Relationship between Forest Management Planning Units and Spatial Distribution of Forest Habitat Components in Koli National Park

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This study examined the relationships between forest management planning units and patches formed by forest habitat components. The test area used was a part of Koli National Park in North Karelia, eastern Finland. Forest management planning units (i.e. forest compartments) were defined by using a traditional method of Finnish forestry which applies aerial photographs and compartmentwise field inventory. Patches of forest habitat components were divided according to subjective rules by using a chosen set of variables depicting the edaphic features and vegetation of a forest habitat. The spatial distribution of the habitat components was estimated with the kriging-interpolation based on systematically located sample plots. The comparisons of the two patch mosaics were made by using the standard tools of GIS.

The results of the study show that forest compartment division does not correlate very strongly with the forest 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 intersection.

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

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1 Introduction

It is evident that forestry and forest management planning needs today a more ecologically oriented approach (Uuttera and Kangas 1995). In Finland, a great amount of effort has recently been put into development of new instructions for forestry practices, which would take the preservation of forest biodiversity into account (e.g. Luonnonläheinen metsänhoito 1994). In addition to practical forestry operations, biodiversity preservation should also be taken into account as an objective in forest management planning calculations. To accomplish this task the division of forest management planning calculation units should be tailored to meet the needs of the management objective (Store 1996).

In the present situation the basic unit for forest management planning calculations is a forest compartment (Kangas and Pukkala 1996). The forest compartment division aims to divide forests into homogenous units in regard to wood production. The criteria for the division are forest site productivity, tree species composition, and the density and stage of the development of the stand. To achieve the objective of biodiversity preservation in forest management planning the forest compartments should be divided, not only in regard to wood production, but also in regard to processes and structures maintaining forest biodiversity at landscape level (e.g. Angelstam 1992, Franklin 1993). When considering maintenance of biodiversity in any given boreal landscape, disturbance becomes a central mechanism. This is because many forest organisms are connected to mosaic of habitats determined by disturbances and the following vegetation succession (e.g. Attiwill 1994, Huston 1994).

The natural disturbance regime of boreal forests is determined to a large extend by macroclimate and edaphic factors, i.e. the geocomponent of a forest habitat (e.g. Zackrisson 1977). Within the timescale of operative forest management planning, a geocomponent of a forest habitat can be considered permanent. The variation of a geocomponent within a forest area is the basis for habitat diversity (Fig. 1). However, the frequency and intensity of disturbances is also affected by the age of the stand due to, for example, the accumulation of unburned biomass (Romme and Despair 1989).

Every stage of forest succession following the disturbance is floristically and faunistically distinctive, and the landscape pattern of different succession stages enhance the distribution and abundance of forest species (Forman and Gor-

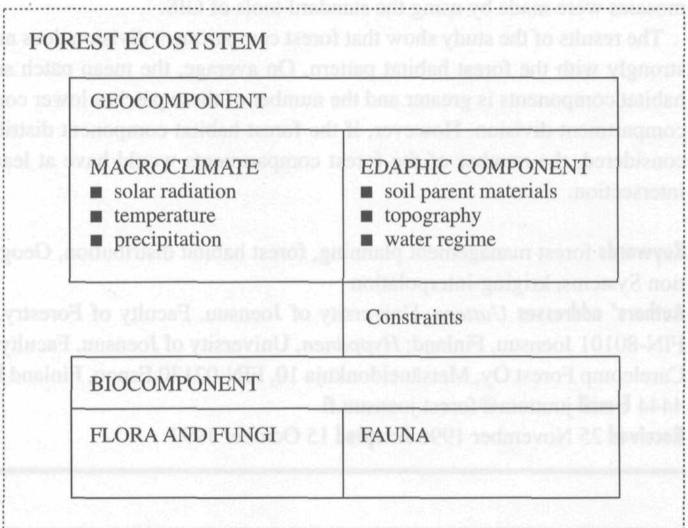

Fig. 1. The concept of forest ecosystem.

don 1986, Haila et al. 1987, Angelstam 1992). Within a shifting mosaic of a forest landscape, the biocomponent of a forest ecosystem (Fig. 1), i.e. the structural and associate flora and fauna (Huston 1994), change constantly. Ecosystem processes like regeneration, growth, and mortality, caused by disturbances of abiotic or biotic nature in different spatial scales, change the composition of a biocomponent (Kuusela 1990, Kuuluvainen 1994). The variation of the biocomponent of a forest ecosystem, particularly the diversity of structural species (Huston 1994), should specify the forest habitat division, determined by the properties of the geocomponent (Fig. 1). In boreal conditions the habitat structure forming structural species are tree species (Sukatsev 1960, Huston 1994).

A set of variables depicting the variation in the properties of the geo- and biocomponent of a forest habitat can be defined to a certain extent (Uuttera and Kangas 1995). A geocomponent can be described by variables depicting the productivity of the site. In the traditional 'wood production oriented' forest management in Finland, the Cajanderian site classification (Cajander 1926), based on plants and plant communities, is used as operational indicator of site fertility. The Cajanderian system has, however, been recently criticised (Kuusipalo 1985, Tonteri et al. 1990, Nieppola 1993). The system does not take enough into account for example topography of the site, the tree stock composition and coverage, and interactions between tree layer and properties of the soil. Therefore, the Cajanderian classification should be specified with variables such as topography, soil texture and acidity of the raw humus of the site, which all affect the productivity, and therefore also biodiversity of the site.

In addition to factors like tree species composition and density of the forest stock, which are important for the 'wood production oriented' management, the vertical structure of forest (e.g. MacArthur and MacArthur 1961) and the amount of decayed wood (Kouki 1993) are seen important for 'biodiversity preservation oriented' management. Therefore the habitat patch mosaic determined based on features of geocomponent should be specified by the existence, composition and structural diversity of the vegetation layers including dead wood.

In many respect, the two approaches to divide forest patches, i.e. 'wood production oriented' and 'biodiversity preservation oriented' approaches, are overlapping. However, regardless of the basis of defining patches, a landscape does not include only a single patch mosaic, but contains a hierarchy of patch mosaic across the range of scales (Wiens 1989, Wiens and Milne 1989). Therefore, it is presumable that coarse 'wood production oriented' patch division includes great variation of 'biodiversity preservation oriented' patches. This study investigates the relationships between the spatial variation of the chosen variables depicting the forest habitat components and forest compartment division conducted by the traditional methods of Finnish forestry.

2 Material and Methods

2.1 Study Area

The 98 ha area of the northernmost part of Koli National Park, Finland, was chosen as the test area (Fig. 2). By the features of vegetation, Koli National Park belongs into the mid-boreal Pohjanmaa-Kainuu district, which is a unit in the Finnish vegetation geographical division (Hakalisto 1989). The sites of Koli National Park are characterized by hills with a relatively good level of fertility and consequently an interesting set of vegetation. In these kinds of areas, the vegetation is exceptionally rich, including many species, which require a specified environment for their existence. The great variation in topography and vegetation offers a good basis for comparisons between the forest patches defined by 'wood production oriented' and 'biodiversity preservation oriented' approaches.

2.2 Method for Determination of the 'Wood Production Oriented' Forest Patch Mosaic

In 'wood production oriented' approach, forests in Finland are preliminarily divided into compartments by using visual interpretation of false colour aerial photographs. This division is ad-

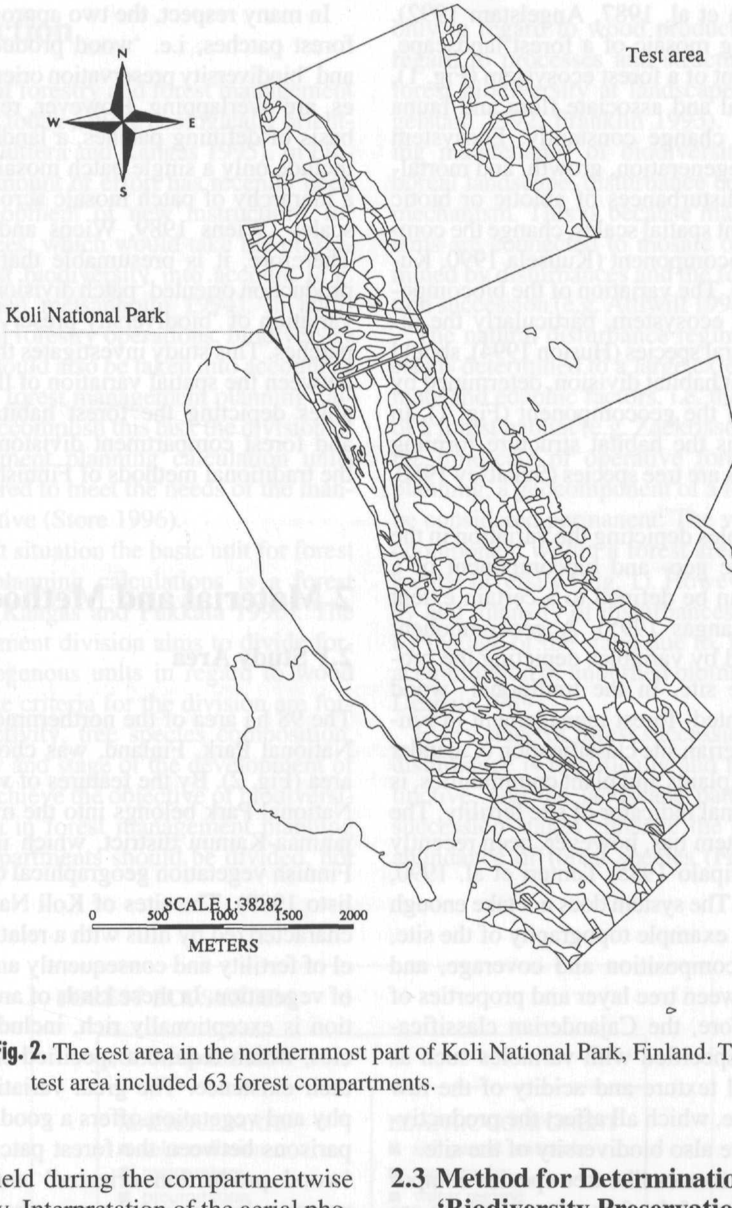

Fig. 2. The test area in the northernmost part of Koli National Park, Finland. The test area included 63 forest compartments.

justed in the field during the compartmentwise forest inventory. Interpretation of the aerial photographs gives information of the dominating vegetation cover and conifer-broadleaved relationship in tree species composition. During the field work the forest compartment division is elaborated by variables such as forest type (Cajander 1926), mean basal area and diameter of the relascope sample median tree.

The test area included 63 forest compartments determined by the traditional methods of Finnish forestry (Fig. 2).

2.3 Method for Determination of the 'Biodiversity Preservation Oriented' Forest Patch Mosaic

In 'biodiversity preservation oriented' approach of this study the spatial distribution of the habitat components, i.e. a chosen set of variables depicting the edaphic features and vegetation (Table 1), was estimated with the spatial interpolation based on systematically located sample plots. After interpolation patches of forest habitat components were divided according to highest pro-

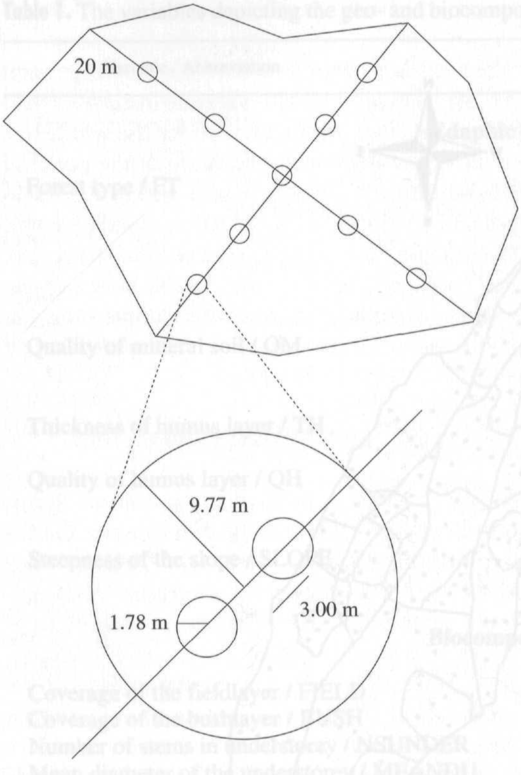

Fig. 3. The locations of the systematic sample plot network within one forest compartment.

portion of existence, measurement units or subjective rules (Table 2).

2.3.1 Habitat Component Inventory Frame

To capture the small scale spatial variation of the chosen variables the assessment has to be made from systematically located sample plots. Because this study examined particularly the small scale variation of the forest habitat components within 'wood production oriented' forest compartments, the systematic sample was taken within each forest compartment determined by 'wood production oriented' approach. Nine sample plots were located along the longest diameter of the compartment and along the perpendicular diameter towards the longest diameter. The first and last sample plot on both diameters were located 20 m from the compartment boundary and the additional plots were located half way between the center plot and plots closest to boundaries (Fig. 3). The shape of the compartment also determines the number of sample plots assessed because no intersections of the sample plots were allowed. Therefore, if the sample plots were located closer than 20 m to each other, the latter plot would not be measured. Also, if the shape of the compartment was very unregular, an additional diameter could be added to achieve more complete cover of the whole forest compartment (See Fig. 4). Following these rules, the planning area was covered with a continuous sample plot network including 363 sample plots (Fig. 4).

2.3.2 Habitat Component Measurements

When a forest structure is assessed for depicting the potential biodiversity of forest, all existing vegetation layers have to be sampled with an equal weight (Uuttera et al. 1996). Therefore, the sample plots in this study are determined to have a fixed radius. The size of the sample plot has to be large enough to represent the whole vegetation association typical for the site (Sukatsev 1960). In this study the sample plot size was determined as 300 m² (radius 9.77 m).

The assessment of the properties of the edaphical factors of the forest habitat was made from the center point of the sample plot. Field and bush vegetation layers were assessed with two 10 m² sample plots within the original plot. Tree layers were assessed from the whole area of 300 m² (Fig. 3).

The criteria used for an edaphic component were: 1) *Forest site type classification* (Cajander 1926), 2) *Quality of the mineral soil layer*, 3) *Quality/quantity of the humus layer*, and 4) *Location of the site in relation to microtopography* (Table 1). The biocomponent of the forest habitat was determined on the basis of existence and composition of the vegetation layers. The layers of forest vegetation were divided in this study into six (6) basic levels: 1) *Emergent tree layer*, 2) *Dominant tree layer*, 3) *Understorey*, 4) *Bush layer*, 5) *Field layer* and 6) *Dead and decaying standing trees and trees of the same category on the ground* (Table 1).

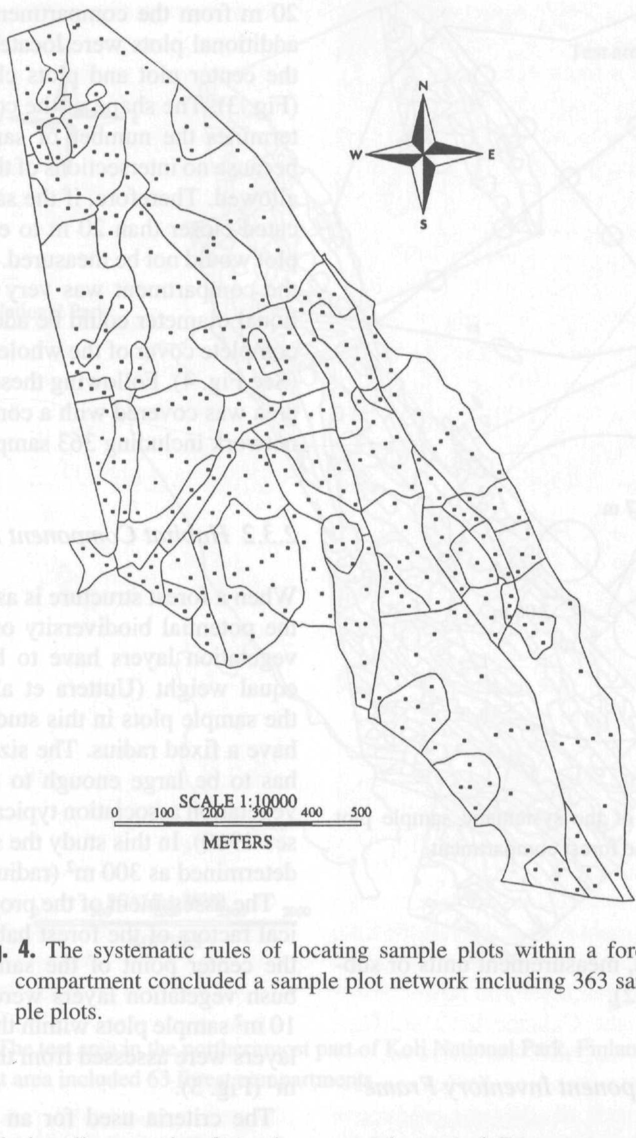

Fig. 4. The systematic rules of locating sample plots within a forest compartment concluded a sample plot network including 363 sample plots.

The field layer includes all vegetation from the height of 20 cm to 50 cm, woody species and the actual field layer species being assessed separately. The bush layer includes vegetation from the height of 50 cm to 150 cm. The bush layer includes also all Common junipers (*Juniperus communis*) and willows (*Salicaceae* sp.), even if they exceed 150 cm, except for sallow (*Salix caprea*), crack willow (*Salix fragilis*) and bay willow (*Salix pentandra*), which can grow to the tree layer. The existence of the field and bush layer was determined by the coverage of the layer (Table 1).

The vegetation layers *Understorey*, *Dominant tree layer* and *Emergent tree layer*, were measured on the basis of variables *Coverage of the layer*, *Mean diameter and height*, *Height variation* and *Proportions of deciduous and coniferous species* in vegetation layers (Table 1).

The 'vegetation layer' *Dead and decaying standing trees and trees of the same category on the ground* was measured with variables 1) *The dominating tree species group*, 2) *Volume* and 6) *The level of decomposition*. In the decaying wood four continual succession stages of the existing invertebrate species can be recognized (Ehnström and Walden 1986).

Table 1. The variables depicting the geo- and biocomponents of the forest habitat and their measurement classes.

Variable / Abbreviation	Measurement classes
Edaphic component	
Forest type / FT	1) *Groves* (OMat, Oxalis-Maianthemum Type), 2) *Grovelike heaths* (OMT, Oxalis-Myrtillus Type), 3) *Fresh heaths* (MT, Myrtillus Type), 4) *Dryish heaths* (VT, Vaccinium Type), 5) *Dry heaths* (CT, Calluna Type), 6) *Barren heaths* (ClT, Cladina Type) and 7) *Rocky lands.*
Quality of mineral soil / QM	Firstly, 1) *Sorted* and 2) *Unsorted.* Secondly, 1) *Silt*, 2) *Fine sand*, 3) *Sand* and 4) *Gravel.*
Thickness of humus layer / TH	1) *Thickness* < 5 cm, 2) *Thickness* > 5 cm, but < 10 cm and 3) *Thickness* > 10 cm.
Quality of humus layer / QH	1) *Humus layer dominated by litter of deciduous tree species* and 2) *Humus layer dominated by litter of coniferous tree species.*
Steepness of the slope / SLOPE	1) *Gentle slopes* < 15 % and 2) *Steep slopes* > 15 %
Biocomponent (flora)	
Coverage of the fieldlayer / FIELD	10 % classes
Coverage of the bushlayer / BUSH	10 % classes
Number of stems in understorey / NSUNDER	ha^{-1}
Mean diameter of the understorey / MEANDU	cm
Mean height of the understorey / MEANHU	m
Height variation in understorey / HEIGHTVARU	m
Proportion of deciduous species in understorey / DECU	10 % classes
Proportion of coniferous species in understorey / CONU	10 % classes
Coverage of the understorey vegetation layer / COVU	10 % classes
Number of stems in dominating tree layer / NSDOM	ha^{-1}
Basal area of the dominating tree layer / BASALD	$m^2\ ha^{-1}$
Mean diameter of the dominating tree layer / MEANDD	cm
Mean height of the dominating tree layer / MEANHD	m
Heightvariation of the dominating tree layer / HEIGHTVARD	m
Proportion of the deciduous tree species in dominating tree layer / DECD	10 % classes
Proportion of the coniferous tree species in dominating tree layer / COND	10 % classes
Coverage of the dominating tree layer / COVD	10 % classes
Number of stems in emergent tree layer / NSEMER	ha^{-1}
Proportion of the deciduous species in emergent tree layer / DECE	10 % classes
Coverage of the emergent tree layer / COVE	10 % classes
Proportion of the deciduous species in dead biomass / DECDEAD	10 % classes
Proportion of the coniferous species in dead biomass / CONDEAD	10 % classes
The amount of dead biomass / DEADVOL	$m^3\ ha^{-1}$
Level of the decomposition / DECOMP	four (4) classes

2.3.3 *Interpolation of the Habitat Component Values*

The values of the variables depicting habitat components were spatially interpolated to cover the whole planning area. The variables with discrete values were interpolated as a probability for existence for each value of the discrete variable. Kriging- method (Matheron 1963) can be considered the best alternative for interpolating the values of habitat component variables. From the interpolation methods, kriging makes the most benefit of the whole data measured from the area (Ripley 1981). In kriging, the spatial variation of different variables is first modelled from the original data and it can vary within the area. From the correlations of residuals of this model, the optimal weight for the sample plot in relation to distance can be determined (Burrough 1986). In smoothing the residuals, the weights of data points in clusters are automatically reduced. Also the radius, within which the component autocorrelates can be determined by the original data, which makes the interpolation more accurate. One of the most important features of kriging is that it provides estimates for the error variance at different parts of the surface (Ripley 1981).

Kriging method includes two steps. Firstly, the spatial structure of the original data is analysed. For this, a variogram, calculated from the data, is used. After this, a model is fitted to the semivariogram. The semivariogram is a method for measuring, presenting and modelling the variation between spatial objects (Matheron 1963). It is a two-dimensional semivariance of spatial variable describing the covariance at a given distance. Generally used models for smoothing the semivariances are linear, spherical, exponential, Gaussian and circular models (Cressie 1991). The second phase of the kriging is the interpolation of the estimated value for each point in the grid with a function (Bonham-Carter 1994):

$$\hat{z} = \sum_{i=1}^{n} w_i z_i \qquad (1)$$

where

n = number of sample plots within the search radius

w_i = distance dependent weight for sample plot i

z_i = observed value of sample plot i

The accuracy of the interpolation was examined by the statistics of the variable estimates and variances given by the method for the whole test area. This gives us an estimation of the possible existing error variance 'peaks' within the interpolated area. Also twenty (20) randomly located test sample plots were measured, and the means and root mean square errors of the biases of the variable estimates on these test sample plots are presented.

2.4 Forest Patch Mosaic Comparisons

In order to form a 'biodiversity preservation oriented' habitat component patch mosaic, the interpolated continuous values of the chosen variables were classified with subjective rules following either the classes of the measurement or alternative feasible rules (Table 2). The classes were made rather strict so as not to deviate the information about the variation. The variables with discrete values were classified according to the probability of existence. The area unit (10 m × 10 m) represented a discrete value with the highest probability of existence. The accuracy of classification of the interpolated values of variables was also investigated by using the test sample plots (20).

The formed 'biodiversity preservation oriented' habitat component polygons were compared to the 'wood production oriented' forest compartment division using standard tools of Geographic Information Systems. The pattern of the two patch mosaics were investigated variables *mean area*, *limits of the area range*, *standard deviation of area, mean perimeter of the polygons*, *limits of the polygon perimeter range*, *standard deviation of the polygon perimeter*. The relationship between the two defined patch mosaics was investigated by examining *the amount of 'biodiversity preservation oriented' habitat component polygons within each 'wood production oriented' forest compartment.*

Table 2. The classification rules of the variables depicting forest habitat components. For explanations of variable codes, see Table 1.

Variable	Rule for classification
FT	The highest probability of existence
QM	The highest probability of existence
TH	The highest probability of existence
QH	The highest probability of existence
SLOPE	Relative steepness 1) < 15 %, 2) > 15 %
FIELD	10 % classes (measurement rule)
BUSH	10 % classes (measurement rule)
NSUNDER	No understorey, Intervals of 10 up to 30 / sample plot
MEANDU	Diameter 1) < 5 cm, 2) > 5 cm
MEANHU	Height 1) < 5 m, 2) > 5 m
HEIGHTVARU	Variation 1) < 50 % of the mean height, 2) > 50 % of the mean height of the understorey
DECU	Proportion 1) < 20 %, 2) > 20 %
CONU	Proportion 1) < 50 %, 2) > 50 %, (dominance)
COVU	10 % classes (measurement rule)
NSDOM	Intervals of 10 up to 50, (closure of the canopy)
BASALD	Intervals of 5 m^2/ha
MEANDD	Intervals of 5 cm
MEANHD	Intervals of 5 m
HEIGHTVARD	Variation 1) < 30 % of the mean height, 2) > 30 % of the mean height of the dominant layer (suppression)
DECD	Proportion 1) < 20 %, 2) > 20 %
COND	Proportion 1) < 50 %, 2) > 50 %, (dominance)
COVD	10 % classes (measurement rule)
NSEMER	1) No emergent tree layer, 2) emergent tree layer
DECE	Proportion 1) < 20 %, 2) > 20 %
COVE	10 % classes (measurement rule)
DECDEAD	Proportion 1) < 50 %, 2) > 50 %, (dominance)
CONDEAD	Proportion 1) < 50 %, 2) > 50 %, (dominance)
DEADVOL	Volume 1) < 5 m^3 ha^{-1}, 2) 5 m^3 ha^{-1} < x < 20 m^3 ha^{-1}, 3) x > 20 m^3 ha^{-1}
DECOMP	The highest probability of existence

3 Results

As can be expected, some of the chosen habitat component variables are somewhat poorly predictable (Tables 3 and 4). The low accuracy of the predicted values are caused either by the small number of sample plots or low autocorrelation of the variable values between the sample plots. The error variances of the discrete habitat component estimators, such as 'Forest type' and 'Quality of mineral soil', given by the models are quite high (Table 3). From the habitat component variables with continuous values, for example the volume of dead wood gets a high error variance of the predicted values. This was expected, even if the features of the physical conditions and the nature of damages may cause spatial autocorrelation of this variable. However, the classification rules for habitat component patch formation (Table 2), made before the final comparisons, evens out these errors caused by the sparse sample or poor autocorrelation (Table 4). Even so, we must examine the values predicted from sparse data with caution. The models themselves act reliably, because there are no 'peaks' in the variances given by the models within the test area, and the standard deviation of the variances of the estimators are low (Table

Table 3. The models used for smoothing the semivariograms of different variables depicting forest habitat components (Model), the range determined by the models ($Range_m$), the mean of the model estimator ($Mean_e$), the standard deviation of the model estimator (Sd_e), the mean of the estimator variance ($Mean_v$), and the standard deviation of the estimator variance (Sd_v) for the whole test area. The results of discrete variables are presented as the probability of existence for each variable value. For explanations of the variable codes, see Table 1.

Variable	Model	$Range_m$	$Mean_e$	Sd_e	$Mean_v$	Sd_v
FT1	Spherical	550	0.026	0.078	0.026	0.001
FT2	Spherical	250	0.474	0.317	0.138	0.007
FT3	Spherical	450	0.441	0.344	0.113	0.033
FT4	Spherical	400	0.027	0.094	0.005	0.000
FT7	Spherical	550	0.002	0.012	0.003	0.000
QM12	Exponential	100	0.011	0.064	0.014	0.004
QM21	Spherical	175	0.033	0.145	0.006	0.003
QM22	Exponential	200	0.036	0.136	0.016	0.007
QM23	Exponential	100	0.895	0.174	0.077	0.015
TH1	Exponential	300	0.180	0.212	0.097	0.010
TH2	Exponential	100	0.374	0.230	0.194	0.039
TH3	Exponential	900	0.434	0.272	0.195	0.005
QH1	Exponential	125	0.462	0.275	0.183	0.015
QH2	Exponential	125	0.517	0.273	0.175	0.014
FIELD	Spherical	450	5.211	1.043	2.606	0.124
BUSH	Spherical	50	0.741	0.218	0.631	0.016
NSUNDER	Spherical	150	15.799	11.157	184.806	38.784
MEANDU	Spherical	175	4.357	1.290	5.974	0.442
MEANHU	Spherical	200	3.808	1.093	2.628	0.257
HEIGHTVARU	Spherical	200	2.514	0.936	1.635	0.221
DECU	Spherical	200	5.106	2.333	8.993	1.116
CONU	Spherical	450	3.198	2.084	5.332	0.384
COVU	Spherical	150	1.204	0.905	1.123	0.234
NSDOM	Spherical	175	14.374	8.937	107.978	21.341
BASALD	Spherical	200	9.685	3.272	20.411	1.993
MEANDD	Spherical	200	23.371	5.722	68.757	4.892
MEANHD	Spherical	300	17.655	3.617	26.429	1.967
HEIGHTVARD	Spherical	90	3.985	0.519	3.200	0.079
DECD	Spherical	175	2.638	2.760	3.759	1.713
COND	Spherical	200	6.619	3.105	4.129	1.572
COVD	Spherical	200	4.683	0.689	3.064	0.124
NSEMER	Spherical	125	0.365	0.739	0.811	0.315
DECE	Spherical	110	0.744	1.913	1.960	1.008
COVE	Spherical	200	0.273	0.475	0.496	0.168
DECDEAD	Spherical	75	3.055	1.758	18.391	0.653
CONDEAD	Spherical	325	2.491	1.325	15.286	0.461
DEADVOL	Exponential	250	18.462	21.526	790.753	56.512
DECOMP2	Exponential	30	0.120	0.086	0.091	0.012
DECOMP3	Exponential	75	0.239	0.154	0.143	0.025
DECOMP4	Exponential	50	0.089	0.056	0.077	0.005

Table 4. The averages of the differences of the variable estimates (Mean) compared to the actual value of twenty (20) test sample plots, root mean square errors of these differences (RMSE), and the proportion of the test plots classified in the right habitat component class based on the variable estimates (%-class). For explanations of the variable codes, see Table 1.

Variable	Mean	RMSE	%-class
FT1	0.054	0.114	1.000
FT2	0.308	0.354	0.840
FT3	0.237	0.325	0.840
FT4	0.018	0.051	1.000
FT7	0.001	0.005	1.000
QM12	0.069	0.236	0.950
QM21	0.010	0.028	1.000
QM22	0.079	0.159	1.000
QM23	0.132	0.206	0.950
TH1	0.010	0.152	1.000
TH2	0.422	0.457	0.680
TH3	0.380	0.459	0.680
QH1	0.400	0.455	0.680
QH2	0.379	0.438	0.680
FIELD	11.149	13.098	0.790
BUSH	5.318	7.797	0.680
NSUNDER	15.797	18.310	0.530
MEANDU	2.123	2.935	0.790
MEANHU	1.444	1.773	0.790
HEIGHTVARU	1.072	1.415	0.740
DECU	29.578	33.972	0.840
CONU	28.000	34.732	0.680
COVU	10.085	12.669	0.530
NSDOM	4.518	6.661	0.790
BASALD	5.423	6.279	0.630
MEANDD	4.953	6.936	0.840
MEANHD	2.662	3.383	0.790
HEIGHTVARD	1.065	1.393	0.950
DECD	22.495	27.343	0.680
COND	19.526	23.706	0.890
COVD	10.935	13.928	0.630
NSEMER	0.499	1.443	1.000
DECE	3.636	9.782	0.890
COVE	2.381	3.767	0.950
DECDEAD	46.906	52.948	0.580
CONDEAD	32.747	39.388	0.840
DEADVOL	14.913	30.172	0.580
DECOMP2	0.157	0.227	0.700
DECOMP3	0.436	0.519	0.600
DECOMP4	0.129	0.227	0.700

3). On average the mean of the standard deviation of the estimator variances is 15 % of the mean variance.

The variation of the habitat component values within each 'wood production oriented' forest compartments is notable (Table 5). Even if the averaging of the sub-plot values (Fig. 3) may decrease the variation, the range of the discrete habitat component existence within one 'wood production oriented' forest compartment can differ from all but non-existence of the component to a dominating feature. The same applies to components with a continuous measurement units. The standard deviation of the habitat component values within a forest compartment exceeds in nearly every case 50 % of the mean value of the component.

To investigate the relationship between 'biodiversity preservation oriented' forest habitat components and 'wood production oriented' forest compartment division, habitat component patches were formed. On average the mean size of the patches formed from the variables depicting forest habitat components exceeds the mean size of the forest compartments (Table 6). The habitat component patches are large enough to be considered as operative units in forestry. Also, in most cases the form of the habitat component patches is less complicated than the form of the 'wood production oriented' forest compartments (Table 6). The relationship between patch perimeter and patch area of habitat component patches is greater than in the 'wood production oriented' forest compartment division only with components *Number of stems in understorey*, *Proportion of deciduous tree species in understorey*, *Number of stems in dominating tree layer*, *Proportion of the deciduous tree species in dominating tree layer*, and *Proportion of the coniferous tree species in dominating tree layer*. These components were also among the variables having the most variation within the test area (Tables 3 and 5) and also the average patch sizes of the habitat components are small (Table 6).

Even if the number of 'biodiversity preservation oriented' patches formed from the forest habitat components is reasonable, it is evident that the 'wood production oriented' forest compartment division does not correlate strongly with the division of the forest habitat component patch-

Table 5. The averages of the means of the variables depicting the components of forest habitat (Mean), limits of the variable ranges (Min, Max), and standard deviation of the variables (Sd) within all 63 forest compartments. For explanations of the variable codes, see Table 1.

Variable	Mean	Min	Max	Sd
FT1	0.028	0.000	0.384	0.078
FT2	0.484	0.000	1.000	0.311
FT3	0.419	0.000	0.994	0.331
FT4	0.023	0.000	0.630	0.091
FT7	0.003	0.000	0.074	0.011
QM12	0.015	0.000	0.491	0.064
QM21	0.039	0.000	0.949	0.148
QM22	0.043	0.000	0.617	0.103
QM23	0.866	0.225	1.000	0.175
TH1	0.152	0.000	0.739	0.171
TH2	0.364	0.070	0.759	0.185
TH3	0.441	0.012	0.875	0.235
QH1	0.485	0.000	0.996	0.254
QH2	0.482	0.016	0.983	0.252
SLOPE	0.173	0.034	0.512	0.120
FIELD	5.291	2.936	7.156	0.962
BUSH	0.726	0.416	1.236	0.200
NSUNDER	15.993	1.731	51.997	10.580
MEANDU	4.156	1.160	7.104	1.145
MEANHU	3.663	0.674	5.298	1.030
HEIGHTVARU	2.380	0.316	4.462	0.798
DECU	4.933	1.418	9.702	2.186
CONU	3.001	0.081	7.591	2.112
COVU	1.196	0.112	3.730	0.712
NSDOM	14.687	4.681	38.184	7.745
BASALD	9.071	3.391	15.188	2.830
MEANDD	22.591	7.454	32.621	5.447
MEANHD	17.076	5.900	23.058	3.548
HEIGHTVARD	3.850	2.731	5.161	0.427
DECD	3.001	0.000	9.825	2.697
COND	6.170	0.256	10.004	3.048
COVD	4.622	2.839	5.748	0.625
NSEMER	0.399	0.000	4.825	0.725
DECE	0.652	0.000	6.577	1.394
COVE	0.301	0.000	2.300	0.426
DECDEAD	2.897	0.215	6.716	1.685
CONDEAD	2.392	0.203	6.077	1.276
DEADVOL	17.093	1.052	104.820	20.256
DECOMP2	0.116	0.033	0.292	0.052
DECOMP3	0.214	0.056	0.504	0.116
DECOMP4	0.093	0.030	0.233	0.036

Table 6. The Average (Mean), and the limits of value ranges (Min, Max) and standard deviation (Sd) of the forest habitat component patch area (Area) and perimeter (Perimeter), and the total number of the formed patches (*P*). Same variables are presented for the 'wood production oriented' forest compartments (FORCOMP). The average number of forest habitat component patches in one 'wood production oriented' forest compartment is also presented for each forest habitat component (*R*). For explanations of the variable codes, see Table 1.

Variable	Area, ha				Perimeter, m				*P*	*R*
	Mean	Min	Max	Sd	Mean	Min	Max	Sd		
FORCOMP	1.5	0.1	9.4	1.9	582.9	121.9	2049.9	404.7	63	1.0
FT	10.9	0.1	48.8	18.3	1355.9	163.4	4353.4	1721.0	9	2.2
QM	7.9	0.0*	92.9	25.6	834.2	80.0	7600.0	2043.0	13	2.0
TH	2.3	0.0*	47.1	8.2	614.0	48.3	8255.6	1556.3	42	3.5
QH	5.8	0.0*	38.5	10.2	1176.0	80.6	6017.2	1555.0	17	2.6
SLOPE	2.7	0.1	47.0	8.5	927.4	92.4	11123.0	2142.2	36	3.9
FIELD	4.5	0.1	38.9	8.6	1119.5	123.2	7704.2	1696.2	22	3.3
BUSH	6.6	0.0*	71.4	18.1	1036.5	34.1	8139.7	2017.2	15	2.3
NSUNDER	2.2	0.0*	35.6	5.5	992.4	68.3	12092.1	1952.2	45	6.5
MEANDU	5.8	0.0*	69.1	16.5	1111.8	40.0	10780.0	2550.0	17	2.3
MEANHU	7.0	0.1	88.4	23.4	895.1	103.2	8203.5	2111.2	14	3.1
HEIGHTVARU	2.7	0.0*	81.0	13.3	554.1	40.0	10960.0	1805.2	37	2.5
DECU	2.6	0.1	23.5	4.7	1181.4	154.8	12151.7	2145.1	38	4.8
CONU	2.3	0.0*	20.0	4.7	879.1	40.0	6820.0	1605.1	43	3.8
COVU	3.6	0.0*	55.8	10.7	1038.2	34.1	12853.7	2444.7	54	3.3
NSDOM	1.5	0.0*	29.1	4.4	726.9	40.0	11680.0	1686.2	64	4.7
BASALD	4.1	0.1	40.7	8.8	1085.6	109.4	9795.9	2059.1	24	3.3
MEANDD	2.3	0.0*	16.7	4.2	955.3	40.0	6420.0	1557.6	43	3.9
MEANHD	4.7	0.1	39.0	9.0	1178.1	124.0	8697.1	1900.9	21	3.3
HEIGHTVARD	19.7	0.3	93.2	41.1	1668.1	226.1	6097.1	2497.9	5	1.7
DECD	1.7	0.0*	27.2	4.2	847.6	34.1	11850.1	1774.6	58	5.7
COND	1.4	0.0*	22.6	3.8	807.3	40.0	11880.0	1811.2	71	5.3
COVD	4.9	0.1	28.3	6.6	1046.0	92.4	4197.4	1067.3	20	2.9
NSEMER	4.3	0.0*	73.9	15.4	872.3	34.1	9970.0	2099.6	23	2.9
DECE	1.3	0.0*	77.1	8.8	446.3	34.1	9814.2	1121.3	77	4.4
COVE	2.9	0.1	78.8	13.5	664.6	64.7	10168.8	1774.8	34	3.3
DECDEAD	4.9	0.1	25.9	7.0	1274.5	133.7	5627.2	1553.1	20	3.1
CONDEAD	2.8	0.0*	44.1	8.8	808.0	40.0	11440.0	2128.9	35	3.1
DEADVOL	4.7	0.1	43.8	9.9	1109.2	92.4	9173.1	1956.9	21	3.1
DECOMP	1.0	0.0*	77.1	7.9	372.5	52.4	16335.3	1680.2	94	4.6

* *The presentation accuracy is not valid.*

es. This can be seen from the calculated variable *R*, which shows the average number of forest habitat component patches within one 'wood production oriented' forest compartment (Table 6). This variable gets its largest values with the habitat components which have the smallest patch sizes and greatest variation. However, in every case, if the forest habitat component variation was considered, the number of the forest compartments would have been at least doubled after the intersection.

The use of combinations of the chosen forest habitat component patch mosaics increases notably the variation of the habitat variation within 'wood production oriented' forest compartment. For example, the combination of the variables depicting the edaphic features of the forest habitat used in this study contain 512 patches for the test area with mean size of 0.2 ha. In this case one forest compartment represents 11.1 patches divided by forest habitat component variables. Naturally, some of these formed patches are not real patches, but caused by the small differences in the results of interpolation of correlated variables. Partly, because of this problem the results of habitat component combinations are not presented.

4 Discussion

The results of this comparison are highly affected by the quality of the patch division in both of the approaches, i.e. 'biodiversity preservation oriented' and 'wood production oriented' approaches. When applying the traditional forest compartment determination method used in Finnish forestry, i.e. aerial photograph interpretation and field inventory, there is a possibility to get a different compartment division depending on the person doing the work. This is the case particularly in forest areas like Koli National Park, which includes a great amount of variation in vegetation. However, in productive forests on average, where the boundaries of compartments (cf. age classes and dominating tree species) are clear due to the management history, the variation of 'wood production oriented' forest compartment divisions can be assumed to be rather small. In this case study, the 'wood production oriented' compartment division was made in finer scale than on average in productive forests. The mean 'wood production oriented' compartment size of the test area was 1.5 ha, when it is on average 2–3 ha in privately owned forests and 5–6 ha in the forests owned by the state or forest companies. Because of the extraordinary features of edaphic factors and vegetation of the test area of Koli National Park, and because of the fine scaled 'wood production oriented' forest compartment division, the results may not be generally applicable in productive forests of the region.

The determination of the boundary values of different habitat component classes is always a subjective decision. A holistic knowledge of the impact of changes in the geo- and biocomponents of a forest habitat on the ecosystem processes and forest biodiversity will not be available in the near future. Therefore, these ecological unit boundaries reflect the geographic limits to which 'type' concepts can be consistently applied (Carpenter et al. 1995). They are wider for units delineated at regional scales and become more precise at local scales where a greater amount of detail is perceptible. In this study the limits of forest habitat component classes were kept tight. Class boundaries were either the measurement classes or the dominance of the component (discrete values), or more subjective limits determined using the information about forest ecology (dominance vs. suppression, crown closure), or using the known variation of the component values in the original data. Therefore, the sensitivity analysis of the effect of changes in boundary values on habitat component patch mosaic would not have brought much further information in this particular data.

On average the mean size of the patches formed of the forest habitat components exceeded the mean size of 'wood production oriented' forest compartments. However, this may be caused by the patches being formed by the classification rule 'no existence of the variable'. This is the case with variables like *Coverage of the bush layer* and *Coverage of the emergent tree layer*. Another reason for large habitat component patch sizes is that, for example, in the case of variable *Quality of mineral soil*, almost the whole test area is unsorted sand, i.e. sandy moraine. Of course, also the classification rules may cause a large maximum patch size, even if the class intervals are quite strict. This may be the case in patches of *Height variation in understorey* and *Height variation in dominating tree layer*. In contrast, the minimum size of the patches may also be decreased by the classification rules. If the variable values differ near the determined class boundary, even a low variation may cause several patches to be separated.

From a wood production point of view, a patch corresponds to a forest stand compartment. However, a stand compartment may not function as a patch from a particular organism's perspective. From an organism-centered perspective patches are dynamic and occur on various spatial and temporal scales (Wiens 1989, Wiens and Milne 1989). A patch at any given scale has an internal structure that is a reflection of patchiness at finer scales, and the mosaic containing that patch has a structure that is determined by patchiness at broader scales (Kotliar and Wiens 1990). Thus, to integrate the assessment of biodiversity into forest management planning, there is a need to revise the traditional approach and observe the area regardless of the 'wood production oriented' forest compartment mosaic of the practical forestry. When the actual operations are planned, the variation within 'wood production oriented' forest compartments should be taken into account when determining the operational forest compartment (different from the management planning unit) and intensity or methods of the treatment.

In addition to the determination of the operational compartments, the approach of the combined variables depicting forest habitat components could be used for finding the small scaled key biotopes within a forest area. This would save the costs of the field work. However, it is not possible to use intensive field inventory data for this purpose, but the same approach could be applied with the existing data of forest inventories, digital elevation models, digital soil maps, aerial photographs and satellite images.

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References

Angelstam, P. 1992. Conservation of communities – the importance of edges, surroundings and landscape mosaic structure. In: Hansson, L. (ed.). Ecological principles of nature conservation. Elsevier Applied Science, London. p. 9–70.

Attiwill, P. M. 1994. The disturbance dynamics of forest ecosystems: the ecological basis for conservation management. Forest Ecology and Management 63: 247–300.

Bonham-Carter, C. F. 1994. Geographic Information Systems for geoscientists: modelling with GIS. Computer Methods in the Geosciences, Vol. 13. p. 154–159.

Burrough, P. A. 1986. Principles of Geographical Information Systems for land resources assessment. Monographs on Soil and Resources Survey 12. 194 p.

Cajander, A. K. 1926. The theory of forest types. Acta Forestalia Fennica 29(3). 108 p.

Carpenter, C. A., Smith, M.-L. & Fay, S. 1995. What do ecological unit boundaries mean? The dual role of ecological units in ecosystem analysis: examples from New England and New York State. In: Thompson, J. E. (ed.). Analysis in support of ecosystem management. Analysis Workshop III, April 10–13, 1995. Fort Collins, C.O. Washington, D. C. U.S. Department of Agriculture, Forest Service, Ecosystem Management Analysis Center. p. 8–19.

Cressie, N. 1991. Statistics for spatial data. Wiley Series in Probability and Mathematical Statistics. John Wiley & Sons, New York. 900 p.

Ehnström, B. & Walden, H. W. 1986. Faunavård i skogsbruket. Del 2. Den lägre faunan. Skogsstyrelsen, Jonköping. 352 p.

Forman, T. T. & Gordon, M. 1986. Landscape ecology. John Wiley & Sons, New York. 619 p.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems or landscapes? Ecological Applications 2: 202–205.

Haila, Y., Hanski, I. & Raivio, S. 1987. Breeding bird distribution in fragmented coniferous taiga in southern Finland. Ornis Fennica 64: 90–106.

Hakalisto, S. 1989. Kolin lehtoalueselvitys. Mimeograph. The Finnish Forest Research Institute. 41 p.

Huston, M. A. 1994. Biological diversity. The coexistence of species on changing landscapes. Cambridge University Press, Cambridge. 681 p.

Kangas, J. & Pukkala, T. 1996. Operationalization of biological diversity as a decision objective in tactical forest planning. Canadian Journal of Forest Research 26(1): 103–111.

Kotliar, N. B. & Wiens, J. A. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for the study of heterogeneity. Oikos 59: 253–260.

Kouki, J. 1993. Luonnon monimuotoisuus valtion metsissä – katsaus ekologisiin tutkimustarpeisiin ja suojelun mahdollisuuksiin. Metsähallituksen luonnonsuojelujulkaisuja, Sarja A, Nro 11. 88 p.

Kuuluvainen, T. 1994. Gap disturbance, ground microtopography, and the regeneration dynamics of boreal coniferous forests in Finland: a review. Annales Zoologici Fennici 31: 35–51.

Kuusela, K. 1990. The dynamics of boreal coniferous forests. SITRA. Helsinki. 172 p.

Kuusipalo, J. 1985. An ecological study of upland forest site classification in southern Finland. Seloste: Ekologinen tutkimus Etelä-Suomen kangasmetsien kasvupaikkaluokituksesta. Acta Forestalia Fennica 192. 77 p.

Luonnonläheinen metsänhoito. 1994. Luonnonläheinen metsänhoito: metsänhoitosuositukset. Metsätalouden kehittämiskeskus Tapio, Helsinki. 72 p.

Matheron, G. 1963. Principles of geostatistics. Economic Geology 58: 1246–1266.

Nieppola, J. 1993. Understorey plants as indicators of site productivity in Pinus sylvestris L. stands. Scandinavian Journal of Forest Research 8: 49–65.

Ripley, B. D. 1981. Spatial statistics. Wiley Series in Probability and Mathematical Statistics, New York. p. 28–77.

Romme, W. H. & Despair, D. G. 1989. Historical perspectives on the Yellowstone fires of 1988. Bioscience 39(19): 695–699.

Store, R. 1996. Maiseman huomioonottavan metsikkökuvioinnin tuottaminen paikkatietojärjestelmällä. Folia Forestalia – Metsätieteen aikakauskirja 1996(3): 245–262.

Sukatsev, V. 1960. Metsätyyppien tutkimisen opas. Transl. Erkki Laitakari. Silva Fennica 99. 181 p.

Tonteri, T., Hotanen J.-P. & Kuusipalo, J. 1990. The Finnish forest site type approach: ordination and classification studies of mesic forest sites in southern Finland. Vegetatio 87: 85–98.

Uuttera, J. & Kangas, J. 1995. Pohjoisen havumetsävyöhykkeen metsäluonnon monimuotoisuuden kvantifiointi alueellisen metsäsuunnittelun tarpeisiin. Folia Forestalia – Metsätieteen aikakauskirja 1995(4): 325–328.

—, Maltamo, M. & Kuusela, K. 1996. The impact of forest management history on the state of forests in relation to natural forest succession. Comparative study North Karelia, Finland vs. Republic of Carelia, Russian Federation. Forest Ecology and Management 83: 71–85.

Wiens, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3: 385–397.

— & Milne, B. T. 1989. Scaling of 'landscapes' in landscape ecology or, landscape ecology from a beetle's perspective. Landscape Ecology 3: 87–96.

Zackrisson, O. 1977. Influence of forest fires on the North Swedish boreal forests. Oikos 29: 22–32.

Total of 32 references