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Differences in forest structure and landscape patterns between ownership groups in Central Finland

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The spatial distribution and connectivity of forest characteristics, such as soil productivity, stage of forest development, forest tree species composition and forest vertical structure, were studied according to forest ownership groups in Central Finland. The study was based on the data from the Finnish National Forest Inventory. The spatial distribution was examined by estimating variograms for compared characteristics. Connectivity of forest characteristics was estimated along the inventory track by calculating the proportions of adjacent sample plots which had the same value of the forest characteristic in question. Results on the spatial distribution and connectivity of dominating tree species, tree species composition and vertical structure of the stand show that differences in stand management have also affected the structure of forest landscape. It seems that the within-stand heterogeneity, required by many forest species, is better maintained in privately owned forests due to more heterogeneous management regimes. This leads to greater spatial correlation and connectivity of the stand structure characteristics. On the other hand, small management units in privately owned forest holdings lead to a more fragmented forest landscape. This is partly avoided in forests owned by the state or forest industrial companies, which have more continuous patches of a single successional stage of forest. However, this can be regarded only as a potential for the preservation of viable forest species populations in the future, because currently successional stages of young forest have the greatest spatial correlation and connectivity.

Introduction

Each species needs an appropriate habitat or set of habitats to survive (e.g., Rosenzweig 1995). In natural boreal forest conditions, the spatial distribution of abiotic properties (climate, soil parameters and water regime) determines the distribution of different forest types and, to a great extent, forest structure characteristics (e.g., Kuusela 1990). On the other hand, trees create the structure of the habitat, produce variability in microclimatic conditions, provide resources, and form the habitat for many associate species (Sukatšev 1960, Huston 1994). According to various studies, forest structure at the stand level seems to be the most important factor for the existence of the majority of boreal forest species (e.g., Esseen *et al.* 1992, Raivio 1992, Haila 1994, Siitonen and Martikainen 1994, Petterson 1997, Wikars 1997). However, the population viability of a number of species is critically connected with the structure of forest landscapes (Angelstam 1992, Hansson 1992, Andrén 1994).

The composition and pattern of forest landscape may affect species either directly, through allocation of resources or suitable habitats, or indirectly by altering inter-specific interactions in the communities modified by landscape structure (e.g., Angelstam 1992, Dunning *et al.* 1992, Wiens *et al.* 1993). In Finnish production forests, i.e. forests under commercial exploitation, the current forest management practises and a large proportion of privately owned small forest holdings (Metsäntutkimuslaitos 1996) have changed the forest structure, i.e. the availability of resources and suitable habitats, both at the stand and landscape levels. At the stand level, the most critical components of habitats for boreal forests species are the lack of deciduous tree species component in young and middle-aged successional stages (e.g., Hansson 1992, Kouki 1993), the decline of vertical heterogeneity of forest structure (e.g., Kuuluvainen 1994), and the lack of decayed (e.g., Linder and Östlund 1992) and burnt biomass (e.g., Zackrisson 1977).

The structure of Finnish forest ownership (*see* above) and the forest planning tradition have caused changes to the natural forest landscape pattern. In forest management, the basic operational unit is the forest compartment. Therefore, critical components of forest habitat structure, existing as a combination of forest stand mosaics of forest holdings, may have lost their connectivity. This may decrease the population viability of some species (Turner 1989, Andrén 1994). At the landscape level the most critical lacking component is the existence and continuity of old forests (e.g. Hansson 1992).

In response to the Convention on Biological Diversity all countries that have signed the agreement are responsible for monitoring the state of habitat diversity (UNEP 1992; Agenda 21, Chapter 15). However, the quantitative information on the state of present forest landscapes from the ecological point of view is scarce (however *see* Syrjänen *et al.* 1994, Kurki *et al.* 1997). If an independent conservation inventory (e.g., Rice 1990) is not conducted, monitoring of the habitat diversity is worthwhile only with a multi-temporal aerial image interpretation, or by a sampling procedure that enables a statistical approach to assess the changes in structural features of forest habitats. The statistical analysis of landscape pattern requires systematic sampling designs, which are widely used in large-scale forest inventories such as national forest inventories (Koehl 1990, Korhonen and Maltamo 1991).

The aim of this study is to examine the spatial distribution and connectivity of certain forest characteristics critical to the existence of boreal forest species. These characteristics include forest soil productivity classes as a potential for habitat structures, forest development stages, compositions of forest tree species and vertical structure of forests. The characteristics were studied within forest ownership groups and were derived from the data of the Finnish National Forest Inventory (NFI).

Material and methods

The study area consisted of the forestry centre districts of South Ostrobotnia, Central Finland, North Karelia and Central Ostrobotnia (Fig. 1) from the same vegetation zone and which have very similar abiotic growing conditions. The data measured on the temporary sample plots of the 8th NFI were used. The temporary sample plots are located in half-square shaped clusters (Fig. 2). The distance between sample plots in the clusters of NFI is 200 m with each cluster containing 21 sample plots. The distance between the clusters is 8 km in north-south direction and 7 km in EW direction.

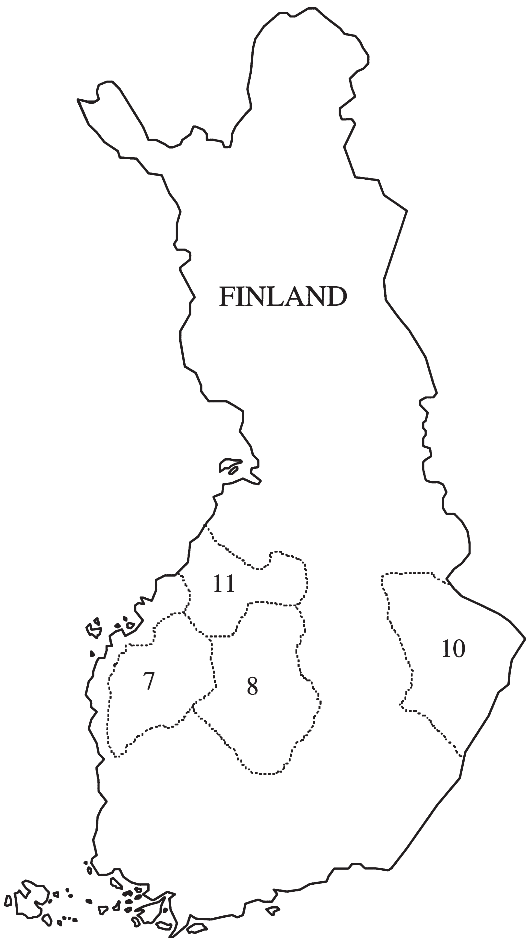

Fig. 1. The study area. The examined forestry centre districts are: 7 = South Ostrobotnia, 8 = Central Finland, 10 = North Karelia, 11 = Central Ostrobotnia (numbered after Metsäntutkimuslaitos 1996).

Several characteristics describing the site and growing stock on the plots are recorded in the NFI (*see* e.g., Metsäntutkimuslaitos 1989). In this study, the forest structure characteristics of interest were the productivity of the site based on the Cajanderian forest site types (e.g., Cajander 1926) according to the Finnish typology (Kalela 1961), stand development stage, dominating tree species, number of tree species, and the number of tree storeys. The number of tree species and the number of tree storeys were estimated from the tree data measured with a relascope (basal area factor 2 m^{2}ha^{-1}) (e.g., Metsäntutkimuslaitos 1989). The diameter distribution of the sample plot was used as a surrogate for the height distribution of the sample plot (e.g.,

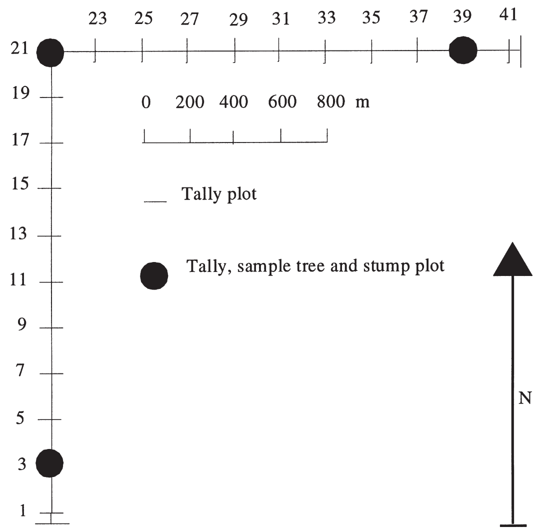

Fig. 2. Sampling scheme of the cluster in the Finnish NFI.

Maltamo *et al.* 1997). The definition of the tree storeys was made using diameter distribution, smoothed with non-parametric kernel-estimation, and a simple determination rule (Uuttera *et al.* 1996).

The spatial distribution of the examined forest structure characteristics was estimated by variograms. Variograms were calculated with the following formula (e.g., Matérn 1960, Ranneby 1981, Ranneby *et al.* 1987):

$$\hat{V}(u) = \frac{1}{2n}\sum_{i=1}^{n}(X(s_i + u) - X(s_i))^2 \qquad (1)$$

where $X(s_i)$ = value of variable X at point s_i, u = distance, and n = number of points.

The spatial connectivity of forest structure characteristics was investigated along the inventory track as the proportion of adjacent sample plots, which had the same value of the forest characteristic in question. The spatial connectivity was arrived at by using the following formula:

$$\hat{C}(u) = \frac{1}{N_{X(si)}}\sum_{i=1}^{n} I(u),$$

$$I(u) = \begin{cases} 1, \text{ if}\big(X(s_i) - X(s_i - e)\big) = 0, \ \forall e = 0,\ldots,u \\ 0, \text{ otherwise} \end{cases} \qquad (2)$$

where $X(s_i)$ = value of variable X at point s_i, u =

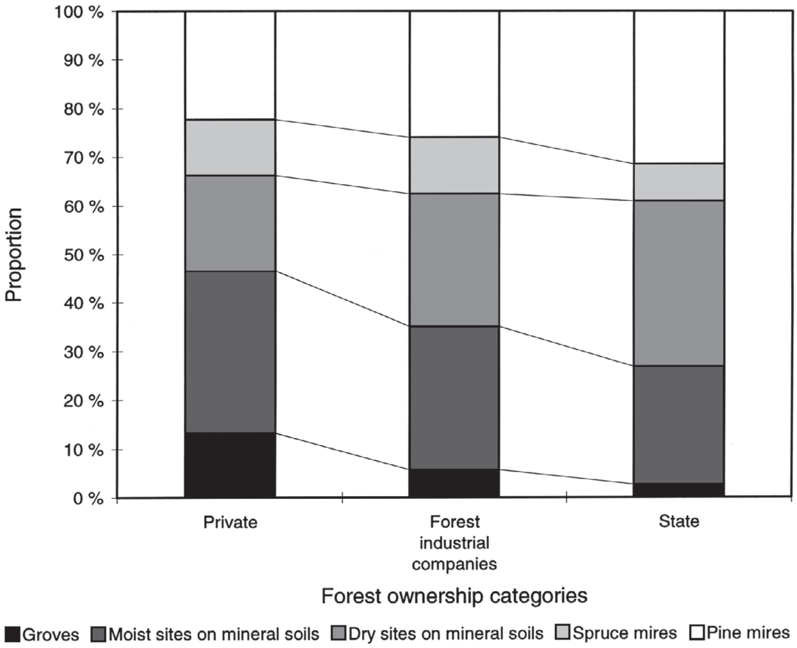

Fig. 3. The proportions of forest site types within the studied forest ownership groups.

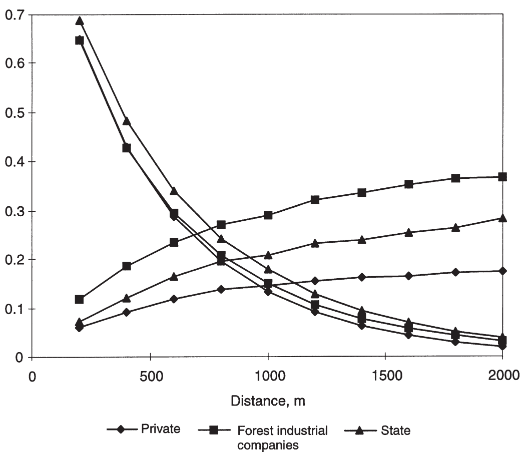

Fig. 4. Spatial distribution and connectivity of forest ownership groups in the whole data. Reversed J-shaped curves describe variograms and convex curves depict connectivity.

length of the queue, (distance between points in queue is 200 m), $I(u)$ = number of the queues of length u, with same value $X(s_i)$, and $N_{X(si)}$ = number of sample plots having the same value of the variable X as the point s_i

In this situation, the variogram simply gives the probability for a sample plot pair of having the same value of a character within a certain distance. The connectivity measure depicts the same characteristic within the distance of 200 m (minimum distance between the sample plots). At greater distances connectivity measures continuity, which means that a character must have the same value, not only at a certain distance, but also in all sample plots in between the investigated distance.

The spatial distribution and connectivity of the examined forest structure characteristics were estimated, firstly, for the whole data, and secondly, for different forest ownership groups, i.e.:
— privately owned forests,
— forests owned by forest industrial companies, and
— state forests.

Results

The relative composition of forest site types is more dominated by fertile forest types (i.e. groves, moist sites and spruce mires) in forests owned by private people compared to that of forests owned by the state or by the forest industrial companies (Metsäntutkimuslaitos 1996, Fig. 3). This fact may have an effect on the spatial distribution and connectivity of forest characteristics affected by the

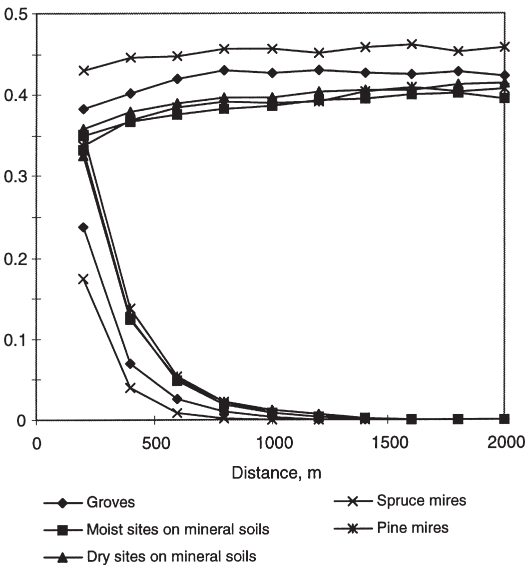

Fig. 5. Spatial distribution and connectivity of forest site types in the whole data. Reversed J-shaped curves describe variograms and convex curves depict connectivity.

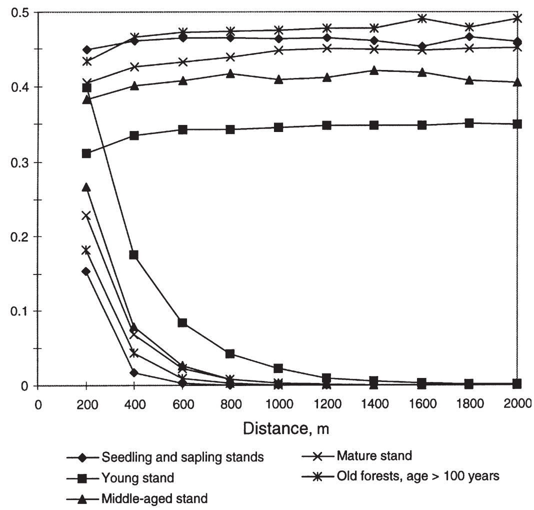

Fig. 6. Spatial distribution and connectivity of stand development stages in the whole data. Reversed J-shaped curves describe variograms and convex curves depict connectivity.

soil fertility, i.e. dominating tree species, number of tree species and number of tree storeys. Furthermore, there were some differences in the spatial distribution and connectivity of forests owned by different forest ownership groups (Fig. 4), and in the proportions of different stages of stand development (Metsäntutkimuslaitos 1996). The state owned forests existed in larger continuous areas compared to the other two forest ownership groups, which gives greater potential for the spatial correlation of stand structure characteristics. Also the distribution of the stand development stages is dominated by young and middle-aged forests in state or forest industrial company owned forests compared to privately owned forests (Metsäntutkimuslaitos 1996). This may increase the structural variation characteristic in young successional stages, i.e. the deciduous tree species component and the number of tree species. However, as shown below, the results on the spatial distribution and connectivity of the stand structure characteristics did not always follow these assumptions.

The forest landscape in Central Finland is a fine scaled mosaic of different forest site types (Fig. 5). Differences in spatial distribution or connectivity between the forest site types are small, except that on average groves and spruce mires appear to exist in smaller or more isolated patches than other forest site types (Fig. 5). It may be due to the great variation in soil fertility that there were no clear differences between the forest ownergroups in the average spatial distribution of the forest structure characteristics mentioned above (Tables 2–4). Hence, the effect of forest site type composition (Fig. 3) can be regarded as non-significant.

When examining the spatial distribution and connectivity of different successional stages of a stand in the whole data, the young and middle-aged forests are clearly existing closer to each other or in larger patches, compared to other stand development stages (Fig. 6). Differences between the other stand development stages are small, but it is worth noting that if old forests (age > 100 years) are observed separately from mature forests (age 80–100 years for conifers, 60–80 years for hardwoods), the spatial correlation between the old forests is the lowest and connectivity about the same as for seedling and sapling stands (Fig. 6).

If the spatial distribution and connectivity of the successional stages are examined between the forest ownership groups, clear differences can be found. All development stages of a stand are spatially less correlated in privately owned forests than those in the other two forest ownership groups

(Table 1). Especially young stands are, on average, closer to each other, or in larger patches, in forests owned by forest industrial companies or by the state, compared to the forests owned by private individuals (Table 1). This may partly be a reflection of the greater proportion of young stands in forests owned by the state or by forest industrial companies (Metsäntutkimuslaitos 1996). On the other hand, mature stands in state owned forests are less isolated or in larger patches than those in two other forest ownership groups (Table 1). There was no differences in the proportion of mature forest area in favour of the state owned forests (Metsäntutkimuslaitos 1996).

The spatial correlation of the dominating tree species was relatively low in all forest ownership groups, but in forests owned by private forest owners it was the lowest (Table 2). In forests owned by forest industrial companies or by the state, pine dominated forests grew, on average, in less isolated or larger patches, compared to privately owned forests (Table 2). On the other hand,

Table 1. Spatial distribution (variogram) and connectivity of stand development stages estimated by forest ownership groups (P = Privately owned forests, F = Forests owned by forest industrial companies, S = Forests owned by the state). Variograms are estimated for all stand development stages (all). Connectivity is presented separately for every stand development stage (Stand development stages: 1 = Seedling and sapling stands, 2 = Young stands, 3 = Middle-aged stands, 4 = Mature stands). u = distance (m).

u	Variogram			Connectivity											
	P all	F all	S all	P				F				S			
				1	2	3	4	1	2	3	4	1	2	3	4
200	0.31	0.26	0.25	0.14	0.33	0.26	0.20	0.19	0.42	0.22	0.23	0.21	0.47	0.27	0.32
400	0.33	0.30	0.28	0.02	0.11	0.07	0.06	0.02	0.20	0.06	0.06	0.01	0.25	0.09	0.13
600	0.34	0.31	0.30		0.04	0.02	0.02	0.01	0.10	0.02	0.02		0.14	0.04	0.05
800	0.35	0.30	0.30		0.01	0.01			0.05	0.01	0.02		0.09	0.01	0.02
1000	0.35	0.32	0.30		0.01				0.02		0.01		0.06		0.01
1200	0.35	0.33	0.32						0.01		0.01		0.04		
1400	0.35	0.30	0.30										0.02		
1600	0.35	0.31	0.31										0.02		
1800	0.34	0.34	0.29										0.01		
2000	0.35	0.28	0.32												

Table 2. Spatial distribution (variogram) and connectivity of dominating tree species estimated by forest ownership groups (P = Privately owned forests, F = Forests owned by forest industrial companies, S = Forests owned by the state). Variograms are estimated for all dominating tree species (all). Connectivity is presented separately for different tree species (1 = Scots pine, 2 = Norway spruce, 3 = Silver birch, 4 = Pubescent birch). u = distance (m).

u	Variogram			Connectivity											
	P all	F all	S all	P				F				S			
				1	2	3	4	1	2	3	4	1	2	3	4
200	0.18	0.15	0.11	0.49	0.33	0.07	0.11	0.53	0.29		0.08	0.61	0.24	0.07	0.08
400	0.20	0.15	0.12	0.26	0.13	0.03	0.02	0.30	0.11		0.03	0.38	0.09		
600	0.21	0.15	0.11	0.14	0.05	0.01		0.18	0.06		0.01	0.25	0.04		
800	0.22	0.17	0.12	0.08	0.02			0.11	0.04			0.17	0.02		
1000	0.22	0.16	0.11	0.05	0.01			0.07	0.03			0.12	0.01		
1200	0.22	0.17	0.13	0.03				0.04	0.02			0.08			
1400	0.23	0.19	0.13	0.01				0.03	0.01			0.06			
1600	0.22	0.18	0.12	0.01				0.02	0.01			0.04			
1800	0.21	0.17	0.15	0.01				0.01	0.01			0.03			
2000	0.22	0.16	0.12					0.01				0.02			

the connectivity of stands dominated by spruce or deciduous tree species was slightly greater in forests owned by private people (Table 2).

The spatial correlation of the two data categories, i.e. forests including one tree species and forests including several tree species, was low and varied greatly between different forest ownership groups (Table 3). However, there was a clear trend in the connectivity of pure (one species) and mixed forests. In privately owned forests, mixed forests were more connected than pure forests (Table 3). In the forests owned by the state or by the forest industrial companies the results were the opposite. When the number of vertical tree storeys was examined, the results correspond to the number of tree species (Table 4). However, there were no clear differences between privately owned and state owned forests in the level of connectivity of forests with heterogeneous vertical structure (Table 4).

Table 3. Spatial distribution (variogram) and connectivity of forests of one or several tree species estimated by forest ownership groups (P = Privately owned forests, F = Forests owned by forest industrial companies, S = Forests owned by the state). Variograms are estimated for both classes (all). Connectivity is presented separately for two data segments (1 = one tree species, 2 = several tree species). u = distance (m).

u	Variogram			Connectivity					
	P all	F all	S all	P		F		S	
				1	2	1	2	1	2
200	0.21	0.24	0.21	0.32	0.42	0.38	0.31	0.42	0.38
400	0.22	0.23	0.22	0.12	0.18	0.15	0.11	0.18	0.15
600	0.23	0.22	0.23	0.04	0.08	0.06	0.04	0.08	0.06
800	0.24	0.25	0.23	0.02	0.04	0.03	0.02	0.04	0.02
1000	0.23	0.24	0.22	0.01	0.02	0.01	0.01	0.02	0.01
1200	0.23	0.24	0.22		0.01			0.01	
1400	0.24	0.22	0.23						
1600	0.24	0.25	0.21						
1800	0.24	0.25	0.26						
2000	0.24	0.23	0.21						

Table 4. Spatial distribution (variogram) and connectivity of forests of one or several tree storeys estimated by forest ownership groups (P = Privately owned forests, F = Forests owned by forest industrial companies, S = Forests owned by the state). Variograms are estimated for both classes (all). Connectivity is presented separately for two data segments (1 = one tree storey, 2 = several tree storeys). u = distance (m).

u	Variogram			Connectivity					
	P all	F all	S all	P		F		S	
				1	2	1	2	1	2
200	0.23	0.22	0.22	0.34	0.36	0.41	0.29	0.39	0.38
400	0.24	0.22	0.23	0.12	0.14	0.18	0.08	0.17	0.15
600	0.24	0.24	0.24	0.05	0.06	0.09	0.02	0.07	0.07
800	0.24	0.23	0.23	0.02	0.02	0.04	0.01	0.03	0.03
1000	0.24	0.23	0.24	0.01	0.01	0.02		0.01	0.02
1200	0.24	0.25	0.25			0.01			
1400	0.25	0.23	0.24			0.01			
1600	0.24	0.26	0.23			0.01			
1800	0.24	0.27	0.24						
2000	0.24	0.22	0.21						

Discussion

The results on the spatial distribution and connectivity of dominating tree species, tree species composition and vertical structure of forest stock show that the differences in stand management among the forest ownership groups (Maltamo *et al.* 1997) have also affected the forest landscape structure. The more continuous patches of young and middle-aged forests in the state owned forests and those owned by the forest industrial companies should have provided better conditions in these ownership categories for the spatial connectivity of dominating deciduous tree species or the number of tree species compared to privately owned forests. The result was, however, quite the opposite. The complexity of the forest habitat increases with the age, which is shown in the state-owned forests where the connectivity of the mature forests is high. This causes also an increase in the connectivity of the number of tree storeys. However, in privately owned forests, where the connectivity of mature forests is lower than in the forests owned by the forest industrial companies or the state, the connectivity of the vertical heterogeneity was still at the same level than in the state-owned forests.

The within-stand heterogeneity, required by many forest species, is better ensured in privately-owned forests due to more heterogeneous management regimes applied (Maltamo *et al.* 1997). This also leads to the greater spatial correlation and connectivity of the stand structure characteristics. On the other hand, small management units in privately-owned forest holdings lead to a more fragmented forest landscape. This is partly avoided in forests owned by the state or forest industrial companies, which have more continuous patches of a single successional stage of forest. This can be, however, regarded only as a potential for the future, because successional stages of young forest have currently the greatest spatial correlation and connectivity.

The main purpose of NFI is to estimate the timber resources in order to ensure the sustainability of timber supplies at the national level. The clusters are designed by minimising the error variance of the volume estimates of one cluster (Matérn 1960, Ranneby *et al.* 1987, Korhonen and Maltamo 1991). The distance between sample plots within clusters is rather long for spatial analysis. Even though there is a great amount of variation in the forest characteristics between the sample plots in a cluster and many plot-to-plot distances are lacking, large scale forest inventories are still worth using when an averaged analysis of the landscape pattern for a large forest area is required. This is, firstly, due to the large temporal and geographical scale of NFI, and secondly, due to lack of defined knowledge about the landscape pattern of Finland.

The usability of the indirect indicators of forest biodiversity, such as stand structure characteristics and average forest landscape pattern, is highly dependent on the level of basic knowledge on the habitat requirements of species. Unfortunately, this basic knowledge is deficient. Also, very little is known about the effects of changes in forest landscape structure on individual species. The scientific justification for new forest management and landscape ecological planning would desperately need more results on the habitat requirements of species at different stages of their life-cycles. However, it is unlikely that the autoecological requirements of all species within an area will ever be known. Therefore, if the preservation of forest biodiversity is set as a goal for forest policy, the best way to accomplish this task is to apply a precautionary principle, i.e., reacting to the changes in the natural forest dynamics at the stand and landscape levels (e.g., Naesset 1997). This would mean maintenance of the natural habitat variation created by the spatial variation of soil properties and topography. In this kind of approach, for example, no artificial limitations for the maximum size of the management units are needed. When landscape ecological approach is applied in tactical forest planning, the differences in the existing landscape pattern between the forest ownership groups should be considered. Based on these results, the role of forests owned by various forest ownership groups would be different in preserving biodiversity in the production forests of Finland. Due to the differences in spatial scale and intensity of the forestry operations between forest ownership groups, critical forest structure characteristics required by certain species would be easier to preserve within stands in privately owned forests. On the other hand, certain landscape characteristics (e.g., contagion) of successional stages of forests would be easier to manage in forests owned by the state or forest industrial companies. However, integrating the indicators connected to landscape ecology into forest planning in Finland will be a time consuming and difficult political process due to the prevailing forest ownership structure.

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