Impact of Regeneration Method on Stand Structure Prior to First Thinning

Comparative study North Karelia, Finland vs. Republic of Karelia, Russian Federation

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Uuttera, J. & Maltamo, M. 1995. Impact of regeneration method on stand structure prior to first thinning. Comparative study North Karelia, Finland vs. Republic of Karelia, Russian Federation. Silva Fennica 29(4): 267–285.

Comparisons were made between artificially and naturally regenerated stands in the south-eastern part of North Karelia, Finland, and naturally regenerated stands in the western parts of the Republic of Karelia, Russian Federation. The effect of soil fertility and silvicultural operations on the stand structure was also investigated.

The results of the study show clearly that when forests are artificially regenerated the stand structure includes less variation when compared with the stands naturally regenerated. Differences between the regeneration methods are clearer the more fertile the forest site is. Within the regeneration method there is also a clear trend in stand structure, with the variation decreasing the poorer the site. The effect of silvicultural operations, i.e. the cleaning of the sapling stand, has disappeared by the time of first thinning, although it appears to have a permanent effect on the dynamics of the tree species within a stand.

The variation of the stand structure can be regarded as an essential factor for the potential biodiversity of the stand also at its young vegetation succession stage. This capacity for maintaining the forest biodiversity, developed at the young vegetation succession stage, becomes increasingly important in subsequent vegetation succession stages. Natural regeneration provides improved possibilities for the operations preserving forest biodiversity, as it generates more dense stands with a wider variation in stand structure, compared to artificial regeneration.

Keywords regeneration strategy, stand structure, potential biodiversity.
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Accepted December 8, 1995

1 Introduction

Preserving the biodiversity of forests has been stated as a common target in several international conferences. The United Nations Conference on Environment and Development Process (UNCED), held in Rio de Janeiro in 1992 (Global biodiversity strategy... 1992), and the resolution produced in conjunction with the Ministerial Conference on the Protection of Forests in Europe, held in Strasbourg 1990 and in Helsinki 1993 (Sound forestry... 1993a, 1993b), are examples of actions that call for the monitoring of forest biodiversity and further development of forest management regimes to maintain ecological sustainability.

Biodiversity has traditionally been assessed at three levels: genetic-, species- and habitat- or ecosystem level (e.g. Erickson 1994). However, there are natural problems in the practical use of methods measuring genetic and species variation (Väisänen and Järvinen 1977, Usher 1980, Magurran 1988, Schowalter 1989, Solbrig 1991, Delin 1992). In addition, several studies have stated that 'diversity indices' reflecting species richness fail to represent long term changes in biodiversity (e.g. Köhl and Zingg 1995). The measurement of habitat structure and composition is significantly 'easier and quicker' compared to methods based on genetic variation and species richness. Therefore, habitat approach appears to be the most promising possibility to measure biodiversity for the purposes of forest management and planning.

As many of the forest flora and fauna species are fixed to a certain habitat and structural elements (Camp 1994, Sukatšev 1960), the habitat composition of a forest area reflects its species richness. In the approach of habitat variation the biodiversity of a forest area is determined as a potential, not actual biodiversity. This is not, however, a disadvantage to the approach, because even a 'empty' habitat may have a crucial effect on the survival of species due to metapopulation dynamics (Gilpin and Hanski 1991).

Forest habitat is a combination of climate, soil, water resources, and vegetation to which species have adjusted and on which they depend. Habitat consists of (i) physical habitat and (ii) community habitat (Fig. 1). Physical habitat comprises of the climate, topography, soil characteristics and water resources of the site. The physical habitat provides a suitable environment and the possibility for a certain community habitat to exist. Due to natural vegetation succession there develops on every physical habitat several vertical vegetation layers (Camp 1994). The layers of forest vegetation can be regarded as the community habitat, provided by the physical habitat and formed by the structural species (Huston 1994). In the natural state, forest vegetation develops towards to the maximal use of the useable biological productivity of the physical habitat (Sukatšev 1960).

Every vertical layer of the community habitat is crucial to the functioning of the whole ecosystem (Camp 1994). As the existing vegetation layers provide the possibility for a particular flora and fauna population to exist, the physical and community habitats create the living conditions for associate species within the habitat (MacArthur and MacArthur 1961, Willson 1974, Cody 1985). The ecosystem and forest community variation is based on these three components (Huston 1994) (Fig. 1). To be able to evaluate the potential biodiversity of the forest habitat, there has to be information of the essential components on the physical and community habitats.

During the past eight decades, a tradition deriving from A.K. Cajander (Cajander 1926) has dominated the forest vegetation research in Finland. A forest site type classification that is based on ground vegetation describes to some extent the nutrient content and water regime of the soil (Cajander 1949, Kalela 1961, Mikola 1982). For this reason it is a good criterion to estimate the productivity of the physical habitat. These estimations are, however, comparable only within the same climatic and vegetation zone.

Tree species are the most dominant species of the forest vegetation association in the boreal coniferous forests (Sukatšev 1960). The upper vegetation layers have a crucial effect on the climate-, soil- and hydrological conditions at the lower layers. The structure of forest stocking, i.e. the number of existing vegetation layers, the number of existing tree species and the diameter distribution of the stocking have a great impact on the potential diversity of forest species (Stage

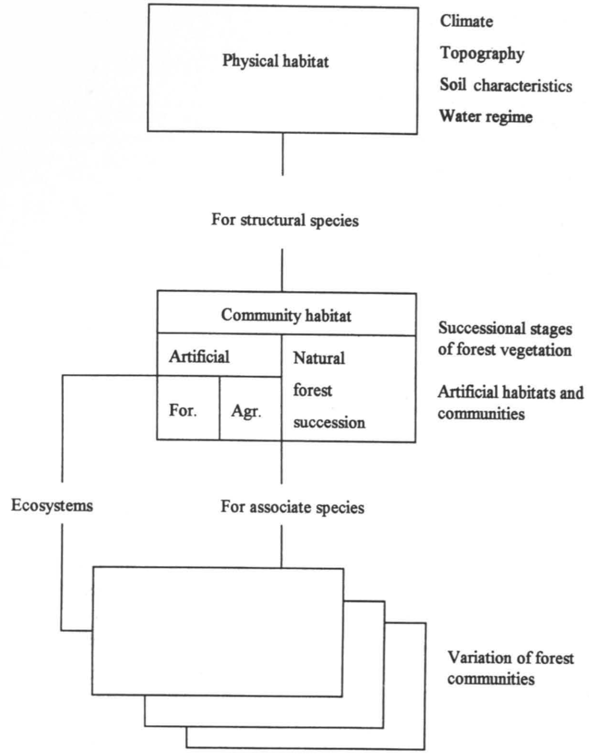

Fig. 1. The concept of habitat and ecosystem diversity.

1973, Angelstam et al. 1990). Therefore, the mixture of tree species and the variation of the stand structure can be regarded as indicators that reflect the variation of the community habitat and the diversity of the potential flora and fauna species of the habitat.

In a natural state the variation of the community habitats in boreal coniferous forests is maintained by the processes within the large and small vegetation succession cycles (Kuusela 1990). Due to the intensive prevention of wild fires and biotic disturbances the large and small natural vegetation succession cycles are nowadays mostly maintained by silvicultural actions. The conducted silvicultural operations and forest management should follow the regional natural dynamics of forests to preserve its community habitat variation determined by the physical habitat distribution.

In a natural state, after a disturbance, the vegetation succession of the boreal zone forest begins with an invasion of pioneer deciduous tree species, such as silver birch (*Betula pendula* Roth.), pubescent birch (*Betula pubescens* Ehrh.) and European aspen (*Populus tremula* L.). Scots pine (*Pinus sylvestris* L.) is also a common pioneer species in dry and poor forest site types, although it is also a strong climax-species (Kuusela 1990). During the large and small succession cycles pioneer species give growing space to the climax species. The most common climax-species in the boreal zone are the Norway spruce (*Picea abies* Karst.) on the moist and fertile forest sites and the Scots pine on the poorer forest sites. In this state, forests have reached their steady-state of climatic climax (Tseplyaev 1965). Applied forest management regimes should promote this natural tree species dynamics and preserve processes maintaining potential biodiversity.

The young stand is commonly known to be the vegetation succession state that have the greatest species richness (e.g. Shafi and Yarranton 1973, Horn 1974, Malmer et al. 1978, Lindholm and Vasander 1987, Zopel 1989). The forest species that prefer this state of succession, have not suffered from human actions and intensive forestry (Väisänen 1992). However, the stand structure of this state of mixed young stands has an essential effect on the existence of the components of community habitat in the subsequent succession stages of the stand. The choice of the regeneration method plays an essential role in the future development of the stand.

The two options for regeneration in forest management are natural and artificial. The important factors from the silvicultural point of view are the spatial distribution, diameter distribution and the tree species mixture of the regenerated stand. The same factors also have an effect on the potential biodiversity of the stand (Buongiorno et al. 1994).

From the economical point of view, a completely naturally regenerated stand can be too dense, and waste the biological potential of the site to non-favoured tree individuals. However, the density of the stand is most likely to increase tree mortality and the separation of the vegetation layers during the further development of the stand. This increases the essential biodiversity key-elements, e.g. the variation of the community habitat and decaying biomass, within the stand.

The aim of this study was to investigate the impact of the regeneration and silvicultural methods on the stand structure prior to the first thinning. Stand structure was studied in south-eastern part of North Karelia, Finland and in southwestern part of Republic of Karelia, Russian Federation.

2 Material and Methods

2.1 Material

2.1.1 Test Areas and Management History

Comparison of the test areas in the Republic of Karelia and Finland offer good possibilities to monitor the impact of different forest management regimes on the biodiversity of forests. The test areas of the study were (Fig. 2):

1. Ladenso forest inventory area, Pitkäranta, Republic of Karelia, Russian Federation (374 000 ha).
2. south-eastern part of North Karelia, Finland (municipalities of Kiihtelysvaara, Kitee, Pyhäselkä, Rääkkylä, Tohmajärvi, Tuupovaara and Värtsilä; 350 011 ha).

Both areas belong to the same subboreal vegetation zone (Ahti et al. 1968), and have similar climatic conditions. Also, parts of the both test areas belong to the same regional soil fertility zone, so-called Sortavala grove district, formed after the last glacial period (Kalliola 1973).

The natural forest dynamics are similar in both test areas but the history of land use and forestry practices have been considerably different during the last fifty years. In Finland both regeneration methods, natural and artificial, have usually included the cleaning of the regeneration areas and of the sapling stand. The purpose of these silvicultural actions is to increase the growing space of the chosen economically valuable individual trees. Cleaning can decrease the variation in diameter distribution and also the number of existing tree species, because the coniferous tree species are often favoured. However, the deciduous tree species regenerate a fast-growing new generation by coppicing (Maltamo et al. 1989).

In Russian Karelia, the stands are almost totally (80 %) regenerated by natural regeneration. In addition to this, 50 % of these clear cut areas are not actively regenerated. Natural regeneration is made whether by utilizing understorey, parent seed trees, regenerative potential of neighboring forest stand or selective cutting. If parent seed trees are used they are not removed from the sapling stand. Methods like selective cutting, where 10–40 % of the stock volume is left to the cutting area, may cause a very irregular and wide

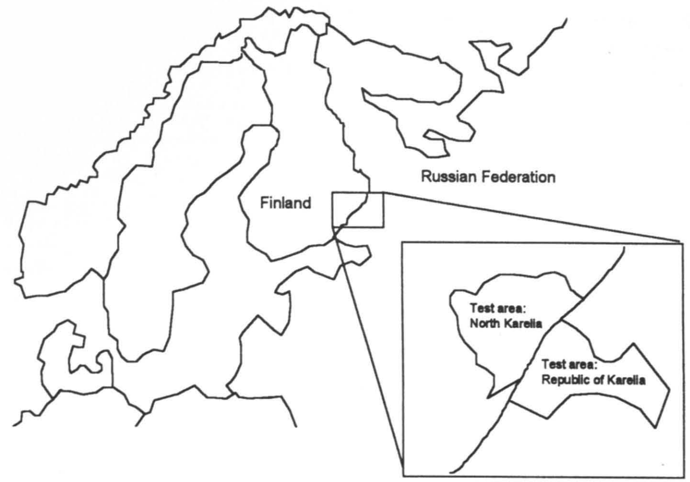

Fig. 2. Locations of the test areas.

stand structure in the next tree generation. Artificial regeneration is applied with greater density (7000–8000 stems/ha) compared to Finland.

The Russian silvicultural methods do not include the cleaning of regeneration areas. In recent years the lack of economical resources has also decreased the cleaning of the sapling stands. In the whole area of the Republic of Karelia the proportion of cleaned sapling stands is about 1 % of the total area of sapling stands (Myllynen and Saastamoinen 1995).

2.1.2 Forest Data Measurements

The data used in this study was the forest resource information from the 8th National Forest Inventory (NFI) in the province of North Karelia, Finland, and from the Ladenso Forest Inventory, in the Republic of Karelia, Russian Federation, measured by the same field instructions as the Finnish NFI (Valtakunnan metsien... 1989, Ladenson metsien... 1991).

The National Forest Inventory of Finland and the Ladenso Forest Inventory were based on systematic cluster sampling. In the NFI one cluster consisted of 21 sample plots which were in the shape of a half-square. The distance between the plots within a cluster was 200 metres, and the distance between clusters was 8 kilometres in a north-south direction and 7 kilometres in an east-west direction. In the Ladenso Forest Inventory the number of plots in a cluster was 15 and the distance between plots 300 metres. The distance between clusters was 7 kilometres in a north-south direction and 6 kilometres in an east-west direction.

The stocking of a stand was described by variables *basal area, regeneration method, stage of stand development, tree species composition, diameter of basal area median tree, age of stocking* and *damage*. The tree data in sample plots was measured by relascope factor 2. Variables *tree species, diameter* and *tree class* were observed or measured from every tree included in a sample plot. Thus the diameter distribution obtained from sample plots is weighted by basal area. The relascope plot information represents stocking of the whole stand within which the plot is measured.

From the whole forest inventory data the sample plots with a young stocking before first thinning were selected. The data was divided into three categories:

I Artificially regenerated stands in North-Karelia (aNK, 96 sample plots),
II Naturally regenerated stands in North-Karelia (nNK, 78 sample plots), and
III Naturally regenerated stands in the Ladenso forest inventory area (nLAD, 116 sample plots).

All stands were regenerated naturally in the Ladenso forest inventory area.

2.2 Methods

2.2.1 Comparison Sectioning and Stand Structure Variables

The impact of different regeneration methods was first investigated in general of the whole data, and second on different forest sites. In addition, comparisons were made on different forest sites, within stands divided according to the conducted silvicultural operations.

The forest sites compared were groves, grovelike sites, moist sites and dry sites. These classes correspond to the Cajanderian forest site types (Cajander 1926): Grove = Oxalis-Maianthemum Type, Grovelike site = Oxalis-Myrtillus Type, Moist site = Myrtillus Type and Dry site = Vaccinium Type. There are some differences in distribution of forest site types between the selected data categories (Fig. 3). This is due to the greater area proportion of the Ladenso forest inventory area belonging to the Sortavala grove district.

The stand structure was investigated with the statistics of six variables: (1) *the diameter of the median tree*, (2) *range of sampled diameters*, (3) *age of the forest stock*, (4) *basal area of the stand*, (5) *estimated number of existing tree storeys*, and (6) *the number of the existing tree species*. The statistical significance of the differences between the means of the stand structure variables between the data categories were examined.

2.2.2 Diameter Distribution Smoothing

For estimating the number of the existing tree storeys the basal area diameter distribution was

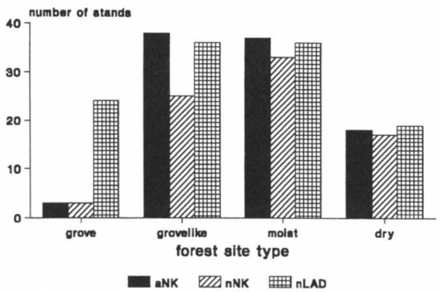

Fig. 3. The distribution of the forest site types in data categories. I. Artificially regenerated stands in North Karelia (aNK), II. Naturally regenerated stands in North Karelia (nNK) and III. Naturally regenerated stands in Ladenso forest inventory area (nLAD). Forest site types: Grove = Oxalis-Maianthemum Type, Grovelike = Oxalis-Myrtillus Type, Moist = Myrtillus Type and Dry = Vaccinium Type.

first modified to stem numbers per hectare using the following formula (Kuusela 1966):

$$n = \frac{10000}{\Pi\left(0.5d\sqrt{\frac{10000}{q}}\right)^2} \qquad (1)$$

where
n = number of stems per hectare
d = diameter, m
q = relascope factor, $m^2\ ha^{-1}$

This was carried out to get equal weighting to all sampled trees. The calculated stem number diameter distribution was then smoothed to a continuous form in order to make the sampled distribution better describe the underlying population (Droessler and Burk 1989). The smoothing was carried out using non-parametric Kernel estimation. The number of the existing tree storeys was interpreted from the peaks of the kernel density estimator.

In non-parametric estimation methods the diameter distribution is determined by the data itself instead of estimating the parameters of some

known distribution (Silverman 1986). The kernel estimator is very flexible and makes it possible to describe stands with an irregular diameter distribution in only one density estimate. These irregular diameter distributions occur particularly in young mixed stands (Cao and Burkhardt 1984). The kernel estimator is the sum of the kernels centred at the observation defined by the following formula:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \qquad (2)$$

where
n = number of observations
h = smoothing parameter
K = kernel function
x = sample from unknown density function
X_i = random variable

The kernel function K determines the kernels' shape. In this study, the kernel function was chosen to be Gaussian. The smoothing parameter h describes the kernels' width.

The selection of the window width parameter h is the most difficult problem associated with the kernel method, because it has the most dominating influence on the shape of the kernel density estimate. Some suitable methods for determining the window width have been presented (e.g. Altman 1990).

In this study, it was important to achieve constant window width for all stands to enable the comparison of distributions between stands. The optimal value for smoothing parameter h was not selected separately for each plot but a suitable value for the data as a whole was found. A sample of plots was fitted using various values of h and then plotted to determine the final value. After choosing the window width the kernel density estimators were interpreted graphically by plotting smoothed diameter distributions for each stand. The interpretation of the number of tree storeys is dependent on the choice of window parameter h. The bigger the window width, the less peaks there are in the kernel density estimator.

3 Results

3.1 Diameter Distribution Smoothing

In kernel estimation the value of window width was chosen to be 2 cm in all stands. Some examples of smoothed distributions are given in Figs. 4 and 5. The chosen plots were Norway spruce dominated stands on grovelike forest sites and Scots pine dominated stands on dry forest sites in all three data categories.

The shapes of kernel estimators in data categories aNK and nNK (Fig. 4) were very close to each other on the grovelike sites. In both cases there existed a spruce storey below a birch storey. This is often the case when spruce stands are regenerated in Finland. In category nLAD (Fig. 4) the diameter distribution on grovelike sites was clearly multimodal and very wide. There exists a spruce storey below, but above this there grows different sized spruces, both birch species and also European aspen. All these were remnants from the previous succession rotations.

In all examples of dry sites there existed only Scots pine. The distribution of Scots pine was clearly unimodal and close to the normal distribution in category aNK (Fig. 5). In category nNK (Fig. 5) there were some parent seed trees left and therefore the distribution is bi-modal. In category nLAD (Fig. 5) the distribution was slightly bi-modal. In both categories nNK and nLAD the diameter range was very wide, which shows that the stocking have germinated over several years after clear cutting.

3.2 Stand Structure Variation

To get an overall picture of the phenomenon the statistics of the stand structure, variables were calculated from the data categories as a whole, without any sectioning due to soil fertility. The limits, means and standard deviation of the stand structure variables are presented in Table 1.

In the overall results a logical trend in the means of stand structure variables could be seen. All means of the chosen stand structure variables increased from the artificial regeneration to the natural regeneration, and were at their greatest in the Ladenso forest inventory area. This

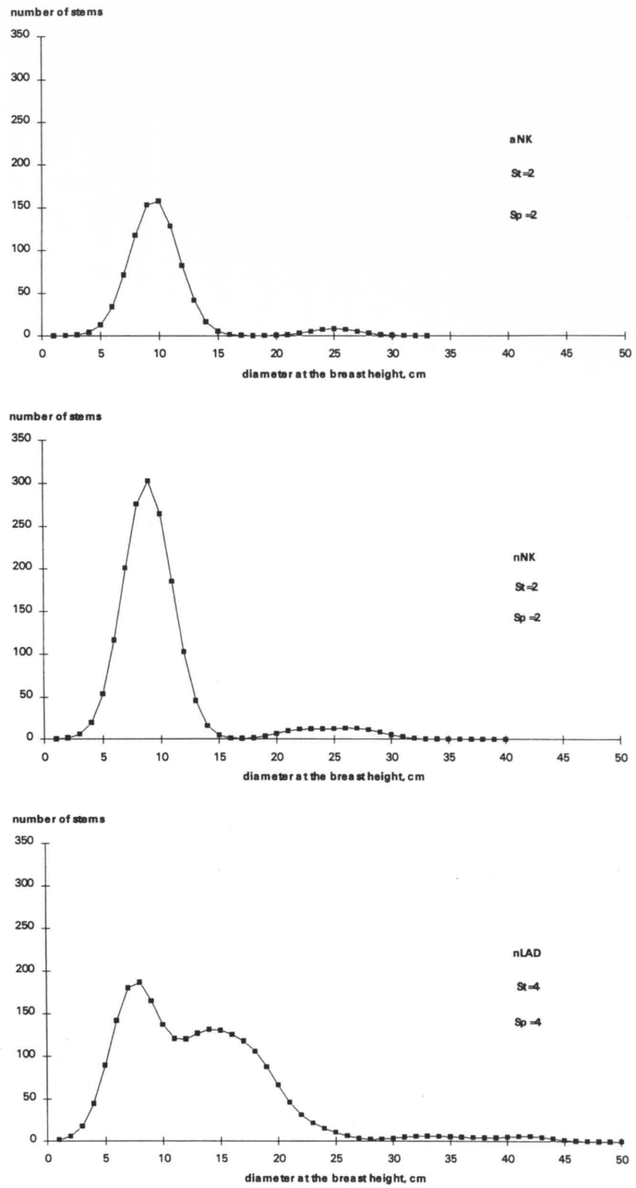

Fig. 4. Examples of the smoothed Kernel density estimators in Norway spruce dominated stands on grovelike sites in data categories I. Artificially regenerated stands in North Karelia (aNK), II. Naturally regenerated stands in North Karelia (nNK) and III. Naturally regenerated stands in Ladenso forest inventory area (nLAD). Number of tree storeys = St, number of tree species = Sp.

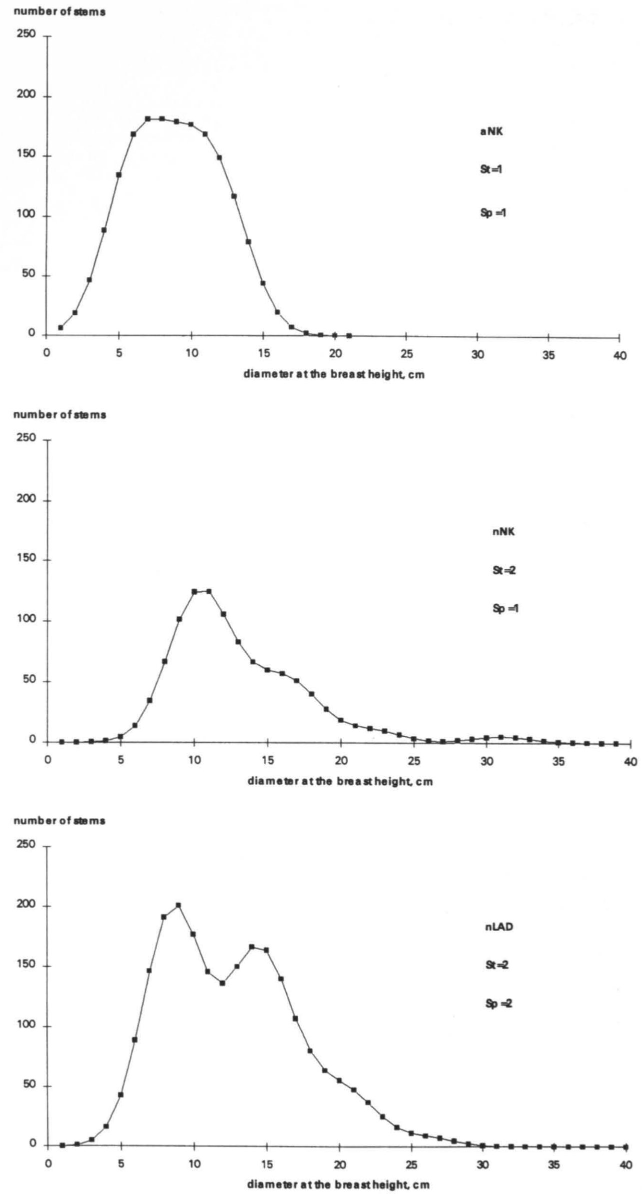

Fig. 5. Examples of the smoothed Kernel density estimators in Scots pine dominated stands on dry sites in data categories I. Artificially regenerated stands in North Karelia (aNK), II. Naturally regenerated stands in North Karelia (nNK) and III. Naturally regenerated stands in Ladenso forest inventory area (nLAD). Number of tree storeys = St, number of tree species = Sp.

Table 1. The limits (min, max), mean values (mean) and standard deviation (Sd) of the stand structure variables in data categories. I. Artificially regenerated stands in North Karelia (aNK), II. Naturally regenerated stands in North Karelia (nNK) and III. Naturally regenerated stands in Ladenso forest inventory area (nLAD).

Category	Variable		min	max	mean	Sd
I. aNK	D	(cm)	4.00	29.50	12.30	3.90
	Age	(yrs.)	12.00	40.00	26.00	5.19
	B-A	(m^2 ha^{-1})	3.00	30.00	15.30	5.57
	Range	(cm)	0.00	64.00	10.60	9.24
	St		1.00	3.00	1.34	0.51
	Sp		1.00	4.00	1.74	0.87
II. nNK	D	(cm)	4.00	29.75	13.70	4.51
	Age	(yrs.)	20.00	80.00	41.00	12.79
	B-A	(m^2 ha^{-1})	4.00	38.00	17.40	7.14
	Range	(cm)	0.00	47.00	13.60	8.82
	St		1.00	3.00	1.62	0.63
	Sp		1.00	4.00	1.90	0.86
III. nLAD	D	(cm)	6.76	29.66	16.10	5.59
	Age	(yrs.)	21.00	85.00	46.00	12.06
	B-A	(m^2 ha^{-1})	1.00	39.00	20.60	8.13
	Range	(cm)	0.00	60.00	20.30	12.17
	St		1.00	4.00	1.97	0.85
	Sp		1.00	6.00	2.50	1.16

Explanations of the variable codes: D = mean diameter of the median trees, Age = mean age of the stands, B-A = mean basal area of the stands, Range = mean of diameter ranges, St = mean of the number of tree storeys, Sp = mean number of existing tree species.

was mainly due to the different time period for the establishment of stands with different regeneration methods.

When using natural regeneration, the age- and diameter distribution develops through seedling germination in different years after the disturbance. As the survived seedlings grow the quantity of regenerated seedlings decreases as a function of time. However, as a certain proportion of the seedlings survive annually, the number of stems i.e. the density of the stand increases. As a result of these processes a stand regenerates with relatively wide heterogeneity in age- and diameter distribution (Kellomäki 1991).

By shortening the time of the stand establishment with artificial regeneration the result of regeneration is usually more like a monoculture forest, one tree species and a one size tree layer. However, on sites regenerated artificially, there is always a certain amount of naturally regenerated seedlings. This fact increases the heterogeneity of the artificially regenerated stands (Kellomäki 1991). If artificial regeneration is not successful, supplementary plantings may be necessary, which may also increase the stand structure heterogeneity.

With natural regeneration the stand achieves a satisfactory density 10–20 years later compared to artificial regeneration (Hänninen et al. 1972, Skogstyrelsen 1975). The time period observed in several previous studies could be clearly seen from the mean ages of the stands (Table 1).

When the stand is established as a result of regeneration over several years it has a wider variation in age and diameter distribution compared to artificial regeneration. The number of existing tree storeys, *St*, increases also due to this same reason. Because the value of the mean diameter is connected to the age distribution of stands, the time period for the establishment of stands with different regeneration methods could also be seen from the mean diameter and the mean of the diameter ranges (Table 1).

Table 2. The statistically significant differences in means of the diameter range, means of the number of tree storeys and the means of the number of tree species between the data categories: I. artificially regenerated stands in North Karelia (aNK), II. naturally regenerated stands in North Karelia (nNK) and III. naturally regenerated stands in Ladenso forest inventory area (nLAD).

	T-value I vs. II	T-value I vs. III	T-value II vs.III
Range (cm)	2.13 *	6.57 ***	4.41 ***
St	3.06 **	6.63 ***	3.38 ***
Sp	1.19	5.50 ***	4.20 ***

Explanations of the variable codes: Range = mean of diameter ranges, St = mean of the number of tree storeys, Sp = mean number of existing tree species. Statistically significant differences are compared between different data sections, *** = prob(T<t) < 0.001, ** = 0.001 < prob(T<t) < 0.01 , * = 0.01 < prob(T<t) < 0.05.

Table 3. The proportions (%) of dominant tree species in different data categories, II. naturally regenerated young stands in North Karelia (nNK), III. naturally regenerated young stands in the Ladenso inventory area (nLAD) and the whole forest resource data of the South-Eastern part of North Karelia (NKw) and the Ladenso forest inventory area (LADw) (Uuttera et al. 1995), including all stages of forest succession.

Tree species	II nNK	NKw	III nLAD	LADw
No stocking		1.4		0.3
Scots pine	41.5	53.0	26.7	37.4
Norway spruce	37.8	35.8	16.4	42.1
Silver birch	2.4	3.9	15.5	7.2
Pubescent birch	9.8	4.8	13.8	8.8
European aspen	1.2	0.1	5.2	1.9
Grey alder	7.3	0.9	20.7	1.9
Other deciduous	0.0	0.1	1.7	0.4
Total	100.0	100.0	100.0	100.0

The naturally regenerated stands are also usually more dense and include more tree species than artificially regenerated stands. This could be seen from the stand structure variables *B-A* and *Sp* (Table 1). The stocking of the stand separates into different tree storeys more readily in dense stands due to the competition between individual trees (Table 1). On avergage the diameter distribution was nearly bi-modal in the Ladenso forest inventory area and close to uni-modal in the artificially regenerated stands of North Karelia.

The variables that best reflects the stand structure, i.e. *Range*, *St* and *Sp*, were selected for closer investigation. The statistical significance of the differences between the means of the chosen variables is presented in Table 2.

The differences between data categories were statistically very significant, except for the mean number of existing species in the comparison of artificial and natural regeneration in North Karelia. This may have been due to the silvicultural operations, forest site type distribution and seed material available on the Finnish side.

To examine the existing potential seed material for natural regeneration in North Karelia compared to the Ladenso inventory area, the proportion of dominant tree species were calculated from the data categories II and III (Table 3).

From the proportions of the existing dominant tree species in naturally regenerated stands on the Finnish and the Russian side could be seen that the seed material available has more variation in the Ladenso forest inventory area.

On the Finnish side the proportions of dominant tree species in the vegetation succession stage of young mixed forests seemed to equal the proportions of the dominant tree species in the following succession stages. The proportion of silver birch became even greater as the vegetation succession developed further. This could be a result of favouring silver birch when thinning middle-aged forests.

In the Ladenso forest inventory area there were clear natural dynamics of the dominant tree species. Here the proportion of pioneer tree species was greater than the proportion of climax tree species in the vegetation succession stage of young mixed stands. In the following succession stages the pioneer tree species gave more space to climax tree species. This could be seen especially in the case of grey alder (Table 3).

The greater proportion of deciduous tree species dominated stands in the Ladenso forest inventory area was partly due to the greater area proportion of groves in the test area. However, the proportions of dominant deciduous tree species were greater in the Ladenso forest inventory area compared to North Karelia during the whole vegetation succession and provided more variable seed material for the natural regeneration.

3.3 Effect of Soil Fertility on Stand Structure Variation

To examine the effect of forest soil fertility on the structure of stands before the first thinning, the chosen stand structure variables were calculated on different forest site types for every data category (Table 4).

Due to the small number of sample plots groves were not taken into account in the comparisons. In the Ladenso forest inventory area where the number of sample plots was reasonable, the variation of stand structure on groves and grovelike sites appeared to be similar.

The results of the comparisons of the stand structure variables on different forest site types showed the expected trend. The variation of the stand structure was at its greatest on naturally regenerated stands on fertile sites and decreased towards poorer sites, except in the case of tree storeys of naturally regenerated stands in North Karelia. If the parent seed trees on poorer sites were not removed this caused a bi-modal diameter distribution. When using artificial regeneration the variation of the stand structure was lower on all forest site types compared to natural regeneration. On very fertile sites differences between the regeneration methods were the highest and decreased towards poorer forest site types.

The differences in the number of existing tree species were not statistically significant between the regeneration methods in North Karelia. This may have been due to the potential seed material available as mentioned earlier. It was also clear that the greatest differences in stand structure variables between Finland and Russian Karelia occur on grovelike and moist sites. In North Karelia, the impact of the regeneration method on stand structure was at its clearest on poor sites.

The fertility of the forest site type has an impact on the structure of the established stand due to the competition of the ground layer vegetation. The most fertile forest sites provide better conditions for several deciduous tree species and the mixture of these species is greater the better the soil fertility (Räsänen et al. 1986). More intensive competition increases the time required to achieve satisfactory stand density, and greater mortality of seedlings will cause a larger variation in the separation of forest layers (Hynönen 1976).

3.4 Effect of Silvicultural Operations on Stand Structure Variation

It can be assumed that the cleaning of the sapling stand, which was the most common silvicultural operation made prior to first thinning, and the removal of parent seed trees have an effect on the dominant species. To investigate the impact of silvicultural operations, categories I and II were divided into two parts according to whether any silvicultural operations were made or not. There were 53 cleaned stands in category I and 25 in category II. Cleaning was not done in 43 plots in category I and in 53 plots in category II. In data category III no silvicultural operations were made and thus it was not taken into account.

The effect of the cleaning or the removal of seeding parent trees on the range of sampled diameters, on the mean number of existing species and on the mean number of the tree storeys was examined in data categories I and II (Table 5). The comparison of the effect of silvicultural operations was not made on groves because of the small number of the sample plots on this forest site. The negative effect of the cleaning of sapling stands on the stand structure is unquestionable. However, it could be seen from the results presented in Table 5 that this effect had more or less disappeared by the first thinning

Table 4. The means of stand structure variables and the statistically significant differences of the number of tree storeys and tree species of the different forest site types. Comparisons are made in the data categories: I. artificially regenerated stands in North Karelia (aNK), II. naturally regenerated stands in North Karelia (nNK) and III. naturally regenerated stands in the Ladenso forest inventory area (nLAD).

	I aNK	II nNK	III nLAD	T-value I vs. II	T-value I vs. III	T-value II vs.III
Groves						
D (cm)	17.7	17.3	17.9			
Age (yrs.)	20.0	28.0	48.0			
B-A (m^2 ha^{-1})	19.0	15.7	20.0			
Range (cm)	25.0	20.3	24.5			
St	1.67	1.67	2.08			
Sp	1.67	2.33	2.71			
Grovelike sites						
D (cm)	12.5	13.4	17.7			
Age (yrs.)	24.0	37.0	46.0			
B-A (m^2 ha^{-1})	14.0	19.2	20.1			
Range (cm)	10.7	15.1	20.6	1.91 *	3.85 ***	2.01 *
St	1.45	1.52	2.17	0.51	4.09 ***	3.63 ***
Sp	1.82	2.16	2.78	1.49	3.71 ***	2.21 *
Moist sites						
D (cm)	12.7	14.0	14.5			
Age (yrs.)	28.0	43.0	45.0			
B-A (m^2 ha^{-1})	17.6	17.1	22.7			
Range (cm)	10.7	12.8	19.8	1.13	4.61 ***	3.10 **
St	1.30	1.61	1.97	2.24 *	4.35 ***	2.07 *
Sp	1.86	1.88	2.56	0.07	3.13 **	3.19 **
Dry sites						
D (cm)	10.2	13.2	13.6			
Age (yrs.)	24.0	42.0	44.0			
B-A (m^2 ha^{-1})	12.4	15.8	18.7			
Range (cm)	7.7	11.6	15.4	2.09 *	3.40 ***	1.52
St	1.17	1.76	1.50	3.24 **	1.73 *	1.13
Sp	1.33	1.47	1.7	0.67	1.61	0.98

Explanations of the variable codes: D = mean diameter of the median trees, Age = mean age of the stands, B-A = mean basal area of the stands, Range = mean of diameter ranges, St = mean of the number of tree storeys, Sp = mean number of existing tree species. Statistically significant differences are compared between different data sections, *** = prob(T<t) < 0.001, ** = 0.001< prob(T<t) < 0.01 , * = 0.01<prob(T<t) < 0.05.

stage. In some cases, the effect was opposite from that expected and the cleaned stands had a wider variation. However, the stand structure variables of the forests that had not been cleaned, had mean values a little closer to those of the Ladenso forest inventory area.

3.5 Effect of Silvicultural Operations on the Natural Dynamics of Tree Species

Despite the fact that silvicultural operations before first thinning seemed to have no significant impact on the chosen stand structure variables,

Table 5. The effect of silvicultural operations before first thinning, i.e cleaning of the sapling stand, to the stand structure of artificially and naturally regenerated stands in North Karelia, data categories I. Artificially regenerated stands in North Karelia (aNK) and II. Naturally regenerated stands in North Karelia (nNK).

	aNK ncl	aNK cl	aNK T-value	nNK ncl	nNK cl	nNK T-value
Grovelike sites						
Range (cm)	11.82	9.76	0.70	15.83	12.6	0.71
St	1.41	1.48	0.33	1.72	1.57	0.62
Sp	1.74	1.71	0.77	2.17	2.14	0.05
Moist sites						
Range (cm)	11.62	10.05	0.76	12.78	13.0	0.04
St	1.43	1.19	1.59	1.5	1.33	0.87
Sp	2.19	1.62	1.87 *	2.0	1.73	0.95
Dry sites						
Range (cm)	8.25	7.2	0.44	12.5	7.33	1.34
St	1.13	1.20	0.41	2.0	1.67	0.48
Sp	1.38	1.3	0.25	1.43	1.67	0.63

Explanations of the variable codes: ncl = No cleaning, cl = Cleaning, Range = mean of diameter ranges, St = mean of the number of tree storeys, Sp = mean number of existing tree species. Statistically significant differences are compared between different data sections, *** = prob(T<t) < 0.001, ** = 0.001 < prob(T<t) < 0.01 , * = 0.01 < prob(T<t) < 0.05.

the treatment could affect the dynamics and relations of tree species within a stand. To examine the dynamics of tree species of different types, i.e pioneer and climax species, the means and maximums of the size distribution of different tree species on all forest sites were investigated (Table 6).

The silvicultural operations made in North Karelia changed the proportional relations of tree species (Table 6), even if they did not have a great effect on the stand structure variables. In the Ladenso forest inventory area, the pioneer deciduous tree species like silver birch and European aspen were in a separate upper tree storey on very fertile sites. On groves and grovelike sites Scots pine was in the same tree storey also, but these, as well as the largest European aspens, were often individual trees from the previous succession rotation left at the clear cutting. On the forest sites of poorer fertility in the Ladenso forest inventory area, Scots pine was the dominant pioneer tree species in relation to the size distribution.

On the Finnish side the same kind of natural tree species dynamics were not seen. It seems that the silvicultural operations before the first thinning decreased the natural competition advantage of the pioneer tree species and favoured the climax tree species.

When the dynamics of different tree species of the same succession cycle was examined, it could be seen that in the stage of young mixed stands the climax tree species had already gained the competitive advantage over the pioneer tree species. Scots pine was on average bigger than Norway spruce. The sizes of silver birch and Norway spruce were close to each other, but silver birch was bigger than pubescent birch. Grey alder was on average smaller than the other considered tree species.

Table 6. The averages of standwise mean and maximum diameters (cm) of tree species on different forest site types in data categories I. Artificially regenerated stands in North Karelia (aNK), II. Naturally regenerated stands in North Karelia (nNK) and III. Naturally regenerated stands in the Ladenso forest inventory area (nLAD).

	I aNK mean	I aNK max	II nNK mean	II nNK max	III nLAD mean	III nLAD max
Groves						
Scots pine					27.7	29.4
Norway spruce					19.9	26.0
Silver birch					18.4	27.5
Pubescent birch					17.9	20.8
European aspen					26.9	33.6
Grey alder					12.6	17.9
Other deciduous					9.4	13.0
Grovelike sites						
Scots pine	15.4	15.5	17.5	22.8	26.2	30.2
Norway spruce	15.4	19.0	14.2	22.0	19.2	24.7
Silver birch	14.0	16.6	20.0	20.8	26.1	30.4
Pubescent birch	8.9	9.0	11.3	13.7	18.6	22.9
European aspen					27.7	28.3
Grey alder	6.5	8.1	11.1	12.6	13.6	16.5
Other deciduous			7.7	8.5	10.7	13.1
Moist sites						
Scots pine	13.7	18.7	15.5	18.7	18.2	21.6
Norway spruce	11.8	14.8	11.9	17.2	17.5	24.0
Silver birch	12.3	14.3	11.4	12.3	17.7	22.2
Pubescent birch	11.2	12.0	13.3	15.3	11.8	16.4
European aspen	12.8	13.0			10.7	14.9
Grey alder	5.6	6.5			16.2	20.3
Other deciduous					8.1	9.0
Dry sites						
Scots pine	10.4	13.8	14.0	18.9	15.9	21.5
Norway spruce	11.5	12.3	11.8	15.4	12.9	18.2
Silver birch					13.2	14.3
Pubescent birch	4.8	7.5			10.5	12.6

4 Discussion

In this study the impact of the chosen regeneration method on the stand structure before first thinning was examined. The data used for the study was the forest resource data of the 8th Finnish National Forest Inventory from North Karelia and the data from the Ladenso forest inventory, Karelia, Russian Federation. The effect of the regeneration method on the chosen stand structure variables (*mean diameter*, *age*, *basal-area*, *diameter range*, *number of tree storeys* and *number of existing tree species*) reflecting the variation of the community habitat (Fig. 1) was examined on different forest sites. The forest site types represent different categories of the productivity of the physical habitat (Fig. 1).

The Cajanderian forest site type classification has often and for various reasons been criticized. The composition of the ground vegetation population differs along the successional stages of overlying stocking (Tonteri 1994, Tonteri et al. 1990). It may, therefore, be asked whether silviculture, logging and other human activities can so much alter the vegetation that determination of the original forest types becomes impossible. It is, however, possible to specify the uncertain forest site type classification with the soil parameters and surface characteristics (Carmean 1975). Unfortunately, this kind of information is not available in the large scale data used in this study.

The tree measurement data weighted by basal area, used in this study, is not the most suitable source of information for the examination of stand structure. In forest inventories, the basal area diameter distributions give more weight to the largest and economically most valuable stems (Päivinen 1980). If the stand structure is examined from the point of view of potential biological diversity (variation of the community habitat) all trees are of equal importance, and should be sampled in the same way (e.g. Norokorpi et al. 1994). Furthermore, the number of sampled trees in one stand should be so large that the diameter distributions of different tree storeys or tree species could be considered separately. In this case some probability distributions e.g. Weibull or Beta, which are easier to interpret, could have been used in describing the tree storeys. However, the forest resource information used here, is the only representative large scale data available.

The benefit of Kernel estimation when using the existing forest inventory data is that the method can be used with a relatively small amount of data. The other advantage of non-parametric methods, e.g. Kernel estimation, compared to parametric probability distributions is that multimodal shapes of diameter distributions can be described with one continuous distribution. When comparing Kernel smoothing to small number of empirical diameters, e.g. sampled trees of NFI plots, the continuous Kernel estimator reflects better the underlying tree population and is easier to interpret.

The results of this study show clearly that when forests are regenerated artificially the stand structure includes less variation when compared to stands regenerated naturally. Differences between regeneration methods become clearer the more fertile the forest site type is. Within the regeneration method there can also be seen a clear trend in stand structure, with the variation decreasing from grovelike sites towards poorer sites.

The different ages of the stands in the data categories may have an influence on the number of tree species and storeys. In data category I the stands were younger and thus the trees were smaller than in other categories. When sampling the trees using a relascope, the less trees that are sampled the younger the stand is. The age of the stand has also a direct effect on the chosen stand structure variable *range*. However, this does not explain the differences in mean range of diameters between data categories II and III.

The stand structure has greater variation in Russian Karelia regardless of the compared regeneration method. That may be due to the forest site type distribution, including more fertile sites. When comparisons are made separately on different forest site types, the effect of this factor is, however, eliminated. Potential seed material available may also have an effect on the stand structure. Forests regenerated naturally in Russian Karelia have more of the stand proportion dominated by deciduous species compared to the corresponding stands of North Karelia. When an established stand is dominated by fast growing deciduous species the development of the germinated coniferous seedlings is disturbed and the variation of stand structure increases (Andreassen 1992).

The differences in stand structure variables between naturally regenerated stands in Finland and in Russian Karelia can also be due to the stands in Russian Karelia having been regenerated with no silvicultural operations whatsoever (Myllynen and Saastamoinen 1995). Also, in some cases stocking in stands of age 40–50 years in Russian Karelia were more or less destroyed during the World War II and after the war these stands regenerated naturally. On the Finnish side the stands have been established by leaving parent seed trees in the regeneration area. This fact has a shortening impact on the time period between the disturbance and the establishment of a satisfactory stand, which could be the main reason for the differences in stand structure.

The cleaning of the clear cut area before regeneration and soil improvement have an effect on the stand structure (Pohtila and Valkonen 1985). In Russian Karelia cleaning of the clear cut area has not been carried out and the trees left after clear cutting often form the emergent tree layer after the sapling stand has been established. Soil improvement decreases the time for stand establishment and may also have a decreasing effect on the variation of stand structure on the Finnish side.

The variation of the stand structure can be regarded as an essential factor for the potential biodiversity of the stand. This capacity for maintaining the potential biodiversity is developed at the young vegetation succession stage. It determines the components of stand structure and becomes increasingly important in the future vegetation succession stages. In the succession stage under examination. i.e. a young mixed forest, the variation of the community habitat cannot clearly be connected to the existence of associate species. However, reflections of the state of the young stand can be predicted for the subsequent succession stages. The existence of habitat components essential to some threatened forest species, e.g. certain saproxylophagous insects, saproxylic fungi and insectivorous birds (Uhanalaisten eläinten ja kasvien seurantatoimikunnan mietintö 1992, Metsätalouden ympäristöopas 1993), is already determined to some extent at the young succession stage.

It seems that natural regeneration provides better possibilities for maintaining forest biodiversity as it generates more dense stands with a wider variation in stand structure, compared to artificial regeneration. On very fertile sites mixed regeneration strategies can be applied and successful regeneration ensured artificially. The wide variation of the stand structure is still ensured, because the differences between the regeneration methods are at their least on fertile sites. However, different kinds of mixed strategies for regeneration in these cases should also be considered to ensure a large enough variation of the stand structure. On moist and dry forest site types, from the point of view of maintaining biodiversity, the natural regeneration method should be applied.

The comparisons were made between stands of average age 20–40 years. Stands regenerated artificially on the Finnish side about 20–40 years ago are the result of the most intensive forestry, aimed at optimal productive monoculture stands. Nowadays, the silvicultural methods and the regeneration methods in Finland have already changed. More mixed strategies are applied to regeneration and not only the most valuable tree species are favoured in applying silvicultural methods.

The cost of this kind of activity to provide the possibility to maintain forest biodiversity in the future could be calculated from the cost relating to the period between times when a satisfactory stand is achieved using different regeneration methods. Also the possible favouring of deciduous species with a lower economical value should be included in this kind of evaluation on the cost of preserving biodiversity.

Acknowledgements

This study was financed by the Maj and Tor Nessling Foundation. The data used in the study was provided by the Finnish Forest Research Institute. Authors would like to thank Dr. Jussi Saramäki and Dr. Taneli Kolström for valuable comments and Mrs. Leena Roihuvuo for revising the English language.

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