# Fill-In Seedlings in Constituting the Stocking of Scots Pine Stands in Northern Finland

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Fill planting is a common procedure following reforestation in Finland. In 1990, 13 % of the total of seedlings planted was used for fill planting. The objective of this study is (i) to survey the survival of fill-in seedlings and (ii) to estimate the spatial pattern of stands to evaluate the importance of fill-in seedlings in constituting the stocking of Scots pine stands in central and northern Finland.

A survey of 63 artificially regenerated Scots pine stands was conducted in 1990. Stand densities varied from 950 to 3925 seedlings/ha. The mean densities of originally planted, fill planted, and naturally regenerated seedlings were 863, 639, and 791/ha, respectively. The survival of originally planted seedlings was 36 % and that of fill-in seedlings 48 %. Death rate of fill-in seedlings of Scots pine increased with longer times between original and fill planting, with higher survival rates of original seedlings, and with increased time since fill planting. The survival rate of Norway spruce seedlings was correlated with temperature sum. Height of the fill-in seedlings was less than that of the originally planted seedlings. Most stands had an even spatial distribution with the exception of sparsely populated stands, which were somewhat clustered. This indicates that dying of seedlings is not randomly spread. Because of poor survival, fill planting seems to be a risky business in most cases.

**Keywords** Scots pine, fill planting, survival of seedlings, spatial pattern.
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# 1 Introduction

Fill planting is used in intensive forestry to ensure the adequate density of artificially regenerated stands. Fill planting is a very common procedure following reforestation in Finland. In 1990, 28 million seedlings out of 220 million planted were used for fill planting. At the same time, 500 kg of seed out of 11 500 kg was used for fill seeding (Yearbook of forest statistics 1990–91). It means that 13 % of the seedlings and 4 % of seed were used for filling. However, little is known about the survival and development of fill-in seedlings.

Wakeley (1968), Miegrot and Lust (1972), Jones (1974), and Chavasse et al. (1981) reported poor development of fill-in seedlings of different pine species. Vanselow (1950) found poor success, whereas Brantseg (1963) reported good results of fill planting in Norway spruce stands. Gemmel (1987) concluded that the yield of fill planting in Norway spruce stands would often be small.

In Finland, Oikarinen and Norokorpi (1986) and Leppälä (1992) made a survey of survival of fill-in seedlings in Scots pine stands. According to Oikarinen and Norokorpi (1986) fill planting had no effect on the density of young Scots pine stands. Leppälä (1992) found that on the average only 48 % of the fill-in seedlings were alive after five years. Liukkonen (1990) found that though the survival of Norway spruce seedlings was much better than that of Scots pine, Siberian larch or silver birch in a fill planting experiment in northern Finland, their increment was very low. Also Braathe (1992) found that juvenile growth of fill-in seedlings of Norway spruce was slower than that of Scots pine.

The Forest and Park Service manages most of the state-owned forests in Finland. It has artificially regenerated more than 60 000 stands covering more than 400 000 ha of forest land since 1972. All the regeneration areas are recorded into a database, which keeps track on the geographical situation, site information, silvicultural treatments, and survey data of the stands. Young stands are surveyed three times after regeneration at the age of three, seven and twelve. Fill plantings have been recorded into the system only since recent years, and there is little information about them in the database. More knowledge is needed to make rational decisions about fill planting.

The Forest and Park Service requires roughly 2000 seedlings capable of further development per hectare. If less than 70 % of it is found in surveys, fill planting is necessary, and if less than 40 % is found, replanting is suggested. According to the database about 15 % of the artificially regenerated Scots pine stands did not fulfill the density requirements. On the average, 1500 seedlings out of the planted ones survive. The average density of young Scots pine stands is 1800 seedlings/ha because of natural regeneration (Saarenmaa 1992).

The Forest and Park Service updated the guidelines for silviculture in 1985 and again in 1990. One of the major changes in 1985 was the raise in planting densities. The number of seedlings required climbed from 2000 to 2500 seedlings/ha in Scots pine plantations. The main reason for this increase was the poor success of artificial regeneration. The aim was to replace fill planting by greater initial numbers of seedlings, which would allow high mortality rates without obligation of fill planting.

"Fill planting in beforehand", which means using higher initial densities than the ones to ensure full density at the time of the first thinning, was to some extent recommended by Yli-Vakkuri (1968). He criticized the idea, though, because mortality in young stands has no regular pattern, but seedlings have a tendency to die in patches.

Gemmel (1987) studied the development of fill-in seedlings in Norway spruce stands in Sweden. It was highly dependent on the size of the gap and the time between the original and fill planting. He concluded that fill planting is more effective in irregularly spaced stands than in regular ones. Also Braathe (1992) reported similar results. However, wide gaps are often caused by poor conditions (Gemmel 1987). It is therefore questionable, if fill-in seedlings will do any better than the original ones.

Dierauf (1992) studied interplanting in loblolly pine stands and found that it was not helpful. Actually it caused harm, because it increased the number of sub-merchantable trees and reduced the average breast height diameter.





This study focuses on Scots pine, which is the most important tree species in Finland's forestry. In 1990, 111 million Scots pine, 60 million Norway spruce, and 22 million seedlings of other tree species were used for planting in Finland. These numbers do not include fill-in seedlings.

The aim of this study was (i) to survey the survival of fill-in seedlings and (ii) to estimate the spatial pattern of stands to evaluate the importance of fill-in seedlings in constituting the stocking of Scots pine stands in central and northern Finland.

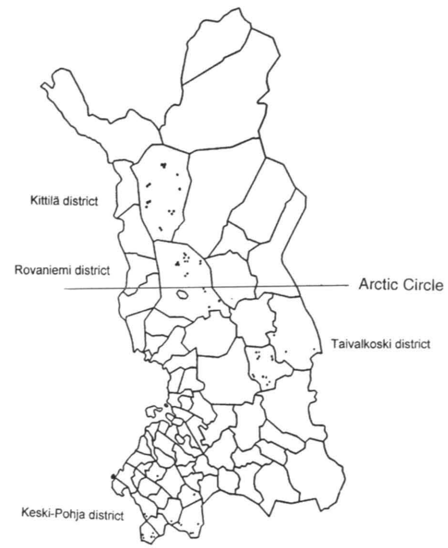



**Fig. 1.** The location of the surveyed stands.

# 2. Material and Methods

## 2.1 Survey

The survey of 63 artificially regenerated Scots pine stands was conducted on state-owned land in northern and central Finland in 1990. Most of the stands were fill planted during 1985–1989. The original planting year varied from 1968 to 1987.

The stands situated in Keski-Pohja, Taivalkoski, Rovaniemi, and Kittilä districts, 15 stands in each except in Rovaniemi district where 18 stands were studied (Fig. 1). The data from Rovaniemi district varied more than the rest of them. There was a couple of seeded stands included and some of the fill plantings were older than five years, as well. The results are mainly based on the three other districts.

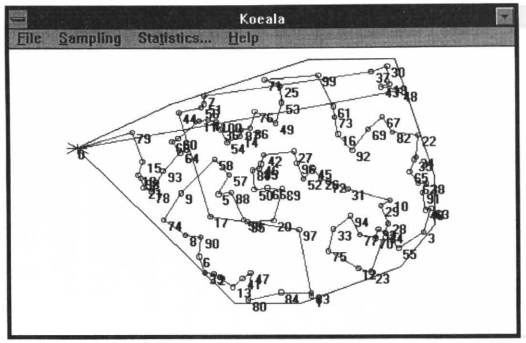
Most of the experimental stands were ploughed before regeneration, and the rest of them were disc-ploughed or mounded. The majority of the stands were either semi-dry or moist site types. Scots pine (38 stands), Norway spruce (20 stands), and Siberian larch (2 stands) were used for fill planting. Three stands were fill planted with mixed pine and spruce.

The information about site type (Cajander 1909), soil quality (indicates factors reducing productivity such as thick humus layer, peat, rockiness, etc.), soil type (gravel and sand, fine sand, silt, gravel and sand moraine, fine sand moraine, and silt moraine), site preparation and regeneration methods, tree species, planting stock, planting density, provenance of the seed, number and type of fill-in seedlings, and the dates and areas of the treatments were derived from the treatment plans recorded routinely for each regenerated stand by the districts of the Forest and Park Service. Inclination and compass direction of the slope, thickness of humus layer (cm), elevation, local temperature sum based on the coordinates and elevation (Ojansuu and Henttonen 1983), and development classes of the adjacent forests were recorded for each stand by the survey group.

## 2.2 Random Sampling

To study the spatial pattern of the stands imposed certain requirements for the surveying method. In a random sample, the sizes of zero plots vary according to the spatial distribution of the population (Pohtila 1980). To get reliable results every seedling should have equal probability to be part of the sample. Therefore a random sampling method was developed.

The coordinates of the boundaries of the stands




| Plot N:o | XCoordinate Meters | YCoordinate Meters | Next Plot N:o | Angle Degrees | Distance Meters |
|---|---|---|---|---|---|
| | | | | | |
| 0 | 1773 | 1110 | 79 | 72 | 29 |
| 79 | 1801 | 1119 | 15 | 166 | 18 |
| 15 | 1806 | 1102 | 18 | 193 | 8 |
| 18 | 1804 | 1094 | 98 | 146 | 2 |
| 98 | 1805 | 1092 | 21 | 168 | 6 |
| 21 | 1807 | 1086 | 78 | 117 | 5 |
| 78 | 1811 | 1084 | 93 | 25 | 13 |
| 93 | 1817 | 1096 | 64 | 38 | 14 |
| 64 | 1826 | 1107 | 68 | 328 | 8 |
| . | | | | | |
| . | | | | | |
| . | | | | | |
| 68 | 1821 | 1113 | 60 | 59 | 4 |

**Fig. 2.** The sample plots were chosen randomly by a computer program, which also gave the orientation from point to point as a compass direction and the distance between plots.

were digitized by using maps from forest management plans. These were used as input data for a computer program, which randomly generated 100 coordinate points for sample plots within the boundaries. Then the program devised a walking route through the stand that visited all the sampling points. Orientation from point to point was shown as a compass direction and the distance between plots (Fig. 2).

Two different types of sample plots were used: circle plots of 4 $m^2$ and distance plots. In each stand, 100 randomly chosen points were used as the middle points for both types of sample plots. The data was analyzed using analysis of variance, correlation coefficients, and regression analysis.

### *2.2.1 Circle Plots*

The circle plots were used to determine the density of the stand. All the seedlings were counted, but a maximum of two seedlings capable of further development were tallied on a plot (Valtakunnan metsänuudistamisen inventointi 1978). The theoretical maximum of seedlings capable of further development was thus 5000 trees per hectare. The rest of the seedlings were tallied as well, but they were considered as not capable of further development because of the lack of growing space. Seedlings capable of further development were classified by origin as follows: (i) originally planted seedlings, (ii) fill-in seedlings, and (iii) natural regeneration.

The densities of the stands were estimated using data from circle plots summing up the originally planted seedlings, fill-in seedlings, and natural regeneration capable of further development. The mortality of the planted and fill-in seedlings was estimated by subtracting the number of trees still alive from the initial number of seedlings, which was derived from treatment plans. The results are based on the seedlings capable of further development.





### *2.2.2 Distance Method*

The spatial pattern was estimated for each stand using distance method. The distances from the randomly chosen points to the nearest originally planted, naturally regenerated, and fill-in seedling were measured. The tree species, origin, capability of further development, height, diameter at the height of 20 % of the total height of the seedlings were recorded. The micro relief of site preparation, the effect of the ground vegetation classified to six different classes (0. no vegetation, 1. *Calluna vulgaris* and *Empetrum nigrum*, 2. *Deschampsia* sp. and *Carex* sp., 3. *Calamagrostis* sp., 4. *Epilobium angustifolium* and 5. shrubs), and the number and mean height of suckers around the seedlings were measured as well.

The origin of seedlings was defined subjectively. It was fairly easy to differentiate between the three different origins. All the stands were site-prepared and the original seedlings were planted fairly regularly. The age difference between the original planting and fill planting was at least three years and the time passed since fill planting was less than six years. The dates of original planting and fill planting were derived from the treatment plans by the Forest and Park Service.

Fill-in seedlings could be recognized from original ones by age counting the number of whorls. Recognition was easy, when other tree species than Scots pine were used for fill planting. It was more difficult to make a difference between two different fill plantings some of the stands being fill planted twice. To recognize natural regeneration from planted seedlings did not cause problems, since the planting stock consisted mainly of container seedlings. Containers decay fairly slowly in northern Finland, and the pots can be seen years after planting.

## 2.3 Cox's Index

The spatial pattern of the stands was studied using zero-plot diagram and Cox's index derived from it (Cox 1971, Pohtila 1980).

Cox's index (Cox 1971)

$$I_c = a \cdot b \cdot k \quad (1)$$

is defined as follows.

Zero-plot percentages p(0) are calculated for circles with varying radii, logarithm transformation is done (p(0) → log p(0)), and a curve is fitted

$$\log p(0) = 2 - \text{constant} \cdot n\pi r^2 = 2 - \text{constant} \cdot m \quad (2)$$

where $m = n\pi r^2$ is the average number of trees/sample plot (n = stand density or trees/area unit, and r = radius).

Parameters a and b can be derived from the curve (2) as follows.

Parameter a corresponds the relative zero-plot frequency when value of m = 1, which is derived solving log p(0) with value m = 1, after which the corresponding percentage $p(0) = 10^{\log p(0)}$ is calculated, and the value of a is derived a = p(0) / 100.

Parameter b corresponds to value of m when log p(0) = 0.7.

In the Poisson structure, equation of curve (2) is

$$\log p(0) = 2 - 0.4343 \cdot m \quad (3)$$

where
a = 0.3679
b = 2.9933

Constant k in Cox's index (1) makes sure that $I_c$ in Poisson structure is 1.

# 3 Results

## 3.1 Survival of Seedlings

The total density of the stands varied from 950 to 3925 seedlings/ha, and the mean density was 2293 seedlings/ha. The mean densities of originally planted, fill planted, and naturally regener-

**Table 1.** Mean and standard deviation of the number of seedlings capable of further development in different districts by origin.

| | Keski-Pohja | | Taivalkoski | | Rovaniemi | | Kittilä | |
|---|---|---|---|---|---|---|---|---|
| | seedlings/ha | s | seedlings/ha | s | seedlings/ha | s | seedlings/ha | s |
| Original seedlings | 1020 | 456 | 845 | 441 | 657 | 297 | 933 | 431 |
| Fill-in seedlings | 702 | 345 | 622 | 363 | 584 | 355 | 650 | 257 |
| Natural regeneration | 508 | 365 | 468 | 259 | 1154 | 435 | 1035 | 432 |
| Total | 2230 | | 1935 | | 2395 | | 2618 | |

ated seedlings capable for further development were 863, 639, and 791/ha, respectively (Table 1).

The number of originally planted seedlings varied much because of the great variation in initial densities. The initial densities varied from 1800 to 3200 seedlings/ha, but it had not statistically significant ($p < 0.05$) effect on the survival of the seedlings.

The number of original seedlings decreased with increasing stand age. Survival of the seedlings declined northwards. Site type had no effect on the survival. Soil type had an effect on the success of fill planting. The result was better in coarse than in fine soil types. There was a statistically ($p < 0.05$) significant difference between fine sand moraine and silt moraine in the survival of fill-in seedlings.

The survival of original seedlings was 36 % and fill-in seedlings 48 % varying from 3 % to 94 %. The time between the original and fill planting and the number of naturally regenerated silver birch seedlings were the most significant factors in the regression model predicting the mortality of fill-in seedlings of Scots pine:

$$\ln(y) = 3.884554 + 0.0060769x_1 - 0.005097x_2 \quad (4)$$

where
$y$ = death rate of fill-in seedlings, %
$x_1$ = time between original and fill planting, years
$x_2$ = number of naturally regenerated silver birch seedlings/ha

More silver birch seedlings meant lower mortality for fill-in seedlings. Their mortality increased when the time between original and fill planting grew longer. The model could explain 65 % of the variation found in the death rates of fill-in seedlings of Scots pine.

The model (4) did not explain death rates of Norway spruce at all. The best prediction was achieved using temperature sum as the independent variable. The higher the temperature sum, the lower the death rate. That model could only explain 36 % of the variation in the death rates of Norway spruce fill-in seedlings.

The survival of the fill-in seedlings was low, when the survival of the original seedlings was high and Scots pine was used for fill planting. The time between the original and fill planting had a positive correlation with the death rate of fill-in seedlings of Scots pine ($p < 0.05$, $r = 0.39$), and the time elapsed since fill planting increased the mortality ($p < 0.05$, $r = -0.47$). Seedling loss was greatest immediately after fill planting. The survival of Norway spruce fill-in seedlings was not correlated either with the survival rates of original seedlings or with the time factor.

The survival rates of the fill-in seedlings varied by tree species. Norway spruce was the best (59 %), Siberian larch was the second best (58 %), and Scots pine was the weakest survivor (44 %). The difference between Norway spruce and Scots pine was statistically significant ($p < 0.05$).

There were on the average 791 naturally regenerated seedlings/ha. Natural regeneration seemed to depend on the development class of the surrounding forests. In the neighborhood of regeneration areas and young stands natural regeneration was scarce. The number of naturally regenerated Norway spruce seedlings increased northwards. Standards were usual in Taivalkoski





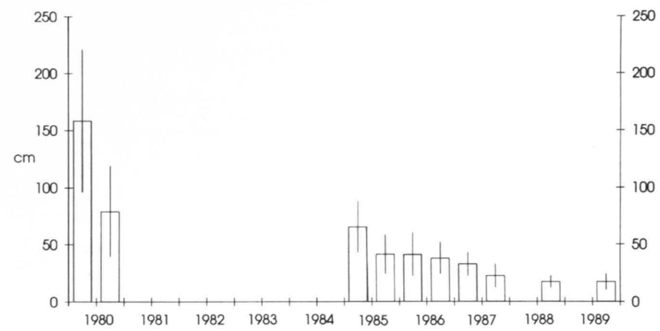



**Fig. 3.** The mean height of the original (darker columns) and fill-in (lighter columns) seedlings in Scots pine plantations.

and Rovaniemi districts. They were probably left to ensure seed production, but in fact they had a negative effect on the survival of Scots pine seedlings.

The height of the fill-in seedlings was smaller than that of the original ones at the same age (Fig. 3).

The effect of field vegetation on fill-in seedlings was studied by analysis of variance. Most of the field vegetation consisted of *Calamagrostis* sp., *Deschampsia* sp., and *Chamaenerion angustifolium*. There was a statistically significant difference in the height of fill-in seedlings by different vegetation types. The mean height of seedlings was lowest in plots without vegetation or plots covered by *C. angustifolium*. The heavy competition in plots covered by the other species probably killed all but the tallest seedlings. The correlation between the height of the fill-in seedlings and number of suckers was not statistically significant.

## 3.2 Spatial Pattern of Stands

The spatial distribution of the stands was studied by Cox's index (Cox 1971, Pohtila 1980). The bigger the index the more clustered the structure (Pohtila 1980). The indices were calculated separately for all the seedlings, originally planted seedlings, fill-in seedlings, and natural regeneration (Table 2).

**Table 2.** Spatial distribution of the stands by Cox's index.

| Origin class | Homogenous | Random | Clustered |
|---|---|---|---|
| | Number of stands | | |
| All seedlings | 28 | 3 | 32 |
| Original seedlings | 46 | 6 | 11 |
| Fill-in seedlings | 40 | 4 | 19 |
| Natural regeneration | 31 | 3 | 29 |

The distributions of originally planted seedlings were usually homogenous, but when the stand density was low they tended to be clustered. The clustered spatial distributions were usually caused by high mortality of original seedlings because of water locked sites or vole damages.

Fill-in seedlings had a homogenous distribution in 40 stands and original seedlings in 46 stands, whereas only 28 stands had a homogenous distribution, if all the seedlings were taken into consideration. Natural regeneration had a homogenous structure in 31 stands. A clustered structure was found in 11 stands when original seedlings, in 19 stands when fill-in seedlings, and in 29 stands when natural regeneration were taken into consideration. Random spatial patterns were quite rare (Table 2).

## 4 Discussion

The average survival of the fill-in seedlings was 48 % which was higher than the 36 % of the original seedlings. The mortality was found, though, to increase with time. The mean age of the fill-in seedlings was lower than that of the original ones, so more mortality was to be expected in the future. Poor success of fill-in seedlings is probably caused by heavy competition of originally planted trees.

The mean height of both original and fill-in seedlings increased with age, but the average height of fill-in seedlings was lower than that of original ones. Fill-in seedlings become easily stunted by inter-tree competition, which slows down their development (Chavasse et al. 1981, Gemmel 1987).

In Sweden, Gemmel (1987) developed models for predicting height and diameter of individual trees in young Norway spruce stands with the special purpose of predicting the development of fill-in seedlings. Those models might be useful also in Finland, though fill planting is much more common in Scots pine plantations.

Gemmel (1987) found that fill-in seedlings of Norway spruce had a lower mean height and mean diameter than those of the original ones. He also noticed that the differences increased with age. According to Braathe (1992), fill planting is most successful, when the height of original seedlings is small. The slow height development causes problems, because trees much smaller than the average are not considered capable of further development.

To reduce the need of fill planting, higher initial planting densities have been recommended (Yli-Vakkuri 1968, Pohtila and Pohjola 1983). In his extensive review, Sjolte-Jorgensen (1967) pointed that the spacing of 2.5 m in Scots pine plantations was better than smaller spacing when the survival of seedlings was concerned. Dierauf (1992) found that if the density was 2000 trees/ha at the age of 20 years, the number of submerchantable trees was increased compared with a density of 1000 trees/ha in a loblolly pine study. Braathe (1992) found that fill-in seedlings developed better with increasing number of zero-square percentage. In this study, high initial densities were no guarantee of better survival of seedlings. Similar results have been reported earlier (Saarenmaa 1990).

In Finland, first commercial thinning is considered to be feasible, if the DBH of the thinned trees is at least 11 cm (Harvennushakkuiden ... 1992). A study by Vuokila (1972) showed that the maximum number of stems with the average DBH of 10 cm was 1600 trees/ha in the best site types and reduced gradually with the decline of site index. He concluded that the volume increment concentrates on some 1600–1400 stems/ha in Scots pine stands. Vuokila (1972) also concluded that the need of fill planting has been exaggerated in Finland.

The spatial distributions were somewhat clustered in sparsely populated stands, but they were homogenous in fully stocked stands. This fact indicates that mortality of seedlings is not randomly spread, but it has a pattern. That is another reason not to use over-large initial densities in planting. The clustered pattern was usually caused by unfavorable environmental conditions, such as water locked sites or vole damages. Also Gemmel (1987) noticed that gaps in plantations are often a result of poor conditions for survival.

In this study, young fill planting stands had a tendency to be more homogenous than older ones, which usually had a clustered pattern. Natural regeneration was clustered in 29 stands out of 63. The dispersal of seeds decreases quickly with increasing distance from the adjacent forest (Hesselman 1934), and that is why the size of the renewal area can affect the spatial distribution of natural regeneration.

Braathe (1992) found that the volume of fill-in trees varied from 0.2 to 58 % of the total volume of fill planted Norway spruce stands at the age of 23 to 28 years. In more than half of his experimental plots, the volume of fill-in seedlings represented less than 10 % of the total volume, and Braathe (1992) concluded that their contribution is too small to justify the cost of fill planting.

In this study, fill-in seedlings of Norway spruce seemed to have a higher survival rate than Scots pine. Similar results were found in a previous study in northern Finland (Liukkonen 1990). The actual yield of fill planting is not known. One of the obstacles to get more precise results quickly, is the lack of fill planting experiments in Finland.





The average number of natural regeneration (791 seedlings/ha) was higher than that of survived fill-in seedlings (639 seedlings/ha). In most cases, natural regeneration alone would have helped the stand density above the fill planting level (1400 trees/ha).

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