FOREST RESTORATION IN THE NORDIC COUNTRIES

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Abstract—The Nordic countries include Iceland, Norway, Sweden, Finland, and Denmark, which range from lat. 54° in southern Denmark to lat. 72° at North Cape, Norway. This region is dominated by the boreal coniferous vegetational zone. Denmark and southern Sweden are, however, located in the deciduous (nemoral) forest zone, whereas the interior part of Iceland and the high altitudes of Norway and Sweden are in the mountainous zone. Forests cover 1, 11, 28, 60, and 66 percent of the land area in Iceland, Denmark, Norway, Sweden, and Finland, respectively. Traditional forestry has mainly concentrated on conifers in the boreal and the nemoral zones. Increased concern about nature conservation and sustainable land use along with economic constraints and reduced softwood timber prices have led to increased focus on growing and regenerating broadleaves. Planting nursery-grown seedlings is the common and preferred method for forest restoration and afforestation. However, this technique is expensive unless wide spacing is used. Direct seeding is a less expensive alternative that may still give acceptable results. This regeneration practice has been examined for a number of broadleaved species within a collaborative project including forest researchers from Mississippi, Estonia, and the five Nordic countries. Results from this work are presented, and conclusions are drawn for forest management and future research and development in this field.

INTRODUCTION

This paper summarizes the context of forest restoration in the Nordic countries and Estonia including the debate on changing aims of future forestry and silviculture. Furthermore, we present the objectives and the main conclusions of a cooperative project between the Nordic countries, Estonia, and the United States on direct seeding of broadleaves. The cooperative project was supported from both national funds from each of the participating countries as well as funds from the Nordic Forest Research Cooperation Committee (SNS).

CONTEXT OF FOREST RESTORATION

The Nordic countries include Iceland, Norway, Sweden, Finland, and Denmark, which range in latitude from 54° N in southern Denmark to 72° N at North Cape, Norway. Estonia is one of the Baltic countries and is located south of Finland (fig. 1). Forest cover ranges from a very limited part of the land area in Iceland to a dominant part in Sweden and Finland (table 1).

The boreal coniferous vegetational zone dominates the area. Denmark and southern Sweden are, however, located in the deciduous (nemoral) forest zone, whereas the interior part of Iceland and the high altitudes of Norway and Sweden are in the mountainous zone (Walter 1985). Forest industry plays an important role for the Swedish, Finnish, Norwegian, and Estonian economy, but the economical importance of wood production is rather marginal for Denmark and Iceland. In general, most of the forestland is private property, which is a relatively new ownership status in Estonia.

The term forest restoration covers very different silvicultural challenges in the Nordic countries. In Iceland, afforestation on totally barren and degraded land, practically deserts, is one important approach to forest restoration. Special attention is paid to restoration of the birch woodlands, which covered more than 25 percent of the land area at the time of settlement in the 10th century (Sigurdsson 1977). In contrast to the Icelandic situation, afforestation efforts in the other Nordic countries and Estonia occur on fertile farmland. Aims of afforestation are rather different within and between the countries. In Finland, Sweden, and Norway the expected extent of afforestation is rather limited (table 1) and serves mainly as an alternative land use to small scale, inefficient agriculture. In Estonia, many small farms have been turned over to the descendants of former owners. They have no experience and knowledge of farming practices, so forestry may be of interest to these landowners as a low-cost, land-use alternative. Consequently, a significant increase in forestland on abandoned farmland is expected in Estonia. In Denmark, the goal of the afforestation program is to double the forested area within one tree rotation (about 100 years). There are several aims of this program including:

- increased concern for sustainability, nature conservation, and biodiversity;
- protection of ground water resources;

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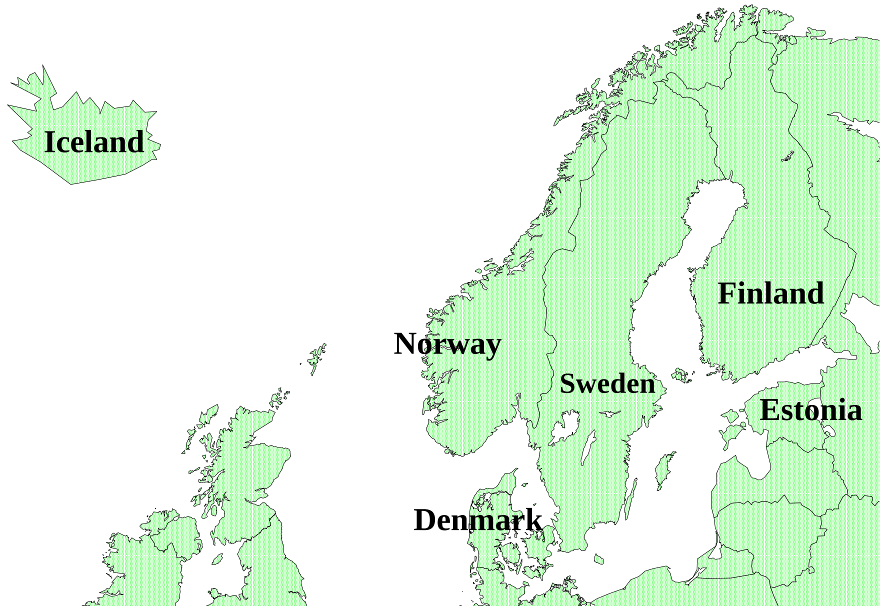

Figure 1—The Nordic countries and Estonia.

Table 1—Forestland and woodlands in the Nordic countries and Estonia[a]

Country	Forestland and woodlands	Forestland, % of total land area	Expected afforestation, % of total land area	Private- (includ. companies) owned forestland
	- - 1,000 km² - -			*- - - - - - - Percent - - - - - - -*
Finland	201	66	1	71
Sweden	244	60	1	78
Estonia	21	50	7	35
Norway	87	28	< 1	85
Denmark	5	11	11	69
Iceland	1	1	2–5	70

[a] Woodlands are roughly nonproductive in terms of wood production. In Iceland, in particular, they cover a significant part of the forested land. Expected afforestation is estimated based on personal judgements for the next 50 to 100 years (Finland, Sweden, Norway, Iceland, and Estonia), or it is based on a political decision (Denmark). In Estonia, the government aims at a 50-percent private forestland rate.

- improvement of recreational values of the landscape; and
- reduction of subsidized agricultural production.

Moreover, at present in the deciduous zone (southern Sweden and Denmark), conifer plantations are being transformed into broadleaf stands, particularly on better soils. Today, conifer plantations cover about 65 to 80 percent of the forestland in this area, and the main species is Norway spruce [*Picea abies* (L.) Karst]. Norway spruce is outside or on the edge of its natural range in Denmark and southern Sweden. The conifers were initially planted due to their high productivity and low cultivation costs. However, they have shown in many cases poor wind stability and health depending on site and species. Such catastrophes not only destroy the existing forests but also leave an area with considerable regeneration problems. The forest climate is lost, and weeds, frost, drought, and wind may cause problems for regeneration.

As illustrated above, the background for forest restoration with respect to ecological conditions and forest industry is very diverse in the Nordic countries. However, cultural, political, and economical similarities of the countries form a common platform for changes and aims in the forestry of these countries.

CHALLENGES IN SILVICULTURE

Traditional forestry in the Nordic countries has concentrated mainly on growing conifers for timber and pulp in the boreal and the nemoral zones. During the past two decades, increased concern over ecological sustainability, nature conservation, and sustainable land use in conjunction with economical constraints and reduced softwood timber prices has led to an increased focus on the use of broadleaf species and close-to-nature forest management. The more diverse and multifunctional aims of forestry have emphasized the need for the forests to be flexible with respect to future outputs as wood and nonwood products and values. Additionally, the importance of such flexibility is stressed by the long production periods in Nordic forestry. The rotation length usually ranges between 50 to 120 years, depending on site, species, silvicultural practices, etc. The problem is that the main role of the future forests cannot be predicted precisely.

The stability of forests can be expressed in terms of resistance and resilience of the forest ecosystem (Larsen 1995). Poor resistance may express a considerable susceptibility of the forest to be damaged or destroyed by strong winds, drought, fire, or a complex of factors. Poor resilience may entail considerable regeneration problems because of the difficulties regaining the forested condition after a catastrophe. Active forest management is crucial for maintaining a stable forest ecosystem. Otherwise, there is considerable risk that the forest will not fulfil the aims of its establishment.

Traditional and close-to-nature forest management is probably best described as relative degrees of forest management, which may overlap. Stands resulting from traditional forest management are usually homogeneous with respect to species and age. In traditional forest management, stands are harvested when the average tree has reached maturity, and planting is the dominant regeneration method with natural regeneration utilized to a lesser extent. Simple administration, apparently cost-effective methods, and convincing economical models are probably the main reasons for the widespread use of this forest-management approach.

In close-to-nature forest management, natural forest ecosystem processes are used and supported by the silviculturist to achieve inexpensive natural regeneration and optimise production value of each tree during the later part of the rotation period. The latter is performed by harvesting single trees as they reach a target diameter; e.g., 57 cm d.b.h. for beech (*Fagus sylvatica* L.) in Denmark and southern Sweden. Close-to-nature forestry is also characterized by the high priority given to the use of site-adapted species in heterogeneous forest structures, which will gradually develop as a consequence of the regeneration system. It should be stressed that stand heterogeneity is not the goal itself but a way to allocate the species to various soil conditions and improve forest-floor conditions for natural regeneration.

Proponents of the principles of close-to-nature forest management regard it as a silvicultural system that may support the multifunctionality of a forest. This may include economic benefits from the extensive use of natural regeneration and single-tree management.

WHY IS DIRECT SEEDING INTERESTING?

In close-to-nature forestry, how is the strong focus on minimizing cultivation costs and promoting site-adapted species relevant to forest restoration? Low cultivation costs may be essential for the long-term economic success of close-to-nature silviculture. Natural regeneration is, in many cases, not a reliable and realistic option on sites that lack relevant seed sources or appropriate germination environments. Wind-dispersed species like birch (*Betula* spp. L.) may, however, have a potential for natural regeneration on bare land. Examples of successful natural regeneration of birch on former farmland or on clear-felled areas are well known. It was common practice in traditional forestry to remove regenerated birch to reduce competition on planted conifers. In Iceland, it is proposed to plant birch at very wide spacings or in clusters to distribute seed sources in the landscape and thereby support the restoration of the birch woodlands (Arad•ttir 1991).

Planting seedlings is the most common practice of today's forest restoration programs. It is a reliable but expensive method, particularly with respect to establishment of broadleaves. It typically costs $0.40 to $0.70 to purchase and plant seedlings. Usually 5,000 broadleaf seedlings are planted per hectare. Direct seeding is an alternative regeneration method that may be less costly. For $1.00 it is possible to buy 20 to 100 acorns or 100 to 200 beechnuts; but, in bumper crop years, the prices may decrease. Consequently, higher seedling densities could potentially be established with direct seeding at lower costs than planting seedlings. High-density stands could also have a positive impact on future stand quality. Table 2 outlines the approximate ranges of costs related to direct seeding and planting of beech and oak. The oak may be either pedunculate oak (*Quercus robur* L.) or sessile oak (*Q. petraea* Liebl.). The question is whether it is possible to

Table 2—Approximate costs for direct seeding of beech and oak in Denmark and southern Sweden[a]

	Direct seeding	Planting
	- - - - *Dollars per hectare*[b] - - - -	
Site preparation	0 – 700	0 – 700
Seeds or transplants	200 – 500	1,200 – 2,400
Sowing or planting	100 – 350	400 – 800
Fence	0 – 1,300	0 – 1,300
Total	300 – 2,850	1,600 – 5,200

[a] The costs depend to a large extent on several factors such as management objectives, economy of the landowner, goals for future wood quality, site quality, deer population, area of the site, and cost of seed/transplants.

[b] United States currency.

achieve the knowledge, skills, and methods that make direct seeding competitive with planting in terms of costs, reliability, and stand quality (Johnson 1981, Kübner and Wickel 1998, Leder and Wagner 1996). Additionally, direct seeding may offer a number of other advantages compared to planting:

- The natural root development of seedlings that developed from direct seeding may be advantageous with respect to future stability against windthrow or drought events.
- The high stock density may reduce the need for deer fences.
- Direct seeding of species mixtures could be a relatively inexpensive way to establish a stand with good potential for structural adaptation to microsite variability.

Governmental subsidies to establish broadleaves are commonly available for foresters and forest authorities in Sweden and Denmark. Subsidies in Denmark (table 3) are supposed to support the fulfilment of the Danish afforestation program and enhance the transformation of conifer plantations into hardwood forests. Subsidies are, however, not necessarily prudent in terms of economical sustainability of forestry, and they call for further research and development that eventually can provide forestry with more inexpensive regeneration methods.

Table 3—Examples of present subsidy programs for afforestation and regeneration in Denmark[a b]

Forest restoration type	Maximum subsidy
Afforestation in areas where it is highly preferred (per ha)	
Planting of broadleaves	$2,900
Planting of conifers	1,900
Direct seeding	1,900
Afforestation in other areas (per ha)	
Planting of broadleaves	1,900
Planting of conifers	1,200
Direct seeding	1,200
Additional subsidies for afforestation	
Pesticide-free afforestation (per ha)	500
Fence (per m)	2
Income compensation (per ha per yr)	350
Regeneration on forest land (per ha)	
Natural regeneration of beech, oak, or ash (*Fraxinus excelsior*)	1,300
Planting beech, oak, ash, or basswood (*Tolia cordata* or *T. platyphyllos*)	3,000

[a] Eight to twelve years after establishment there must be a minimum of 2,500 to 4,000 saplings (depending on species and site type) per hectare with an average height of more than 1 m.
[b] United States currency.

CURRENT PRACTICE

There is limited current knowledge and experience on direct seeding broadleaves in the Nordic countries. However, direct seeding was commonly practiced to establish beech and oak in southern Sweden and Denmark during the late 19th and the early to mid-20th century. The intensity of these former regeneration efforts far exceeded the present level in terms of labor input, and today it seems relevant to draw an analogy to horticulture. Intensive weeding and pest-management practices were applied together with the use of very high seed densities. Stock densities exceeding 100,000 seedlings per hectare were not unusual. Regulations on provenance use reduced-seed availability and consequently led to the increased use of nursery stock.

Today, direct seeding of oak is gaining new popularity for afforestation of farmland in southern Sweden and Denmark. The method is regarded as reliable, and costs are between 30 to 50 percent of costs for planting seedlings. Oak seeding can be reliable on bare farmland because of the absence of small rodents, as they have no access to vegetative cover. Moreover, European oaks typically exhibit pioneer characteristics, which make them well adapted to the site conditions on open fields.

DIRECT SEEDING PROBLEMS

At present, there are a number of practical reasons for the limited use of direct seeding. Insects, slugs, rodents, birds, and deer can consume large amounts of seeds and young seedlings (Nielsson and others 1996). Late-spring frost may damage sprouting seedlings, and germination can fail or be delayed due to drought or incompletely broken seed dormancy. Moreover, seed availability is limited by protocols established for seed-source approval. These limiting factors must be addressed if direct seeding is going to be a planting alternative.

Furthermore, it is difficult to successfully incorporate new methods into silvicultural practice. Increasingly, many foresters face time constraints in their work, which reduces the time available for learning new regeneration methods.

DIRECT SEEDING RESEARCH AND DEVELOPMENT

The ultimate goal of the joint Nordic project on direct seeding of broadleaves was to develop new, reliable, and inexpensive regeneration methods compared to the conventional practice of planting seedlings. Furthermore, it was the aim of the project to test new methods on a range of typical site types for forest restoration.

The main hypothesis was that seedlings could be established through direct seeding with similar success as seen for planted nursery seedlings if:

- seed was of high quality;
- seed dormancy was broken by a relevant pretreatment procedure before sowing; and
- seed and established seedlings were protected against pests.

Additionally, it was hypothesised that short seeding tubes (10 to 25 cm tall) could protect seed and seedlings sufficiently. Light-seeded species like birch and alder (*Alnus* spp. Ehrhart) were, however, not expected to benefit from the protection against rodents. Instead, the tubes were supposed to create a calm and moist microclimate. This would hypothetically prevent light seeds from being blown away, improve seed germination, and improve initial seedling growth.

WHAT WAS INVESTIGATED?

Approximately 50 field experiments were established in the participating countries from spring 1995 until spring 1998. As many as three experiments were carried out at the same site in successive years. The main emphasis in the Nordic countries was generally on pedunculate oak, beech, and birch (*Betula pubescens* Ehrh. or *B. pendula* Roth) (table 4), but other species were also tested. In Mississippi, water oak (*Q. nigra* L.) was investigated, and in Estonia, grey alder (*Alnus incana* Moench), pedunculate oak, and birch were investigated. In Denmark, a number of other species were tested including wild cherry (*Prunus avium* L.), hawthorn (*Crataegus monogyna* Jacq.), ash (*Fraxinus excelsior* L.) and sycamore maple (*Acer pseudoplatanus* L.).

Various types of short seed tubes were tested. The tubes were manufactured in Denmark especially for this project, and their design was changed from year to year after evaluation of preliminary results. Initially (1995), the tubes were 25 cm tall, 28 mm in diameter, and were made out of polyethylene. In 1996 tubes of biodegradable plastics (mainly a mix of cellulose and starch) were used. Tube lengths and diameters tested ranged from 5 to 25 cm and 14 to 38 mm, respectively.

There were generally two types of experiments:

- Some experiments were relatively intensive and included both planted seedlings and sown seed; the latter seeded with and without seed-tube protection. These experiments were intensively monitored. Some of these intensive studies also included treatments with different densities of a lupine (*Lupinus nootkatensis* Donn ex Sims) cover crop (Iceland), weed control treatments (Norway, Denmark, Sweden, Estonia), or soil preparation (Sweden).
- Other experiments were nonintensive and were often established in close collaboration with forest managers (Denmark, Finland). These low-budget trials served as a supplement to the more intensive experiments allowing direct seeding and the seed tubes to be tested at a range of sites in different years.

CONCLUSIONS OF THE DIRECT SEEDING PROJECT

Results are not presented here since some of the work is still in the process of being published. However, some of the main research conclusions, implications for forest management, and directions for future research are summarized.

SEED TUBES

Seed tubes showed promising preliminary results with both light-seeded and heavy-seeded species. In many cases, germination was good in the tubes, and they protected the seed and seedlings from rodents and weevils. However, it was not complete protection, and, in some cases, the tubes even increased rodent problems because the animals learned that the tubes contained food. Additionally, some

Table 4—Main species and site types of the experiments in the participating countries

Country	Main species	Site types
Iceland	Birch (*Betula pubescens*)	Severely disturbed or partially reclaimed soils, which are being colonized by lupines
Norway	Birch (B. *pendula*)	Agricultural fields
Sweden	Beech (*Fagus sylvatica*) and pedunculate oak (*Quercus robur*)	Clearcut following a conifer stand, conifer shelterwood, or agricultural fields
Denmark	Beech (*F. sylvatica*) and pedunculate oak (*Q. robur*)	Clearcuts following conifer stands, conifer or broadleaved shelterwoods, or agricultural fields
Finland	Pedunculate oak (*Q. robur*)	Agricultural fields
Estonia	Birch (*B. pendula*)	Agricultural fields or a clearcut following a conifer stand
United States		
Mississippi	Water oak (*Q. nigra*)	Agricultural fields

seedlings suffered from winter frost damage. The warm and moist microclimate inside the seed tubes apparently prevented some seedlings from developing frost hardiness. Other problems encountered included waterlogging in the tubes, poor light conditions caused by soil sticking to the tubes, and frost heaving of the tubes. Moreover, some of the biodegradable materials used for tube construction apparently decreased germination of birch, alder, and beech. In summary, the seed tubes tested in these experiments did not lead to new, reliable, and inexpensive regeneration methods.

FOREST MANAGEMENT

In spite of the shortcomings of the seed tubes, we did obtain relevant knowledge that can be applied towards future forest management, research, and development. On the degraded sites of Iceland, planting gave higher rates of birch establishment than did direct seeding, but the seeding success varied between sites and appeared promising on some sites. Furthermore, a properly managed lupine cover crop improved birch establishment. On farmland in Norway and Estonia, no reliable methods were found for direct seeding birch and alder. In these countries, weed competition was identified as a main problem for the small seedlings.

The research indicated that heavy seeded species, like beech and oak, may be successfully established by direct seeding on sites and in years with low rodent populations. However, competitive weeds may still need to be controlled, particularly on fertile soils. Additionally, site suitability of each species must be considered for inexpensive and successful regeneration. For example, beech favors the environmental conditions under a shelterwood, whereas oak is better adapted to the microclimate of clearcuts or farmland.

FUTURE RESEARCH AND DEVELOPMENT

The Nordic project on direct seeding broadleaves has identified the need for further development of silvicultural skills, methods, and direct-seeding techniques. Additionally, there is a need for monitoring methods and rodent population control in concurrence with seeding of heavy seeded tree species. Likewise, the development of pretreatment methods aimed particularly at sites to be direct seeded is regarded as an important field of research.

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