Natural Regeneration in a Shelterwood of Norway Spruce (*Picea abies* (L.) Karst.) on Former Heathland

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A substantial part of heathland in Denmark has been converted to other land uses, such as farming or forestry. For forestry purposes, non-native tree species such as Norway spruce and mountain pine have been used in the conversion process. An objective is now to transform these, mostly single species, even-aged plantations into mixed stands of predominantly native species. The aim of this study is to investigate the use of natural regeneration in the conversion of a Norway spruce stand into a mixed stand. A shelter was established in a 50 year-old Norway spruce stand consisting of approximately 550 stems/ha. In 1997 site preparation was carried out using six different implements. In 2000 the number of naturally regenerated seedlings was counted in site prepared and unprepared parts of the stand. The results show that natural regeneration under a shelter is possible even without site preparation (more than 60.000 seedlings per ha. after two years growth), but site preparation significantly improves regeneration (more than 200.000 seedlings per ha. after two years growth). A number of tree species can regenerate, but the existence of seed sources plays a vital role for the mixture of species in the regeneration. The study has also shown a positive influence of machines driving on the site making some slight humus and soil disturbance.

Keywords: Denmark, heathland, natural regeneration, Norway spruce, *Picea abies*, scarification, site preparation, shelterwood

Introduction

Around the year 1800, hardly any forests were present in the western part of Denmark and approximately half of the land area was covered by heath growing on a poor, sandy soil. Forests covered only about three per cent of the total land area and were found exclusively in the more fertile eastern parts of Denmark. During the past 200 years, most of the heath has been converted to other land uses – mainly farming and forestry (Sabroe 1966). At present, the Danish forest area is approximately 10% of the total land area.

The majority of the plantations on the former heathland was afforested using mountain pine (*Pinus mugo* Turra) planted directly or after soil scarification. At the time of regeneration after the first rotation, Norway spruce (*Picea abies* (L.) Karst.) became the most commonly used tree species, although Norway spruce is not a native tree species in Denmark. Approximately 80 % of the conifer plantations dominating in the forests in the western part of Denmark consist of Norway spruce (Tøttrup 1997).

Norway spruce has several advantages in plantations on poor soil such as easy regeneration, rapid juvenile growth, and good timber quality (Schmidt-Vogt 1987). However, several disadvantages have become apparent. Even-aged Norway spruce plantations are susceptible to windfall, and in the twentieth century substantial forest areas have been destroyed by storms. Root rot (caused by the fungus *Heterobasidion annosum* (Fr.) Bref.) has become increasingly common, and it is not unusual that more than half of the trees in a Norway spruce plantation is infected with this fungus. As a result of these disadvantages, the objectives have been set to transform these plantations into mixed forests composed partly of native broad-leaved species (Anon. 1994, Clausen 1995). A method has been developed where the spruce plantations at a rather young stage (height < 15 m) are used as shelterwood stands under which several species are planted with or without site preparation (Neckelmann, 1995). The advantages of this method are a low risk for frost together with a shelter not so sensitive to windthrow. The planted species include silver fir (*Abies alba* Mill.), noble fir (*Abies procera* Rehd.), Douglas fir (*Pseudotsuga menziesii* (Mirb. Franco), grand fir (*Abies grandis* (Dougl.) Lindley), larch spp. (e.g., *Larix x eurolepis* Henry), beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.).

Natural regeneration of these spruce plantations has only been proposed in exceptional cases. This is partly because of bad experiences, but mostly because planting of Norway spruce appeared to be a reliable and cheap method (Magnussen 1985). In the other Scandinavian countries – where Norway spruce is a native tree species – natural regeneration is far more common (Skoklefald, 1989; Hånell, 1993; Holgen & Hånell, 2000). Natural regeneration may be used in Denmark on certain localities or supplemented by planting or sowing (Magnussen 1985). In this way, the cost of regeneration is likely to be lower than planting exclusively.

The aim of the study is to investigate the natural regeneration under a Norway spruce shelterwood in the conversion into a mixed stand of partly native species.

Materials and methods

The study area was a stand of 8.6 hectares in the northwestern part of Denmark (56° 30' N, 8° 22' E) (Figure 1). The soil was poor and sandy and covered by an approximately 10 cm thick layer of raw humus, and no hard pan was found in the soil.

In the stand Norway spruce dominated, which was planted in the period 1947-1950 under a shelter of mountain pine, which in turn was planted on open heathland 100 years ago. It was a typical stand for this kind of site. More than 93% of the trees were Norway spruce, but other species found in the stand included grand fir (4%), Scots pine (*Pinus silvestris* L.) (2%), Japanese larch (*Larix leptolepis* (Sieb. & Zucc.) Endl.) (<0.5%), and Douglas fir (<0.2%). The shelterwood was established in 1997, consisting of approximately 550 shelter trees per hectare. In the spring of 1998, site preparation was carried out, and 3000 plants per ha were subsequently planted – with species composition of 50% beech, 30% silver fir, 15% oak and 5% Douglas fir. Natural seed fall took place in spring 1999. The shelterwood was weed-free when established owing to the density of the original stand.

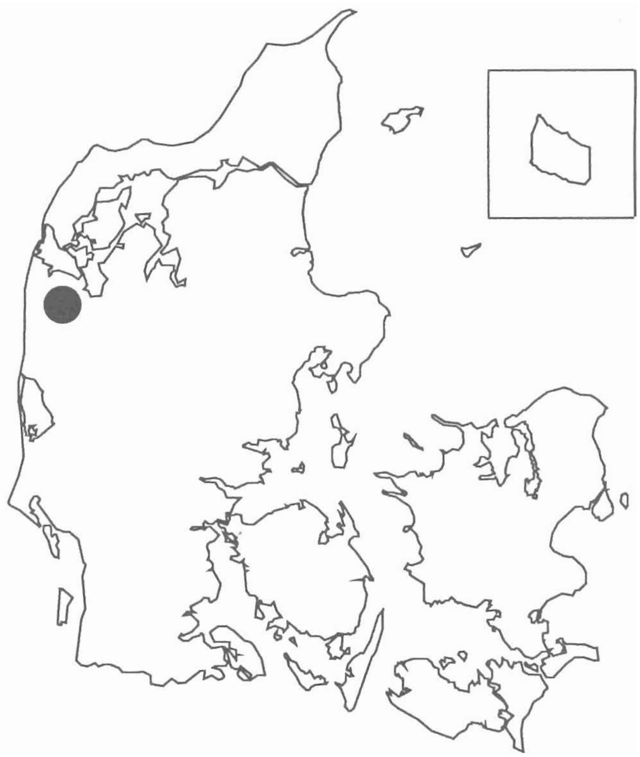

Figure 1. The locality of the study

The experiment consists of four blocks, six site preparation treatments randomised in each block (24 plots, 0.3-0.45 ha each). The plots were divided in either 4 or 6 sub-plots according to size resulting in a total of 108 sub-plots. Regeneration was sparse in the western part of the stand because of draught and the two western most plots were therefore excluded from the study (Figure 2).

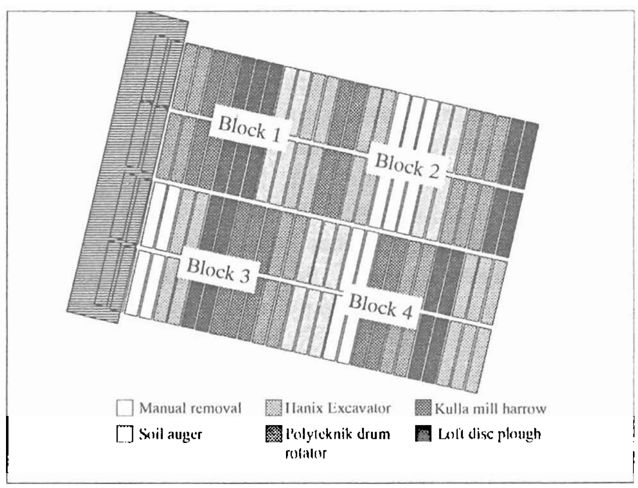

Figure 2. Experimental layout

The treatments were one manual and five mechanized site preparation methods. *Manual removal* of the humus layer in a 30 cm × 30 cm square with a forestry spade was done in the spring of 1998 just before planting. Mechanized site preparation was carried out in the autumn of 1997.

The *Loft disc plough* produces a 40–60 cm wide strip. The depth depends on the disc angle, and the discs can roll over stumps and larger roots. The *Kulla mill harrow* has three tines that remove the humus layer and harrows the upper part of the mineral soil (0-5 cm). The patches are approximately 60 cm wide and 100 cm in length. The *Polyteknik drum rotator* has a hydraulically driven drum on which two oblique ribs are mounted. The ribs push aside the humus, when the drum intermittently rotates backwards. The patches are approximately 60 cm wide and 100 cm in length. The *soil auger* is boom-mounted on a harvester (Thomsen 1998). The soil auger makes circular planting holes with a diameter of 40 cm and loosens the soil to a 60-cm depth. An oblique rib on a horizontal plate removes the humus layer.

The *excavator* used in this study was a small belt driven Hanix n450 excavator equipped with a normal 50-cm bucket. The scarification consisted of digging up a bucket-full and inverting the profile. This scarification method is known as inverting site preparation (Fjeld 1994; Örlander et al. 1998). The holes were 50 cm wide and 100 cm long, but the mineral soil was spread over a larger area. The depth of the treatment was estimated to 50 cm at the deepest point.

In each of the 100 sub-plots, four measurement areas of 1 m² (a metal ring) were systematically laid out. Three measurement areas were placed on site prepared soil, and one was placed on unprepared soil, creating a total of 300 measurement areas on site prepared soil and 100 measurement areas on unprepared soil. The circular measurement area was used for all treatments meaning that also partly unprepared soil was included because the measured area was mostly larger than the site prepared area. The species and number of seedlings inside the ring were recorded. The measurement areas on site prepared soil was centred on the planting hole or strip while the measurement areas on unprepared soil was placed on soil without visible site preparation.

Analyses of the effect of site preparation on regeneration density were only conducted on Norway spruce because regeneration density of other species was either too sparse or too dependent on the location of seed sources. The weighed average number of Norway spruce seedlings pr. m² ($N_{average}$) in each sub-plot was calculated as $N_{site\ prepared} \times Pr + N_{unprepared} \times (1 - Pr)$. $N_{site\ prepared}$ is the average number of Norway spruce seedlings per m² in sample plots placed on site prepared soil, and $N_{unprepared}$ is the number of Norway spruce seedlings per m² in sample plots placed on unprepared soil. Pr is the weight between the two types of sample plots.

The difference between the treatments was analysed using the following model.

$$Y_{it} = \mu + a_t + e_{it}$$

where Y_{it} is the observation, μ is the overall mean and a_t is the fixed treatment effects (t = 1, .., 6). The statistical analysis was conducted using the GLM procedure in SAS for Windows 6.12. Bonferroni's t-test of differences between the means was used to test the differences between the treatments. Both the block effect and the covariate, shelterwood density, were shown to be non-significant.

Results

Distribution of species

Seedlings of eleven different species were found on the site: Norway spruce, grand fir, willow (*Salix sp.*), birch (*Betula sp.*), larch, Scots pine, rowan (*Sorbus aucuparia*), European beech, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), oak and sycamore. Norway spruce accounted for 98% of the seedlings (Tab. 1).

Table 1. Distribution of seedlings and species in site prepared and unprepared areas

Species	Numbers counted		Proportion of total, %		Weighted average numbers per ha
	In unprepared soil	In site prepared soil	In unprepared soil	In site prepared soil	
Norway spruce	2 030	13 174	98.6	98.2	275635
Grand fir	15	80	0.7	0.6	1820
Larch	0	18	0.0	0.1	191
Scots pine	2	15	0.1	0.1	347
Western hemlock	0	9	0.0	<0.1	137
Willow	2	59	0.1	0.4	1056
Birch	1	38	<0.1	0.3	662
Rowan	4	8	0.2	<0.1	375
Beech	3	5	0.2	<0.1	150
Oak	1	3	<0.1	<0.1	91
Sycamore	0	1	0.0	<0.1	7
Total	2 058	13 410	100.0	100.0	280471

The average number of seedlings was 41 per m² in prepared soil and 19 in unprepared soil. There was no regeneration at all in 2.8% of the prepared areas and in 7.4 % of the unprepared areas.

The lowest number of Norway spruce seedlings per m² in site prepared soil was found in the plots prepared with manual removal of humus. The highest number was found in plots prepared with the Polyteknik drum rotator and the soil auger, but no significant difference was found between the five mechanical implements (Table 2).

Table 2. Norway spruce seedlings per m². Within a column, values marked with the same letter are not significantly different ($p<0.05$ level)

Treatments	Seedling in site prepared soil (No. m^{-2})	Seedling in unprepared soil (No. m^{-2})	Weighted average of seedlings (No. m^{-2})
Manual removal	10^{a}	5^{a}	6^{a}
Soil auger	54^{b}	16^{ab}	27^{ab}
Kulla mill harrow	37^{b}	16^{ab}	21^{ab}
Polyteknik drum rotator	58^{b}	19^{ab}	29^{b}
Loft disc plough	45^{b}	34^{b}	39^{b}
Hanix excavator	44^{b}	20^{ab}	31^{b}

The lowest number of Norway spruce seedlings per m² in unprepared soil was also found in the plots prepared with manual removal. The highest number was found in the plots prepared with the Loft disc plough, but again there was no significant difference between the mechanical implements (Table 2).

Discussion

The extent of natural regeneration is noteworthy on a poor soil such as the one studied – a locality that was virtually treeless a century ago. The results have shown that over the past 100 years, it was possible to establish a forest climate and improve the soil to such a degree that natural regeneration now can take place.

The regeneration consists of eleven different tree species – of which six are native and five non-native. Seed sources of Norway spruce, grand fir (incl. silver fir), larch, and Scots pine were present in the original stand while willow, birch, rowan, western hemlock, beech, oak, and sycamore were not present, although seed sources of the latter species were present in the neighbouring stands.

Site preparation increases the number of seedlings per m² for most, if not all, species, but the effect varies. Seedlings of larch, western hemlock, willow, and birch are present almost exclusively in the site prepared soil. Seedlings of Norway spruce, grand fir (and silver fir), and Scots pine occur in both site prepared and unprepared soil, but more abundantly in the site prepared soil. There are too few seedlings of rowan, beech and oak to evaluate these species, but they are able to germinate in site prepared soil as well as in unprepared soil.

The soil seems to be affected by site preparation even in areas where site preparation is not visible (i.e. in unprepared soil). Light compaction and humus layer disturbance of the soil caused by driving in the stand is one possible factor, which could explain the higher number of Norway spruce seedlings in plots prepared with the excavator, the Loft disc plough, the Polyteknik drum rotator, and the Kulla mill harrow compared with plots prepared with manual removal. The higher number of Norway spruce seedlings in the plots where site preparation was done with the soil auger is more difficult to explain because the soil auger operated from the striproad. It might be coincidental.

Natural regeneration of Norway spruce without site preparation using a shelterwood is possible, but the number of seedlings is much lower than after site preparation. In the actual study enough seedlings are found also in the plots prepared with manual removal, but in other cases with less favourable conditions site preparation might have been necessary to obtain enough seedlings. In the mechanically site prepared plots the high number of seedlings represents a potential problem because this could necessitate costly cleanings. The seedlings counted in this study were mainly two years old, and therefore it is reasonable to assume high mortality levels in succeeding years.

With the exception of manual removal of humus all types of site preparation damage some roots of the shelterwood trees and thereby reduce the physical stability of the stand (Fjeld 1996, Westerberg & von Hofsten 1996). From this point of view it would be desirable to regenerate spruce stands without site preparation, which would also reduce regeneration costs.

A large number of Norway spruce seedlings makes it questionable as to whether it is possible to create a mixed stand: do other species have a chance to develop in competition with the all-dominant Norway spruce? Species like larch, birch, oak and Scots pine grow fast at the early stages, and they should be able to compete in the first many years, while species like silver fir, grand fir and beech would have to be favoured in cleanings before they can compete. The presence of other species than Norway spruce shows the potential, and sowing could be considered if natural seed sources of desired tree species are inadequate. Planting on areas without natural regeneration would be another way to introduce new species.

Conclusion

Looking at the weighed average it is obvious that mechanical site preparation improves natural regeneration of Norway spruce compared with manual removal.

The study has shown a positive influence of machines driving on the site and making some slight humus and soil disturbance. A practical implication could then be to use for example ATV's (small four wheel driven machines)(Nordfjell 1995) with wheel chains and to drive systematically in the stand in order to improve the natural regeneration. It could be a cheap and lenient site preparation method in this type of stands.

Natural regeneration under a shelter of spruce is possible on former heathland in Denmark. A great variety of tree species are able to regenerate but the existence of seed sources plays a vital role for the mixture of species in the regeneration. With Norway spruce dominating in the shelter stand, as well as in adjacent stands, it is difficult to obtain a varied seed source. Site preparation improves natural regeneration of most species but enough regeneration might prevail without site preparation. Future studies are necessary to determine the specific conditions where it is possible to recommend regeneration by the use of shelterwood without site preparation as pointed out by Örlander and Karlsson (2000). According to this, it is important to be able to determine the survival rate of the natural regeneration within the ensuing few years.

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ЕСТЕСТВЕННОЕ ВОЗОБНОВЛЕНИЕ ЕЛИ ОБЫКНОВЕННОЙ (*PICEA ABIES (L.)* KARST.) ПОСЛЕ ВЫБОРОЧНЫХ РУБОК НА БЫВШИХ ВЕРЕСТКОВЫХ ЗАРОСЛЯХ

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Резюме

Большое часть верестковых зарослей в Дании бьио облесено или использовано для сельскохозяйственных целей. В лесном хозяйстве для облесения верестковых зарослей использовались неместные древесные породы, такие как ель обыкновенная и сосна горная. В настоящее время эти чистые насаждения превращаются в смешанные насаждения с преобладанием местных пород.

Целью данной работы является исследование методов естественного лесовосстановления для превращение чистых насаждений ели обыкновенной в смешанные древостои.

Выборочные рубки проведены в 50-летнем древостое ели обыкновенной, число стволов после рубки оставленно 550 шт/га. Использованно 6 способов подготовки почвы.

Результаты показали, что лесовозобновление после выборочных рубок возможно и без подготовки почвы (более 60000 сеянцев на 1 га), однако подготовка почвы значительно содействует естественному лесовозобновлению (более 200000 сеянцев на 1 га).Смешанные древостои возможны, если имеются семенные деревья разных пород.

Ключевые слова: Дания, верестковые заросли, естественное лесовозобновление, ель обыкновенная, подготовка почвы.