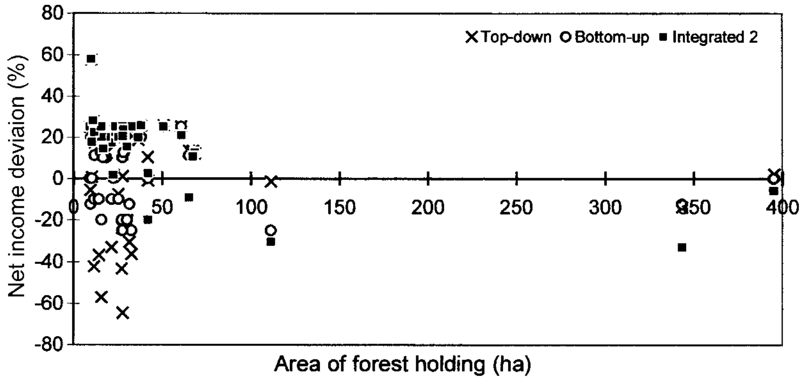

Fig. 1. Proportional deviation of net incomes from the income of the optimal holding-level plans in different planning approaches (Integrated 1 model is not included in the figure because it is not directly comparable to other models due to a different total net income level).

the landscape-level objective. In the bottom-up model, after determining those forest plans that were assumed to be acceptable, no further attention was given to the equal treatment of forest owners. In fact, the standard deviation of net incomes in the 20 smallest forest holdings was only 10% in the Integrated 2 model while in the bottom-up model it was 16%.

The greater deviation of net incomes in the Integrated 1 model as compared with Integrated 2 was partly caused by the lower level of total net incomes. The results of these models, however, illustrate the effect of using rigid constraints. This indicates that the constrained variables were considered to be the most important. If all objective variables are considered to be of equal importance, and the relative differences in the objective variable levels in Table 1 are summed, the total loss in the Integrated 2 model was 11 percentage points compared to the Integrated 1 model.

Discussion

From the perspective of ecological objectives, there is a distinct need for planning approaches that can simultaneously consider objectives targeted at different levels of areal aggregation. In a multiple private ownership planning situation, the acceptable allocation of the effects of different objectives must also be ensured by including this feature in the employed planning models. This study showed that several planning approaches can be successfully used for integrating landscape-level considerations into forest-holding-level planning. In fact, some of the approaches have been presented in earlier studies, and several optimization techniques and alternative planning models for each technique beyond the approaches illustrated in this study are available, (e.g. Navon and Weintraub 1986, Davis and Liu 1991, Pukkala and Kangas 1993, Pykäläinen *et al.* 2001).

Integrated regional planning approaches not only permit landscape ecological considerations in private forests, but they may be useful when the criteria for regional forest certification are evaluated. The positive net gains that can be achieved by simultaneously considering forest-holding and landscape-level objectives support their utilization. In addition to ecological benefits, timber production may also benefit from regional planning due to the possibilities of scheduling the cuttings of different holdings to correspond to their growing stock structures. This occurrence is called the “allowable-cut effect” (Davis and Johnson 1986).

The aim of this study was to illustrate alternative planning approaches for management planning of private forestry concerning multiple ownership, and to get an insight into their performance. Only one landscape was used in the case study. Although the achieved results are partly specific to the ownership pattern, age class distribution and initial pattern of forests in the planning area, the main features of the presented approaches remain the same. It is impossible to determine which of the presented approaches is the best since the ranking greatly depends on the comparison criteria used and the planning situation in general. No approach or method can be best in all planning situations.

In regard to the top-down approach, the case study results were achieved by assuming a single landscape-level decision-maker. Although this approach produces the most efficient allocation of resources, it also results in a very uneven distribution of economic and ecological responsibilities among forest owners. This is not in accordance with demands for social sustainability. Therefore, a compensation system for adjusting the uneven distribution between forest owners may be required with this approach. In practice, the information from the top-down approach can be used as advisory information when primarily applying other approaches. The model can be directed towards the integrated model by means of a stepwise procedure in which strict constraints are first determined for holdings where the owners are not willing to participate in regional planning. Secondly, those forest owners who allow some deviation in objective variables are identified, and more flexible goal constraints can be used to determine their objectives. What remains are the forest owners who are willing to put more value on ecological goals. The feasibility of the created plans can be improved through an iterative process. In addition, it is possible to prevent large shortfalls from holding-specific targets in any of the presented approaches by adding forest-holding-level constraints for the variables of interest.

Integer variables representing alternative plans were used in the bottom-up approach. This can cause some losses in objective variables since discrete plans do not fully cover the feasible solution space. However, the use of integer variables can be justified because forest owners may only deem feasible whole plans, not any combinations of them. In addition, non-linear relationships or indivisibilities can exist among some of the decision variables (Navon and Weintraub 1986). If other holding-level solutions are required, they should be agreed upon with the corresponding forest owners.

In the case study, the area of old forest was assumed to sufficiently express the ecological requirements set for the study area, which is a simplifying assumption. In a real planning situation, the ecological potential of the area may be assessed first, taking into account the neighboring areas as well. On the basis of this assessment, the species requiring special consideration and the corresponding ecological features are then chosen. The ESC-strategy presented by Mykrä and Kurki (1998), can be applied to develop a feasible case-wise operationalization of the biodiversity maintenance goals in managed forests. Indicators that reliably measure the ecological quality of the planning area and its temporal development should also be developed to assist practical planning.

The spatial layout or the size distribution of old forest patches was not considered in the case study. If spatially related objectives were used, the top-down and integrated approaches would be superior to the bottom-up approach. This is due to the fact that in the latter approach discrete plans would limit the solution space in respect to spatial variables more seriously than in the case of non-spatial variables. If spatial objectives were used in the integrated approach, the minimization of economic costs caused by ecological objectives would synchronize the occurrence of critical habitat types across forest-holding borders. As a result, for example, larger uniform old forest areas could be formed compared to the situation where the plans are produced at the level of individual forest holdings and ignoring spatial interdependencies between forest holdings. Forest owners with nature conservation goals represent a further opportunity in regional planning. By identifying such forest owners, it will be possible to better aggregate the critical resources in and around their forest holdings (Kurttila *et al.* 2001). Spatial objectives often require that the planning problems are solved by using heuristic optimization techniques. In each of the presented approaches it is, however, possible to divide the landscape into specified zones, each zone having individual objectives (e.g. Nalli *et al.* 1996). In the bottom-up approach the borders of these zones have to coincide with forest-holding borders.

Managing biodiversity on nonindustrial private forest lands is often a matter of intercession and compromise between ecological benefits, social fairness, and economic considerations. Forest plans have to be acceptable to all participants. The use of approaches presented in this article is only one step in the process aiming at improved ecological conditions and acceptable distribution of impacts among participants. Additional information concerning e.g. principal justifications of the used ecological objectives, use of economic incentives, and creation of overall positive attitudes among participants are also most likely needed in this process. However, guidance and negotiation, collaboration and co-ordination among adjacent landowners and flexibility retained by forest owners should be preferred over strict rules when multiple-ownership forest-planning approaches are implemented (e.g. Sample 1994, Brunson *et al.* 1996). As is always the case in forest planning, the decision context has to be clarified, for example, by providing forest owners with information concerning ecological objectives and benefits and quantitative information about the interdependencies between conflicting objectives in a planning situation.

The optimization methods were applied in this study primarily to illustrate the regional planning approaches. They do not, in themselves, serve as any framework for interaction and negotiation between forest landowners. Important subjects for future studies include how to utilize optimization methods efficiently in interactive and participatory planning processes, and how to elaborate the alternative solutions produced by optimization. The combined use of "hard" optimization and "softer" planning approaches is worth developing especially in landscape-level planning of private forestry, where human interaction between stakeholders is at least as important as numerical optimization calculations. Hybrid methods having the advantages of both optimization and "softer" approaches might support the collaboration, coordination and negotiation necessary for finding good compromise solutions in practical planning better than applying "hard" or "soft" approaches alone.

This study illustrated planning models available for regional forest planning. Organizations that carry out planning should be conscious of existing models and adopt their use. In the following phases of the research, the approaches should be tested in practical planning situations. The ability of planning organizations to support landscape-level planning should be clarified. When forest owners participate in a real planning process, their attitudes to regional planning and willingness to cooperate can be identified, and the need for the use of economic incentives can be found out. It is possible that economic incentives would greatly enhance participation in the planning process and implementation of the created plans.

References

Andrén H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* 71: 355–366.

Bettinger P., Boston K. & Sessions J. 1999. Combinatorial optimization of elk habitat effectiveness and timber harvest volume. *Environ. Model. Assess.* 4: 143–153.

Brunson M.W., Yarrow D.T., Roberts S.D., Guynn D.C. & Kuhns M.R. 1996. Nonindustrial private forest owners and ecosystem management. Can they work together? *J. For.* 94(6): 14–21.

Connelly B. 1996. A definition of hierarchical analysis in forest planning. In: Martell D.L., Davis L.S. & Weintraub A. (eds.), *Proceedings of a workshop on hierarchical approaches to forest management in public and private organizations*. Petawawa National Forestry Institute, Canadian Forest Service, Information Report PI-X-124. p. 1.

Davis L.S. & Johnson K.N. 1986. *Forest management*. Ed. 3. McGraw Hill, New York.

Davis L.S. & Liu G. 1991. Integrated forest planning across multiple ownerships and decision makers. *For. Sci.* 37(1): 200–226.

Edenius L. & Elmberg J. 1996. Landscape level effects of modern forestry on bird communities in North Swedish boreal forests. *Landsc. Ecol.* 11: 325–338.

Forest protection in southern Finland and Ostrobotnia. 2000. *The Finnish Environment* 437. 284 pp. [In Finnish with English summary.]

Fries C., Lindén G. & Nillius E. 1998. The stream model for ecological landscape planning in non-industrial private forestry. *Scand. J. For. Res.* 13: 370–378.

Helle P. & Järvinen O. 1986. Population trends of North Finnish land birds in relation to their habitat selection and changes in forest structure. *Oikos* 46: 107–115.

Kurki S. 1997. *Spatial variation in the breeding success of forest grouse: The role of predation in fragmented boreal forest landscapes.* Ph.D. thesis. University of Turku, Ser. AII, 102 pp.

Kurki S., Nikula A., Helle P. & Lindén H. 1999. The effects of landscape fragmentation and forest composition on breeding success of grouse. *Ecology* 81: 1985–1997.

Kurttila M., Uuttera J., Mykrä S., Kurki S. & Pukkala T. 2001. Decreasing the fragmentation of old forests in landscapes involving multiple ownership in Finland:

economic, social and ecological consequences. *For. Ecol. Manage.* [In press].

Luonnonläheinen metsänhoito. 1994. Metsänhoitosuositukset. Metsäkeskus Tapion julkaisuja 1994:6. 74 pp.

Martell D.L., Davis L.S. & Weintraub A. (eds.) 1996. *Proceedings of a workshop on Hierarchical approaches to forest management in public and private organizations*. Petawawa National Forestry Inst. Canadian Forest Service, Information Report PI-X-124. 165 pp.

Mönkkönen M., Reunanen P., Nikula A., Inkeriöinen J. & Forsman J. 1997. Landscape characteristics associated with the occurrence of the flying squirrel Pteromys volans in old-growth forests of northern Finland. *Ecography* 20: 634–642.

Mykrä S. & Kurki S. 1998. ESC — strategy for rational operationalization of forest biodiversity maintenance in Finland. *Silva Fenn.* 32(4): 389–399.

Nalli A., Nuutinen T. & Päivinen R. 1996. Site-specific constraints in integrated forest planning. *Scand. J. For. Res.* 11: 85–96.

Navon D. & Weintraub A. 1986. Operational model of supply for wildland enterprises. *TIMS Studies in the Management Sciences* 21: 353–370.

Oksanen-Peltola L. & Paananen R. 1995. Metsäsuunnittelu — yksityismetsätalouden toiminnan perusta. *Työtehoseuran metsätiedote* 546. 8 pp.

Pukkala T. 2000. *Monsu metsäsuunnitteluohjelma. Ohjelmiston toiminta ja käyttö*. 67 pp.

Pukkala T. & Kangas J. 1993. A heuristic optimization method for forest planning and decision-making. *Scand. J. For. Res.* 8: 560–570.

Pukkala T., Kangas J., Kniivilä M. & Tiainen A.-M. 1997. Integrating forest-level and compartment-level indices of species diversity with numerical forest planning. *Silva Fenn.* 31(4): 417–429.

Pykäläinen J., Pukkala T. & Kangas J. 2001. Alternative priority models for forest planning on the landscape level involving multiple ownership. *Forest Policy and Economics* 2: 293–306.

Sample V.A. 1994. Building partnership for ecosystem management on mixed ownership landscapes. *J. For.* 92(8): 41–44.

Siitonen J. & Martikainen P. 1994. Occurrence of rare and threatened insects living on decaying *Populus tremula*: a comparison between Finnish and Russian Karelia. *Scand. J. For. Res.* 9: 185–191.

Weintraub A. & Cholaky A. 1991. A hierarchical approach to forest planning. *For. Sci.* 37(2): 439–460.

Virkkala R. 1987. Effects of forest management on birds breeding in northern Finland. *Ann. Zool. Fenn.* 24: 281–294.

Virkkala, R. 1991. Population trends of forest birds in Finnish Lapland in a landscape of large habitat blocks: consequences of stochastic environmental variation or regional habitat alteration? *Biol. Conserv.* 56: 223–240.

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