

# Integrating Forest-level and Compartment-level Indices of Species Diversity with Numerical Forest Planning

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The study proposes a technique which enables the computation of user-defined indices for species diversity. These indices are derived from characteristics, called diversity indicators, of inventory plots, stand compartments, and the whole forest holding. The study discusses the modifications required to be made to typical forest planning systems due to this kind of biodiversity computation. A case study illustrating the use of the indices and a modified forest planning system is provided. In the case study, forest-level species diversity index was computed from the volume of dead wood, volume of broadleaved trees, area of old forest, and between-stand variety. At the stand level, the area of old forest was replaced by stand age, and variety was described by within-stand variety. All but one of the indicators were further partitioned into two to four sub-indicators. For example, the volume of broadleaved trees was divided into volumes of birch, aspen, willow, and other tree species. The partial contribution of an indicator to the diversity index was obtained from a sub-priority function, determined separately for each indicator. The diversity index was obtained when the partial contributions were multiplied by the weights of the corresponding indicators and then were summed. The production frontiers computed for the harvested volume and diversity indices were concave, especially for the forest-level diversity index, indicating that diversity can be maintained at satisfactory level with medium harvest levels.

**Keywords** forestry decision-making, biodiversity conservation, environmental planning, simulation, heuristics

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# 1 Introduction

## 1.1 Diversity Indicators

Forest management affects the forest ecosystem through stand treatment. When species biodiversity is among the management objectives, it is important to know how diversity is affected by stand treatment and natural stand development. In forest planning, diversity needs to be connected to those properties of individual stands, which are controllable by the forest manager; the diversity measure is useless in forest management planning unless the dependence of the measure on the characteristics of the stand compartments is known. Therefore, stand characteristics form the basis for biodiversity computations in forest management planning.

The simplest way to measure species diversity in forest planning is to relate it directly to stand characteristics. This is the most sensible way when the habitat requirements of different species and their contributions to overall species diversity are poorly known. The characteristics used for predicting diversity may be called *diversity indicators*.

In commercially managed forests, species diversity can be conserved in different ways. One way is to exclude small enclaves within production forest, so-called key biotopes and other habitat patches of rare species, from timber harvesting operations. Practices preserving or enhancing diversity may be used outside key biotopes, e.g. managing forests so that the volume of deadwood material accumulated increases. A network of ecological corridors and stepping stones with special management may be arranged to enable the movement of organisms between habitat patches.

The central task of forest planning is to compare the consequences of different management options for a given area, so that the option with the most favourable consequences may be selected. Assuming that the most important key biotopes and occurrences of rare species are always protected, as stipulated by the present forestry legislation of Finland, the decision alternatives do not differ from each other in this respect. Therefore, it is not necessary to include key biotopes or habitats of rare species in the diversity measure that is developed for the comparison of forest plans.

Based on this rationale, forest planning needs estimators that relate species diversity to characteristics which are controllable by the forest manager and relevant to species diversity. An additional requirement is that these characteristics must be easily measurable and their future development must be predictable.

The most commonly mentioned indicators of species diversity of managed forests in Finland are the quantity of deadwood, volume of certain broadleaved tree species, area or existence of old forests, and within-stand and between-stand variety in the ecosystem (e.g. Red Data Book of Finland 1992, Haila et al. 1994, Kouki 1994, Kuusipalo and Kangas 1994, Raivio 1995). Lack of charred wood has also been mentioned as a factor limiting biodiversity (Parviainen and Seppänen 1994). However, unless prescribed fire is used as a silvicultural treatment, the decision alternatives do not differ from each other in this respect.

There is usually plenty of dead and decaying wood in the forest in the forms of stumps, roots and small trees. The factor limiting species richness are usually the large stems of different tree species in different stages of decomposition. Standing deadwood and downwood are different habitats, and they may be used as separate diversity indicators.

Lack of broadleaved trees often decreases diversity in Finnish forest ecosystems. Some species, e.g. aspen (*Populus tremula*) and some willow species (e.g. *Salix caprea*), are often regarded to be more important than the others.

The area of old forest is another diversity indicator. However, old forest is a vague concept. In managed forests there are but few stands older than the normal rotation lengths, and the increase in the amount of such forests, therefore, improves the ecosystem's diversity. These 'commercially old' forests are not, however, 'biologically' old, the latter being better from the viewpoint of biodiversity. Because commercially and biologically old forests are different habitats, there is a need to divide old forests into at least two categories.

Increasing the amount of deadwood, the volume of broadleaved trees and the area of old forests usually enhances the diversity in a commercially exploited forest. Variety of the habitats may also be used as an indicator of species diversity. Forest-level variety may be described

for instance in terms of the length of the boundaries between different kinds of forest stands. This way of describing variety also measures the length of the edge zones between different habitats (Pukkala et al. 1995). At the stand level, variety may be measured via the within-stand variation of stand characteristics, such as tree size, species composition, and stand density.

## 1.2 Diversity Index

Determining the manners in which the indicators contribute to the diversity yields an exact diversity estimator, which may be called as *diversity index*. As long as species diversity cannot be unambiguously measured in the field, this definition is more a subjective agreement, or decision, than the result of statistical and objective computation. Important issues to be responded to are those of who is authorised to place weights to the indicators, and by which technique the estimator is developed.

As long as there are no officially stipulated diversity measures, the decision-maker himself has the right to determine the diversity indicators and their weights. The weights reflect his/her values and his/her conception of diversity. If the decision-maker feels unable to personally define the diversity measure, he/she may invite one or several specialists to make the evaluation. A forestry organisation may also agree about a common estimator based on the opinions or recommendations of one or several specialists.

If several decision-makers or specialists are involved, it is possible to use the averages of their evaluations as the definition, or to seek consensus (Kangas et al. 1993, Alho et al. 1996). A frequently used method with several decision-makers or experts is the Delphi technique; the opinions of persons are gradually converted into an agreement or common opinion (Dalkey and Helmer 1962).

## 1.3 Scales of Measurement

Diversity occurs on different scales, and the relevant scale is not constant. For some planning situations, and for some species, small-scale measurement is important, whereas in other cases

large-scale evaluation may be required. In routine planning of non-industrial private forests, the largest unit is usually the forest owned by one decision-maker, typically an individual forest holding. Usually there is not enough knowledge on the neighbouring forests and, more importantly, the neighbouring forest is not under the control of the said decision-maker. Therefore, the development of this forest is unknown, making it useless when comparing the decision alternatives. A completely new planning approach, including practices of information sharing and group decision making, is needed to facilitate landscape-level planning of private forestry in Finland.

The other scale, for which species diversity needs to be computed, is that of a stand compartment. This scale is needed when comparing management options for individual compartments, but it may also be an important characteristic in forest-level decision-making. At the forest level, good average stand diversity may be a management objective.

## 1.4 Purpose of This Study

Kangas and Pukkala (1995) proposed a method for comparing alternative plans with respect to forest-level diversity. Their method which is based on the rationale given above, is applicable in routine numerical forest planning. The method is suitable to the forest-level diversity assessment only, and the estimator is quite rough.

One consequence of practical biodiversity conservation is that of avoiding vast contiguous clear-fell operations. The practice of making several small openings in mature forest and leaving uncut areas in-between has become increasingly common in practical forestry. The same applies to the use of mixed strategies and combinations of methods in stand regeneration (henceforth referred to as *partial treatments*).

The present study's primary purpose was to improve the capability of a planning system to accommodate diversity indices from what was presented by Kangas and Pukkala (1995). First, the possibilities to measure forest-level diversity index were enhanced. Secondly, corresponding computation system for stand-level diversity was developed. In the resultant planning system, each

stand compartment was described by several records – e.g. plots – representing different places of the compartment. This facilitated the computation of within-compartment variety of any stand characteristic. Several records per compartment also made the planning calculations independent of compartment boundaries, which are subjective and often serve timber management only, and enabled partial treatments.

The subsequent sections proceed first to describe the changes necessitated by diversity computation in the forest planning system. A case study illustrating the use of the indices is provided. Finally, some practical and theoretical questions on the application of the proposed methods are discussed.

## 2 Planning System with Diversity Assessments

### 2.1 Present Planning

Typical forest planning systems in Finland necessitate the subdivision of the forest into compartments. Forest planning searches for such a combination of treatments for the compartments that the objectives of the decision-maker are fulfilled. This is accomplished through computer simulation and optimisation.

Several treatment schedules are produced for each compartment over the planning period, by means of computer simulation, to find out the effects of alternative management options on the characteristics relevant to the management objectives.

Based on the predictions produced by simulation, optimisation selects that combination of treatment schedules of compartments which is optimal at the forest level when viewing the forest as one unit.

### 2.2 Inventory

Computation of diversity indices entails a few changes in the typical Finnish compartment-inventory method. Firstly, all or more tree species need to be recorded separately. Secondly, the

quantity of deadwood must also be measured or estimated. Deadwood can be measured in terms of basal area or number of stems per hectare, together with the mean diameter or height of each type of deadwood. The species and the number of years since death, or the stage of decomposition, need to be recorded, as well as whether the deadwood cohort is standing deadwood or downwood.

Thirdly, stand characteristics must be measured in several places, and these measurements must be recorded separately. This enables the computation of within-stand variety and the simulation of partial treatments. The places in which stand characteristics are recorded must be objectively selected, a systematic grid of relascope or circular plots being the most obvious sampling design.

### 2.3 Computations

The stand simulator, which produces information on the management options, should be able to simulate

- the development of economically unimportant species,
- the accumulation of deadwood, and
- the partial treatments.

The simulator must be able to compute the present and future values of the stand characteristics which are indicators of stand-level diversity or are used to compute forest-level indicators.

The computation of within-stand variation and the simulation of partial treatments are possible when the stand records of a compartment (e.g. sample plot records) are treated separately by the simulation system; this was done in our case study. This facilitates the simulation of such treatments as 70 % clear felling, leaving 30 % of the plots untouched, etc.

### 2.4 Planning

Planning searches for the best combination of treatment schedules of the compartments on the basis of, on one hand, the management objectives of the decision-maker and, on the other hand, the information produced by the simula-

tions. In essence, planning is always a matter of optimisation, regardless of whether or not numerical optimisation algorithms are used.

Indicators of forest-level diversity can be regarded as ordinary objective variables in optimisation. Stand-level diversity index may be selected as another objective in the form of the area-weighted mean diversity index of stands.

Were the diversity index directly proportional to the indicator variables, and were there no spatial indicators, any method of multi-objective linear programming (e.g. goal programming) could be used in optimisation. If these prerequisites are not true, heuristic optimisation algorithm such as HERO (Pukkala and Kangas 1993) may be used.

### 3 Case Study

#### 3.1 Case Study Area

The case study area was a forest holding of 41.8 hectares consisting of thirty-two compartments. The sites were rather fertile, and broadleaves of

various species were common (42 % of the standing volume). Many stands were quite young, and the quantities of old forest and deadwood were small. The between-stand and within-stand variety corresponded to normal cases among managed forests. Therefore, from the viewpoint of diversity, the case study area was reasonably good with respect to content of broadleaves, average with respect to variety, and rather poor with respect to deadwood and old forests.

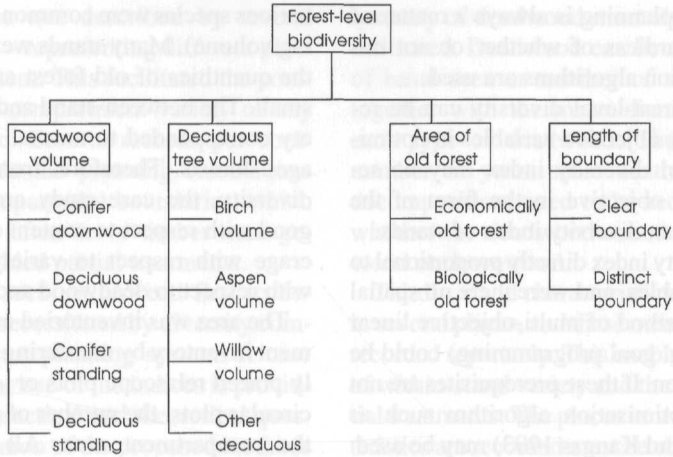
The area was inventoried employing compartment inventory by measuring 3–25 systematically placed relascope plots or – in young stands – circular plots, the number of plots depending on the compartment area. All broadleaves were measured separately, as were the different deadwood cohorts.

#### 3.2 Estimators for Species Diversity Indices

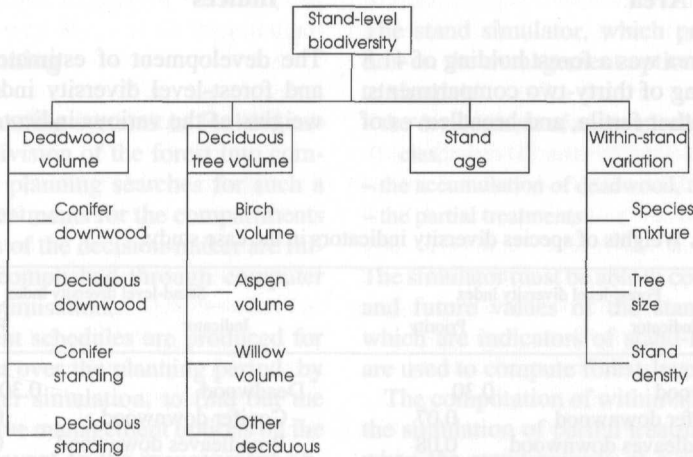
The development of estimators for the stand- and forest-level diversity indices involved the weights of the various indicators (Table 1), and

**Table 1.** Weights of species diversity indicators in the case study.

Forest-level diversity index		Stand-level diversity index	
Indicator	Priority	Indicator	Priority
Deadwood	0.30	Deadwood	0.30
– Conifer downwood	0.07	– Conifer downwood	0.07
– Broadleaves downwood	0.08	– Broadleaves downwood	0.08
– Conifer standing	0.07	– Conifer standing	0.07
– Broadleaves standing	0.08	– Broadleaves standing	0.08
Broadleaves	0.25	Broadleaves	0.25
– Birch	0.04	– Birch	0.04
– Aspen	0.09	– Aspen	0.09
– Willows	0.08	– Willows	0.08
– Other broadleaves	0.04	– Other broadleaves	0.04
Old forest	0.25	Stand age	0.25
– Commercially old	0.10	Variety	0.20
– Biologically old	0.15	– Species mixture	0.08
Variety	0.20	– Tree size	0.06
– Clear boundary	0.08	– Stand density	0.06
– Distinct boundary	0.12		



**Fig. 1.** The way of estimating forest-level species diversity index from characteristics that can be computed by a forest planning system.



**Fig. 2.** The way of estimating stand-level species diversity index from characteristics that can be computed by a forest planning system.

the sub-priority functions of each indicator. Pair-wise comparisons and the eigenvalue technique as applied in the Analytic Hierarchy Process (AHP; Saaty 1977) were used to develop the estimator.

This study used stand characteristics in a hierarchical way in developing the estimator. Hierarchical description greatly decreased the number of comparisons needed for deriving the weights

of indicators. First, four main indicators were named; namely, (1) *deadwood*, (2) *broadleaved trees*, (3) *old forest*, and (4) *variety*, both at stand level and at forest level (Figs. 1 and 2). At forest level, *old forest* was described by the area of old forest, and at the stand level by stand age (basal-area-weighted mean age of trees).

Secondly, the main indicators were divided into sub-indicators. The four sub-indicators of

**Table 2.** Decay classes used in the case study, their relative importance (number of deadwood equivalents), and the probabilities for standing deadwood of falling down within a five-year period.

Years since death	Decay class	Number of deadwood equivalents	Probability of falling down		
			Pine	Spruce	Deciduous
0–1.99	1	0.3	0.1	0.2	0.4
2–9.99	2	0.8	0.2	0.35	0.6
10–29.99	3	1.0	0.3	0.5	0.8
30–59.99	4	0.8	0.7	0.9	1
60–100	5	0.6	0.9	1.0	1

deadwood were the volumes ( $\text{m}^3/\text{ha}$ ) of standing conifers, standing broadleaved trees, conifer downwood, and hardwood downwood (Figs. 1 and 2). Deadwood consists of wood in different stages of decomposition, and these stages are not equally important. Because of this, the deadwood volumes were converted into deadwood equivalents by multiplying their volumes with factors expressing the relative importance of the stages (Table 2). The volume-equivalents obtained in this way were then scaled in such a way that their total volume was equal to the unconverted deadwood volume.

The second main indicator, broadleaved trees, was partitioned into the volumes ( $\text{m}^3/\text{ha}$ ) of birch, aspen, willow, and other broadleaved trees. The sub-indicators of deadwood and broadleaved trees were the same at both the forest level and stand level.

*Old forest* was described at the forest level by the proportions (%) of commercially and biologically old forests in the total surface area. *Mean tree age* measured this component at the stand level. The minimum ages of commercially and biologically old forest were taken to be the following:

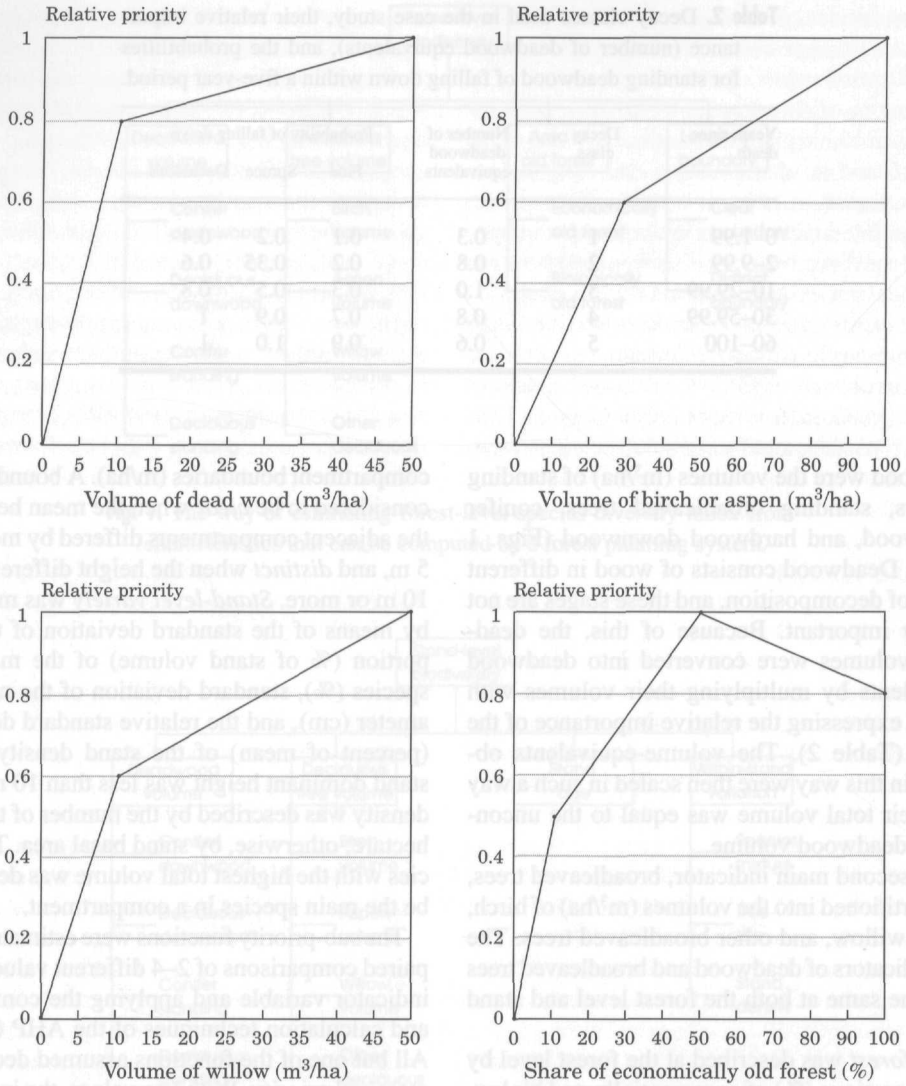
Tree species	Commercially old forest (years)	Biologically old forest (years)
Pine	120	160
Spruce	100	140
Broadleaves	80	120

Forest variety was measured at the forest level by the lengths of clear and very clear (distinct)

compartment boundaries ( $\text{m}/\text{ha}$ ). A boundary was considered to be *clear* when the mean heights of the adjacent compartments differed by more than 5 m, and *distinct* when the height difference was 10 m or more. *Stand-level variety* was measured by means of the standard deviation of the proportion (% of stand volume) of the main tree species (%), standard deviation of the mean diameter (cm), and the relative standard deviation (percent of mean) of the stand density. If the stand dominant height was less than 10 m, stand density was described by the number of trees per hectare; otherwise, by stand basal area. The species with the highest total volume was defined to be the main species in a compartment.

The sub-priority functions were estimated using paired comparisons of 2–4 different values of the indicator variable and applying the comparison and calculation techniques of the AHP (Fig. 3). All but one of the functions assumed decreasing marginal priority. With low values, the indicators rapidly improved the diversity index, but once the level of the indicator reached a sufficient quantity, additional increments improved the index more slowly. For example, the deadwood indicators and the less common broadleaves increased the diversity index rapidly with values ranging from zero to  $10 \text{ m}^3/\text{ha}$ , but only slowly thereafter.

When computing the diversity index, the contributions of the lowest-level indicators to the index were computed by their respective sub-priority functions (Fig. 3). These values were multiplied by the weights of the sub-indicators. These products were then summed, the result being the diversity index.



**Fig. 3.** Sub-priority functions for some diversity indicators. The sub-priority functions were similar for all four sub-factors of deadwood, and similar for commercially and biologically old forests.

**3.3 Simulation**

Altogether 189 treatment schedules were simulated for the thirty-two compartments using the program developed by Pukkala (1993). This program was modified due to the need to simulate the development of deadwood and commercially less important broadleaves. The plots placed within a single compartment were kept separate. The

stand characteristics for a compartment were obtained as means of plotwise characteristics. The planning period was 10 years (simulations covered 10 years), and treatments were simulated midway through the 10-year period.

Partial treatments were simulated by treating different plots within a compartment in different ways. Examples of partial treatments were 50 % clear felling and planting, and thinning 50 % of



the plots. In another case, the regeneration area was planted partly to pine, partly to spruce, and partly to birch. In some thinnings, part of the compartment was left unthinned to promote self-thinning and the accumulation of deadwood. A pine stand growing on a rather poor site could be regenerated partly naturally, through seed-tree felling, and partly by clear-felling and planting, with a third of the plots perhaps thinned or left untouched.

The development of aspen, willows, and other commercially less important broadleaves is most easily simulated by growth, birth and mortality models prepared for these species. In the absence of these models, we multiplied growth estimates of silver birch by species-specific correction factors ranging from zero to one. The multiplier was equal to one until the tree had reached a height at which the growth of the species began to slow down below the growth rate of silver birch. It approached zero value when the tree had reached the maximum size for the particular species. The mortality rate of commercially less important species was increased by multiplying the mortality prediction obtained from a self-thinning model for birch (Hynynen 1993) by an age-dependent factor; this caused the surviving probability to approach the value of zero when the tree reached its maximum age.

The accumulation of deadwood was simulated as follows. The mortality rate was predicted using the self-thinning models of Hynynen (1993) and the age-dependent factors mentioned above. The dead trees of a given species and diameter class formed a new deadwood cohort. The probability that a new deadwood cohort remains standing was taken as being 0.75 for pine, 0.5 for spruce, and 0.75 for broadleaves. In the simulation, standing trees fell down in accordance with the probabilities given in Table 2. The decay class of the tree changed when the number of years since death exceeded the lower limit of the decay class, thus affecting the quantity of deadwood equivalents (Table 2) that one cubic metre of deadwood corresponded to.

### 3.4 Production Frontiers

The HERO algorithm for heuristic optimisation

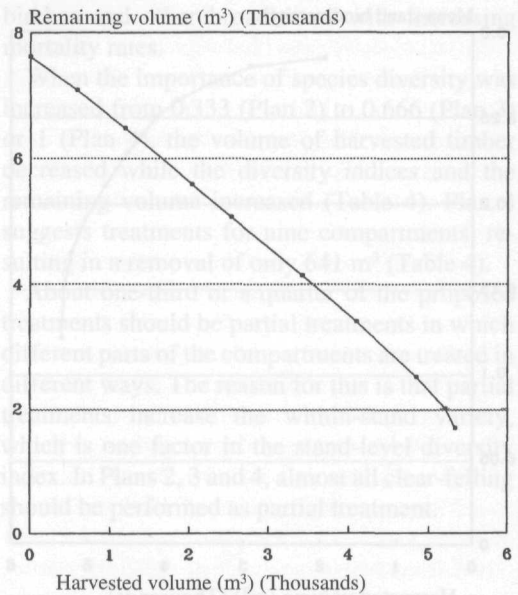
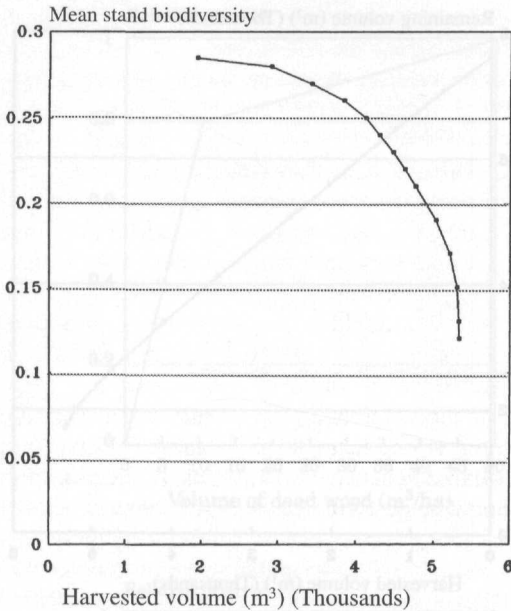


Fig. 4. Production frontier between remaining standing volume (in 2005) and harvested volume (in 1995–2004).

(Pukkala and Kangas 1993) was used to compute the production frontiers for some relevant variables and for producing alternative plans. When producing a production frontier for two variables, these variables were selected as the objectives in the optimization. Their relative importance was changed gradually, and after every change a new optimum was solved, producing one more point on the production frontier.

The production frontiers show that the remaining standing volume (in 2005) decreases almost linearly as a function of the harvested volume (Fig. 4). The mean diversity index of the compartments at the end of the 10-year planning period also decreases with increasing harvest, but the relationship was concave, thus showing an increasing rate of transformation (Fig. 5). The mean stand diversity index was maximised by employing a cutting level of 2000 m<sup>3</sup>/10 a.

The production frontier between the forest-level species diversity index and the harvested volume is strikingly concave, indicating that forest-level biodiversity is only slightly, or not at all, affected by low- or medium-level felling



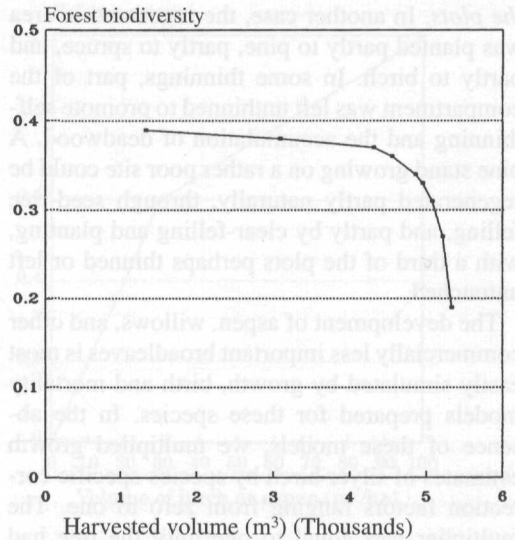
**Fig. 5.** Production frontier between mean stand diversity index (in 2005) and harvested volume (in 1995–2004).

(Fig. 6). This assumes that fellings are not located in ecologically sensitive areas. The forest-level diversity index is maximised if the ten-year harvests amount to 1300 m<sup>3</sup>. The results suggest that harvests do not necessarily impair species diversity unless the harvested volume is high. Kangas and Pukkala (1995) obtained a similar relationship between forest-level diversity index and harvested volume in another forest with a simpler diversity index (see also Holland et al. 1994). Were species diversity at later points in time (e.g. after 20 or 50 years) another objective (or constraint), besides biodiversity in 2005, the 10-year timber harvests would most probably be less than what the production frontier in Fig. 6 suggests.

### 3.5 Alternative Plans

Four alternative plans were produced by giving varying levels of importance to the following management objectives (Table 3):

- Harvested volume during 1995–2004



**Fig. 6.** Production frontier between forest-level diversity index (in 2005) and harvested volume (in 1995–2004).

- Remaining standing volume in 2005
- Mean diversity index of stands in 2005
- Forest-level diversity index in 2005

In Plan 1, the importance of the diversity indices was zero, with the other two objectives being equally important. In Plans 2, 3, and 4, diversity gradually became more important, until (in Plan 4) the stand- and forest-level diversity indices were the only objectives (Table 3). In Plans 2, 3 and 4, stand- and forest-level diversity indices were equally important.

The utility of the forest owner was assumed to depend linearly on the harvested volume and diversity indices. The utility through the remaining volume increased to a relative value of 0.8 when a target volume of 4000 m<sup>3</sup> was reached. After this, the utility increased slower, until it reached a value equal to one with the highest possible remaining volume (7625 m<sup>3</sup> by 2005).

The remaining and harvested volumes are about the same in Plans 1 and 2. This means that taking species diversity as a third management objective, equally important with the harvested vol-

**Table 3.** Importance of decision criteria in alternative forest plans.

Criterion	Plan 1	Plan 2	Plan 3	Plan 4
Remaining volume	0.5	0.333	0.166	0
Harvested volume	0.5	0.333	0.166	0
Diversity index	0	0.333	0.666	1
– stand level	0	0.166	0.333	0.5
– forest level	0	0.166	0.333	0.5

ume and the volume of remaining growing stock, does not markedly affect the values of these objectives (Table 4). However, it does improve forest-level diversity index by 12 % (from 0.33 to 0.37) and mean stand diversity index by 9.5 % (from 0.21 to 0.23). These increases are possible practically without any deterioration in the other management objectives, indicating that Plan 1 is clearly inefficient if diversity is of any importance to the decision maker.

Both stand- and the forest-level diversity indices improve from or equal to their initial (present) values in all the plans, including Plan 1. This is mainly because of the increased volume of deadwood in all plans; several compartments were quite dense or contained dense sub-areas, in which significant self-thinning was about to start. Some stands were also dominated by quite old

birches and other broadleaves with increasing mortality rates.

When the importance of species diversity was increased from 0.333 (Plan 2) to 0.666 (Plan 3) or 1 (Plan 4), the volume of harvested timber decreased while the diversity indices and the remaining volume increased (Table 4). Plan 4 suggests treatments for nine compartments, resulting in a removal of only 641 m<sup>3</sup> (Table 4).

About one-third or a quarter of the proposed treatments should be partial treatments in which different parts of the compartments are treated in different ways. The reason for this is that partial treatments increase the within-stand variety, which is one factor in the stand-level diversity index. In Plans 2, 3 and 4, almost all clear-felling should be performed as partial treatment.

## 4 Discussion

The proposed method to deal with species diversity provides an approach to the matter, rather than being a fixed method. The diversity indicators as well as their weights and sub-priority functions can be changed. However, changing the set of indicator variables usually necessitates modifications in the whole planning system, which means that the indicators cannot be

**Table 4.** Values of some forest-level variables in alternative plans.

Variable	Initial value	Plan				Unit
		1	2	3	4	
Remaining volume (2005)	5310	4000	4005	5127	6910	m <sup>3</sup>
Broadleaves volume (2005)	2212	1710	1616	2215	2703	m <sup>3</sup>
Forest diversity index	0.24	0.26	0.37	0.39	0.39	-
Mean stand diversity index	0.12	0.14	0.14	0.16	0.17	-
Harvested volume		3463	3439	2300	641	m <sup>3</sup>
Clear-felling area		9.4	8.6	2.8	1.5	ha
Thinning area		15.6	17.4	14.4	2.4	ha
Other felling area		5.7	9.2	7.6	3.9	ha
No. of treated compartments		27	30	23	9	-
No. of partial treatments		11	9	8	2	-

changed for every planning situation.

The case study provided a practical example of the required parametrisation of the species diversity indices and of the reshaping of forest planning tools. The parameters presented are only educated guesses, as there are not enough research results to enable statistical computation of reliable parameters.

The diversity estimators used in the case study are not proposed to be correct or represent the best possible knowledge. Especially the variables through which variety was measured may not be the most relevant. Forest-level variation was described by the length of the boundaries between habitats, which describes the amount of transitional zones and variation in stand properties. Alternative and additional indicators are for instance various habitat diversity indices computed from the proportions of different stands. The within-stand variety indicators described the place-to-place between-plot variation. Other variables such as tree species composition and diversity indices computed from the frequencies of tree species could also be used to describe habitat variation within distances shorter than the distance between plots.

It was assumed that the partial contributions of the indicators to the diversity index are additive. The relationships were not linear nor the rates of transformation constant because of the non-linearity of the sub-priority functions. An additive function was used in the absence of exact knowledge about the correct form and due to the fact that there is a widely tested technique for converting experts' or decision maker's opinions to additive function (Saaty 1980). If additivity assumption does not hold, it is possible to transform and combine indicators. Another alternative is to estimate directly the interactions of indicators and add the interaction terms to the additive function (Keeney and Raiffa 1976). If this is not possible, another function must be selected; the calculation system and the heuristic optimization do not prevent the use of non-additive diversity measures.

In the case study, the approach was applied to planning of a forest holding of non-industrial forest landowner. The same calculation principles are, however, applicable to planning of larger forest areas such as publicly owned forests

and landscape-level planning of forest areas consisting of several private forest holdings.

The changes in planning entailed by the diversity computation include the measurement and simulation of deadwood components and additional tree species, and the measurement and separate treatment of several stand records per compartment. Especially when simulating the accumulation of deadwood, new models and research are required concerning the death and decomposition of trees.

Several stand records per compartment make it possible to compute variables that describe within-stand variety. They also ease the job of simulating partial treatments. Several records per compartment improve growth and removal estimates and estimates of the species composition and size distribution in the stock removed (Pukkala 1990).

The main drawback of the inclusion of diversity indices is increased field work in forest inventory. More plots should be measured and more measurements taken on each plot. Simulation and optimisation also become more complicated, but the computational burden can be given to the computer and the additional complexity can be almost completely hidden from the planner and the decision-maker.

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The results of the study show that forest compartment division does not correlate very strongly with the larger habitat pattern. On average, the mean patch size of the forest habitat components is greater and the number of these patches lower compared to forest compartment division. However, if the forest habitat component distribution had been considered, the number of the forest compartments would have at least doubled after infestation.

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**Keywords** forest management planning, forest habitat distribution, Geographic Information Systems, kriging-interpolation

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