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Variation in the Results of Norway Spruce Planting and Scots Pine Direct Seeding in Privately-Owned Forests in Southern Finland

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This study describes the variation in the planting results for 3-year-old Norway spruce (*Picea abies* (L.) Karst.) and 4-year-old Scots pine (*Pinus sylvestris* L.) using direct seeding in privately-owned regeneration areas in southern Finland. The study material consists of operative forest regeneration quality management inventory areas from the years 2000–2006. The effect of both the regional and the administrative levels as well as ecological factors was modelled on the basis of the hierarchy structure forestry centre, Forest Owners' Association (= FOA), forestry professional, regeneration area and sample plot. The major part of the variation occurred at the sample plot and regeneration area level. Particular attention was paid to observation of the clustered spatial distribution of Scots pine seedlings. The FOA and forestry professional levels explained 5% of the variation in Norway spruce planting and 11% of the variation in Scots pine direct seeding. Applied forest regeneration operations, site and soil characteristics were included in the fixed effects. In the planting of Norway spruce the most important factor explaining the regeneration result was soil preparation. Mounding produced better results than patching and disc trenching. The site and soil characteristics were other important factors in the operations. The selection of direct seeding of Scots pine on too fertile, fine textured or moist sites yielded poor results.

Keywords forest regeneration survey, forest regeneration inventory, quality control, quality management, *Picea abies*, *Pinus sylvestris*
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1 Introduction

The requirements for information about the success of forest regeneration operations and factors affecting the end results were first raised at the end of the 1960's in Finland. The main goals of the inventories were to discover the practices applied in forest regeneration, the results gained using various methods, and possible future activities to ensure the further development of the stands (Yli-Vakkuri et al. 1969). Ten years later the next survey was carried out in southern Finland on a proportion of the sample plots of the 7th National Forest Inventory (Räsänen et al. 1985). By then the need to coordinate information about the whole regeneration chain had increased so that optimized decisions could be taken. The emphasis was on gaining a general view of the regeneration results at regional level and not on the variation in the results between the local operational actors. Differences were found between forestry centres in the selection of forest regeneration methods, which could not be explained simply by reference to differences in natural conditions.

Compared to the 1970's the proportion of soil preparation in artificial regeneration increased from 60% to 90% in the 1980's (Finnish statistical … 2007). Another big change in the 1980's was the adoption of containerised seedlings, the production of which reached a proportion of over 70% by the end of the 1980's (Rikala 2000, Finnish Statistical … 2007). The largest annual planting areas were attained in the 1980's. Scots pine still dominated in artificial regeneration. Direct seeding and natural regeneration of Scots pine were studied in the inventories, which were conducted by Kinnunen (1993). Saksa (1992), for his part, concentrated on Scots pine planting. The main emphasis was on improving the methods of artificial regeneration and soil preparation.

Forest regeneration practices changed in Finland in the 1990's compared with the previous decade. The total area made up of the various cutting areas aiming at natural regeneration grew by over 100 000 ha compared with the 1980's (Finnish Statistical … 2007). Hence, the proportion of cuttings aiming at natural regeneration increased from 25% to 30% of the total regeneration area. In terms of artificial regeneration, the proportion of planting decreased from 82% to 74%, and the proportion of direct seeding increased from 18% to 26%. There were also reports of delays in regeneration activities in several instances in the mid-1990's (Hartikainen and Kokkonen 1996, Saksa 1998). The operational environment of forestry professionals was changing (Luonnonläheinen metsänhoito … 1994, Saksa et al. 1999, Karppinen et al. 2002, Karppinen 2005). This led to a re-evaluation of objectives and applied methods in forest regeneration. In this kind of situation the ecological and silvicultural principles of wood production were easily forgotten by forestry professionals when they were trying mainly to provide the best information available to forest-owners (Kalland 2002, 2004). These principles provide the foundation for the operations to establish fully stocked, healthy, well-growing young stand without any delays, and with reasonable costs (Räsänen 1981).

The forest industry companies' own forest management has also faced a change in its values and a changing operational environment, to which the professionals concerned have reacted differently. Some of the companies have considered their own forests to be a low-interest rate burden; others have considered the forests to be a strategic asset. In Tehdaspuu, and later in UPM-Kymmene, the objectives and methods of forest regeneration also faced re-evaluation at the beginning of the 1990's (Kalland 2002). The changes in the operational environment, e.g. the need for biodiversity, had to be combined with wood production without any loss of efficiency. The operational foresters were preserved from the confusion of contradictory objectives and this way unpredictable results, as the quality management system emphasized the activity of local actors in terms of three main elements: 1) agreement on clear objectives and definitions; 2) knowledge of key factors leading to success; and 3) objectively measured and analysed feedback from their own working performance (Kalland 2002, 2004).

The forest regeneration inventory method developed by Tehdaspuu and Metsäteho gained its operational form in 1993 (Hämäläinen and Räsänen 1993, Kalland 2002). The method was applied and further developed by UPM-Kymmene starting from 1997. Initially, 30% of the regeneration areas were sampled, but after a while full coverage was applied (Kalland 2002). In 2004, with 10 years of experience and with an inventory coverage of 40 000 ha, the inventory tool that was applied has come to be considered a cost-efficient and effective part of the quality management system (Kalland 2004).

Encouraged by good results from the forest industry company UPM-Kymmene's improvements in forest regeneration, the Finnish Forest Research Institute began developing an inventory method for privately-owned forests together with six forestry centres and volunteering Forest Owners' Associations (= FOAs). Forestry centres are responsible for the sustainable management and use of forests at the regional level; the maintenance of their diversity; other tasks relating to the promotion of forestry; control of the compliance with forestry legislation, and management of public authority tasks (Act on … 1995). FOA is a forest owner's body, the purpose of which is to promote profitability of forestry practiced by forest owners and the realisation of the goals they have set for forestry, and to advance the economically, ecologically, and socially sustainable management and utilisation of forests (Forest Management … 1998).

The development of the quality control inventory method and consecutive field inventories were conducted in 2000–2006 (Saksa and Kankaanhuhta 2007). Since the control of variation in different product varieties is one of the main elements of quality management (Juran 1951, Deming 1986, Lillrank 2003), the management practices of forestry centres and FOAs were considered hypothetical sources of variation. In this study, the two most common regeneration chains, Norway spruce (*Picea abies* (L.) Karst.) planting and Scots pine (*Pinus sylvestris* L.) direct seeding, were selected from the inventory data to be explored with multilevel statistical models.

The aim of this study was to reveal the magnitudes of the main factors influencing the planting and direct seeding results in order to develop quality management techniques for forest regeneration in privately-owned forests. The first goal was to discover the results of Norway spruce planting and Scots pine direct seeding, the variation between the different FOAs, and the extent to which the variation in regeneration results could be explained in terms of both regional and administrative levels and also ecological factors. The second goal was then to discover what the ecological and operational factors were that would explain the regeneration outcome.

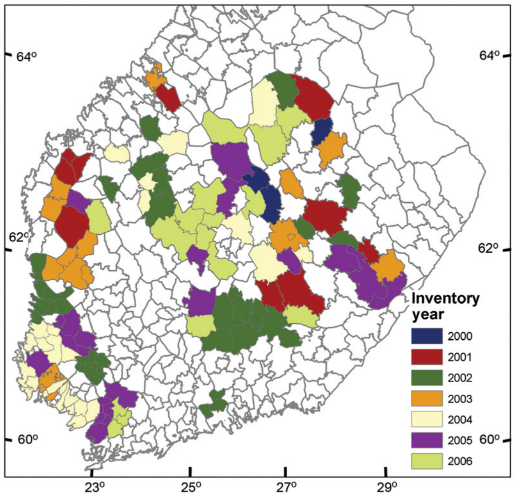

Fig. 1. Forest regeneration quality inventory coverage of Norway spruce planting and Scots pine direct seeding in 2000–2006. Some of the municipalities were inventoried twice. The first inventory year is shown in the map. (Copyright of the map layer and municipality borders: Maanmittauslaitos, lupanro MYY/179/06-V).

2 Material and Methods

2.1 Inventory Method

The regeneration results for three-year-old planting areas of Norway spruce (8557 ha) and four-year-old direct seeding areas of Scots pine (4948 ha) were inventoried (Fig. 1). At this stage the quality resulting from the regeneration operations could be seen and the development of sprouts and broadleaves had not yet substantially disturbed the results. The inventories were carried out in the area of six forest centres in southern Finland: Lounais-Suomi, Häme-Uusimaa, Etelä-Savo, Etelä-Pohjanmaa, Keski-Suomi and Pohjois-Savo (Table 1). However, not all of the forest centres appeared in the inventories every year. The FOAs

Table 1. Yearly inventories at different forest centres.

Forest centre		Inventory year 2000	2001	2002	2003	2004	2005	2006	Total
Norway spruce planting									
Lounais-Suomi	area, ha	0	0	104	63	235	319	99	819
	% of total	0	0	1	1	3	4	1	10
Häme-Uusimaa	area, ha	0	0	275	0	0	0	545	820
	% of total	0	0	3	0	0	0	6	10
Etelä-Savo	area, ha	0	140	327	323	272	613	240	1915
	% of total	0	2	4	4	3	7	3	22
Etelä-Pohjanmaa	area, ha	0	25	61	70	102	180	121	560
	% of total	0	0	1	1	1	2	1	7
Keski-Suomi	area, ha	0	0	0	0	223	330	525	1079
	% of total	0	0	0	0	3	4	6	13
Pohjois-Savo	area, ha	488	521	475	429	450	417	585	3365
	% of total	6	6	6	5	5	5	7	39
Grand total	area, ha	488	687	1241	885	1282	1860	2116	8557
	% of total	6	8	15	10	15	22	25	100
Scots pine direct seeding									
Lounais-Suomi	area, ha	0	0	254	255	133	197	56	894
	% of total	0	0	5	5	3	4	1	18
Häme-Uusimaa	area, ha	0	0	66	0	0	0	95	160
	% of total	0	0	1	0	0	0	2	3
Etelä-Savo	area, ha	0	22	126	38	173	209	98	665
	% of total	0	0	3	1	3	4	2	13
Etelä-Pohjanmaa	area, ha	0	380	523	72	635	329	457	2396
	% of total	0	8	11	1	13	7	9	48
Keski-Suomi	area, ha	0	0	0	0	16	89	126	231
	% of total	0	0	0	0	0	2	3	5
Pohjois-Savo	area, ha	92	149	58	10	152	44	97	601
	% of total	2	3	1	0	3	1	2	12
Grand total	area, ha	92	552	1026	375	1108	867	928	4948
	% of total	2	11	21	8	22	18	19	100

in the above-mentioned forest centres participated in the inventories voluntarily in order to develop their regeneration activities. They were not chosen randomly. The FOAs consisted of one or several municipalities, and the locations of the inventories are shown at the municipality level.

It was recommended that the full coverage of the regeneration areas within a FOA should be inventoried in the first round. The minimum size of the regeneration area was set at 0.5 ha. Field afforestations, supplementary plantings and areas difficult to reach, e.g. islands, were excluded from the inventories. The background material for the inventories was collected from the paper files and electronic registries of the FOAs by local staff. Listings of the regeneration areas from the forestry districts were also utilised. The identification information about areas, regeneration cutting, soil preparation, and regeneration year were extracted from the registries. In addition, the size of the regeneration area, the seedling material size (bare-root, small or large containerised seedlings) and the executor of the planting work (FOA or private forest owner) were all recorded. The mean effective temperature sums (lower threshold +5 C) at municipality level were included in the data-set, based on the method described by Ojansuu and Henttonen (1983). It was not possible to obtain more exact information because of a lack of coordinates for all of the regeneration areas.

The forest regeneration result was measured applying a systematic, regular-shaped sampling grid, which was constructed using a compass and measuring line to mark its cardinal points. Areas of 0.5–2.0 ha were measured using 15 sample plots. The larger regeneration areas were measured using 20 sample plots. In regeneration areas larger than 10 ha, a sample plot was measured for each area of half a hectare. With this sample size it was possible to obtain 5–20% accuracy vis-à-vis crop-trees, depending on the irregularity of spacing in the regeneration area (Eid et al. 1986, Hämäläinen and Räsänen 1993). The systematic regular sampling grid was chosen in order to gain as reliable results as possible from, in spatial terms, heterogeneously distributed regeneration areas (Pohtila 1977). The size of a temporary circular sample plot was 20 m^2 (radius 2.52 m). The plots were delimited with a metal wire attached to an anchored centre pole. This size was chosen, because the variation in seedling densities between sample plots remains significantly smaller than in smaller sample plot sizes (Eid et al. 1986). In larger sample plot-sizes the risk of not detecting seedlings increases, especially when the researcher is working alone (Eid et al. 1986, Kempe 1995). The sample plot size was also comparable to the area that one tree covers in a mature stand. This emphasizes the significance of the empty sample plots.

The variables recorded from the regeneration area at the sample plot level were: site type, soil type, soil preparation method, regeneration method, and target tree species. In addition, the degree of stoniness preventing soil preparation and any wetness that might reduce the regeneration result were recorded. The above-mentioned site type classification for mineral soils was applied in accordance with the model established by Cajander (1926, 1949): *Oxalis-Maianthemum type* (OMaT = very rich), *Oxalis-Myrtillus type* (OMT = rich), *Myrtillus type* (MT = damp), *Vaccinium type* (VT = sub-dry), *Calluna type* (CT = dry) and *Cladonia type* (ClT = barren). For peatlands, the same main classes (very rich, rich etc.) were applied on the basis of Laine and Vasander (1990). The soil types were classified as coarse, medium or fine mineral soil, or as a peat layer thicker than 20 cm. Soil preparation methods were classified in terms of patching, disc trenching, mounding, no preparation or other. This classification was used to describe the generic soil preparation treatment in the area represented by the sample plot. The regeneration method also included information, for example, about planting, manual, or mechanised sowing. The type of sowing was confirmed from the registries of the FOAs. Mechanised sowing was mostly executed by disc trenching machinery, but also excavator based sowing equipment was used in some FOAs. According to the forestry professionals, the sowing method was decided in the negotiations between the forestry professional and the forest owner.

In the planted regeneration areas the planted seedlings and crop-trees and the total number of trees were recorded according to their tree species. The crop-trees included planted seedlings and naturally regenerated supplementary seedlings. However, the concentration in the present study has been on only planted spruce seedlings. The prerequisite for a crop-tree was that the size (>50% of planted seedlings) and vigour of a seedling should be sufficient for timber production, and only conifer seedlings were recorded as crop-trees. The minimum distance between the recorded crop-trees was one metre, and their maximum number was set at 6 crop-trees per sample plot, which is equivalent to 3000 per ha. If there happened to be a larger number of good-quality planted seedlings, which was quite rare, they were all included. The aim of these prerequisites was to sort out the clustering effect of seedlings in any sample plot and at the level of the regeneration area (Pohtila 1980).

The total number of seedlings was counted in the context both of planting and of direct seeding. The total number of seedlings was counted by tree species for Norway spruce, Scots pine, seed-origin birches, and other broadleaves, including sprout-origin birches. The seedlings included were required to be healthy, at least 5 cm in height, and the distance between the counted seedlings needed to be greater than 30 cm. The maximum number of trees was set at 20 seedlings per plot for every tree species. The 20 seedlings were recorded as such even in the case of there being more than 20 seedlings in the plot.

The principal criteria for a regeneration area to be included in the modelling data set were that the main regeneration method was either Norway spruce planting or Scots pine direct seeding. Regeneration areas containing mixed regeneration methods and significant vole damage were excluded from the study.

Table 2. Main stand level characteristics of Norway spruce planting and Scots pine direct seeding stands.

Class variable	Norway spruce planting No. of stands	(%)	Scots pine direct seeding No. of stands	(%)
Inventory year				
2000	288	5.9	54	2.2
2001	360	7.4	259	10.6
2002	721	14.8	526	21.5
2003	517	10.6	187	7.6
2004	688	14.1	566	23.1
2005	1055	21.6	407	16.6
2006	1250	25.6	448	18.3
Planted by / Sown by				
FOA	2074	42.5	1627	66.5
Forest owner	2156	44.2	616	25.2
Other	35	0.7	68	2.8
Unknown	614	12.6	136	5.6
Seedling material				
Bare-root	504	10.3	–	–
Small containerized	1430	29.3	–	–
Large containerized	2600	53.3	–	–
Unknown	345	7.1	–	–

Table 3. Main characteristics of the Norway spruce planting and Scots pine direct seeding datasets.

Variable	N	Mean	SD	Min	Max
Norway spruce planting					
No. of planted seedlings(*)	77989	2.79	1.51	0	9
No. of supplementary seedlings	77989	0.70	1.12	0	6
Regeneration area, ha(*)	4879	1.75	1.42	0.20	17.50
Temperature sum, dd (*)	119	1195.50	86.37	1016.60	1340.60
Scots pine direct seeding					
No. of pine seedlings(*)	39523	6.21	5.20	0	20
Regeneration area, ha(*)	2447	2.02	1.75	0.20	17.80
Temperature sum, dd (*)	112	1193.39	90.36	1008.00	1340.60

(*) = variable used in modelling.

2.2 Description of Data

2.2.1 Norway Spruce Planting

The Norway spruce planting data set consisted of 4879 regeneration areas containing 77 989 sample plots. The areas covered 92% of the total inventoried Norway spruce planting area. Regeneration areas containing mixed regeneration methods covered 7% of the total data set and those with vole damage 1%. These areas were excluded from the analysis. As the data set included the inventory years 2000–2006, the planting years were 1997–2003, respectively (Table 2). Over 60% of the data areas were planted in 2001–2003. Almost equal numbers of planting work were carried out by FOA professionals and private forest owners. Large containerized seedlings were used in over half of the regeneration areas, while small containerized seedlings were planted in almost one third of the regeneration areas.

The most common classes of plot level characteristics were used as a reference class in the modelling. The most common site type was MT with a proportion of 70% (Table 4). Patching was the most common site preparation method (42%).

Table 4. Main plot level characteristics of Norway spruce planting and Scots pine with direct seeding.

Class variable	Norway spruce planting No. of plots	(%)	Scots pine direct seeding No. of plots	(%)
Stony soil	2514	3.2	2928	7.4
Wet soil	2270	2.9	1828	4.6
Site type (*)				
OMaT	478	0.6	37	0.09
OMT	19606	25.1	1104	2.8
MT	54731	70.2	18341	46.4
VT	3142	4	17997	45.5
CT	27	0.03	1927	4.9
ClT	5	0.01	117	0.3
Soil preparation				
No preparation	3410	4.4	544	1.4
Patching	32895	42.2	6755	17.1
Disc trenching	27897	35.8	30606	77.4
Mounding	13399	17.2	1462	3.7
Other	388	0.5	156	0.4
Soil texture				
Coarse mineral	2767	3.5	5474	13.6
Medium mineral	49163	63.0	25155	63.7
Fine mineral	20721	26.6	6132	15.5
Peat	4304	5.5	2527	6.4
Unknown	1034	1.3	235	0.6
Sowing method				
Manual	–	–	16621	42.0
By machine	–	–	22902	58.0

(*) Site type according to Cajander (1926, 1949). Peatlands classified according to Laine and Vasander (1990).

Nearly two-thirds of the plots were on medium coarse mineral soil (63%), and the average size of the regeneration areas was 1.8 ha (Table 3). In the modelling of the Norway spruce planting the dependent variable was the number of planted seedlings at plot level. The average number of planted seedlings at plot level was 2.8 seedlings and there were 0.7 supplementary crop-trees. The average temperature sum at the municipality level was 1196 dd.

2.2.2 *Scots Pine Direct Seeding*

The Scots pine direct seeding data set consisted of 2447 regeneration areas that included 39 523 sample plots. The areas covered 91% of the total inventoried Scots pine direct seeding area. The regeneration areas with mixed regeneration methods covered 9% of the total data set, and they were excluded from the analysis. As the data set included the inventory years 2000–2006, the sowing years were 1996–2002, respectively (Table 2). The inventories tended to be somewhat concentrated on the last three inventory years: 58% of the data was sown in 2000–2002. Two thirds of the areas were sown by FOAs. The FOAs executed 88% of mechanised sowing and 37% of manual sowing.

The most common classes of plot level characteristics were used as a reference class in the modelling. The most common site type was MT, with a proportion of 46% (Table 2). Disc trenching was the most common site preparation method (77%), and there was 58% of mechanised sowing at plot level. Nearly two-thirds of the plots were on medium coarse mineral soil (64%). The average size of the regeneration areas was 2.0 ha (Table 3). In the modelling of the Scots pine direct seeding the dependent variable consisted of the total number of pine seedlings at plot level. The average number of Scots pines per sample plot was 6.2 seedlings. The average temperature sum at the municipality level was 1193 dd.

2.3 Analysis Methods

The models for the regeneration results consisted of separate models of the number of planted seedlings per 20 m^2 plot for Norway spruce planting and the number of all Scots pine seedlings in the case of direct seeding. The structure of the data was hierarchical, and as a result multilevel or mixed modelling was applied (e.g. Goldstein 1996, Snijders and Bosker 1999). The data contained a five-level nested hierarchy: forestry centre, FOA, forestry professional, stand, and plot level (Table 5). Since the observations at the different levels were correlated, random effects were added to the model forming the variance component model, where a variation of the intercept was permitted across the four levels (Snijders and Bosker 1999). The observations made during the same year could also be cross-correlated, but because there were 1–3 inventory years included per single forestry professional or FOA, the inclusion of a year as a random effect was considered unreasonable.

Table 5. Number of hierarchical units in Norway spruce planting and Scots pine direct seeding.

Class variable	Norway spruce planting				Scots pine direct seeding			
	No. of units	Units in one upper class			No. of units	Units in one upper class		
		Mean	Min	Max		Mean	Min	Max
Forestry center	6				6			
FOA	41	7	2	10	39	7	2	10
Forestry professional	284	7	1	21	228	6	1	15
Municipalities(*)	119				112			
Regeneration areas	4879	17	1	140	2447	11	1	88
Sample plots	77989	16	10	36	39523	16	10	29

(*) Forestry professionals may work in the area of several municipalities: in Norway spruce planting 10% and in Scots pine direct seeding data set 19%. On the other hand they may work only in a part of a municipality, which would give the model a crossed structure.

The amount of variation explained by the different hierarchical levels was modelled using normal multilevel models or Linear Mixed Models (= LMMs), since the scale of variance components at different levels in the Poisson-distributed Generalized Linear Mixed Models (= GLMMs) was not the same at the lowest level. The models were created for untransformed counts of seedlings per 20 m^2 plot simply in order to obtain the proportion of variation or variance components for any empty or "final" models. The significance of the parameter estimates was checked, but the real estimate of the various factors affecting the regeneration result was made in the GLMMs described later in this section. The general form of the LMMs was:

$$y_{mlkji} = f(X,\beta) + u_m + u_{ml} + u_{mlk} + u_{mlkj} + \varepsilon_{mlkji} \qquad \text{Eq. 1}$$

where y is the number of seedlings, $f(.)$ is the fixed part of the model, X is a vector of fixed predictors, and β is a vector of the fixed parameters. The subscript i refers to a plot, j to a stand, k to a forestry professional, l to a FOA and m to a forestry centre. The u_m, u_{ml}, u_{mlk} and u_{mlkj} are random effects that denote: forestry centre, FOA, forestry professional and stand levels. The ε_{mlkji} is the normally distributed residual or error term at plot level. Respectively, σ_m^2, σ_{ml}^2, σ_{mlk}^2, σ_{mlkj}^2 and σ_ε^2 are between-forestry centres, between-FOAs, between-forestry professionals, between-stands, and within-stand or -plot level variances. This kind of model with no fixed parameters is sometimes also called a variance components model owing to the fact that the variance is partitioned into components corresponding to each level in the hierarchy (Rasbash et al. 2004). The proportion of total residual variation either refers to the variance partition coefficient (= VPC) or to the Intra Class Correlation (= ICC) (Rasbash et al. 2004). The ICC has two interpretations: 1) the correlation between two randomly drawn units in one randomly drawn group, or 2) the proportion of total variability that is due to the differences between groups (Rasbash et al. 2004, Snijders and Bosker 1999). For example, the following equation is applied to calculate the proportion of variation between the forestry centre (u_m), FOA (u_{ml}) and forestry professional (u_{mlk}) levels and the total variance:

$$\rho_{MLK}(Y) = \frac{\sigma_m^2 + \sigma_{ml}^2 + \sigma_{mlk}^2}{(\sigma_m^2 + \sigma_{ml}^2 + \sigma_{mlk}^2 + \sigma_{mlkj}^2 + \varepsilon_{mlkji}^2)} \qquad \text{Eq. 2}$$

The models used to obtain the VPCs were estimated using the restricted maximum likelihood (REML) method both in SAS/STAT 9.1.3 PROC MIXED and in MLwiN 2.02 (RIGLS) (SAS Institute Inc. 2004, Rasbash et al. 2004).

The models describing the factors affecting the regeneration result were constructed as GLMMs. The dependent variables, as seedlings per 20 m^2 plot, were count data. As a result, GLMMs containing assumptions of the Poisson distribution were used in the final regeneration result models (McCullagh and Nelder 1989, McCullogh and Searle 2001). Poisson models with log-link functions have also been applied by Wilson and Maquire 1996, Hyppönen et al. 2005, and Miina and Saksa 2006). The general form of the GLMMs with the Poisson distribution was:

$$y_{mlkji} \sim \text{Poisson}(\pi_{mlkji}),$$
$$g(\pi_{mlkji}) = \eta_{mlkji} = f(X,\beta) + u_m + u_{ml} + u_{mlk} + u_{mlkj} \quad \text{Eq. 3}$$

where y is the dependent variable, $g(.)$ is a log-link function, η_{mlkji} is the linear predictor, $f(.)$ is the fixed part of the model, X is a vector of the fixed predictors, and β is a vector of the fixed parameters. The subscript i refers to a plot, j to a stand, k to a forestry professional, l to an FOA, and m to a forestry centre. The u_m, u_{ml}, u_{mlk} and u_{mlkj} are random effects that denote forestry centre, FOA, forestry professional and stand levels. The effects have a zero mean, and they are normally distributed with constant variances. The random terms are assumed to be uncorrelated across the levels.

A Poisson variable y with a mean π also has a variance of π (Rasbash et al. 2004). However, there may be more or less variation, var(e_{mlkji}), depending on the phenomenon (McCullagh and Nelder 1989, Goldstein 1996). Extra variation may be taken into account permitting either extra Poisson variation if the data exhibits more variation (= overdispersion), or permitting less variation (= underdispersion). Typically, planted seedlings are evenly distributed in the regeneration area, which means that underdispersion may occur. Direct-seeded and natural seedlings are usually more clustered, which easily causes overdispersion. In order to deal with the previously mentioned cases of dispersion, Penalized Quasi-Likelihood (= PQL) with 2nd order Taylor series expansion was applied, since 1st order PQL and MQL methods tend to overestimate some of the variance parameters (Goldstein 1996, Rasbash et al. 2004). McCullogh and Searle (2001) have also made the same observations. The models were fitted using MLwiN 2.02 software (Rasbash et al. 2004). The results were also compared with estimates calculated using the R package version 2.5.1 applying 1st order PQL (glmmPQL), since 2nd order PQL was not available (Venables and Ripley 2002). Candidate models were evaluated mainly by means of Wald tests, with conformity to earlier results of research and likelihood information, where available. Residual checks were applied at various hierarchical levels as well as with the fixed variables.

3 Results

3.1 Norway Spruce Planting

The average number of planted seedlings was 1388 per ha (std. deviation 378 seedlings per ha) and median 1400 seedlings per ha. The averages of planted seedlings varied between FOAs from 1200 to 1600 per ha (Fig. 2). The proportion of variation explained by the different hierarchical levels was modelled with the linear mixed model, where variance is partitioned into components corresponding to each level in the hierarchy. The ICCs calculated showed that the observations at the hierarchical levels of FOA and forestry professional were both correlated and they explained a small part of the variation (Table 6). A small part of the variation was also assigned to the forestry centre level, but it was not statistically significant in this case. However, the forestry centre level was left in the model, because it describes the true correlation structure of the data caused both by regional differences in weather and soil conditions and also by the hypothetical differences in the silvicultural practices and administrative cultures.

The forestry centre level accounted for 0.3% of the variation and with fixed effects 0.5%. At the same time, the forestry centre and the FOA level accounted for 1.8% of the variation and with fixed effects for 1.7%. The upper levels and the with forestry professional level together accounted for 5.6% of the variation. Again, the combination of the regeneration area level and the upper levels together accounted for 23.2% of the variation. The largest proportion of the variation could be accounted for by means of the sample plot level and the second greatest by means of the regeneration area level. If the forestry centre level had been omitted, its variation would have been assigned to the FOA level. Since the significant fixed effects, which are more thoroughly described in the GLMM modelling, were included in the model, the total variance was reduced by 2%. According to the likelihood information, the applied hierarchy structure provided a better fit for the model with fixed effects than did the hierarchy structure, where the forestry centre, FOA, municipality, stand, and plot level were

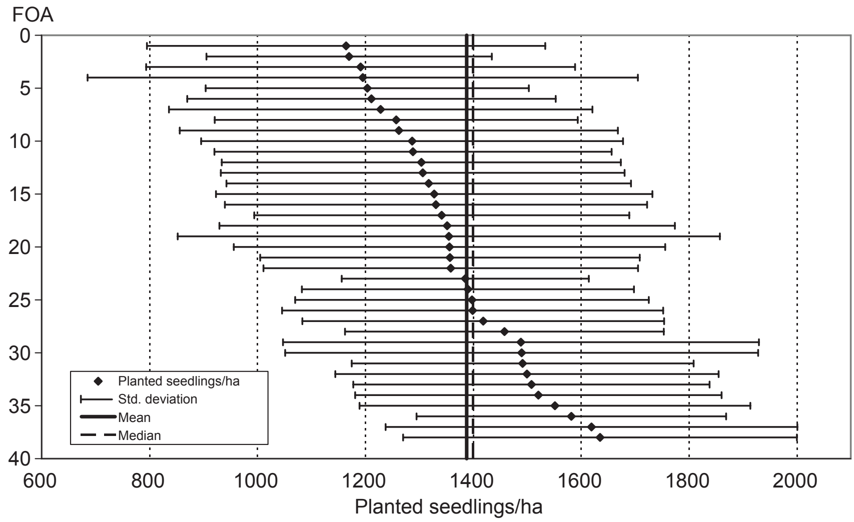

Fig. 2. Variation of Norway spruce planting results between Forest Owners' Associations (=FOAs). Dots indicate area-weighted averages for planted seedlings at the regeneration areas in the FOAs. The bars indicate standard deviations on both sides of the dots. The solid line indicates the general mean and broken line the general median. The FOAs with < 10 ha regeneration area were omitted from the figure.

all included.

In the case of the Norway spruce planting, the statistically significant variables included in the final GLMM were: site type, soil preparation, soil texture, stoniness, and wetness of soil (Table 7). The number of planted seedlings in the reference class was 1365 per ha (exp{1.0047}*500 = 1366) and, e.g., stony soil reduced the number of planted spruces by 28% (exp{–0.3233} = 0.72). The estimated Norway spruce planting GLMM fixed effects and random effects were consistent.

Wet soil reduced the number of planted seedlings by 27%. The site types were combined to gain more general models as rather few observations were obtainable in the OMaT, CT, and Clt classes. Site types that were more fertile than MT reduced seedlings by 3%. In the case of VT, CT, and Clt, the reduction was 2%. Patching was the most common soil preparation method, so it was used as a reference class. If there was no soil preparation in the area of the sample plot, the seedlings were reduced by 20%. Compared with disc trenching, there was practically no effect. Mounding proved to yield the best results with a 9% increase in the number of planted seedlings. The effect of other miscellaneous soil preparation methods provided no statistically significant results.

Medium coarse mineral soil was the most common soil texture class. There was a reduction of 4% in the number of seedlings planted in fine mineral soil. Soil class peat reduced the number of planted seedlings by 10%. The effect of temperature sum, inventory or planting year, seedling type (bare-root, small or large containerised seedlings), executor of planting work and time difference between harvest and regeneration activities did not prove statistically significant. The interactions were also omitted from the final model.

The normal probability plots of the estimated residuals supported the approximate normality of the random effects. There was no evidence of non-constant residual variation in the residual plots. The residual variation at plot level was modelled using the dispersion parameter var(e_{mlkji}), which is interpreted as the difference in the spatial distribution of trees from the Poisson distribution. The parameter value was 0.6635, which means that there was underdispersion due to the even spatial distribution of the seedlings compared with the Poisson distribution.

Table 6. Norway spruce planting, with variance explained at different hierarchical levels: ICC. The fixed effects or predictors are the same as in Table 7.

Level	Variance estimate	Std. error	Proportion, %	ICC (VPC)
Linear mixed model without fixed effects				
Forest Centre	0.0078	0.0102	0.3	0.3
FOA	0.0336	0.0145	1.5	1.8
Professional	0.0885	0.0124	3.8	5.6
Reg. area	0.4042	0.0108	17.6	23.2
Residual	1.7659	0.0092	76.8	100.0
Linear mixed model with fixed effects				
Forest Centre	0.0115	0.0116	0.5	0.5
FOA	0.0262	0.0125	1.2	1.7
Professional	0.0873	0.0122	3.9	5.6
Reg. area	0.3957	0.0106	17.6	23.2
Residual	1.7278	0.0091	76.8	100.0

Table 7. Parameter estimates, variance components and approximate standard errors for the number of planted spruces. The reference class applied was no stones, no wetness, MT site type, patching and medium coarse soil type. The proportion (%) shows the effect of parameter compared to reference class.

Predictor	Number of trees per 20 m^2			Proportion, %	
	Planted spruces	Std. error	EXP(estimate)	(+ / –)	
Intercept	1.00470	0.02248	2.73		***
Stony soil	–0.32330	0.01338	0.72	–28	***
Wet soil	–0.31190	0.01361	0.73	–27	***
Site type (*)					
OMaT or OMT	–0.03534	0.00635	0.97	–3	***
VT or CT or Clt	–0.02309	0.01156	0.98	–2	*
Soil preparation					
No preparation	–0.22390	0.01809	0.80	–20	***
Disc trenching	0.00611	0.01007	1.01	1	ns
Mounding	0.08474	0.00944	1.09	9	***
Other	0.06397	0.05339	1.07	7	ns
Soil texture					
Coarse mineral	–0.00943	0.01277	0.99	–1	ns
Fine mineral	–0.04093	0.00594	0.96	–4	***
Peat	–0.10510	0.01070	0.90	–10	***
var(u_m)	0.00149	0.00163			
var(u_{ml})	0.00373	0.00189			
var(u_{mlk})	0.01468	0.00202			
var(u_{mlkj})	0.06127	0.00162			
var(e_{mlkji})	0.66350	0.00349			

* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. “ns” = non significant at 0.1 level.

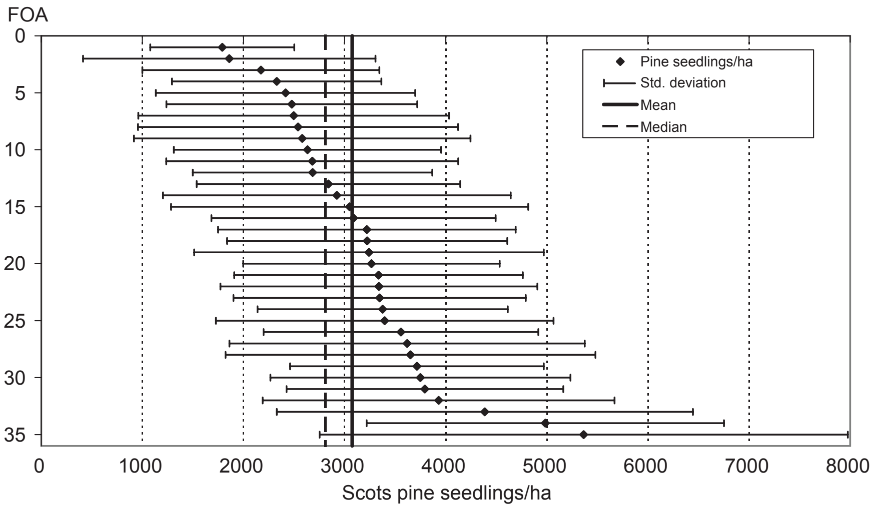

Fig. 3. Variation of Scots pine direct seeding results between Forest Owners' Associations (= FOAs). Dots indicate the area-weighted averages of pine seedlings in the regeneration areas in the FOAs. The bars indicate standard deviations in both sides of the dots. The solid line indicates the general mean and the broken line the general median. The FOAs with < 10 ha regeneration area were omitted from the figure.

3.2 Scots Pine Direct Seeding

The average number of Scots pine seedlings was 3075 per ha (std. deviation 1644 seedlings per ha) and median 2813 seedlings per ha. The averages for Scots pine seedlings varied between FOAs from 2000 to 5000 seedlings per ha (Fig. 3). The proportion of variation explained by the different hierarchical levels was modelled using the linear mixed model employing a hierarchy structure similar to that used in Norway spruce planting (Table 8). In this case the forestry centre level was statistically significant in the model with fixed effects when the likelihood information was studied. A larger part of the variation could be explained with reference to the upper levels as compared with the Norway spruce planting. The forestry centre level accounted for 2.2% of the variation. The forestry centre and FOA level accounted for 6.9%, while in the case of fixed effects it was 6.5% of the variation. The forestry professional level together with the upper levels accounted for 13.4% and with fixed effects 12.7% of the variation. The regeneration area level together with the upper levels accounted for 41.1% and with fixed effects 38.1% of the variation.

The largest proportion of the variation could be accounted for by the sample plot level, with the second largest proportion by the regeneration area level. The variances in the pine direct seeding were in a different magnitude from those in the spruce planting. The sample plot level variance was particularly large. This was due to the clustered spatial structure of the established seedlings within the stand, which could be regarded as overdispersion in the Scots pine direct seeding GLMM. If the forestry centre level had been omitted, its variation would have been assigned almost completely to the FOA level. Since the significant fixed effects, which are more thoroughly described in the GLMM modelling, were included in the model, the total variance was reduced by 9.3%. According to the likelihood information, the applied hierarchy structure provided a better fit with the models than did the hierarchy structure, where the forestry centre, FOA, municipality, stand, and plot level were included.

For the Scots pine direct seeding the statistically significant variables included in the final GLMM were: site type, soil preparation and texture, sowing method, stoniness, and wetness of soil (Table 9). The estimated fixed and random parameters for the Scots pine direct seeding

Table 8. Scots pine with direct seeding; variance explained at different hierarchical levels: ICC. The fixed effects or predictors are the same as in Table 9.

Level	Variance estimate	Std. error	Proportion, %	ICC (VPC)
Linear mixed model without fixed effects				
Forest Centre	0.6047	0.5576	2.2	2.2
FOA	1.2942	0.5021	4.7	6.9
Professional	1.8048	0.3265	6.5	13.4
Reg. area	7.6765	0.2597	27.7	41.1
Residual	16.3353	0.1200	58.9	100.0
Linear mixed model with fixed effects				
Forest Centre	0.5584	0.4992	2.2	2.2
FOA	1.0768	0.4217	4.3	6.5
Professional	1.5524	0.2798	6.2	12.7
Reg. area	6.3999	0.2204	25.5	38.1
Residual	15.5506	0.1146	61.9	100.0

Table 9. Parameter estimates, variance components and approximate standard errors for the total number of regenerated pines. The reference class applied was no stones, no wetness, MT site type, disc trenching and medium coarse soil type. The proportion (%) shows the effect of parameter compared to reference class.

Predictor	Number of trees per 20 m²			Proportion, %	
	Pine seedlings	Std. error	EXP(estimate)	(+ / –)	
Intercept	1.6219	0.0620	5.06		
Stony soil	–0.3836	0.0195	0.68	–32	***
Wet soil	–0.3724	0.0228	0.69	–31	***
Site type					
OMaT or OMT	–0.4931	0.0361	0.61	–39	***
VT	0.2882	0.0110	1.33	33	***
CT or ClT	0.3550	0.0232	1.43	43	***
Soil preparation					
No preparation	–0.5863	0.0620	0.56	–44	***
Patching	0.0170	0.0314	1.02	2	ns
Mounding	0.0826	0.0404	1.09	9	*
Other	–0.0287	0.1466	0.97	–3	ns
Soil texture					
Coarse mineral	0.0445	0.0138	1.05	5	**
Fine mineral	–0.1680	0.0147	0.85	–15	***
Peat	–0.1684	0.0190	0.85	–15	***
Sowing method					
Manual	–0.1555	0.0282	0.86	–14	***
var(u_m)	0.0127	0.0128			
var(u_{ml})	0.0340	0.0130			
var(u_{mlk})	0.0443	0.0082			
var(u_{mlkj})	0.1866	0.0066			
var(e_{mlkji})	2.5776	0.0190			

* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. "ns" = non significant at 0.1 level.

GLMM were consistent. The number of pine seedlings in the reference class was 2531 seedlings per ha. Stony soil reduced the number of seedlings by 32%. Wet soil, for its part, reduced the number of seedlings by 31%. Site types that were more fertile than the MT reference class reduced the number of seedlings by 39%. VT increased the number of seedlings by 33% compared with MT. The combined fertility classes CT and ClT increased the number of seedlings by 43%. Disc trenching was the most common soil preparation method and it was used as the reference class. No soil preparation reduced the number of seedlings by 44%. Mounding, in contrast, increased the number of seedlings by 9%. Almost 90% of the mounded plots were sown manually, and the rest of the plots were sown by a machine, which was attached to an excavator. Patching and other soil preparation methods provided no statistically significant difference from disc trenching.

Medium mineral soil was the most common soil texture class. Coarse mineral soil increased the number of seedlings by 5% compared with medium mineral soil. Fine mineral soil and peat reduced the number of seedlings by 15%. Compared to the sample plots sown by machine, manual sowing reduced the number of seedlings by 14%.

The effect of the inventory or regeneration year proved statistically insignificant, while the temperature sum at the municipality level proved to be statistically insignificant in the presented hierarchy structure. The forestry centre level covered part of the large-scale weather variation. The size of the stand, the executor of the regeneration work, and the time difference between harvest and regeneration activities all proved to be statistically insignificant. Both the interactions and also the inventory/sowing years were omitted from the final model.

The normal probability plots of the predicted random effects supported the approximate normality of the random effects. There was no evidence of non-constant residual variation in the residual plots. The residual variation at the plot level was modelled using the dispersion parameter var(e_{mlkji}), which is interpreted as the difference in the spatial distribution of trees from the Poisson distribution. The parameter value was 2.5776, which means that there was overdispersion due to the clustered spatial distribution of the seedlings compared to the Poisson distribution.

4 Discussion

The regeneration results varied between the FOAs in both the Norway spruce planting and the Scots pine direct seeding (Figs. 2 and 3). A certain proportion of the variation could be attributed to the administrative and regional hierarchical levels. The results, however, indicated that the different methods and the way they were executed were the most common factors influencing the regeneration results.

The limitations of the study material available were twofold. First, the FOAs volunteered for the quality control inventories; they were neither a random nor a systematic sample. However, the coverage of the inventories has to be considered as worthwhile. Second, the data used in this study was originally measured for operational quality control purposes, not for modelling causal relationships (Saksa et al. 2002). Because of this, the data was not balanced. Despite the previously mentioned shortcomings, the statistical analysis of the study material yields much more information compared with the plain description of data with cross-tabulations and graphs.

In the case of the Norway spruce planting the concentration was on planted seedlings, not the crop-trees, which also include natural supplementary seedlings. There was also a slight risk in the inventories that the planted and naturally generated seedlings would be mixed, but especially in the plots where soil preparation has been carried out the risk of misinterpretation is fairly small. In addition, there were also numerous factors, e.g. the numbers of planted seedlings or amount of self-sown seed, different machines, different operators of the machines, soil preparation practices, and earlier silvicultural treatments, all of them influencing the regeneration result, and which could, therefore, not be included in the analysis.

The greatest proportion of variation could be attributed to the sample plot level and the second greatest proportion to the regeneration area level, both for the Norway spruce planting and for the Scots pine direct seeding. The hypothesis that there would be a certain amount of variation in the regeneration results that could be attributed to the administrative levels gained some confirmation. In the case of the Norway spruce planting there was a total of 5% variation attributable to the FOA and forestry professional levels. In the case of the Scots pine direct seeding the hypothesis received further confirmation since, altogether, there was some 11% variation attributable to the FOA and forestry professional levels. However, the amount of variation was expected to be even somewhat greater in the case of the Norway spruce planting, where the variation attributable to the forest centre level was very small and ultimately insignificant. In the case of the Scots pine direct seeding the forestry centre level included 2% of the variation. The interpretation of the variance at this level was twofold: variation in weather and soil conditions and hypothetical differences in the practices of the different forestry centres implementing direct seeding. There has been some evidence of adaptation of the various methods and practices of forest regeneration under similar conditions in the various forestry centres (Räsänen et al. 1985, Kinnunen 1993). These findings have, however, been at a more general level concerning differences in the proportions of artificial and natural forest regeneration. According to the inventory data used in this article, e.g. the proportions of mechanised and manual sowing varied from 25% to 75% in different forestry centres.

In the case of Norway spruce planting the most important aspect to be considered by operational actors was soil preparation, the significance of which cannot be overemphasized. Mounding provided better results than patching, while disc trenching was at the same level as patching. In the case of non-prepared areas, there was a clear reduction in the number of planted seedlings. At the time of the inventories, mounding was mostly combined with ditching. As a result, there will obviously be fewer planting spots than in patch mounding (upturned humus resulting in flat mounds with a double humus layer) or in inverting (humus upturned and placed in the same patch). The results for mounding were also supported by previous studies (Saksa et al. 1990, Örlander et al. 1990, 1998). The positive effect of soil preparation compared with non-prepared plots was also similar to that reported in previous studies (e.g. Raulo and Rikala 1981, Kinnunen 1989). The potential preventative effect of soil preparation methods against possible pine weevil damage was also in line with other studies (Söderström et al. 1978, Örlander and Nilsson 1999). However, the proportion of pine weevil damage could not be recorded thoroughly by means of this inventory method. With reference to soil preparation in the survey data, there are two possible shortcomings: the soil preparation may have been misinterpreted by the inventory personnel, and the data was not balanced.

The actual planting densities were not available for inclusion in this inventory data, a fact that also influenced the accuracy of the models. The recommended planting densities may also have influenced both the applied planting densities and the number of planting spots in excavator-based soil preparation methods. In the 1990's the recommended planting densities were fairly low: 1400–1800 seedlings per ha (Luonnonläheinen metsänhoito 1994). Saksa et al. (1990) found that the reduced planting densities at forestry centre level also influenced later results when their results were compared to the inventory results obtained by Raulo and Rikala (1974). The seedling type did not prove to be a statistically significant factor affecting the number of planted seedlings, although the hypothesis was that larger seedlings would survive better. There may have been several reasons for this, e.g. the smaller size of some seedlings would possibly have had to be compensated by a larger number of seedlings, or larger seedlings might have been used on more fertile and difficult sites.

The effect of site type was small but clear. On most of the fertile sites (OMaT and OMT) the number of planted seedlings declined a little compared with MT. The competition posed by vegetation is severe on the more fertile site types, which reduces the possibility of seedlings surviving (Cajander 1949, Yli-Vakkuri et al. 1969). In addition, excessive vegetation may provide more shelter for pine weevils, which increases the risk of damage (Petersson et al. 2006). Although the time between the harvest and regeneration activities did not prove to be significant in this case, there are clear results of the positive effects of fast regeneration activities and mounding after harvest (Nilsson and Örlander 1999). On less fertile sites (VT, CT or ClT) than MT there was also a reduction in the number of planted seedlings. However, in these cases the excessive field vegetation is not considered a problem (Cajander 1949). The most probable reason was the dry conditions caused by more coarse soil textures on these site types (Örlander et al. 1990). Scots pine would have been a better alternative as a tree species, although e.g. the risk of moose damage may have affected the selection of tree species.

The effects of the soil features were consistent. Fine mineral soil reduced the number of planted seedlings compared with medium coarse mineral soils. This was predictable because of the features of fine soils: hardening when drying, compact and airless when moist, and prone to frost heaving (Örlander et al. 1990, Goulet 1995). According to the results obtained, peat reduced the number of planted seedlings to the greatest extent. The reason for this could, however, be twofold: either the ground water levels had not been taken care of and there were too few proper planting spots or there has been a soil water deficit at the moment of planting (Örlander and Due 1986, Örlander et al. 1990). There is also an increased risk of frost damage in these probably low areas (Holgén and Hånell 2000). If the ground water levels had not been taken care of by means of soil preparation at the inventoried plots, the number of planted seedlings declined even further. Stony soils preventing proper soil preparation reduced the regeneration result in the same magnitude as excessive wetness.

In the case of Scots pine the direct seeding site type was the most important single factor of all of the inventoried variables affecting the regeneration result. Applying direct seeding in too fertile sites yielded poor results. The most fertile site types, OMaT and OMT, reduced the regeneration results compared with MT. The majority of the MT plots were too fertile for Scots pine direct seeding, since the number of pine seedlings increased by a third if the site fertility class was VT. The result was even better for the drier site types CT and ClT. The results were similar to those obtained in previous studies (Yli-Vakkuri et al. 1969, Kinnunen and Mäki-Kojola 1980, Kinnunen and Nerg 1982). The linear mixed models of Scots pine direct seeding accounted for the larger proportion of variance at the stand level compared with Norway spruce planting. This was probably, at least partly, caused by the difficulties experienced by forestry professionals in marketing the most suitable regeneration method appropriate to the forest owner. This was also supported by the fact that 49% of the sample plots were on MT or a richer soil type, and that Saksa and Kankaanhuhta (2007) found that only one-third of the direct seeding on MT led to a good regeneration result. A part of these sites should have been planted with Norway spruce.

A coarse mineral soil increased the number of seedlings a little in comparison with medium coarse mineral soil. Fine mineral soils reduced the number of seedlings to the same extent as peat. This should be taken into account when selecting the regeneration method. The effect of soil type was in conformance with previous studies (e.g. Lähde 1974).

Mechanised sowing produced better results than manual sowing. Kinnunen (1992), on the other hand, did not obtain statistically significant differences between manual and mechanised sowing. In mechanised sowing there seems to have been used greater amount of seed compared with manual sowing (Kankaanhuhta et al. 2009). The possible other reasons for the result may have been freshly exposed moist mineral soil, the probability of seed landing on many kind of seedbeds suitable for varying germination conditions, and better timing in the early summer (between May and the beginning of June). Disc trenching and patching produced practically the same results. Disc trenching provided clearly better results than leaving soil unprepared, while mounding provided better results than disc trenching. However, the area of mounding was fairly small. The positive effect of soil preparation was in line with previous results in terms of both direct seeding and natural regeneration (Kinnunen and Nerg 1982, Karlsson and Örlander 2000, Hyppönen et al. 2005). The effect of mounding has also been reported in the context of natural regeneration of Scots pine (Kinnunen and Mäki-Kojola 1980).

Excessive wetness reduced the Scots pine direct seeding result by almost one-third. Kinnunen (1982) has reported damage caused by wetness, which has been concentrated in the first two growing seasons after sowing. Soil stoniness reduced the results in the same magnitude. In both cases the effect of these extreme conditions has been quite obvious. Poorer regeneration results on stony soils have also been reported by Kinnunen (1993) and Hyppönen et al. (2005). The sowing years, and hence a degree of annual variation in the weather and seed crops, were omitted from the final model. There were mostly one or, at best, two inventory years per forestry professional or municipality. In order to study properly the real annual variation, there would have needed to be inventory results obtained from a greater number of points in time and involving the complete six forestry centre coverage every year.

In the course of the inventories made of forest regeneration quality management a great variation in regeneration results was observed between operational actors in every regeneration chain (Saksa and Kankaanhuhta 2007). The main idea in quality management is to reduce the variation in operational results or end products by means of continuous improvement (Ishikawa 1985, Deming 1986). The most effective method is to select a small proportion of factors, which will account for a high percentage of the quality losses (Juran 1951). As a practical conclusion, some of the main development points still remain to be addressed. In Scots pine direct seeding the variation in the results obtained in the various regeneration areas was considerable, and depended on the local circumstances and skills of the forestry professional to market the proper regeneration chain. Direct seeding should be directed toward less fertile sites than MT with medium coarse mineral soil. Soil preparation and mechanised sowing are also recommended. In Norway spruce planting, soil preparation, preferably mounding, with a sufficient number of proper planting spots especially in more fertile site types than MT is recommended. The skills of the forestry professional in adapting to the prevailing circumstances, in negotiating with their customers, and in obtaining feedback about their actions cannot be overemphasised.

The models provided in this study can be applied in order to gain some rudimentary estimates of the factors affecting the quality of regeneration as well as to develop more advanced techniques for improving forest regeneration service processes. Information about the key factors influencing the results and about adaptation to local circumstances are principal components for local forestry professionals to produce good-quality forest regeneration services. In future research there is a need to gain more knowledge about information-intensive management and control techniques appropriate for forest regeneration services applying, e.g. background information about the operational records and databases of the FOAs. The emphasis should be on providing the operational actors with genuine feedback about their actions at the various stages of the forest regeneration service process.

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