Regeneration Practices in Scandinavia: State-of-the-Art and New Trends

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Introduction

This overview will focus on the boreal forest of Scandinavia including Sweden, Finland and Norway. The presentation about regeneration practices, including nursery operations and stand establishment, will, regarding nursery operations, focus on containerized stock since it is the type of stock that is totally dominating in these countries.

The forest plays a fundamental role in the ecological, social and cultural well-being of people and this really refers to the Scandinavian countries mentioned. Out of the total land area, under the coniferous forest limit, productive forest and other wooded land represent a large part. (Table 1).

The ownership of this forest is quite different in the respective countries (Table 2). In Sweden, private owners and companies are the dominating landowners. In Finland, private owners and the state owns 90% of the land while the forestland in Norway to a very large extent is privately owned.

Regeneration practices include very few species due to long-term environmental adaptation. In the boreal forest of Scandinavia forest stands are also quite pure dominated by one tree species and also to a large extent even-aged due to management practices. Table 3 shows the species dominating the forestland in the respective countries.

This situation is of course reflected in the regeneration practices regarding the species produced in the nursery (Table 4).

Containerized production is the totally dominating method of producing seedlings as can be seen in Table 5.

Table 1. *Forest land out of the land area under the coniferous forest limit (millions of hectares).*

Country	Land area	Forest land	%
Sweden	41.0	30.3	74
Finland	30.5	26.2	86
Norway	14.8	9.2	62

Table 2*. Ownership (in percent) of forest land.*

Country	Private	Company	State
Sweden	51	39	10
Finland	57	10	33
Norway	80	8	12

Table 3*. Dominant tree species by percent of forest land area.*

Country	Scots pine	Norway spruce	Silver/Downy birch
Sweden	51	39	10
Finland	57	10	33
Norway	80	8	12

Table 4. *Nursery plant production in 2004 for the respective counties by volumes and most important species.*

Country	Volumes (millions)	Scots pine %	Norway spruce %	Birch %	Others %
Sweden	320	37	58	1	4
Finland	163	34	61	4	1
Norway	23	3	93	1	3

Table 5. *Nursery plant production in 2004 by volume and stock type.*

Country	Volumes (millions)	Container %	Bareroot %
Sweden	320	90	10
Finland	163	96	4
Norway	23	98	2

Containerized Nursery Practices

Regarding nursery practices, containerized production is quite similar in the respective country and therefore the following presentation gives a general overview that reflects the major steps in state-of-the-art production.

Containerized systems were first introduced in Finland in the late 60s as the paperpot system originally used for producing rice plants in Japan. It was shortly after then also introduced in Sweden. In this system the seedlings were supposed to be planted together with the paper container.

After experiences in the field with disturbances in the root development due to a slow decomposition of the paperpot container, rigid plastic containers were introduced in the early 70s. The first system had a smooth interior wall and a flat bottom design with a small drainage hole. This design often led to root deformations in the nursery especially in the form of root spiralling. After planting, very few roots grow out from the root system and the fibre structure in the root/stem zone was often seriously disturbed. This situation implied initial stability problems after planting especially for pine seedlings. For stands with these problems there is also a risk that future timber quality can be affected due to, for example, the presence of compression wood.

The introduction of vertical ribs to guide the roots and a new bottom design in the second generation of plastic container systems prevented root spiralling and allowed more intensive root egress during field establishment.

During recent years a third generation of container systems, using different concepts of side slits, have been successfully introduced. All these systems, based on air pruning, produces a lot of active root tips evenly distributed over the whole surface of the growing media and allows a uniform and intense root development after planting.

In Scandinavian boreal forest conditions it can also be of importance for regeneration success to have a lot of active root tips in the upper part of the root system. This due to the fact that root growth in Scots pine and Norway spruce are activated at a temperature of about 5C°. At a planting site in early spring temperature conditions in the soil can differ extensively. In the very upper soil layer temperature during the day can promote root growth while the temperature in the bottom of the root system is to low.

The window for intense root growth activities between the time of planting and the initiation of cell elongation in the shoot is very narrow in Scandinavian boreal forest conditions. Regarding the thin green line concept the presence of a lot of active root tips in the upper part of the root system can therefore be of importance for regeneration success.

The major steps in state-of-the-art production of containerized seedlings start with sowing. Normally one seed per container is sown in highly automated filling and sowing lines. To improve seed quality an extensive tree improvement program, using seed orchards, have been running during many years in Scandinavia.

In Sweden the work is done in close co-operation between public organisations and the major forest companies and is paid for on a 50/50 basis. The seed orchards however is owned and run by the companies. In Sweden the second generation of orchards will now be commercially utilised and the genetic gain in wood production is expected to be about 20%. The first generation has generated a gain of about 10%. The third generation of orchards now under establishment is expected to give about 30% more volume in the future. In Finland and Norway the tree improvement program and the seed orchards are run and paid for by public organisations. In both countries they are now utilising the first generation of orchards and as for the first generation in Sweden the gain in productivity has been about 10%.

When sowing, the growing medium used in the nursery is normally a pure peat mixed with dolomite lime. The container stock is generally grown at densities ranging from 400 to 1000 seedlings per square meter depending on if it is grown for one or two years in the nursery.

During the germination and early growth the seedlings are kept in plastic greenhouses that each can contain up to 2 million seedlings. Depending on geographical location, greenhouse cultivation starts somewhere between the beginning of March and the end of April. The greenhouse has equipment for irrigation and fertilisation and some nurseries control the distribution of water by computers connected to sensors measuring the weight of the container cassette. Also fertilization is conducted through the irrigation system.

Some nurseries also use additional light supply during greenhouse cultivation. This is done to prevent bud set of early sown northerly provenances of Norway spruce. Due to the long nights in early spring, there is a risk for bud set to occur only some weeks after germination. If this happens there will be no more shoot growth during the rest of the vegetation period but by breaking the night with a short light exposure this risk can be prevented.

Also blackout equipment are used in many nurseries during greenhouse cultivation to regulate the growth of Scots pine seedlings. During the first year of growth, only primary needles are normally developed regarding Scots pine seedlings. A long night treatment some weeks after germination will induce bud set. When again exposed to the normal photoperiod, bud break will occur and secondary needles will be developed on the new shoot and you will have a one-year old seedling with the characters of a two-year old one. This technique has been developed to meet the customer demand for a “short and fat” seedling regarding needle biomass and stem diameter.

After the greenhouse phase that covers about 2 to 3 months the seedlings are moved to outdoor areas for completion of growth and hardening off. As for the greenhouse, irrigation and fertilisation at the outdoor area are also managed by using travelling booms. The container cassettes are normally stored on raised pallets all the way from sowing until lifting for field distribution or winter storage. This system facilitates the internal transportation and it also contributes to an effective air pruning of the root system.

To be able to prepare Norway spruce seedlings for planting out in the fall or cold storage during winter, many nurseries are using outdoor blackout equipment for initiation of early bud set. This long night treatment is normally conducted during 2 or 3 weeks in August and is a very effective way to promote the hardening process of Norway spruce during late summer and early fall.

When the seedlings are ready for cold storage they are moved from the outdoor area to the packing line where they normally are put in cardboard boxes. The seedlings are often cold stored during winter in storage facilities at minus 4 ^{o}C, but a lot of seedlings are also stored outdoors on raised pallets. If there is a sufficient snow cover the quality of the seedlings will not be affected. But during cold winters with less snow cover there is a substantial risk for severe root damages due to low temperature exposure.

After the winter storage the distribution to the planting site is often carried out by specially designed trucks. The final strategic distribution of seedling boxes over the site is normally done manually or often also by small four wheelers and in some cases by helicopter.

Stand Establishment Practices

Under this heading the most important methods used for stand establishment in Scandinavia are presented.

Before establishment the regeneration area is normally left for a couple of years to let logging debris decompose to facilitate soil preparation. A very important reason is also to minimise the risks for damages to the seedlings due to attacks from the pine weevil, one of the major problems for regeneration success in Scandinavia. Later in this presentation methods used to improve the situation will be discussed.

Scarification is the dominating method in all countries for preparation of regeneration areas. Different methods for scarification are used depending on local site conditions. In drier sites harrowing is normally used while mounding is used on sites with a higher water table and sites exposed to frost heaving. Due to environmental concerns and the concern for damages to relics of culture in the ground, less radical methods like mounding or scarified patches are more and more used.

In general the public attitude towards forestry has affected the legislation in Scandinavia towards a more restrictive attitude against for example radical site preparation the use of herbicides and clear cutting over large areas. In Sweden for example the new forest legislation now states very clearly that environmental concerns in forest management are of equal importance compared to timber production. This is for example expressed in the question of bio-diversity where forest areas with endangered species often are converted into national parks.

As can be seen from the following figure planting is the dominating method in the respective country but due to adjustments in forest legislation the possibilities for land owners to practice natural regeneration has increased in resent years.

The most common areas for natural regeneration in the boreal forest of Scandinavia is areas with sandy soils and a relative thin humus layer dominated by Scotch pine. Normally about 100 seed trees are left per hectare and soil scarification is done adjusted to the prognosis for a good seed year. The regeneration result is often very good and to lover costs than planting or seeding. Due to the large amount of seedlings that normally establish over the regeneration area there is also favourable conditions for good quality timber production in the future.

Also seeding is conducted on areas with about the same conditions as described for natural regeneration and normally with pine seeds. A very shallow scarification is recommended where only the humus layer is removed in stripes or patches. Often the seeding is done in combination with soil preparation where the soil first is

Table 6. *Different regeneration methods used in Scandinavia during 2004 expressed in percentage of the total regenerated area.*

Country	Natural regeneration	Seeding	Planting	No measures
Sweden	22	2	75	1
Finland	23	20	56	1
Norway	25	2	71	2

prepared to optimise germination conditions after witch the seeding is conducted.

When using strips, 20-25 seeds are distributed per meter and when using seeding in patches 15-20 seeds are distributed in each patch. When using patches about the same amount is prepared per hectare as for the amount of seedlings when using planting, that is about 2000-2500 per hectare depending on site index.

Seeding is a sensitive method where the results can be very variable depending on climate conditions. If successful the costs are lower than for planting and the potential for a good timber quality in the future is equal to natural regeneration.

Planting is the most common regeneration method in boreal Scandinavia both for pine, spruce and birch. It is conducted over a wide range of site conditions and as mentioned the regeneration site is scarified 2-3 years after clear felling by harrowing or mounding. In both cases the distance between the tracks after harrowing or between mounds are about 2 meters. The distance between planted seedlings is also about 2 meters giving a normal plant spacing of 2500 seedlings per hectare.

Planting is normally done by hand with a special planting tool. This planting tool is designed like a tube where the seedling can slide down into the planting hole made by the tool. A skilled worker can plant up to 3 000 seedlings a day using this method. The seedlings can also be planted with machines that have been developed in Scandinavia. For some machines the seedlings are distributed by compressed air through tubes to a scarified spot prepared by the machine. The vehicles can also be equipped with special sensors that avoid planting in rocks or stones.

The regeneration result after planting is often quite good. However, the thin green line between success and failure is often depending on the possibilities to reduce the damages caused by the pine weevil, a major if not the major problem for successful forest regeneration both in Sweden, Finland and Norway.

The pine weevils are attracted by the smell from fresh felling areas and if young seedlings are available at the site the weevil feeds on the bark and normally kills the plant by girdling it. If no protective measures are conducted in areas with a lot of pine weevils you can often expect a survival rate of less than 50%.

Measures taken in regeneration practices in Scandinavia to reduce damages from pine weevils involves different kinds of silvicultural measures such as delayed planting, scarification and the use of resistant plant material.

By letting the clear-cut area rest for 2-3 years before planting the population of weevils will be substantially reduced due to lack of fresh feeding material for the second generation of weevils reproduced in the stumps of the old stand and normally emerging two vegetation periods after clear felling.

A careful scarification before planting will also reduce the damages since it had been shown that seedlings surrounded by mineral soil are less exposed to attacks from the weevil than seedlings planted in humus or close to the humus layer.

Seedling quality and seedling size are also factors of importance to reduce the damages. A vital seedling will respond to the bark damages by an intensive flow of resin which will improve the chances of survival. Also a seedling with a thick stem will have better chances of survival. In trials conducted, the survival rate was dramatically improved for seedlings with a stem calliper of half a cm or more.

Besides silvicultural measures to prevent damages from the pine weevil chemical and technical protection are also used including insecticides, mechanical devises or different kinds of coatings that will prevent the weevil to feed on the stem bark.

Chemical treatments have during many years shown good results. Due to concerns for the environment and human health some of these chemicals have been forbidden and there is, since many years, a general discussion in Scandinavia over the future use of insecticides in planting operations.

This situation has implied a growing interest for alternative methods to chemical treatments. These include different kinds of mechanical devises. A lot of mechanical devises attached around the seedling have been tested with varying results. Besides the protection ability against damages the cost for the device and application is often quite high making large-scale introduction more difficult.

During recent years methods for coating of the stem with glue or wax have therefore been tested. With this technology seedlings can be treated in the nursery in a cost efficient way and planting capacity compared to untreated seedlings will not be reduced. Results for some of these coating methods have also been very promising and raised a lot of interest for expanding the efforts in the development of this technology among forest companies and private land owners.

New Trends in Regeneration Practices

Regarding regeneration practices these are some examples of new trends.

- A growing interest for pre-cultivation followed by transplanting to a larger container mainly for production of large spruce seedlings.
- Storage in freezers at about –4C° is increasing.
- Less radical methods for site preparation like moulding is gradually replacing harrowing.
- Interest in machinery planting is increasing in Sweden and Finland.
- A growing interest for very small containerized seedlings for sites with moderate or low weed competition and also for sites where extensive damages from the pine weevil can be expected.

Regarding the increased storage in freezers, at temperatures below 0°C, the trend is related to the extensive root damages due to low root temperatures during outdoor storage that many nurseries have experienced. Outdoor storage of containerised seedlings on raised pallets in combination with less natural snow cover during the latest years is the background to this situation. Also problems with moulds developing during winter in cold storage with a temperature over 0°C is another factor of importance for the increase in freeze storage.

As mentioned before negative effects of radical methods for site preparation are discussed more and more both from environmental and cultural aspects. Also new forests legislation where environmental concerns have been identified as of equal importance compared to timber production has contributed to the trend against softer methods for site preparation.

The growing interest for machinery planting is connected with a situation where labour for planting operations is harder and harder to find. This is due to rapid urbanisation in many parts of Scandinavia, leaving few people in forested areas at the countryside. Since machinery planting is restricted only to sites suitable for this planting method, a movement towards professional planting crews, as in Canada and the US, can be foreseen.

In recent years many nurseries have noticed a growing demand for large container stock, mainly of spruce. This due to successful regeneration results at fertile sites with extensive weed competition. This demand have also been further more expressed as a result of the major wind throw that hit southern Sweden in the beginning of 2005 which will imply an additional demand of at least 200 million seedlings during the nearest years to come.

When producing large container stock in Scandinavia today, that is containers with a substrate volume over 100 cc and a density under 400 seedlings per m², seedlings are germinated in greenhouses and grown for about 3 months before they are mowed to open land. Seedlings are then grown on open land for the rest of the vegetation period. After winter storage on open land the seedlings are grown for another vegetation period before planting in the fall or next spring.

The low utilisation level of the expensive greenhouse area with a low seedling density in combination with shortage of greenhouses and difficulties for many forest nurseries to have investments approved for additional greenhouses have raised interest for pre-cultivation and transplanting technology.

In initial tests pre-cultivation of conifer seedlings and broad-leaves have been performed under a short period at high seedling densities using both pure peat and stabilized rooting media. Depending on expected difficulties to grow seedlings successfully at very high densities in conventional greenhouses some major companies in Sweden have successfully tested pre-cultivation in a system with a very precise level of climate control and large growing capacity. The system is developed in Sweden by the company QS Growing Systems.

In the system the seedlings are pre-cultivated in a mobile multiple floor production facility not affected by outdoor climate. No pesticides or insecticides are used and the water and fertiliser are recycled. The system also utilises 90% of the waste heat from the production. The cultivation period, under optimal germination and growth environments, extend over a period of 2 to 4 weeks at a density of 2000 to 4000 seedlings per m² depending on species. After cultivation the seedlings are quality graded using a grading and re-plug robot. The production system

is certified according to the ISO regulations and has also been environmentally approved based on life cycle analysis.

At a convenient time, decided by the customer, the pre-cultivated seedlings are delivered to the nursery. Transplanting at the nursery is then carried out by a mobile unit used in horticultural transplanting operations. The unit has a capacity of transplanting 25 000 seedlings per hour and the computer system allows that transplanting of pre-cultivated seedlings can be done using any optional container system. By adjusting the time of transplanting to the local climate at the specific nursery the continuous cultivation of the transplanted seedling can be done on the nursery outdoor area without the need of greenhouses.

The companies involved in the tests have identified several advantages with this system.

- The nursery will have a cost-efficient and high quality seedling, grown from there own seed, with no losses due to containers without seedlings or containers with poor quality seedlings.
- No needs for complementary or new capital investments in conventional greenhouse technology with high running costs.
- Nurseries that already have invested in a containerized system can use this system and belonging equipment.
- Environmental stress will be reduced due to less need for greenhouse cultivation.

The interest for planting very small seedlings, so called mini-plants, on specific sites are the result from successful regeneration results in Finland and trials in Sweden conducted by Dalarna University in close co-operation with many of the major forest companies in Sweden.

Mini-plants are defined as containerized seedlings with a root volume of about 20 cc and a density of close to 1500 seedlings per m² and grown for about 10 weeks before planting. The main reason for the interest is the possibilities to reduce regeneration costs both in nursery production, storage, distribution and planting. An additional benefit could also be that these small seedlings are less damaged by pine weevils, compared to seedlings of conventional size, something that has been noticed in the first trials conducted.