METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 790, 2000
FINNISH FOREST RESEARCH INSTITUTE, RESEARCH PAPERS 790, 2000

Forest Regeneration in the Northern Parts of Europe

Proceedings of the Finnish-Russian Forest Regeneration Seminar in Vuokatti, Finland, Sept. 28th – Oct. 2nd, 1998

E. Mälkönen, N.A. Babich, V.I. Krutov and I.A. Markova (eds)



VANTAAN TUTKIMUSKESKUS – VANTAA RESEARCH CENTRE

METLA

METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 790, 2000
FINNISH FOREST RESEARCH INSTITUTE, RESEARCH PAPERS 790, 2000

Forest Regeneration in the Northern Parts of Europe

Proceedings of the Finnish-Russian Forest Regeneration Seminar in Vuokatti, Finland, Sept. 28th – Oct. 2nd, 1998

E. Mälkönen, N.A. Babich, V.I. Krutov and I.A. Markova (eds)

VANTAAN TUTKIMUSKESKUS – VANTAA RESEARCH CENTRE

E. Mälkönen, N.A. Babich, V.I. Krutov and I.A. Markova (eds) 2000. Forest Regeneration in the Northern Parts of Europe. Proceedings of the Finnish-Russian Forest Regeneration Seminar in Vuokatti, Finland, Sept. 28th – Oct. 2nd, 1998. Finnish Forest Research Institute. Research Papers 790. 217 p. ISBN 951-40-1757-9, ISSN 0358-4283.

Editors: E. Mälkönen, Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN-01301 Vantaa, Finland.
Tel. +358-9-857 051

N.A. Babich, Arkhangelsk State Technical University, Faculty of Forestry, Severnaya Dvina Emb. 17, Arkhangelsk, 163007, Russia. Tel. +7-8182-44 91 56

V.I. Krutov, Forest Research Institute, Karelian Science Centre of Russian Academy of Sciences, Pushkinskaya 11, Petrozavodsk, 185610, Russia. Tel. +7-8142-76 81 60

I.A. Markova, Saint-Petersburg State Forest Technical Academy, Faculty of Forestry, Institutsky per. 5, St. Petersburg, 194018, Russia. Tel. +7-812-550 08 34

Key words: artificial regeneration, natural regeneration, planting material, regeneration technique, seed crop, site preparation, understorey

Publisher: Finnish Forest Research Institute, Unioninkatu 40 A, FIN-00170 Helsinki, Finland

Accepted by Kari Mielikäinen, Research Director, 20.12. 2000

Graphical, word-processing and layout work: Ms. Anne Siika and Ms. Sari Elomaa

Language correction: Dr. John Derome

Sales: Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN-01301 Vantaa, Finland. Tel. +358-9-857 051

Gummerus Kirjapaino Oy
Jyväskylä 2001

Contents

Preface 5

1. Natural conditions and forest management 7

V.F. Tsetkov and E. Mälkönen: Natural conditions and forest management in the northern parts of Europe 7

D.V. Trubin: Forest management in the North of European Russia 17

2. Current state and planning of forest regeneration 23

N.I. Vyalykh: Final felling and reforestation system in the North of European Russia 23

G.A. Chibisov: Regeneration processes based on site typology in the North of European Russia 29

N.A. Babich, A.I. Barabin and G.S. Tutygin: The current state and problems of forest regeneration in the North of European Russia 35

P. Wallenius: Planning of regeneration areas in Finland 41

3. Natural regeneration and retention of understorey 49

E. Kubin: Natural regeneration of forests in Finland 49

A.D. Volkov, V.I. Sokovets and V.A. Ananiev: The role of coniferous understorey in stand formation on clear-cut areas in the taiga zone of the Russian northwest 59

M. Moilanen: Finnish experiences in making use of the understorey 65

Photos 75

4. Seed crops and seed orchards 87

T. Hokkanen: Seed crops and seed crop forecasts for a number of tree species 87

B.V. Rayevsky: Scots pine provenance trial in the Republic of Karelia 99

A.A. Mordas: Experiences in the establishment of Scots pine seed orchards in the Republic of Karelia 107

V.Ya. Popov and D.Kh. Faizulin: The establishment of second-order Scots pine seed orchards 113

V. Koski: Utilisation areas of seed sources 121

5. Planting stock production **127**

R. Rikala: Seedling production for reforestation 127

V.A. Mochalov: Planting stock production and increasing forest yield in the North of European Russia 141

6. Artificial regeneration **147**

H. Mannerkoski and E. Mälkönen: Soil preparation for forest regeneration 147

M. Hyppönen: Artificial forest regeneration techniques in Finland 159

V.I. Krutov and A.I. Sokolov: Artificial regeneration and forest protection in the Republic of Karelia 169

I.A. Markova: The main factors contributing to successful growth of forest plantations in northwestern Russia 175

A.F. Chmyr: Experiences in growing spruce under a shelterwood with an even alternation of tree species generations 183

A.F. Chmyr and E.L. Maslakov (†): Norway spruce group plantations under a forest cover and in open areas 189

P. Puttonen: Follow-up of forest regeneration and quality standards for plantations and sapling stands 197

7. Environmental impacts **211**

E. Kubin: Environmental impacts of forest regeneration 211

PREFACE

Many forestry countries have made commitments to international agreements on the sustainable use of forests. A fundamental requirement for sustainable forestry and long-term economic exploitation of forests is their successful regeneration after final felling.

Over the past decade the goals and methods of forest regeneration have changed considerably. Besides the establishment of a new stand, other important goals for the forest regeneration phase have emerged such as conservation of biological diversity, protection of watercourses and enhancement of the landscape management, improving the wood quality and increasing the profitability of forest regeneration work.

In connection with the extension of the goals of forest regeneration it becomes necessary to assess the adequacy of our knowledge if we are to ensure successful regeneration. It is particularly important to exchange opinions regarding this most important phase of forest management between regions of similar natural conditions, such as Finland and Northwest Russia.

During the last few years Finnish-Russian co-operation on forestry has mainly been carried out within the Finnish-Russian Development Programme on Sustainable Forest Management and Conservation of Biological Diversity in Northwest Russia. The present seminar on Forest Regeneration has also been arranged and funded within the framework of this Development Programme.

I am grateful to all the experts who have participated in this seminar, and to the many people who have taken part in arranging the seminar. An especially important contribution to the arrangements has been made by Vuokatti College and by the Muhos Research Station of the Finnish Forest Research Institute. I would also like to express my thanks to all those who have taken part in preparing the proceedings of the seminar. We hope that the publication of the seminar presentations will make at least some contribution towards solving the problems of forest regeneration and that the proceedings could convey research results and experiences to both countries.

Eino Mälkönen

1. NATURAL CONDITIONS AND FOREST MANAGEMENT

NATURAL CONDITIONS AND FOREST MANAGEMENT IN THE NORTHERN PARTS OF EUROPE

V.F. Tsvetkov [1] and E. Mälkönen [2]

1) Arkhangelsk State Technical University, Severnaya Dvina Emb. 17, Arkhangelsk, 163007, Russia

2) Finnish Forest Research Institute, Vantaa Research Centre, Jokiniemenkuja 1, FIN-01300 Vantaa, Finland

Introduction

Although the northern parts of Europe have a very high coverage of forest, the growing conditions, forest density and forest environment are rather diverse. The standard of living and social and political conditions in northern Europe vary considerably. As a result, there are considerable differences in the organisational structure and efficiency of forest management in the region. However, only used capasity of the natural potential of forest production and the properties of the forest ecosystems can be the true criteria for silvicultural efficiency.

Forestry is strongly determined by the prevailing natural conditions. This does not only apply to the properties, productivity and availability of the forests in the region, because the extent of forest exploitation, the level of profitability of the forest industries, and the degree of integration of the forestry sector within the overall economic structure of the individual countries and regions, are directly connected to the climatic, pedological and hydrological conditions.

The territory of the northern parts of Europe is not defined very clearly in geographical terms. In this article it is considered to include those territories that are located within the boreal climatic zone. In general, these territories lie to the north of latitude 60° (Fig. 1). Part of the most northern territories in the region are located beyond the tree line.

Geological basis

The orography of the northern part of Europe is very heterogeneous. Extensive areas with a typical mountainous terrain, as well as regions with a large number of lakes and swamps, are widely represented. Tectonic peneplained, foundation-denudation, and moraine-hilly and lake-glacial types of relief, are predominant in the western part of the region in the area belonging to the Baltic shield. Mountainous formations, which are part of the Scandinavian mountain system, are widespread in a number of coastal areas in the west. In Russia (the Kola Peninsula, the northern and central part of the Republic of Karelia) they are represented by separate mountain masses that are offshoots of the Scandinavian

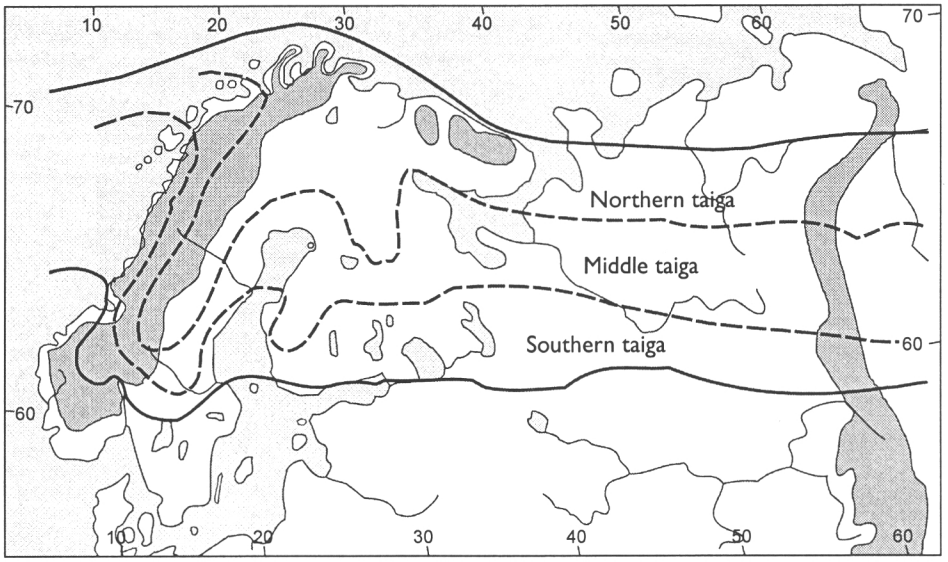


Figure 1. Boreal forest zone in Europe (Ahti et al. 1968, Tuhkanen 1984).

mountains, and a number of other relatively small mountainous formations that include groups of block mountains and individual boulders on the plains. The eastern and southern parts of the region are characterised by less mountainous relief. Higher moraine-glacial ridge plains, sloping and slightly hilly plains alternating with broad swampy lowlands covered with a very large number of lakes, are widely represented. Areas with lower-lying plains, the base of which is formed by sedimentary deposits of the most ancient eluvium, are found in the eastern part of the region.

The geological base of the region is formed in the west by raised platforms of the Baltic shield comprising the most ancient rocks (crystal shale, granite, gneiss and granite-gneiss). In the eastern part along the Russian plain the geological situation is determined by structures of the Moscow syncline. A thick layer of friable sediments overlaps the crystalline plate. The platform foundation consists of sedimentary metamorphic rocks: sands, clays, limestone and marls (Спиридонов 1978).

Almost the whole of the northern part of Europe bears distinct traces of several glaciation periods and sea offensives (transgressions). The traces of the last (Valday) glaciation period are the most clearly evident. Both in the west, where the layer of quaternary sediments is thin, and in the east, where it is thousands of meters thick, visible structures characteristically repeat the ancient underlying foundation. Platform formations are everywhere dissected by deep fractures, resulting in a characteristic alternation of plains and plateaus.

Orographic landscapes of peneplained foundation-denudation glacial formations are the most widespread in the region (Раменская 1964, Север... 1966, Казакова 1971, Чертов and Дыренков 1973, Спиридонов 1978, Чертов 1981, Громцев 1983, Переверзев and Никонов 1989, Исаченко 1995):

– not dissected, in some places inclined plateaus, 150–200 m high,

– not dissected, almost flat plains overlying ancient rocks of the sedimentary complex, 150–180 m high,

– not dissected, almost flat plains with deep quartenary deposits, 150–250 m high,

– flat and inclined elevated plains and plateaus formed by crystalline platforms from rocks of the Baltic shield, 200–400 m high,

– plateau-like, smoothed off, slightly dissected denudation up to 400 m high,

– low- and middle-mountainous formations (plateau-like smoothed off heights up to 400–600 m),

– extremely swampy or lake-covered lowlands in coastal areas, up to 50 m high,

– slightly dissected low, ridge-hilly plains, 80–120 m high.

Soil conditions

Northern taiga, podzolic and swamp-podzolic soils are predominant. Soils of the mountainous-forest and mountainous-tundra type are also represented in areas of the Scandinavian upland, on the Kola Peninsula and in some parts of Karelia. The podzolic type is primarily represented by ferrous, illuvial-ferrous, illuvial-humus-ferrous podzols comprising sand and sandy loam (Белов and Барановская 1969, Скляров and Шарова 1974, Подзолистые... 1980, 1981). Loamy and two-layer sandy-loamy soils on heavy loam are common on the Russian plain in the eastern part of the region. Soddy podzolic soils occur in small patches throughout the middle taiga sub-zone, but more rarely in the northern taiga sub-zone. The latter is usually confined to ancient river valleys, as well as to areas with deposits of carbonaceous soil-forming rocks.

Humid conditions and the subsequent occurrence of gleying phenomena during the course of podzolisation are a characteristic feature of soil formation in the boreal zone. In the northern taiga and near-tundra sub-zones, soil formation in more than half of the forested areas takes place under temporary or periodic water-logging.

In the east, the groundwater table is usually close to the surface. Hydrogen ions are the predominant cation not only in the soil solution but also on the mineral colloids of subsoil loams. A deficiency of many elements, primarily N, P and Ca, is characteristic of the acidic soils in the taiga zone.

According to Dimo (1968), most of the soils in the eastern parts of the region are frozen for relatively long periods (for 6 months and more) each year. Seasonally frozen (from 3 to 6 months) soils also frequently occur in the western part of the region. Permafrost is present only in the extreme northeast, and only on non-forested lands (hummocky marshes in the forest tundra areas of the Arkhangelsk Region and the Republic of Komi). The most common types of forested site are (Чертов 1981):

– slightly undulating plains with accumulations of glacial overburden; gley podzolic and paludified podzolic loam and sandy loam soils,

– flat, fluvioglacial lowlands; extensive paludified podzolic soils and podzols with superficial gleying, formed on two-layer sediments,

– elevated, gently sloping plains consisting of morainic sediments covered with sandy loams; a predominance of podzolic loamy soils,

– glacial elevated, hilly plains; ferro-podzolic sandy and sandy loamy soils,

– elevated fractured and ridgey plains with morainic sediments; sandy loamy, sandy boulder and stony ferrous podzols,

– flattened, lake-glacial watershed plains; podzol gleying and paludified slightly podzolic soils,

– terraced uplands and plateaus on the foothills with deluvial-illuvial sediments; fine sand loamy podzols, with peat-gleying, paludified podzolic soils.

Climatic conditions

The region lies in three climatic zones (Рихтев and Чикишев 1966): temperate, sub-arctic and arctic. Forest vegetation is present in the first two zones only. The thermal conditions, which limit plant growth, are determined both by the radiation regime and by the prevailing climate in the region. According to a number of sources (Физико-географическое... 1965, Григорьев 1966, Жаков 1969, Пивоварова 1977), the annual total solar radiation varies from 60–70 Kcal/cm^2 in the north (69° N) to 100–130 Kcal/cm^2 (58–59° N).

The annual radiation balance in the near-tundra and in the northern taiga area is equivalent to 25–30 Kcal/cm^2; and in the middle-taiga to 28–32 Kcal/cm^2. The thermal conditions during the summer vary to a considerable extent in the individual zones. The summer isotherms in the region tend to follow the latitude. In coastal areas they run approximately parallel to the coastline, and during the summer the temperature decreases on moving towards the sea. In the sub-arctic area the latitudinal temperature gradient during the summer is 8–10 times higher than that in the middle of the continent (the southern part of the Republic of Komi).

During the winter the thermal conditions are almost completely independent of the radiation factor. Only 3–4% of the annual thermal radiation sum accumulates during the four winter months in the eastern part of the region. As is the case in the other northern regions, the thermal conditions during the winter are to a great extent determined by the circulation pattern of the atmosphere, i.e. by the movement of atmospheric fronts at different heights. In fact, the whole region is subjected to weather fronts moving in from the west. Only the southeastern areas are affected by the movement of northern air masses.

Active cyclone activity is characteristic of the region, the cyclones moving from west to east. In years of high solar activity cyclones move across the northern regions, while in periods of low solar activity they mainly pass to the south of the boreal zone (Барабой 1976). As a result, the climate of the region is extremely unstable. On the Kola Peninsula, for instance, long-term data show that no summer month is guaranteed free from frost, while no winter month is guaranteed free from thawing episodes.

The region is characterised by excessive humidity. Total annual precipitation in the near-tundra areas of the eastern part of the region averages 300–400 mm, and in the taiga zone proper 500–600 mm. Total precipitation is markedly higher in mountainous areas. In some areas, total annual precipitation varies considerably. There are clear differences in the climatic conditions in the individual zones and regions. The climatic conditions in the more continental eastern part of the region are much more severe than those in the maritime western part.

Distribution of forests

The vegetation cover in the region is rather diverse owing to the immense size of the territories and the considerable heterogeneity of the landscape and climate. Continuous vegetation covers 93–75% of the region. The only areas devoid of continuous vegetation are the arctic deserts on islands

in the northern seas. Over 60% of the plant species in the eastern part of the region are boreal species (Мартыненко 1974). The eastern part (north of the Russian plain) of the region is the scene of "confrontation between Siberian and European floras". Arctic and alpine species are widely represented in a number of areas. For this reason, the limits of the geographical distribution of over 40% of the species occur in the region (Малышев 1972).

The vegetation in the region is mainly represented by forest (taiga), tundra, forest tundra and peatland types of vegetation. Sub-zones of the near-tundra, northern taiga and middle taiga forest type can be distinguished in the forest cover (over 75% of the land surface) (Львов 1966, 1969, Чертовской et al. 1978, Семенов 1990).

The forested area in the western part of the region is almost 60 Mha, and in the Russian part of the region ca. 56 Mha (Kuusela 1990, 1994). The highest proportion of forested land out of the total land area is in Finland in the west, and in the Republic of Komi in the east. Forest land in the region is characterised by a low proportion of open forests (4–8%).

Coniferous forests are predominant in the area and amount to 80–83% of the forest area (Photos 1 and 2). Spruce forests penetrating to the east account for 65% of the coniferous stands. Norway spruce (*Picea exelsa* (L.) Karsten) is very common in the western part of the region, while Siberian spruce (*P. obovata* Ledeb.) grows in the eastern part. It is widely accepted that the border between these species runs along the valley of the Northern Dvina river. In actual fact, the area in which these two species occur together forms a tremendous strip several thousand kilometres wide. The borders of the distribution areas of tree species such as Scots pine (*Pinus sylvestris* L.), Siberian larch (*Larix sibirica* Ledeb.), Siberian fir (*Abies sibirica* Ledeb.), Siberian cedar pine (*Pinus cembra* subsp. *sibirica* (Du Tour) Krylov) and silver birch (*Betula pendula* Roth) run through the region.

The pedological, geological and hydrological conditions of the native forest vegetation in the region can be combined, on the basis of ordination principles (Смолоногов and Фирсова 1966, Фирсова and Зубарева 1966), into 16–17 types of forest ecosystem (Table 1). These forest ecosystem types can be further divided into specific natural sub-zones, i.e. each of the forest ecosystems shown in Table 1 will have sub-types at the sub-zone level, and within sub-zones at the provincial and regional level. The mountainous sub-types occur in areas with mountainous terrain at the sub-zone level.

The near-tundra area covers approximately 20% of the region. However, its precise borders and biogeocenotic nature have still not been finally resolved. Forest tundra and typical forest ecosystems are distributed throughout the area of near-tundra forest. Forests of the northern taiga type, i.e. spruce-birch, pine-spruce, birch and spruce forests of site classes V-Vb (sometimes IV and even III according to Orlov), are widely distributed throughout the southern part, as well as along river valleys in the northern parts. The forest groups in the northern part of the sub-zone are represented by open woodlands, coppices, dwarf and creeping vegetation as well as shrubs. The average volume of the tree stands varies from 20–45 m^3/ha in the north up to 90–110 m^3/ha in the south. The proportion of wetlands and tundra ranges from 35–45% in the north down to 20–30% in the southern parts of the sub-zone.

The proportion of forest-covered areas in the northern taiga region is estimated to be approximately 60–70%. The forest vegetation is interspersed with swamps and wet-

Table 1. Matrix for ordinating site conditions (example).

| Site characteristics | Characteristics and indicators of site conditions | | |

lands, which account for 20–28% of the forest land. There are also treeless mountains, mountainous tundra and forest tundra. Forest stands of simple structure and mixed species composition are predominant throughout most of the forest-covered areas in the northern taiga sub-zone. A small number of dominant species in the tree story, and relatively few plant species in the lower stories, are characteristic features of these forests. The average site class in the western part of the sub-zone is IV–VI according to Orlov's scale, and IV,7–V,3 in the eastern part. Pine forests are predominant in the western and southern parts of the sub-zone, while spruce forests are predominant in the eastern part (the Arkhangelsk Region and the Republic of Komi). Larch stands are also present in the east. The average volume of the growing stock is estimated to be 95–125 m^3/ha.

The middle taiga sub-zone covers more than 40% of the region, and includes typical taiga forests. All the features characteristic of taiga forest ecosystems are expressed most clearly in the eastern part of the region: monotony of the dominant tree species wide distribution of one- or two-species forests, with a simple structure. The unique simplicity of the canopy structure of light coniferous forests and the deep vertical closure of dark coniferous forests are other characteristic features of the taiga. Dark coniferous forests are dominant in the eastern part of the region, while pine and pine-birch forests are predominant in the central and western parts. The average site class of the forests in the western part is III,5–IV,4, and in the eastern part IV,1–IV,7. The average volume of the growing stock at felling age varies from 130–180 m^3/ha in the west to 110–160 m^3/ha in the east.

The total volume of stemwood in the European boreal forests is estimated to be about 11 550 Mm^3, of which 51% in Russia and 49% in Norway, Sweden and Finland.

The forest resources of the North of European Russia are equal in size to those of the Nordic countries, but their growth is only one-third of that in the Nordic countries. This points that only a small part of the Russian boreal forests are managed on a regular basis, and the natural dynamics of the forest ecosystems mainly control the functioning and structure of the forests (Kuusela 1990).

About 75% of the forests in the northern sub-zone, and all the forests in the near-tundra sub-zone in Russia, are economically inaccessible: forest growing for industrial purposes based on the existing management system is not profitable. The situation is due to the small standing timber volumes, low density of the growing stock, and the absence of transportation routes. However, including low productivity stands in the allowable cut increases the actual cut volume, but this would be at the expense of productive areas in regions with a developed infrastructure.

Forests substantially modified by man are predominant in the western part of the region. Forests of indigenous and quasi-indigenous types represent 68–75% in the near-tundra and northern taiga areas of the Russian part of the region (Телегин 1981). The proportion of young and middle-aged stands decreases throughout the region; from the west to the east from 35–45% to 15–20%, and from the south to the north from 25–45% to 15–25%.

Protected forests and forests with felling restrictions cover about 1.3 Mha (ca. 6.5% of forest land in Finland (Finland's... 1999). In Sweden the proportion of protected forests is on the some level than in Finland.

The corresponding figure for the whole of Russia is over 8 Mha (approximately 14%). Commercial logging is carried out in almost all the forests in the western part of the region, excluding forest reserves. Commercial forests (groups II and III) in the Russian part of the region occupy about 50 Mha or 77% of the forest-covered area.

Forest exploitation and the degree of forest management vary considerably throughout the region. The differences between the forest management systems in the individual countries in the region are due not only to differences in natural conditions and the properties of the forests, but also to economic differences. Differences in national forest policy, in the economic structure, in the forms of forest ownership and in the forest management systems, are also important. Industrial exploitation of the forests is carried out throughout most of the region. Private forest ownership predominates in the Scandinavian countries, while in Russia forest land belongs to the State and the local communities.

REFERENCES

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968. Vegetation zones and their sections in north western Europe. Ann. Bot. Fenn. 5: 169–211.

Finland's national forest programme 2010. 1999. Ministry of Agriculture and Forestry. Publications 2/1999. 37 p.

Kuusela, K. 1990. The dynamics of boreal coniferous forests. Gummerus Kirjapaino Oy. Jyväskylä. 172 p.

Kuusela, K. 1994. Forest resources in Europa. European Forest Institute. Research Report 1. 154 p.

Tuhkanen, S. 1984. A circumboreal system of climatic-phytogeographical regions. Acta Bot. Fenn. 127. 50 p. + 2 app.

Барабой, В.А. 1976. Солнечный луч. Наука. Moscow. 240 p.

Белов, Н.П. & Барановская, А.В. 1969. Почвы Кольского полуострова. Наука. Leningrad. 147 p.

Григорьев, А.А. 1966. Закономерноти сироения и развития географической среды. Мысль. Moscow. 382 p.

Громцев, А.Н. 1983. Ландшафтные закономерности структуры и динамики среднетаежных сосновых лесов Карелии. Кар. Фил. АН СССР. Petrozavodsk. 157 p.

Димо, В.Н. 1968. Зонально-провинциальные особенности температуры почв СССР и классификация температурного режима. Тепловой и водный режим почв СССР. Наука. Moscow. p. 5–57.

Жаков, С.Н. 1969. Влияние Арктики на климат СССР. Гидрометеоиздат. Leningrad. 84 p.

Исаченко, Г.А. 1995. Экологическая география Северо-Запада России. Ч. 1. Русское географическое общество. St. Petersburg. 206 p.

Казакова, О.Н. 1971. Ландшафты Мурманской области. Природа и хозяйство Севера. Вып. 3. Северный филиал Русского географического общества. Apatity. p. 8–12.

Львов, П.Н. 1966. Использование леса в защитных целях на Севере. Сев.-Зап. кн. изд.-во. Arkhangelsk. 103 p.

Львов, П.Н. 1969. Европейский Север как лесоводственно-экономический район. Информац. Бюлл. Научного Совера по комплексн. использованию таежных территорий. Irkutsk. Т. 2: 83–89.

Малышев, Л.И. 1972. Флористические спектры Советского Союза. История флоры и растительности Евразии. Наука. Leningrad. p. 17–40.

Мартыненко, В.А. 1974. Сравнительная характеристика бореальных флор Северо-Востока Европейской части СССР. Автореферат диссертации на соискание ученой степени к. б. н. Leningrad. 28 p.

Переверзев, В.Н. & Никонов, В.В. 1989. Почвообразование в Кольской Субарктике. Наука. Leningrad. 170 p.

Пивоварова, З.И. 1977. Радиационная характеристика климата СССР. Гидрометеоиздат. Leningrad. 336 p.

Подзолистые почвы Центральной и Восточной частей европейской территории СССР: на суглинистых почвообразующих породах. 1980. Наука. Leningrad. 304 p.

Подзолистые почвы Центральной и Восточной частей европейской территории СССР: на песчаных почвообразующих породах. 1981. Наука. Leningrad. 200 p.

Раменская, М.А. 1964. К типологии лесных ландшафтов Карелии. Возобновление леса на вырубках и выращивание сеянцев в питомниках. Кар. кн. изд.-во. Petrozavodsk. p. 5–21.

Рихтер, Г.Д. & Чикишев, Г.А. 1966. Север Европейской части СССР. Очерк природы. Мысль. Moscow. 237 p.

Север Европейской части СССР. 1966. Наука. Moscow. 452 p.

Семенов, Б.А. 1990. Предтундровые леса. Международный симпозиум «Северные леса: состояние, динамика, антропогенное воздействие» в Архангельске. Ч. 2. Moscow. p. 173–188.

Скляров, Г.А. & Шарова, А.С. 1974. Почвы Архангельской области. Сев.-Зап. кн. изд.-во. Arkhangelsk.

Смолоногов, Е.П. & Фирсова, В.П. 1966. Лесорастительные условия и почвы возвышенности Люлин Вор. Труды Института биологии УФ АН СССР. Вып. 55: 3–21.

Спиридонов, А.И. 1978. Геоморфология Европейской части СССР. Высш. школа. Moscow. 336 p.

Телегин, Н.П. 1981. Классификация и инвентаризация лесов Европейского Севера СССР и скандинавских стран. Лесоведение и лесоводство. Обзорная информация. Вып. 2. ЦБНТИ. Госкомлес. Moscow. 35 p.

Фирсова, В.П. & Зубарева, Р.С. 1966. Почвенно-лесорастительные условия северной части Уфимского плато. Труды Института биологии УФ АН СССР. Вып. 55: 23–45.

Цветков, В.Ф., Чертовской, В.Т., Чибисов, Г.А. & Листов, А.А. 1984. Системы лесного хозяйства на зонально-типологической основе. АИЛиЛХ. Arkhangelsk. 88 p.

Цветков, В.Ф. 1990. Системы ведения хозяйства на Европейском Севере России. Материалы международного симпозиума «Северные леса: состояние, динамика, антропогенное воздействие» в Архангельске. Ч.1. Госкомлес СССР. Moscow.

Чертов, О.Г. 1981. Экология лесных земель. Наука. Leningrad. 192 p.

Чертов, О.Г. & Дыренков, С.А. 1973. Построение классификационных систем биогеоценозов на примере лесов Карельского перешейка. Труды Петрозаводской лесной опытной станции. ЛенНИИЛХ. Вып. 2: 74–80.

Чертовской, В.Г., Елизаров, Ф.П., Семенов, Б.А. & Корняк, В.С. 1978. Лесорастительные усоловия и продуктивность притундровых лесов. Вопросы таежного лесоводства. АИЛиЛХ. Arkhangelsk. p. 32–42.

Физико-геогафическое районирование Северо-Запада СССР. 1965. ЛГУ. Leningrad. 248 p.

FOREST MANAGEMENT IN THE NORTH OF EUROPEAN RUSSIA

D.V. Trubin

Department of Forestry of the Arkhangelsk Region, Prospekt Troitski 14, Arkhangelsk, 163061, Russia

Pre-history and development of the Forest Service

Last year marked the 200th anniversary of the Russian Forest Service. The service traces its beginnings to May 26, 1798, when Czar Paul I signed a decree establishing a Forestry Department, a state agency with the responsibility to manage, protect, and conserve Russian forests (Шубин and Гиряев 1998). At about that time, or soon after, laws were enacted to enforce basic principles of forestry, and these laws have survived unchanged to our day. They gave first priority to state ownership of forest land, the right to allocate forest areas for reserves according to primery state interests and to maintain them as wildlife refuges, to charge fees for forest exploitation, to make woodlands outside the areas of state interest available to any entrepreneur and the public at large, and to enforce adherence to the principle of continuity and uniformity in fixing annual allowable timber cuts. The Forest Service has grown in both scale and scope during its 200-year history.

It has endured a succession of dramatic changes in the country's political and economic life, while retaining its institutional structure and fostering its basic management principles and professional traditions.

Whatever government ruled the country during the period, it always included a department to manage the Russian forestry. The forestry service started out as the Forest Department, which was reformed into the Central Forestry Board after 1918. The succession of name changes continued as the Main Forest Board, the Main Forest Protection Board, the Forestry Ministry in 1947 and, finally in 1992, the Federal Forest Service of Russia.

The agency's principal duties were to lay down forest policy guidelines for the whole country, draft forestry laws and regulations, set up forestry services in the country's forested areas, appoint territorial agency heads, run staff-training facilities, initiate research in forest inventory, and preside over many more of the tasks given to the forestry service.

The evolution of the territorial forestry service in the northern parts of European Russia (the present-day Leningrad, Murmansk, Arkhangelsk, and Vologda Regions, and the Republics of Karelia and Komi) represents a true reflection of the history of forestry practices in the country.

The earliest territorial forest management authority in the region – the Arkhangelsk-based Northern District Board of Russia's Forestry Department – also has a 200-year history. It was staffed by officers called "district chief forest rangers", who had forest guards under their direct supervision. As well as guarding the forests, the board was responsible for forest inventories, above all of stands of timber suitable for shipbuilding, and regulated timber sales and decided on the rotation age.

About 40 state forest districts were formed in the first half of the last century within the administrative borders. They were supervised from provincial centers such as St. Petersburg, Olonets (Petrozavodsk), Arkhangelsk, and Vologda, by the provincial chambers of state property and land management.

At the turn of the century the district forestry units started to split up into smaller units and, by the beginning of the 20th century, their number had risen to almost 200. The move was dictated by the booming lumber industry and extraction of chemical raw materials from wood, and was a response to the growing number of logging companies and intensive farming units. At that time between 7 to 10 Mm^3 of timber were harvested annually. Large sawmills were built in some northern cities, Arkhangelsk being by far the most important sawmilling center. Northern timber came to hold a prominent position in the world timber market.

This was a period when the overwhelming majority of forests belonged to the state (the Ministry of Finance). The only exception were woodlands owned by the Imperial court (Crown forests), most of which were located in the northern parts of the Vologda Region and in the southern districts of the Arkhangelsk Region. Occupying a total area of about 2 Mha, they were managed by the Velsk Crown District. These forests were more intensively studied and managed than those in other parts of the country. They had five times as many forest guards as the state forests, and the best forest rangers in northern Russia were posted there. Advanced silvicultural methods and exploitation techniques were applied and tested before they were introduced anywhere else, the felled timber being processed at the Crown's own modernised timber plants and sawmills. Considering the time and geographical location, the Velsk Crown District could be called the forerunner of modern forestry enterprises in Northern Europe (e.g. MODO, SCA-Skoy, or Enso-Gutzeit).

The peasants in northern Russia, who were under the jurisdiction of the Ministry of Finance and did not own woodlands, obtained whatever wood products they needed from state forests. It was not until beginning of this century that the Ministry of Finance began allocating forests to peasant village communities. After the Revolution in 1917, these forests were incorporated into collective and state farm lands, which could now be used by the farms without time limits and were managed by specialised forestry agencies of the Ministry of Agriculture.

For some time after the revolution the state forest districts retained their leading role in forest exploitation but, in the 1930's and 40's they, their function was reassigned to cater for the needs of the large logging companies. During these decades, the northern forests had to bear the heavy burden of the country's exports, the most important export commodity in Russia at the time being timber. The attentions of the Soviet government resulted in the destruction of the woodlands in the individual regions. It was assumed that the principle of sustainable forest management could be applied at the national level, rather than within small localised areas.

The priorities of the booming advance in science and engineering and in investment policies were clearly directed towards logging and woodworking operations, forest regeneration and management having a low priority.

However, it cannot be disputed that the northern areas in general received a powerful economic boost; dozens of large logging companies were started, the old sawmills modernised with a five-fold rise in produc-

tivity, and several of Europe's largest pulp and paper mills were built. These investments required enormous state credits against swelling exports. The territories teemed with abundant labour drawn from the huge waves of migrants.

Serious mistakes were, however, made in geo-economic policy. There was too much woodworking capacity concentrated in a few regional centres, such as Arkhangelsk, Petrozavodsk, Syktyvkar and Kotlas, hundreds of kilometres away from the logging sites. Temporary timber-hauling roads – wooden planked, narrow gauge railway, ice or dirt track – were cut out to develop the forests. This wide range of access roads has left us without a permanent forest road network. The cutting plans in many areas were too high to sustain productivity, the stands being stripped clean of productive stock. Finally, the changeover from selection cutting to clearcutting was made too quickly without paying attention to the logistics.

Silvicultural measures directed at artificial reforestation on a commercial scale were launched 30 years too late.

It was only after the Forestry Ministry was instituted in 1947, and a system of local forestry authorities formed, that slow moves began to bring the interests of forest exploitation and maintenance into balanced. The proportion of artificial reforestation on clear-cut areas increased to 15% as late as the 1960's and 70's, following the establishment of seed production and tree nurseries, the development of mechanical soil preparation equipment, and creation of the economic prerequisites needed in establishing large-scale forest plantations.

Russian forestry today

Since the establishment of the Forestry Ministry in 1947, and some subsequent institutional reorganisation, the territorial structure of the forest industry has gradually attained its current form.

The northern Regions of Murmansk, Arkhangelsk, St. Petersburg and Vologda, and the Republics of Karelia and Komi, have regional forestry boards, or committees, directly under the Federal Forest Service. Each of them maintains a network of forest management units (leskhoz), further divided into forest districts. Table 1 shows the organisational structure of Russian forestry.

The functions of the forestry agencies are defined in the Federal Forest Code, statutory rules, and other relevant regulations. They can be roughly grouped as follows:

Table 1. Organisational structure of forestry.

Region or republic	Area of forest land, Mha	Number of "leskhozes"	Number of forest districts	Employees
Murmansk	9.7	10	70	300
Arkhangelsk	27.0	29	200	1800
St. Petersburg	4.6	35	300	2500
Vologda	8.6	30	190	1600
Karelia	14.8	24	150	1300
Komi	38.0	33	220	1500
Total	102.7	161	1130	9000

– protection of forests against fire, unauthorised logging, pests and diseases,

– management of forest exploitation, including forest inventories, determining logging rates, standing timber sales, and monitoring forest harvesting sites,

– reforestation methods, establishment of seed production and tree nurseries.

Forest management functions are distributed according to the organisational hierarchy: regional forestry department, forest management unit (leskhoz), and forest district.

At the regional level, contact is maintained with the state authorities of the respective Federation member (subject) to enforce their knowledge in forestry. This includes, in the order of priorities, drafting and adopting regional laws and bylaws relating to forest management and nature conservation, allocating forest resources and making decisions on their exploitation by calling for tenders and holding forest auctions, developing and implementing urgent measures to put out major forest fires and control any other natural disasters and emergencies. In addition, the boards compile, within the scope of their powers, financial and annual production plans for individual forest management units, examine and approve forest management plans, and recruit and assign leskhozes and forest districts employees. They also interact with specialised provincial agencies of the Federal Forest Service, such as forest planning and inventory units in St. Petersburg, Petrozavodsk, Vologda, and Arkhangelsk, the bases of air forest fire control in Petrozavodsk, Arkhangelsk, and Syktyvkar, and zonal forest seed stations in St. Petersburg, Petrozavodsk, Arkhangelsk, Syktyvkar, and Vologda.

At the leskhoz level, forest inventory is carried out, forest areas leased out in accordance with resolutions of the regional commissions, forest auctions are held for logging in short-term use (for one year), forest land is transferred to logging companies in accordance with cutting permits, general supervision is exercised, and other forest management actions within the respective administrative boundaries are dealt with.

Forest districts guard and protect their forests, monitor logging operations and any other forms of forest use, plan and implement tree planting and tending programs, operate seed production facilities, grow planting material in nurseries, carry out thinning, and perform all the work required in a well-managed forest.

In the two or three decades prior to the 1990's, a network of mechanised forest improvement stations existed in the northern parts of the country. They constructed drainage systems on an area of almost 1.5 Mha. About half of the drained land was located in paludified forest, and half in open peatland. Plantations were established on some of the drained peatlands and, as a result, forest belts were formed around some northern cities (e.g. Severodvinsk and Arkhangelsk) located on swampy lowland.

Forest management

Forest management is the responsibility of state-owned forest planning and inventory units, the Northwestern (in St. Petersburg), Karelian (at Petrozavodsk), and Northern (at Vologda), with a branch office in Arkhangelsk. There are 450 experts employed by those companies. Forest management is based on an inventory of the leskhoz reserves that is made once every 10–15 years. This is used as a starting point for a forest management plan for the area within each forest management unit for the next 10 years. The forest inventory is carried out

annually on 7 to 8 Mha of forest land. A combination of measurements and visual estimations is used for determining the standing volume. A site estimate factor is applied, with the help of aerial photographs, to a forest block similar to the control site. The inventory results are then used to review the existing forest data records, make corrections to the state forest accounts, and to compile a detailed description of the forest land within the leskhoz boundaries. The data are used to calculate the annual allowable cut, which is approved by the Forest Service and, to prepare a 10-year plan for all forest management activities.

All updated forest inventory data, including area forest maps, are delivered to each leskhoz in paper and magnetic form.

Forest exploitation

During the four or five decades prior to the early 1990's, forests in Russia's northern lands were developed by state-run commercial logging companies under the supervision of the Ministry of Forest Industry and a number of other government departments.

For example, the Arkhangelsk Region had some 50 logging companies, the structure of which changed only slightly over the decades. They were assigned a specific forest area with an allowable cut. The harvested volume amounted annually to around 500 000 m^3. The logging companies delivered logs to the sawmills and pulp and paper mills under an "assortment plan" approved at the ministerial level.

Logging operations followed a standard pattern: clear-cutting, narrow-strip cutting on forest plots, tree felling by chain saw, and logs or whole trees skidding to the loading points.

Timber was removed only in the form of logs by trucks or narrow-gage railroad to lower yards near the main roads. The logs were cut into assortments, graded, and delivered to woodworking plants. During the last 20 years felling machines and skidders (up to 40%) have been introduced at the logging sites and, in more recent years, their foreign-made counterparts.

In the 1990's the state logging industry was privatised. Holding companies were set up to run the public share of the industry, but they are now relatively insignificant and account for 10 to 30% of the stock market. Their shareholders have sold their stock over the years. Their assets are gradually being concentrated in the major stockholders, including woodworking companies. Some companies have managed to sustain their output and, are now stabilising their operations and starting to modernise. Others have gone bankrupt and been replaced by newcomers. The current time is mergers between logging companies and sawmilling and pulp and paper companies, which helps to avoid the administration restraints from government bureaucrats.

Redistribution of the assets of the logging companies is being accompanied by a redrawing of the boundaries of the forest bases assigned for harvesting. However, it is already done by lease tenders, rather than by ministerial edicts. A typical leasing contract binds the lessor, or the forest management unit, to provide on a long-term planned basis growing stock (for up to 49 years) at relatively moderate rentals (8 to 15 RUR/m^3) of harvested timber, the lessee strict fulfilling of the silvicultural standards in logging and reforestation measures.

The forest reserves in the Arkhangelsk Region, for example, have been leased to 150 leaseholders. Most of them are joint-stock companies, which are based on the former commercial logging companies. The rest are sawmills, small partnerships, co-operatives and entrepreneurs.

Forest users without a lease on forest land, purchase timber at auctions held every month in the regional centre and district towns. Timber is auctioned off at prices double or triple the lease rental rates.

Reforestation

The current forestry act requires logging companies to carry out reforestation. The reforestation methods to be applied on a cutting site are specified in the logging permit issued by a forest management unit, which also contains forest management plan recommendations.

About 30% of the clear-cut areas (40 000 to 50 000 ha a year) are reforested artificially (half by seed and half by seedlings and nursery transplants). On 55% of the clear-cut areas the understorey is protected by special felling and skidding methods. The proportion of forest floor damaged by skidding must not exceed 15%, and destruction of the understorey must be kept below 40%. The remainder of the clear-cut areas are regenerated naturally.

Seed production and nursery operations are the sole responsibility of leskhozes and forest districts. Between 80% and 90% of the required seed is harvested during logging operations and is purchased by the leskhoz. Seedlings are grown in the open (60%) and in greenhouses (40%). The region maintains seven greenhouses for the production of containerised seedlings. Two of the greenhouses have Russian-made equipment, but the total output of seedlings is relatively modest.

Tree planting is managed by the forest districts geting support from, who are refunded for the costs incurred at current rates. The predominant technique is planting seedlings in furrows made by forest ploughs at a spacing of three to four meters. If there is too much logging residue on the site, strips are cleared before plowing. Planting machines are used on about 10% of the reforestation areas. Forest seeders equipped with tilling equipment are used to sow seeds in inaccessible clear-cut areas.

The northern regions have about 4 Mha of artificially regenerated forest. Most of them are no more than 30 years old. Much of this forest land is heavily overgrown with birch and aspen sprouts, making commercial logging a problem. Forest management units lack the funds needed to properly manage their forests, while those who utilise the forest lack the motivation.

Development trends

Today, with the country in the grips of a crisis, forestry is among the worst-off industries. However, there are some favourable trends:

– The updated forest laws are well matched to the new economic environment, and lease terms provide the logging companies with incentives for forest improvement.

– Society at large is beginning to favour the idea of sustainable forest management, with a major role assigned to silviculture.

– The forestry authorities have managed to preserve their experts and skilled work force, as well as their professional traditions, and a memory of how things should be run.

REFERENCES

Шубин, В.А. & Гиряев, Д.М. 1998. Леса России. Изд. Энциклопедия сел и деревень. Moscow. 207 p.

2. CURRENT STATE AND PLANNING OF FOREST REGENERATION

FINAL FELLING AND REFORESTATION SYSTEM IN THE NORTH OF EUROPEAN RUSSIA

N.I. Vyalykh
Northern Research Institute of Forestry, Nikitov str. 13, Arkhangelsk, 163062, Russia

System of final fellings

In order to achieve effective reforestation for the rational and sustainable forest use and management in the northern part of European Russia, the Northern Research Institute of Forestry has developed a system, to be applied in final felling operations, that comprises the following timber-harvesting methods: clear-cutting with understorey retention (progressive cutting), and selection, gradual, and combined felling (Мелехов 1962, Волосевич et al. 1987).

Clear-cutting with understorey retention. This method is applied to even-aged stands with a density of 0.5 or less that contain sufficient coniferous understorey to ensure reforestation of the area. During clear cutting all the trees with a diameter of 14 cm are felled, and the maximum number of understorey trees is retained.

Survival of the understorey is closely related to the cutting techniques used and to the cutting season. Our studies have shown that the understorey is best protected in wintertime when the trees are felled in narrow strips. The tops are felled towards the skidding lines, and the trees are extracted by pulling them out by their tops (Вялых 1968, Вялых et al. 1987). This method makes it possible to protect up to 80% of the understorey. The understorey retained on clear-cut sites has a high survival rate. Two to three years after harvesting it has good height and diameter growth. Shade-favouring coniferous species are gradually replaced by light-demanding conifers. The assimilation intensity of the trees increases.

We have found that the retained understorey develops and, on a Piceetum myrtillosum type within 50–60 years after felling, a stand is transformed into a pure spruce stand or a spruce stand containing an admixture of deciduous species with a growing volume of up to 220 m^3/ha. This means that logging operations can be carried out on the same site 50 years after it was felled and the understorey retained (Чертовской 1968, Вялых 1971).

Selection cutting. This method is used to remove overmature and mature trees in a stand, to stimulate a recovery in stocking and forest regeneration by allowing younger trees and new growth to mature, to improve forest productivity and the water-course protection functions of forests, and to increase long-term forest use.

Selection cutting is practiced in pure and mixed spruce, pine, spruce-larch, and

spruce-pine stands of uneven age growing on drained sites of the Pin./Pic. oxalidosum, myrtillosum and vacciniosum types with a density ranging from 0.6 to 1.0.

The first trees to be cut are large, overmature, faulty or dead individuals, and also some of the mature trees whose growth is retarded or whose wood has deteriorated in quality. Relatively young trees, well under the mature age, and some of the larger trees with a good growth rate, as well as all the understorey of coniferous species, are left standing. Selection cutting involves cutting the mature trees in a number of steps. After cutting the area always still has trees of different age. The intensity of selection cutting can range from 30 to 50% of the stand volume, and 10 to 30% of the number of trees. Logging operations are repeated every 15 to 20 years. Between 400 and 500 trees in the overstorey, and at least 2 500 trees in the understorey, are left per hectare. The density of the stand after selection cutting should not be less than 0.4. Selection cutting must, under all conditions, ensure the sustainability of the remaining part of the stand.

Forest sites designated for selection cutting are cleared in narrow strips using TDT-55A tractors and chain saws. The width of the harvested strip felled by selection cutting methods must be equal to 1.5 of the average height of the stand to be cut, or 30 to 35 m. The trees are cut manually by chain saw assisted by another logger or by means of a hydraulic wedge. Trees are felled at an acute angle to the skidding lane. The branches are cut off directly on the strips or at the loading points. Full-length trees are hauled by their tops or crowns along the skidding lanes (Photo 3). Selective cutting leaves 80 to 90% of the understorey standing. The total area of the skidding lanes on a selectively cut area must not exceed 15% of the site area, with another 3% taken up by loading points (Правила... 1994).

Selection cuttings rarely damage the ground vegetation or forest floor in the strips between the skidding lanes. Natural reforestation with coniferous species is facilitated throughout the whole area of selectively cut stands (Вялых et al. 1987).

Studies have shown that diameter growth in a spruce stand of the fourth site class increased by 100 to 150% within 15 years after being cleared by selection cutting with a thinning intensity of 40 to 50%, compared to the diameter on the plots before felling and in reference areas. The average annual volume increment after cutting amounts to between 2.5 and 4.4 m^3/ha.

The benefits of selection cutting include prevention of a change in tree species over the whole cutting area, a better yield of tall stems, a rotation reduction of mature trees by 40 to 50 years, and retention of the nature conservation functions and biodiversity of the stands (Чурпов 1992).

Selection cutting on forest land in the northern part of European Russia has a higher management efficiency than clear-cutting operations.

Gradual cutting. This technique is used in pine, spruce, and pine-spruce stands growing on drained soils. The timber in such stands is harvested in several stages over the lifetime of one or more age classes. The final stage is clear cutting, but leaving the understorey and small-diameter trees to continue growing.

The purpose of gradual cutting is to facilitate the establishment of a new stand of coniferous species, improve the conditions for the existing understorey and small-diameter trees, and allow younger trees or the understorey to grow to maturity. Gradual cutting may be either short-term, when all the mature trees are removed over a pe-

riod of 20 years, or long-term, when cutting is extended for up to 40 years.

There are various forms of gradual cutting: gradual even-cutting, cutting on even strips, long-term gradual cutting and group-gradual cutting. They are typically carried out in stands of even or uneven age, where two tree generations are present on the same site.

Short-term, gradual even-cutting is conducted in two or three stages within a single age class. Three-stage cutting is used in stands with a density of 0.8 to 1.0, while a density of 0.6 to 0.7 requires only two stages. In the first stage of three-stage cutting, the stand is thinned to a density of 0.6 or 0.7. The second stage is applied six to eight years later, provided that there is a viable understorey, in order to reduce the understorey density to 0.4 or 0.5. The third, final stage involves complete removal of the remaining trees in the stand.

Two-stage cutting is used where the density is between 0.6 and 0.7, if there is an understorey or second canopy layer. In the first stage the tree stand is cut to a density of 0.4 or 0.5.

Short-term gradual cutting along narrow strips, which is used in dry pine stands growing on Pinetum cladinosum, moss-cladinosum or callunus types, involves clear-cutting along every second (even-numbered) 35 to 40 m wide strip, and only 15 to 30% of the trees being removed on the odd-numbered strips. The stand is cut in two stages over a period of 8 to 10 years. In the first stage the cutting intensity ranges from 50 to 60%. In the second stage between 10 and 15 seed trees per hectare are left standing. This technique allows pine forests to regenerate without species succession, increases the standing volume of the remaining trees after the first stage by 15 to 20%, and maintains the protective functions of the forest.

Long-term gradual cutting is carried out in even-aged mature pine stands with a second storey of middle-aged or premature spruce on Pinetum myrtillosum and oxalidosum types, in uneven-aged pine stands on Pinetum vacciniosum and cladinosum types with a minimum of 350 to 400 young, small-diameter trees per hectare and the understorey, and in mixed, uneven-aged pine-spruce stands on P. myrtillosum and oxalidosum types that have a maturing or middle-aged generation of coniferous species. This type of cutting is also used in uneven-aged spruce stands of Piceetum vacciniosum type with small-diameter spruce trees and understorey. The purpose of the first stage is to remove up to 60% of the mature and overmature trees. At least 350 to 400 small-diameter trees per hectare are left; these are not mature trees nor part of the understorey. The final stage is completed 30 to 40 years later, when the trees reach rotation age. In this stage all the trees that have matured in the interim are removed, apart from the coniferous understorey.

Combined felling. This logging method combines final and thinning cutting. They are carried out in secondary deciduous-spruce stands (birch-spruce and aspen-spruce stands with spruce of the next generation in the second canopy layer), and in pine-deciduous stands with an admixture of spruce (Мелехов 1962).

The main aim of this cutting method is to transform deciduous-spruce stands into spruce stands, and to improve the condition and growth of the spruce trees. Combined felling operations usually remove mature deciduous trees in two stages, leaving a maximum number of spruce trees (Photo 4).

The first cutting stage involves the removal of aspens or birches aged between 40 and 50 years. Deciduous trees are felled at an intensity of 40 to 50% of the stand volume. The second stage is done 10 to 15 years later, when the remaining deciduous species are finally removed. Two-stage cutting of the deciduous storey helps the spruce trees to gradually adapt to the new growing conditions, and allows thin deciduous trees to grow to marketable size. The condition of the spruce storey improves markedly within three years after the deciduous species have been removed.

After the first combined cutting stage, the assimilation capacity of the spruce trees increases, they receive more sunlight, and the needle biomass increases. The ecological conditions improve significantly, and the growth rate of spruce is tripled.

Combined felling allows deciduous wood to be used rationally, facilitates the transformation of deciduous-spruce forests into pure spruce stands, and increases the productivity of the stand.

Studies on the effects of the new Sofit X machine on the survival of understorey in clear-cutting operations in spruce stands of Piceetum myrtillosum type show a 38.6% survival rate for understorey on clear-cut strips. About 15% of the remaining understorey are damaged as a result of the operations. The width of the strips between skidding lanes is 8.1 m, the lanes being 4.7 m wide.

The survival rate of the understorey increases to 58% on sites felled by a combination of Timberjack 618 and Timberjack 480B machines, when the trees are cut and transported vertically to the skidding lanes. The average width of the skidding lanes is 5.5 m, and the stand strip between the skidding lanes is about 14.5 m. Understorey damage is decreased to about 5% of the total understorey. These machines give the best results on sites which are logged, leaving the understorey under the forest canopy, regardless of the number and height of the understorey.

Selection cutting using a combination of Lokomo 990 (harvester) and Lokomo 910 (forwarder) was tested in pine and spruce stands during wintertime (Photo 5). 70% of the stand volume was removed, 13.9% of the remaining trees were damaged, and the understorey survival rate was 64%. The average width of the skidding lanes was 4.6 m, and of the strips 15.2 m wide. It should be noted, however, that the use of this combination of machines in selection cutting resulted in considerable damage to the young promising trees left on the site, which later on may develop butt rot.

When using Sofit X harvesters for felling, branching and log bucking together with Sofit 6F forwarders for gradual felling in a fresh Piceetum myrtillosum stand, the average width of the skidding lanes was 5 m, with 9.5 m strips left between the lanes. The average width of the strips was 14.5 m, and the total area of the skidding lanes amounted to 34.5% of the area of the stand. The cutting intensity was equal to 64% of the volume, and 46% of the number of trees. About 760 trees were left to grow to maturity per hectare. After felling, the stand had a density of 0.5. During felling 22% of the trees were damaged, 24% of them seriously. Typical damage included stem debarking and crown cropping. The understorey had a survival rate of 75%. In gradual cutting this combination of machines therefore failed to fully meet the forest management standards.

Lokomo 990 harvester and Lokomo 910 forwarder were tested in combined cutting operations in fresh 60-year-old aspen-spruce and birch-spruce stands of myrtillosum type. In order to perform the operation

with these machines, the site was divided up into 20 m wide strips. A 5 m wide corridor was cut by the harvester down the middle of each strip. A section up to 7.5 m wide on both sides of the strip (within the reach of a hydraulic boom) was simultaneously harvested. The assortments were stacked at understorey-free points on both sides of the corridor. Birch and aspen were removed, and better-growing spruce and deciduous trees were left on the cut area.

Combined cutting resulted in a reduction in stand density to 0.5 or 0.6. The spruce understorey was largely freed from the deciduous shelter. Between 700 and 800 trees were left standing per hectare.

The area taken up by the skidding lanes varied between 20 and 25% of the strip. Between 18 to 20% of the growing trees were damaged. Spruce trees were damaged the most. The understorey had a survival rate of 72%, 52% of it completely undamaged.

The studies we have completed show that the techniques currently being used in felling operations need to be further improved when carrying out clear-cutting, selective, gradual, and combined tree felling operations in order to reduce their negative effect on the forest environment and to facilitate effective reforestation.

Forest management requirements on logging operations and different methods of logging

Different forest management requirements are set on different logging methods. Regardless of the growing conditions, the techniques actually used should not destroy or damage the understorey or small-diameter conifer trees. A logging plan should be drawn up for each block to be harvested before the operations are started. This plan gives the logging and skidding methods, methods for clearing the felling sites, maps of logging roads and spurs, skidding lanes, loading points, machinery parking lots, areas where understorey and small-diameter trees should to be retained, and their survival rate. Before the start of logging operations, the sites are divided up into blocks in accordance with the actual conditions, and boundaries are determined between blocks, the main skid roads and spurs and the loading points.

Logging operations are carried out during winter on water-logged sites where viable understorey and small-diameter trees are to be retained after logging.

The survival rate of coniferous understorey in strips (not counting the skidding lanes) must be at least 70% of the original number before cutting in clear-cutting operations, and 80% in gradual and selection cutting.

In addition to the understorey, seed trees, seed tree groups, seed tree clusters, and seed tree strips must be left standing on all sites.

The total area of loading points, machinery parking lots and other auxiliary areas on sites over 8 ha in size should not exceed 5% for clear-cutting operations followed by reforestation, 4% for gradual and clear-cutting operations with understorey retention, and 3% for selection cutting operations. On sites under 8 ha in size, the loading points may occupy the following areas: up to 0.4 ha for clear-cutting operations followed by reforestation, 0.3 ha for gradual operations and clear-cutting operations preceded by reforestation, and 0.25 ha for selection cutting operations.

The total area of the skidding lanes in clear-cutting operations followed by reforestation must not exceed 20% of the felling site. For gradual, combined, and clear-cutting operations, with the understorey left

undisturbed, the figure is 15%, and the skidding lanes should not be more than 5 m wide.

In clear-cutting operations involving the use of machines, the total area of the skidding lanes is to be kept within 30% of the felling area.

When hauling timber in summertime on wet and excessively wet ground or fresh clayey soils, the skidding lanes have to be reinforced with slash for hauling. The length of the skidding lanes should not exceed 250 m for the first and the second stand groups, and 300 m for the third stand group. In wintertime when the soil is frozen, the recommended length of skidding lanes can be increased.

Skidding is to be avoided on excessively wet ground (particularly in spring and autumn) in order to maintain the water permeability and physical properties of the soil.

When hauling timber in summertime when the soil is not frozen, measures should be taken to prevent soil damage, deep rut formation and disturbances to the root systems of the trees left growing. Deterioration of site quality for further reforestation of conifers should be avoided.

The skidding lanes on sites with heavy clay and loamy clay, water-logged and moist soil (moss and myrtillosum types of pine and spruce forests) should be reinforced with slash. The total area of surface soil layer, leading to exposed mineral soil, should not exceed 20% of the felling area.

On dry sandy soil (in Pinetum cladinosum type forests), where damage to the forest floor results in wind erosion and inhibits reforestation, the total area of damaged humus layer should not exceed 15% of the felling area.

The maximum number of trees damaged in gradual and selection cutting operations is to be within 5% for even and gradual cutting, and 3% for selection cutting.

This system of final cutting allows forests to be timely renewed, and to increase the productivity of boreal forest in the northern part of European Russia.

REFERENCES

Волосевич, И.В., Чибисов, Г.А. & Вялых, Н.И. 1987. Способы рубок главного пользования в лесах различных групп и их проектирование. In: Вопросы экономики лесного хозяйства и лесоустройства на Европейском Севере. Arkhangelsk. p. 87–103.

Вялых, Н.И. 1968. О возобновлении леса путем сохранения подроста в условиях ельников черничников Архангельской области. Сев-Зап. кн. изд-во. Arkhangelsk. p. 67–73.

Вялых, Н.И. 1971. Жизнеспособность подроста ели на вырубках Архангельской области. In: Сб. работ по лесному хозяйству и лесохимии. Arkhangelsk. p. 49–59.

Вялых, Н.И., Листов, А.А. & Чибисов, Г.А. 1987. Пособие по естественному возобновлению леса на Европейском Севере. Arkhangelsk. 27 p.

Мелехов, И.С. 1962. Рубки главного пользования. Гослесбумиздат. Moscow. 329 p.

Правила рубок главного пользования в равнинных лесах Европейской части Российской Федерации. 1994. Moscow. 32 p.

Чертовской, В.Г. 1968. О возобновлении леса в связи с рубками на Севере. Рубки и восстановление леса на Севере. Arkhangelsk. p. 10–44.

Чупров, Н.П. 1992. Проблемы лесопользования на Европейском Севере. In: Повышение продуктивности лесов Европейского Севера. Arkhangelsk. p. 3–22.

REGENERATION PROCESSES BASED ON SITE TYPOLOGY IN THE NORTH OF EUROPEAN RUSSIA

G.A. Chibisov
Northern Research Institute of Forestry, Nikitov str. 13, Arkhangelsk, 163062, Russia

Introduction

Reforestation is one of the main problems in forestry in the northern part of European Russia. The problem can be divided into two main issues. The first is associated with the establishment of plantations, and includes seed production, breeding for high yield forms of tree species, the production of planting stock in the open and in a controlled environment, establishment of forest plantations using efficient site preparation methods and silvicultural treatments. The second issue includes the relationship between natural regeneration and cutting methods that ensure the stability of forest ecosystems, the maintenance of forest soil fertility, and the development of measures for promoting natural regeneration.

The forests growing in the north are characterised by both natural (endogenic) and anthropogenic (exogenic) succession. As a result of long-term, intensive forest utilisation and the effect of forest fires, anthropogenic forests are predominant.

Regeneration and the subsequent formation of forests follows a regional pattern in accordance with the forest site type distribution. This is reflected in the rate of regeneration, species composition, stocking and the intensity of ecological and phytocoenotic factors.

Three forms of regeneration can be defined depending on the degree of human interference: regeneration after clear-cutting and forest fires, regeneration after partial cutting, and establishment of plantations (Table 1). The first form of forest regeneration has the widest range of succession types, starting with those associated with clear-cutting. Natural forest regeneration takes place through the regeneration of subsequent or preliminary generations, or a combination of the two.

Table 1. Types of forest formation processes.

Group	Forest-forming factors	Forming stands	
		After spruce stands	After pine stands
1	Clear-cutting, forest fires	Deciduous-spruce, spruce-deciduous, pure spruce, pure deciduous (birch stands, aspen stands)	Pine-deciduous, pine-deciduous with spruce, pure pine
2	Partial cutting (gradual, selection etc.)	Pure spruce or with the admixture of deciduous, spruce	Pure pine and spruce, admixture of deciduous
3	Artifical regeneration	Deciduous-spruce	Pine-deciduous, pure pine

Types of clear-cut areas

The taiga sub-zones are characterised by an increase in the stocking level and regeneration period and in the phase of maximum growth on moving from south to north and from more fertile to less fertile sites. The degree to which the bio-ecological properties of the individual tree species are expressed depends on the edaphic conditions and, to a considerable extent, also on the type of clear-cut. The type of clear-cut has a strong effect on forest regeneration, and is determined by the species composition of the ground vegetation, which serves as an indicator of site quality and regeneration success.

The types of clear-cutting areas are characterised by forest zones. *Cladonia* cutovers are predominant in the open taiga: *Deschampsia* cutovers in the northern subzone and, *Calamagrostis* cutovers in the southern sub-zone. The transition to *Calamagrostis* cutovers in the middle subzone of the taiga is clearest on sites affected by fire. Burned cutovers, covered with *Calamagrostis*, is a common type of cutover under such conditions.

In the northern sub-zone, the regeneration period for conifers on clear-cut areas of pine forests of Pinetum cladinosum and sphagnosum types ranges from 5 to 10 years if seed trees are still present on the clear-cut area. Deciduous regeneration is slow, the regeneration period varying from 10 to 15 years in pine forests Pinetum vacciniosum, myrtillosum, polytrichosum and menyanthese-sphagnosum types. On burned cutovers the period is reduced to 5 to 10 years. On cutovers of Pinetum myrtillosum type forests deciduous species regenerate within 3 to 5 years.

On cutovers of Piceetum vacciniosum, myrtillosum and polytrichosum type spruce forests the regeneration of conifers takes from 15 to 20 years (5 to 10 years after fire on cutovers). Deciduous species usually restock the area within 3 to 5 years, but on paludified sites it takes 10 years.

In the middle sub-zone, the regeneration of conifers on cutovers of Pinetum oxalidosum, vacciniosum, myrtillosum and polytrichosum pine stands takes 10 to 15 years, and deciduous regeneration 5 to 10 years. In water-logged conditions the regeneration of conifers takes from 5 to 10 years, and deciduous regeneration is extremely slow.

Deciduous species regenerate rather satisfactorily on clear-cut areas in all types of spruce forest within 5 years. Fresh Piceetum myrtillosum and herboso-sphagnosum sites are an exception since regeneration takes about 10 years. The regeneration of conifers on cutovers of Piceetum oxalidosum spruce sites takes 10 years, on cutovers of Piceetum vacciniosum and myrtillosum spruce forests 20 years, and on paludified sites more than 20 years. The regeneration time decreases by about 5 years on burned sites.

In the southern sub-zone the regeneration period is generally 5 years shorter than that in the middle sub-zone. Deciduous species regenerate 2 to 3 years earlier, and deciduous species regenerate faster on clear-cut spruce sites than on corresponding pine sites. The effect is considerable when measures are taken to promote regeneration.

In order to accelerate the process of forest formation the theory and practice are seeking to improve the application of final cuttings. Clear-cutting in narrow strips, partial cutting and modifications of this technique (selection cutting of varying intensity, extended gradual cutting, gradual strip cutting, complex cutting etc.), as well as extensive clear-cutting, are applied.

Clear-cutting in narrow strips (strip width 50 to 150 m) has some common features with extensive clear-cutting. Similar types of cutover are formed, although the regeneration period after clear-cutting in narrow strips is shorter because the remaining strips provide a reliable source of seed. The regeneration of conifers in the middle and northern taiga sub-zones takes from 3 to 5 years on cutovers of Pinetum cladinosum pine stands, from 5 to 6 years on cutovers of P. vacciniosum pine stands, from 6 to 8 on cutovers of P. myrtillosum pine stands, and from 8 to 10 years (up to 15) on cutovers of P. sphagnosum pine forests. On cutovers of Piceetum myrtillosum spruce stands it takes 4 to 6 years, and on cutovers of P. sphagnosum spruce stands from 6 to 8 years.

In general, the cutovers in pine and spruce forests regenerate satisfactorily, including with conifers – hardwoods 60%, hardwoods – conifers 17 to 20% and hardwoods 20 to 23%. The conifer regeneration is very slow in the latter case.

Understorey

The high regeneration potential in taiga forests is due to the presence of abundant understorey. The number of young spruce growth in spruce stands of Piceetum hylocomiosum type is 3 000 to 20 000 trees/ha. In Piceetum vacciniosum stands in the northern sub-zone the number is 4 000 to 5 000 trees/ha, in the southern sub-zone 15 000 trees/ha, in fresh and moist P. myrtillosum stands 3 000 to 4 000 and 17 000 to 19 000 trees/ha, respectively, and in P. magnoherbosum spruce forests 3 000 to 4 000 and 24 000 trees/ha, respectively. The smallest number occurs in Piceetum polytrichosum spruce stands in the northern sub-zone (1 000 to 2 000 trees/ha), and in the middle sub-zone (2 000 to 3 000 trees/ha).

There is a similar regeneration pattern in pine stands. Regeneration in pine stands in the northern taiga sub-zone is rather satisfactory. The number of seedlings and young growth usually exceeds 3 000 to 5 000 trees/ha in dry pine stands. The number is less than 1 000 to 2 000 trees/ha only in pine stands on paludified sites. Pine stands in the middle taiga sub-zone generally regenerate rather well. In most of the pine stands the number of conifer seedlings and young growth is greater than 3 000 to 4 000 trees/ha.

The age of most of the young spruce growth in spruce stands in the southern taiga sub-zone is less than 20 to 30 years, in the middle taiga sub-zone 40 to 60 years, and in the northern taiga sub-zone usually 80 to 100 years. The young spruce growth in the medium sub-zone retain a high viability up until the age of 50 to 60 years, and in the northern sub-zone up until 70 to 80 years. The young coniferous growth is obviously an important reserve in the forest-formation process. The silvicultural importance of young growth has been studied extensively, and the need to preserve the young growth during cutting in order to promote natural regeneration under northern conditions is beyond dispute.

After partial cutting, forest formation takes either through subsequent and preliminary regeneration (in the case of uniform and non-uniform gradual cuttings) or preliminary regeneration only (in the case of extended gradual and selection cuttings). The regeneration and formation period is short and the species composition limited. After the first gradual strip cutting in pine stands, pine starts to restock the clear-cut strips already within the first year after cutting. Long-term observation of the seed crop shows that there is sufficient seed for regeneration even in years with a poor crop. Cutting results in relatively successful re-

generation, and the proportion of conifers increases on moving from paludified sites to dry ones. After extended gradual cutting in pine stands with a spruce admixture, pine regeneration is not sufficient, especially on the Pinetum myrtillosum forest type. It is better on Pinetum vaccinioso-cladinosum types, but spruce also gradually replaces pine in these forests too. The number and age of the young growth vary considerably and depend on the degree of canopy closure.

Immediate and subsequent regeneration can also take place in the case of intensive selection cutting. The number of young growth in the previous generation in uneven-aged spruce stands may vary considerably, but even in the northern sub-zone it is usually not less than 2 500 to 3 000 trees/ha. In the middle and southern subzones the minimum number is even higher. The young growth that survives and grows on clear-cut sites after cutting is not usually uniformly distributed over the area. The subsequent regeneration is intensively taken place in the first years after cutting. 15 to 20 years after cutting the number of new young growth does not appear to be lower than the number of originally retained young growth and, 20 to 30 years later, the new growth is completely dominant (90 to 95%).

After intensive selection cutting, the situation becomes favourable enough to maintain, for an extended period, a regeneration level that results in the continuous accumulation of growth, and the possibility to restore the original uneven-aged structure of the stand.

Spruce plantations established by sowing only slightly differ from those formed through natural regeneration. The target of forest growing should be set at the initial stage, i.e. in a plan that takes into account not only the species composition and zonal and site-type features, but also wood consumption.

Forest formation processes

The relationship between individual tree species in forest ecosystems plays an important role in the forest formation process. In other words, the composition of stands during the forest-forming process is not only an important indicator in planning management measures, but also a major factor affecting the success of forest formation.

The evaluation of forest formation and the determination of forest types, especially at an early age, based on a single forest-forming species or on the type of previous forest, do not reveal the economic importance of the type of forest and are not sufficient for long-term forestry planning and management.

Dynamic forest site type classification (Мелехов 1966, 1968, 1980 and 1989, Колесников 1967, Буш 1974, Буш & Иевинь 1976, Набатов 1975, Чибисов 1993) provides considerable opportunities for the above. Melekhov drew attention to the importance of taking into account the origin of each type of forest, and the importance of each stage in the process of forest formation and the origin of the succession stages. He also pointed out the importance of determining further development trends, and of understanding what may occur in the future in the case of a natural trend of events, and what may be the result of different forms of anthropogenic impact.

It is possible, on the basis of the specific features used to define forest types and the reproduction and age dynamics of forests, to classify forests as forest biogeocenoses. The type of biogeocenosis reflects, to a considerable degree, the structural and functional specificity of the young growth,

and the trends and rate of change in the species composition. This makes it easier to make decisions concerning the choice and intensity of management measures, and to draw up targets for forest production that are in accordance with the environmental and growing conditions. The name of a biogeocenosis should reflect the role of a tree species as an edificator at a certain stage. Table 2 illustrates the dynamics of forest types according to the type of regeneration. The individual sub-zones of the taiga may have biogeocenoses of the same name, but they vary in yield and stocking. The site index class decreases and the stocking increases regularly on moving from south to north.

The forests of the taiga zone have a high natural regeneration potential, and it is therefore one viable means of reforestation.

Table 2. Forest type classification (the northern sub-zone of the taiga).

Climax forest type (basic)	Forest formation stages		Subsequent forest type
	Cutover type	Forest biogeocenoses type	
Pine stands:			
Pinetum cladinosum	*Cladonia*	*Cladonia* pine	Pinetum cladinosum
		Cladonia spruce	Piceetum cladinosum
Pinetum vacciniosum	*Deschampsia*, burned, with *Epilobium* and *Calluna*	*V. vitis-idaea* pine and birch	Pinetum vacciniosum
		The same with spruce in the overstorey	Pin./Pic. vacciniosum
		V. vitis-idaea spruce	Piceetum vacciniosum*
Pinetum myrtillosum, fresh	*Deschampsia*, burned, with *Epilobium*	*V. myrtillus* deciduous-pine	Pinetum myrtillosum
		V. myrtillus birch-pine	The same
		V. myrtillus deciduous-pine with spruce in the overstorey	Pin./Pic. myrtillosum
		V. myrtillus spruce	Piceetum myrtillosum, fresh*
Pinetum polytrichosum	*Polytrichum*	*Polytrichum* pine-birch	Pinetum polytrichosum
	Sphagnum-Polytrichum	*V. myrtillus* pine-birch, moist	Pinetum myrtillosum, moist
		Sphagnum pine	Pinetum sphagnosum
		Sphagnum birch	Betuletum sphagnosum**
Spruce stands:			
Piceetum oxalidosum	High grass	*O. acetosella* birch-spruce	Piceetum oxalidosum
		O. acetosella aspen-spruce	The same
		O. acetosella spruce-hardwoods	
Piceetum vacciniosum, fresh	*Deschampsia*, burned, with *Epilobium*	The same, *V. myrtillus*	Piceetum myrtillosum, fresh
Piceetum polytrichosum	*Polytrichum*	*Polytrichum* birch	Betuletum polytrichosum**
	Sphagnum-Polytrichum	*Polytrichum* birch-spruce	Piceetum polytrichosum
		V. myrtillus birch-spruce, moist	Piceetum myrtillosum, moist
		Polytrichum spruce-birch	Piceetum polytrichosum
		V. myrtillus spruce-birch, moist	Piceetum myrtillosum, moist
Piceetum sphagnosum	*Sphagnum*	*Sphagnum* birch	Betuletum sphagnosum
		Sphagnum birch-spruce	Piceetum sphagnosum
		Sphagnum spruce with birch	The same

* If there are seed trees, spruce stands with different proportions of pine (mixed spruce and pine stands) may be formed
** Species change, forest type change

It can be controlled, and therefore considered to be an active form of reforestation. Natural regeneration is a very diverse process with regard to the duration of stand formation, and it has a high nature conservation value. The unsolved problems include the optimisation of natural regeneration processes in coniferous forests with regard to cutting, biological diversity and gene reserve conservation. Identifying critical levels for the impact of management practices on forest ecosystems is of particular importance.

REFERENCE

Буш, К.К. 1974. Пути развития советской лесной типологии. Лесоведение 6: 3–11.

Буш, К.К. & Иевинь, И.К. 1976. Некотырые аспекты развития динамической типологии леса. In: Современные исследования типологии и пирологии леса. Arkhangelsk.

Колесников, Б.П. 1967. Некоторые вопросы развития лесной типологии. In: Типы и динамика лесов Урала и Зауралья. Sverdlovsk.

Мелехов, И.С. 1966. Леса севера европейской части СССР. Леса СССР. Т. 1.

Мелехов, И.С. 1968. Динамическая типология леса. Лесное хозяйство 3: 15–20.

Мелехов, И.С. 1980. Лесоведение. Лесная пром-сть. Moscow.

Мелехов, И.С. 1989. Лесоводство. Агропромиздат. Moscow. 302 p.

Мелехов, И.С., Корконосова, Л.И. & Чертовской, В.Г. 1965. Руководство по изучению концентрированных вырубок. Moscow.

Набатов, Н.М. 1975. Об этапах образования типа леса. Лесной журнал 4: 10–16.

Чибисов, Г.А. 1993. Целевое воспроизводство лесов на основе динамической типологии леса. Лесной журнал 2–3: 3–10.

THE CURRENT STATE AND PROBLEMS OF FOREST REGENERATION IN THE NORTH OF EUROPEAN RUSSIA

N.A. Babich, A.I. Barabin and G.S.Tutygin
Arkhangelsk State Technical University, Severnaya Dvina Emb. 17, Arkhangelsk, 163007, Russia

Tree species composition of the forests

The forests in the region primarily consist of boreal coniferous species, and have developed over the centuries as a result of the combined effects of natural and anthropogenic processes. In the northern sub-zone of the taiga about 50% of the forest grows on intermittently water-logged or paludified land (site class V), the tree canopy is semi-closed, and the stand structure relatively simple. The middle taiga sub-zone is occupied by an increasing proportion of Piceetum oxalidosum and P. vacciniosum type forest. In pine forests the area covered by Pinetum cladinosum and dwarf-shrub types typical of the north decreases, and in spruce forests the area of Piceetum polytrichosum, P. sphagnosum and stream-bank types also clearly decreases. The average site class of these types is 4.3

The forest-forming species of commercial importance are Norway spruce, Scots pine, and silver birch. The distribution of the forest-covered area according to the dominant tree species is (data from 1993):

Region/ Republic	Spruce	Pine	Birch
		%	
Arkhangels Region	56.9	27.0	14.5
Vologda Region	29.5	24.9	36.9
Republic of Komi	55.5	24.7	15.0

Logging operations have disturbed the natural forest ecosystems, mainly through their effect on natural regeneration. The displacement of pine in the taiga zone by deciduous species and spruce is nowadays widespread.

The change in tree species has been especially strong during the past decades as a result of increases in logging volumes and the total clear-cut area following the introduction of efficient forest harvesting machines such as the VM-4, VTM-4, LP-19 and LP-49.

Intensive exploitation of forests in the northern part of European Russia has resulted in a decrease in the total area of mature pine stands by 1.83 Mha (22.3%) during 1961–1982; in the Vologda Region by 8.7%, in the Arkhangelsk Region by 16.9% and in the Republic of Komi by 27.8%.

In the majority of cases the replacement of conifers by deciduous species does not correspond to the requirements of the national economy. The replacement of coniferous by deciduous species reduces total forest productivity by 30–50%.

Current state and problems of forest regeneration

The main forest management problem in the regions is a gradual transition from clear cutting to selection cutting. It is clear that the modern principles of selection cutting need to be improved and studied in detail.

One reliable method of preventing a change of tree species, and thus enhancing the productivity of taiga forests, is the establishment of forest plantations. We consider that the ratio between natural and arti-

ficial regeneration should be kept extremely flexible. If, for example, the forecast of the seed crop for the next two or three years is not favourable, forest plantations should be established. However, if the logging operations are carried out in a good seed year or if the seed forecast for the next 2–3 years is favourable, then the proportion of natural regeneration should be increased. This ratio could vary in different parts of the region (Table 1).

Long-term studies on the seed production of spruce and trial implementations of our recommendations have provided information on a number of topics:

– The morphological forecasting method, which enables us to predict the yield of a seed year by counting the number of female buds on the crown whorls of an "indicative" tree one year or more before seed ripening, has been improved.

– We have found that late spring frosts occurring before sexual and asexual budbreak do not have any marked effect on the accuracy of the seed production forecast. The number of damaged female strobiles varies between years, and there is inverse correlation with the flowering abundance.

– A new scale was created for quantitative evaluation of the seed crop. This enables us to plan, on the basis of an accurate spruce "flowering" forecast, spruce regeneration well in advance.

– New equations for cone and seed crop estimations were compiled.

– We have found that the proportion of class 1 seed is at least 60–80% in abundant seed crops. In contrast, the yield of class 1 seed in years with a small seed crop is very low, and proportion of non-standard seed increases sharply.

– The economic viability of spruce cone collection has proved to be good only in years with an abundant crop. This provides sufficient seed for all regeneration activities during periods with poor seed years. The estimated profitability (%) in harvesting 1 kg of seed using 5-point scale estimation of the seed year is -15.99, -3.49, +7.94, +18.23, +81.61.

– In carrying out the forecasting work, regions have been chosen where the macrostrobiles have not been damaged by late spring frosts, thus guaranteeing that accurate data are collected on the potential and actual cone crop.

The results of this research are presented in detail in a doctoral thesis (Barabin 1990), and are partially included in the paper "Recommendations for forest seed production in the Russian Federation" (1994).

Table 1. Forest plantations as a proportion of the annual clear-cut area.

Region		Republic of Komi	Reference
Arkhangelsk	Vologda		
22	–	–	Shuzhmov and Sinnikov 1968
25	30	20	Pobedinsky 1977
16	19	11	Lvov et al. 1980
Forest plantations should be established on no more than 15–25% of all clear-cut areas			Tyurin 1987
26	30	20	Pisarenko and Merzlenko 1990
24	29	13	Chibisov 1992

In recent years research has been started on differentiation of pine and larch shoots. It has been possible to distinguish the "signal" whorls and crown sectors with maximum occurrence of macrostrobiles. This will facilitate more accurate seed production forecasts and a quantitative survey of the latent and actual seed crop.

For many decades the main species planted in the region was pine. This is understandable because, ever since the clear-cutting method was first introduced in 1929, the most highly productive pine stands have been cut first. Foresters subsequently favoured pine when choosing the tree species. Thus, pine plantations accounted for 94.4% of the total area regenerated in 1956 in the Arkhangelsk Region.

Over the years pine stands became less subjected to harvesting, and final cutting operations gradually shifted to spruce stands. Traditionally cone collection was mainly carried out on felled trees in clear-cut areas during the logging operations; the decrease in pine harvesting gradually led to a shortage of pine seed. Infrequent pine seed years and insufficient time for the seeds to ripen in unfavourable years made the problem worse. Abundant seed crops occur at intervals of up to 8 years. In the Arkhangelsk Region seed production on pine is 2- to 3-fold and sometimes even 6-fold less abundant than in the more southerly regions of its natural distribution. Foresters were subsequently forced to choose spruce even though the soil conditions were not favourable for this species. Furthermore, extensive and sometimes groundless spruce introduction in the region was favoured by the fact that spruce seedlings in greenhouses in the north are less susceptible to diseases and pests than pine. The survival rate of spruce in plantations is also rather high.

The main cultivated tree species in the region is now spruce. For example, in 1971 the proportion of spruce plantations in the Republic of Komi was 27 % of the cultivation area, and within 11 years (by 1981) it had already increased to 52%. In the Vologda Region the ratio between pine and spruce plantations was 90:10 in 1931–1940. During the 5-year period 1981–1985, spruce plantations were established 85 104 ha but pine plantations only 7 233 ha. A tendency to preserve the ratio at this level has also been evident in the Arkhangelsk Region.

The growing of spruce monocultures is a current problem in forestry in the northern part of European Russia. It will have to be solved on a zonal-typological basis, taking into account the zoning of plantations and experience gained in the growing of coniferous plantations.

For many years sowing was the main method used in establishing forest plantations in the region. Good seed germination and high seedling survival are promoted by the moderate air temperatures in summer (the average July temperature is 15–17°C) and sufficient precipitation during the growing season. The proportion of planting in artificial regeneration has increased as a result of improvements in the quality of the established plantations and the intensity of forest management. The selection of regeneration method should be based on the soil conditions and type of cutting area. Sowing should not be used in cutting areas on loamy soils, as well as on areas rapidly covered by grasses and herbs (grass and herb cutting areas). On such sites it is recommended to plant with 5- to 6-year-old transplants.

It is impossible to perform all the required planting within the short spring period in the north. This is mainly due to the lack of mechanised tools and equipment,

poorly developed road network and remoteness of the cutting areas.

Our studies have shown that autumn regeneration does not give good results (Table 2). High survival with freshly lifted pine seedlings can only be achieved after spring planting, before bud opening. Spruce seedlings and transplants show good survival if they are lifted in the nursery and planted on the regeneration area before bud burst or 10–15 days after the buds start to burst. In addition to the fact that the duration of this process is short and varies from year to year, it is very difficult to forecast this time interval and schedule the regeneration work accordingly.

There are good prerequisites for expanding the planting season in the region. The end of spring and beginning of summer are rather favourable for the survival and growth of trees on clear-cutting areas.

Up until recently, containerised planting stock has not been widely used owing to the rather high costs. The main planting stock used in establishing plantations is bare-root seedlings and transplants. Techniques have been developed for this type of planting stock, and practical experience has been gained in the artificial postponement of bud opening.

Seedlings and transplants of spruce and pine are lifted in the nurseries when the soil thaws. The planting stock is put into boxes, the roots being covered with moist peat or packed into rolls in polyethylene film. In storage the temperature is kept at 0... +3°C (using ice or refrigeration) and a relative humidity of 90–95%. In such conditions evapotranspiration is low, reducing the plants' energy consumption.

Storing the planting stock enables us to prolong the planting season for spruce and pine until mid-June in the northern and middle sub-zones of the European taiga. Retardation of bud opening alleviates post-planting stress because the balance between water consumption and transpiration is not very critical compared to plants that start to grow before transplanting. The maximum storage period for pine seedlings is 40 days, and for spruce seedlings and transplants 50 days.

Larch often starts to grow before the soil has thawed in the nurseries and regeneration sites, and this shortens the planting period for bare-root larch seedlings in the spring. Strong shifts in metabolism from dormancy to active growth period make it impossible to store planting stock after spring lifting without disturbing their physiology.

Table 2. Average plantation survival according to data from the end of the second growing season.

Planting season	Survival, %	
	Pine	Spruce
Spring, before bud opening on seedlings and transplants	96.1 ± 0.4	97.3 ± 0.3
Spring, between the start of the growing season and pine flowering	64.6 ± 1.8	89.7 ± 0.5
Summer, between pine and *Calluna* flowering	35.3 ± 1.1	59.7± 2.6
Late summer, starting at *Calluna* flowering up until birch yellowing	78.0 ± 1.9	72.6 ± 2.0
Autumn, period between birch yellowing and soil freezing	46.6 ± 1.5	40.1± 1.7

Another biological peculiarity of larch – annual needle shedding – creates favourable conditions for winter-spring storage. After needle fall the metabolism of larch drops to a minimum level, thus promoting the storage of planting stock.

For winter-spring storage the seedlings are lifted in the nurseries at the time of needle yellowing and shedding (usually in the latter half of October). The planting stock is put into boxes and the roots are covered with peat with a 60% moisture content. The boxes containing the planting stock are kept in an unheated store in the dark until March–April. The boxes are then moved to a store and kept under similar conditions as for spruce and pine. Larch planting stock must be planted within 30 days after larch starts to grow in the nurseries.

The success of artificial regeneration can be improved by carrying out the tending of seedling stands at the correct time. In most of the clear-cutting areas in the northern part of European Russia, mineralised belts and furrows become covered with grassy vegetation at a slower rate than in the southern parts of Russia. This means that chemicals need to be applied only once after sowing seed or planting seedlings. After planting spruce it is not necessary to use any treatment at all. It is ecologically sound and economically viable to apply herbicides along the rows of transplants. The impact of chemicals on the environment will be reduced if they are applied in solid form, preferably as pills or granules.

Our experience gained in the region shows that strict compliance to the technical recommendations during establishment and growing the plantations results in highly productive stands dominated by the cultivated species.

Pine plantations on sites of Pinetum myrtillosum type in the middle taiga subzone accumulate 35–64% more stem wood by the age of 40 years than natural pine stands. The corresponding figure for the Pinetum vacciniosum type is 24–64%. In the northern taiga sub-zone the increase on the P. vacciniosum type is 34%. In the P. cladinosum type in the northern taiga subzone the difference in stem wood accumulation between natural and artificially regenerated sites is insignificant.

Another advantage of establishing plantations is that clear-cut areas can be planted already in the year following harvesting, while in natural condition the regeneration process on burned or clear-cut areas lasts for 10–15 and sometimes even 20 years.

Conclusions

The increased productivity of plantation forests is due to the following:

– Use of the correct soil preparation methods on specific forest site types.

– Homogeneous soil conditions for tree growing.

– The planting of tree species on sites corresponding to their biological and ecological requirements.

– Use of high-quality seed and planting stock.

– Even distribution of the planting stock over the cutting area.

– Planted trees grow evenly without suffering from die back, thus ensuring the survival of a certain number of trees per hectare.

– The presence of naturally regenerated deciduous species improves soil quality.

– The natural regeneration of deciduous and coniferous species, which is an essential structural element for the formation of fully stocked mixed forest stands.

Forest plantations should be established on sites where natural regeneration is not successful. Only a combination of natural and artificial regeneration ensures the timely regeneration of clear-cutting areas with economically valuable tree species.

REFERENCES

Барабин, Л.И. 1990. Закономерности семеношения ели на Европейском Севере и основа лесосеменного прогнозирования. Автореферат дисс. доктора с.-х. наук. Moscow. 35 p.

Львов, П.Н., Ипатов, Л.Ф. & Плохов, А.А. 1980. Лесообразовательные процессы и их регулирование на Европейском Севере. Лесная пром-сть. Moscow. 113 p.

Наставления по лесосеменному делу в Российской Федерации. 1994. Moscow. 159 p.

Писаренко, А.И. & Мерзленко, М.Д. 1990. Создание искусственных лесов. Агропромиздат. Moscow. 270 p.

Побединский, А.В. 1977. Повышение продуктивности лесов лесоводственными мероприятиями. In: Повышение продуктивности лесов лесоводственными примерами. ВНИИЛМ. Moscow. p. 3–24.

Тюрин, Е.Г. 1987. Воспроизводство хвойных лесов. Лесное хозяйство 9: 42–45.

Чибисов, Г.А. 1992. Рубки ухода за лесом на Европейском Севере. Лесоводственно-биологические основы и зонально-типологические программы. Автореферат дисс. доктора с.-х. наук. St. Petersburg. 41 p.

Шугимов, А.А. & Синников, А.С. 1968. Лесовосстановительные мероприятия в Архангельской области. In: Рубки и восстановление леса на Севере. Сев.-Зап. кн. изд.-во. Arkhangelsk. p. 94–111.

PLANNING OF REGENERATION AREAS IN FINLAND

P. Wallenius
Finnish Forest and Park Service, Vernissakatu 4, FIN-01300 Vantaa, Finland

Planning systems

Of the area owned by the Finnish Forest and Park Service, 3.3 Mha (34%) are commercially exploited forestry land. About 20 000 ha (0.6%) of forestry land are regenerated each year. The amount of improvement cuttings is increasing, and currently totals ca. 30 000 ha/a. A total of approx. 4.3 Mm^3 is cut per annum.

Utilisation of the forests is based on site information for all the forests owned by the Forest and Park Service. The information consists of maps, site-specific information on the soil and stands, as well as information about sites of nature conservation value. The site information includes a number of restrictions on the use of commercial forests during the different planning stages and in programmes related to the use of the forests. Forest use is also affected by local expertise and environmental aspects. The planning systems include regional planning of natural resources and landscape-ecological planning, and the programmes include a waterside protection programme. The planning systems are shown in diagrammatic form in Figure 1.

Planning at different levels

Strategic planning of forest use is carried out within the framework of a regional natural resource planning programme. A separate plan is made for each of the seven areas of the Forest and Park Service. An updated plan will have been drawn up for

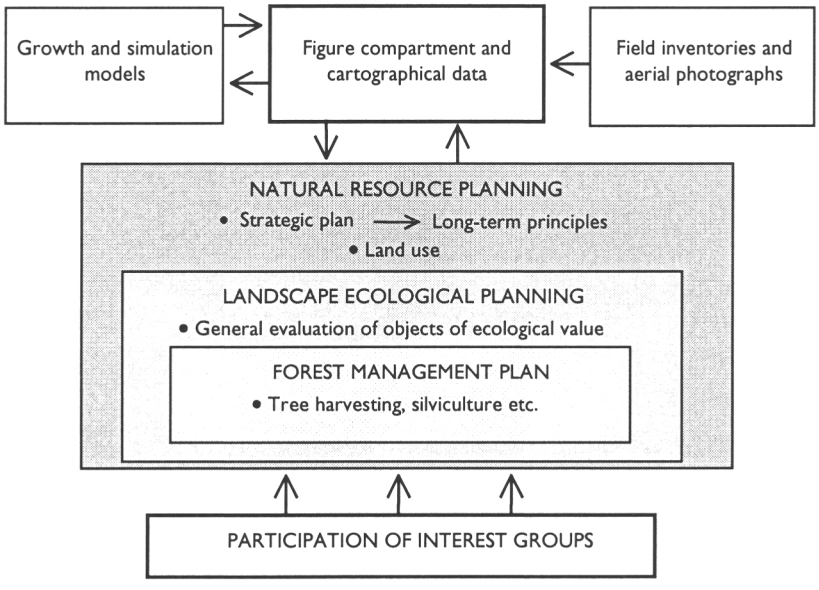


Figure 1. The planning systems.

each area by the end of the year 2000. The plans will be used to determine the principles for land use in the whole area concerned. These principles cover all aspects, ranging from environmental protection to forestry. The plans will be prepared in co-operation with the different profit units of the Forest and Park Service.

All the data available on the planned area will be compiled in the initial planning stage, and an extensive round of public consultations and hearings will be arranged in order to give all interest groups and members of the public the opportunity to state their opinions and aims concerning the use of local land and forests. Such involvement will continue throughout the planning project, and three or four steering groups will be formed from the interest groups to participate throughout the planning project and to oversee the decision making. Several alternatives for land use in the region will be drawn up and used to find a balance between environmental protection, forestry and recreation.

The alternatives will also be compared to current practices in the region. The alternative which best meets the individual goals will be chosen on the basis of the response of the planning group, the steering groups comprising interest groups, and the public at large. A sustainable cutting volume will then be determined for the area consistent with the realisation of the other goals. A draft of the plan will be presented extensively to interest groups and the public, and their response will be taken into account before making the final decision.

Decisions on ecological principles will be made during landscape ecological planning. This is a plan for an area of 10 000–100 000 ha, and it specifically stresses the ecological features of the area. All the land owned by the Forest and Park Service will be included in the landscape ecological planning by the end of the year 2000. Landscape ecological plans will be made for different parts of Finland at the same time. A new project, involving a steering group comprising the different profit units of the Forest and Park Service and local interest groups, will be established for each planning project. Participation will be the same as in landscape resource planning, i.e. both interest groups and the public will be given an opportunity at meetings or in working groups to express their opinions and contribute their knowledge and expertise for use in the planning process.

The aim in landscape ecological planning is to identify specific ecological sites on the basis of information from a variety of sources and by paying visits to the sites. Plans will be made for their conservation and management (Hallman et al. 1996). Figures 2 and 3 show the structure and timetable of a landscape ecological plan.

An effort will be made to connect larger nature conservation sites in the planning area by so-called ecological corridors and stepping stones that enable organisms to move from one area to another. Over the long term these connections provide a range of species with better possibilities to reproduce and survive (Korhonen and Savonmäki 1997). The special sites presented in the plan, and the measures they require, will be entered in the site data system and taken into account e.g. in the regeneration plans. A map from a landscape ecological plan is illustrated in Figure 4.

Specific plans will be made for special areas such as camping sites, conservation sites, wilderness areas, and include decisions on the use and management of each particular area.

The cutting sites and silvicultural work sites are defined in the plans for stands

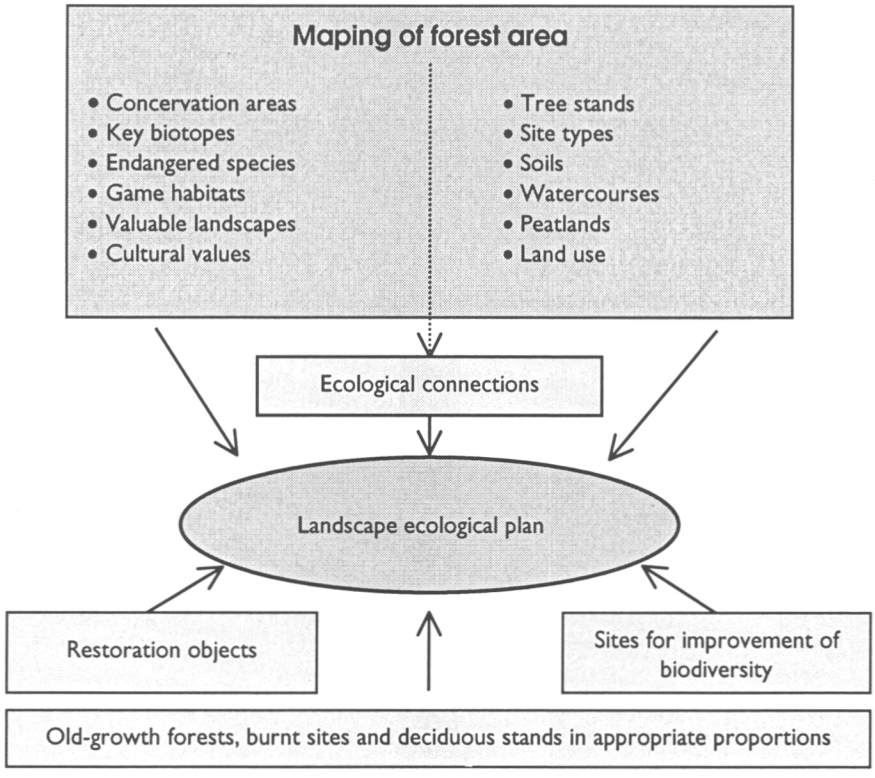


Figure 2. Structure of landscape ecological planning

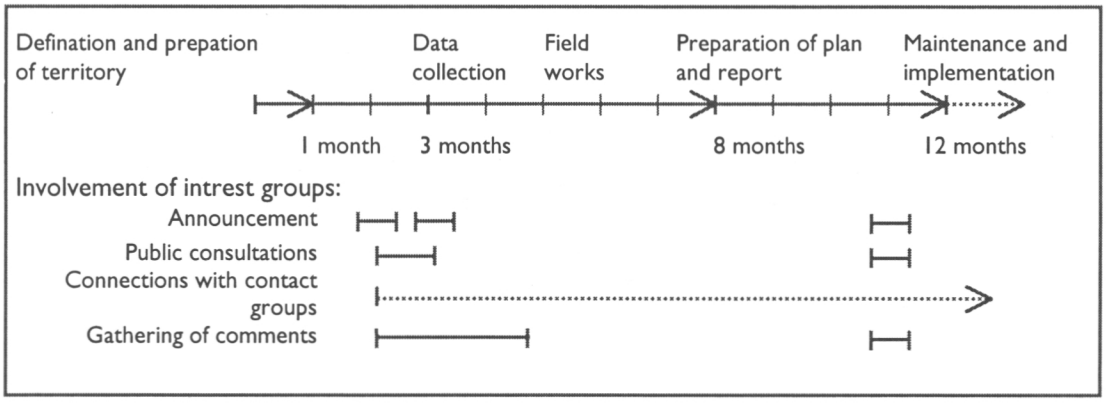


Figure 3. Timetable of landscape ecological planning (example).

marked for cutting, which are site-specific work plans. Plans for stands marked for cutting take into account all the plans made on a broader scale, and include decisions concerning forest regeneration, improvement cutting and other forestry measures, as well as objects of ecological value that are to be preserved but which are not mentioned in the more general plans. The planning of a forest road network for each stand

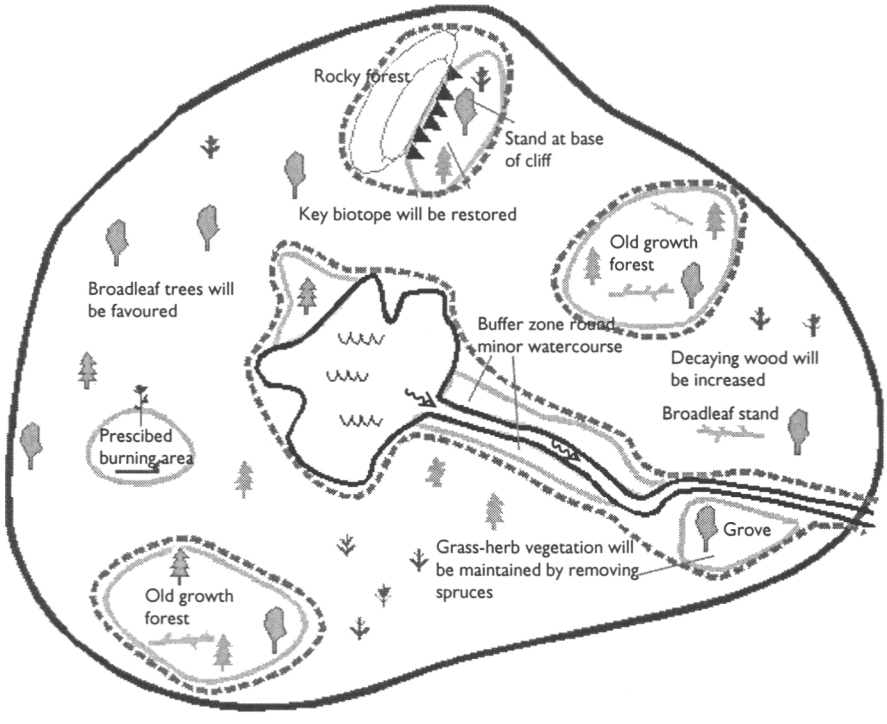


Figure 4. Example of a landscape ecological map.

marked for cutting is also included. The plans for stands marked for cutting are, in practice, controlled by the forestry guidelines of the Forest and Park Service, the environmental manual of the Forest and Park Service, and any special regulations concerning restrictions on the use of forests. The environmental system of the Forest and Park Service, which was certified in 1998, also encourages the maintenance of sites of ecological value in all its plans concerning forest management and in their implementation. The environmental system was constructed in accordance with the ISO 14001 standard, and it has been certified by the international Det Norske Veritas certification organisation. The environmental system covers all the activities of the Forest and Park Service, and it has set goals for the continuous improvement of environmental management in all activities affecting the environment in the individual sections of the organisation.

Choosing a site for regeneration

In planning regeneration sites, the guidelines of the environmental manual and the regeneration criteria of the forestry guidelines of the Forest and Park Service must be observed (Photo 6). The most important criterion is the rotation period for the site class in question, which is determined according to the climatic conditions and soil fertility. If this criterion is met, regeneration is permitted. The Forestry Act, which also applies to the Forest and Park Service, sets restrictions concerning age and stem diameter for forest regeneration, but they are not as strict as those of the Forest and Park Service guidelines. When an area includes several compartments suitable for regenera-

tion, the final choice is also affected by the market situation (i.e. what sort of timber is in demand), the time of year when cutting is performed (i.e. the carrying capacity of the soil), and the relationship between the compartments (i.e. the stand marked for cutting in relation to the stand type or long-term activities). The planning also takes into account the needs and wishes of interest groups and the local inhabitants. Their opinions have already been heard in connection with natural resource planning and landscape ecological planning, and when planning which stands are to be cut.

Individual targets with respect to both the total volume and type of timber are set when planning cutting work in the forests of the Forest and Park Service. As a number of stands have usually already been planned for cutting, this means that the type of timber to be cut can be decided in accordance with the market situation. Areas in the same stand with a similar carrying capacity are also chosen so that the whole stand can be cut at the same time. Due to the market situation, it is sometimes necessary to select stands for cutting within a short period of time in order to satisfy the demand. However, even in these cases all the factors affecting stand planning are taken into account.

The principles applied in the stands to be cut are determined by the area planner. The plan can be a detailed plan or only a basic plan. In the latter case, the detailed planning is left to the person responsible for carrying out the work, i.e. the machine operator or the forest worker. All the plans and sources of information mentioned above are used in the planning work. The plans are drawn up in good time before cutting, i.e. six months or more, but in some cases the plan has to be made almost immediately before it is implemented. The Forestry Act assumes notification of forest use, i.e. a cutting plan, at least 14 days prior to cutting, but exceptions are permitted. Stand-wise planning is increasingly being carried out in the form of co-operation between the departments of forestry and environmental conservation of the Forest and Park Service. There is also increasing co-operation with outside interest groups, especially in cases where there are conflicting goals on the cutting site.

Principles of regeneration

The principles applied in regeneration are based on research carried out in different parts of Finland, and on the forestry guidelines derived from this work. The preferred regeneration method is natural regeneration if the conditions permit it, followed by sowing and planting. In many cases a combination of these methods is used.

The proportion of natural regeneration in the forests of the Forest and Park Service is currently 40–50%. Sowing and planting are used to about the same extent, i.e. ca. 30%. Native tree species are used for regeneration in Finland; the species or combination of species used varies to some extent within a regeneration area. An existing stand suitable for further growing is always utilised, if possible, in the establishment of a new stand. A regeneration area is cleared only when the existing stand actually prevents the establishment of a new stand, or when clearing is necessary for landscaping reasons. The soil is prepared over almost the entire regeneration area (Hänninen et al. 1995). The soil preparation method is chosen according to the soil and moisture conditions, and is to be kept as light as possible. The main method is disc ploughing, which accounts for 60–70% of the total area prepared. Other methods include patch scarification in areas with a thin humus layer, and mounding in areas with a thick humus layer. The forest land owned by the

Forest and Park Service is not ploughed. In moist areas ditch mounding is frequently used, with small ditches draining off excess water from the regeneration area. First-time ditching is no longer used on land owned by the Forest and Park Service, but the ditches in earlier drained areas are kept in good condition.

In addition to the regeneration method, important issues in regeneration planning include landscape-related factors, the size of the regeneration area, game issues, specific environmental issues, water protection and other uses of the forests. Features that are also taken into account when planning a forest regeneration area include which trees are to be left, prescribed burning and forest road construction. The use of prescribed burning in regeneration is being encouraged because fire plays an important role in boreal forest ecosystems, but the area treated with prescribed burning has been small owing to the reduced size of logging areas and unfavourable weather conditions. Fewer and fewer forest roads are nowadays being built, and those that are built are generally the main haulage roads. Basic reconstruction and the maintenance of old roads involve a significant amount of work.

The regeneration principles changed radically in the early 1990's. The size of the regeneration area decreased considerably and is currently 3–4 ha. Landscape factors, water protection and special ecological characteristics are taken into account on all sites, and an average of 10 m^3 of trees per hectare are usually left as so-called legacy trees. These trees are generally old trees, primarily deciduous trees, and are left to maintain the amount of decayed trees required by threatened organisms. Currently about 15% of the trees that could be cut are left uncut in the regeneration areas of the commercial forests of the Forest and Park Service for environmental and nature conservation reasons. This amount does not include the nature conservation areas.

Planning documents

The site information system produces the basic information needed in planning the regeneration area. The information collected from all earlier planning processes is recorded in the site information system. This information, together with the opinions of the public and the results of the planner´s field work, form the basis for the regeneration plan. The plan is revised on the basis of information collected from other sources, with field surveys being carried out in the area if necessary. The documents generated in the planning of forest regeneration include a general map, a stand map, a figure compartment list of measurements and tree volumes, as well as information about important environmental objects on the site. In the case of sites of considerable ecological importance, there is co-operation with representatives of the environmental protection sections and, if necessary, also with the environmental centre in order to produce an acceptable plan. Information about the plan is also sent to the buyers of the timber. All the plans concerning the regeneration areas are public, and available at cost price from the offices of the Forest and Park Service.

Follow-up and maintenance

All the procedures concerning regeneration and other preparatory work in the forests are recorded in the site information system within six months after the procedures have been carried out at the latest. The site information is also updated in association with other planning and implementation measures, and can also be updated separately if necessary. Site preparation and its success are checked annually from a sample comprising approx. 10% of the prepared

sites. The activities are controlled on the basis of this follow-up, and a report is published. In the follow-up, special attention is paid to the environmental aspects of the regeneration area, i.e. how well the goals of the environmental work have been taken into account in the different planning and implementation stages. Personnel from both the forestry and environmental protection sections participate in the follow-up. It is also a principle that an inspector from a specific area does not inspect his own area. Follow-up over several years has shown a clear improvement in the management of the environment, and activities are currently of a high standard. In addition to the follow-up, continuous improvement of the environmental system is also being monitored, and these together produce feedback to the different parts of the organisation for the future development of activities.

The Forest and Park Service has made substantial efforts in Finland in looking after the environment and biodiversity, and in developing activities from the environmental point of view. The activities are constantly being revised in the light of new research and experience, and it is expected that major new challenges will appear in the near future.

REFERENCE

Hallman, E., Hokkanen, M., Juntunen, H., Korhonen, K.-M., Raivio, S., Savela, O., Siitonen, P., Tolonen, A. & Vainio, M. 1996. Alue-ekologinen suunnittelu. Metsähallituksen metsätal. julk. 3. 59 p.

Hänninen, E., Kärhä, S. & Salpakivi-Salomaa, P. 1995. Metsätalous ja vesiensuojelu. Metsätehon opas. Helsinki. 23 p.

Korhonen, K.-M. & Savonmäki, S. (eds) 1997. Metsätalouden ympäristöopas. Metsähallitus. Vantaa. 130 p.

3. NATURAL REGENERATION AND RETENTION OF UNDERSTOREY

NATURAL REGENERATION OF FORESTS IN FINLAND

E. Kubin

Finnish Forest Research Institute, Muhos Research Station, Kirkkosaarentie 7, FIN-91500 Muhos, Finland

Timing of regeneration felling

In Finland, regeneration felling aimed at either artificial or natural regeneration can be carried out when the stand to be felled meets certain criterion laid out in the forestry legislation. These criteria are 1) a minimum mean stand diameter at breast height, 2) a certain stand age, or 3) some special reason. In recent years, mean stand diameter has become the primary criterion used in determining regeneration maturity; it is a useful parameter especially in stands that have been thinned at some stage. Stand age has a secondary role, and is of more importance in naturally regenerated stands that have been left unmanaged for a long time, or when diameter growth has been slow (Mielikäinen 1997). Both the minimum age and minimum diameter depend on the forest site type and on the geographical location.

When mean stand diameter is used in determining the timing of regeneration, it should be at least 23–27 cm (depending on the tree species and site type) in southern Finland, 22–25 cm in Pohjanmaa–Kainuu, and 22–23 cm in Lapland (Table 1). Similarly, the minimum age limits for regeneration maturity vary between 50 and 130 years. Special reasons for carrying out regeneration felling are connected to stand properties such as poor quality or poor growth of the stand.

When to rely on natural regeneration

Finnish forestry legislation states that natural forest regeneration may be employed if the conditions on the site are favourable enough to produce natural seedling material on the basis of advance assessment of the tree stand, soil and ground vegetation. Moreover, it is assumed that the landowner maintains the conditions necessary for restocking by means of site preparation and the control of competing vegetation. These preconditions are not considered to exist, e.g. if there is no certainty that seeding is sufficient, or if the vigorous development of ground vegetation following felling is likely to prevent restocking through natural regeneration. The more northern the location, the smaller the amount of seeding that is considered sufficient. In southern Finland, restocking is often threatened by excessive growth of grassy vegetation.

The individual forestry organisations have their own recommendations (Luonnonläheinen... 1994, Metsän... 1996, Hokajärvi 1997), based on similar principles,

Table 1. Stand age and mean stand diameter criteria for stand regeneration in compliance with the decision of the Ministry of Agriculture and Forestry (1997).

Tree species and site type	Mean stand diameter, cm			Mean stand age, a		
	Lapland	Pohjanmaa - Kainuu	Rest of Finland	Lapland	Pohjanmaa - Kainuu	Rest of Finland
Scots pine						
Moist or more fertile upland site	23	25	27	110	90	70
Dryish upland site	23	24	25	120	100	80
Dry upland site	22	22	23	130	120	100
Norway spruce						
Grove-like site or more fertile upland site	23	24	25	100	80	70
Moist upland site	22	23	24	110	90	80
Silver birch and downy birch						
Grove-like site or more fertile upland site	–	–	–	60	60	50
Moist upland site	–	–	–	60	60	60
Moist upland site or more fertile upland site	22	23	24	–	–	–

concerning the selection of regeneration method. Natural regeneration is recommended when the preconditions needed to obtain an economically valuable stand within a reasonable period of time exist, and to achieve a result superior to artificial regeneration with respect to the yield, costs and risks. The recommendations also include the principle of exploiting natural advance growth, seeding by neighbouring stands, and the combination of methods on the same regeneration site. In fact, it is clear that sites where artificial regeneration is applied often have considerable numbers of wildlings, as much as half the number of seedlings to be grown (e.g. Pohtila and Valkonen 1985, 1985 Räsänen et al. 1985, Saksa 1987).

The popularity of natural regeneration has varied in Finland over the course of time. A significant turning point in forest management occurred at the end of the 1940's (Leikola 1986, 1987). Up until then, selection felling and associated fellings had been the rule, and the forests were usually either regenerated artificially or left to regenerate naturally without any active measures on the part of the landowner. The significance of good seed crops (Heikinheimo 1932,1937), soil properties and soil preparation for restocking was known (Tertti 1938), but practical forestry lacked methods for the large-scale implementation of soil preparation. Restocking often therefore took place slowly or remained incomplete. With the growing need for wood adding to the need for regeneration felling, intensive stand-specific treatment replaced the earlier methods (Appelroth et al. 1948), and clear-felling, seed-tree and shelterwood methods became the prevailing regeneration methods (Heikinheimo 1948, Mikola 1956).

Increased wood consumption and positive experience with artificial regeneration soon led to the widespread adoption of methods favouring clear-felling and artificial regeneration. This development took place at the expense of natural regeneration to such an extent, that by the 1960's, the goals of some forest regeneration pro-

grammes presupposed that all regeneration would be carried out artificially. The area of natural regeneration subsequently fell rapidly (Fig. 1). Nowadays, natural regeneration and sowing together account for more than half of the annual regeneration area, most of the natural regeneration involving pine.

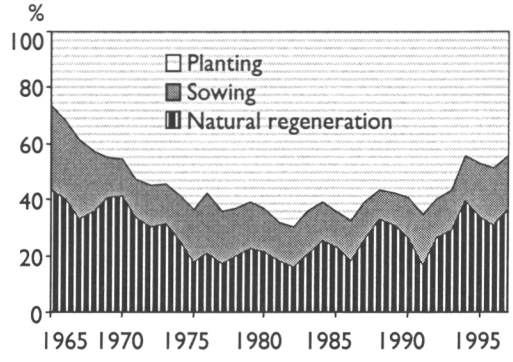


Figure 1. The relative proportion of natural regeneration, sowing and planting in Finland during 1965–1997 (Finnish... 1998).

Natural regeneration of pine

Natural regeneration of pine in Finland relies on the seed-tree method. This method can only be used when there is sufficient production of mature seed. Studies have shown, for instance, that the seed crop in the same climatic conditions is the better, the more fertile is the site (Sarvas 1962). In the relatively warm conditions of southern Finland, enough mature seed is produced each year to ensure regeneration, but the fequency of abundant seed years decreases on moving northwards. When the effective temperature sum (threshold value +5°C) is below 950 °C·d, only part of the pine seed will mature and the success of natural regeneration will become considerably uncertain. However, it has also been found that there is large tree-to-tree variation within a stand as regards seed maturation, and that mature seed are produced by some tree individuals even when the growing season is unfavourable (Ryynänen 1982). When the effective temperature sum falls below 700 °C·d, seed no longer mature (Henttonen et al. 1986).

In addition to having a sufficient seed crop with good germination capacity, another important factor is site preparation. The oldest studies on restocking from seed trees (Sarvas 1949, Lehto 1956, 1969, Oinonen 1956) showed that restocking is often quite uneven. The coarser-textured the soil, the more seedlings there were. However, the presence of a thick moss and humus layers impaired the restocking result. On coarse-textured soils, young growth often emerged already before the seed trees had been established and, in some cases, it was considered that the new stand could be established by simply releasing the understorey (Vaartaja 1951). As the results of natural regeneration were rather variable as recently as in the early 1960's, and there was some uncertainty with respect to the practical application of the method, the possibilities of artificial regeneration were considered to be clearly superior to those of natural regeneration. Research work also concentrated for quite a long time on artificial regeneration and the problems associated with it (Leikola 1987).

Research into the natural regeneration of pine intensified in the 1980's. Recent results indicate that natural regeneration has succeeded clearly better than earlier owing to the development of site preparation methods (Kinnunen and Mäki-Kojola 1980, Kinnunen 1993, Norokorpi 1983, Valtanen 1984). Nowadays, there are always two alternatives (artificial and natural) to choose between in forest regeneration, and sites unsuitable for natural regeneration have consequently been regenerated artificially. Site

preparation has also markedly improved the speed at which the natural regeneration of pine takes place (Photo 7). If a good seed crop is obtained on soil prepared the previous summer, restocking will occur within one year even, and leaving the seed trees on the site does not further improve the restocking result (Fig. 2). On the contrary, the mean height of the advance growth will be impaired to an ever increasing extent, the longer the seed trees are retained (Kubin 1998). This is the case especially if the seed trees are left for longer than 4–5 years.

The use of natural regeneration of pine has become more common during the past few years. New information on the possibilities and constraints of the method, its lower costs compared to artificial regeneration, and undoubtedly also its environmental friendliness, have contributed to this trend. However, despite the fact that it is a natural process, active natural regeneration of pine requires meticulous planning and implementation. The following conclusions can be drawn on the basis of the guidelines provided by the practical forestry organisations (Luonnonläheinen... 1994, Metsän... 1996, Hokajärvi 1997), as well as the latest research findings (Kubin 1998, Valtanen 1998):

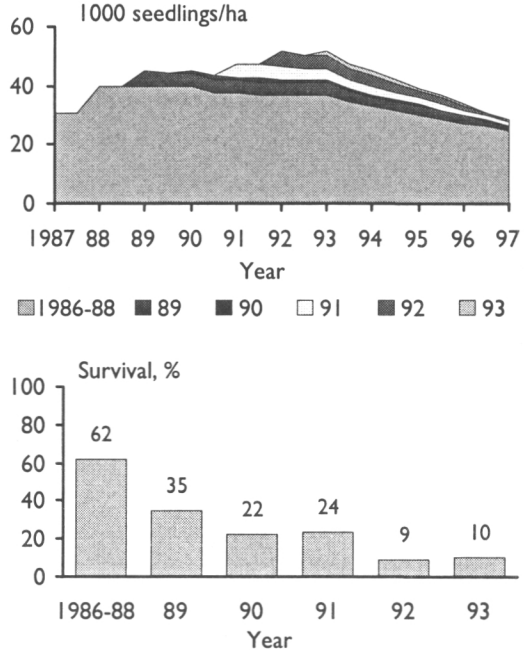


Figure 2. The number of seedlings emerging annually per hectare and their survival in 1997 in Kuhmo (64°15'N, 29°32'E). The seed trees were removed in winter 1993/1994, eight years after felling the original stand (Kubin 1998).

– It is best suited for dryish and less fertile upland forest sites where overstorey contains vigorous trees with large crowns.

– The number of seed trees to be left varies between 20 and 50 per hectare depending on site fertility and seed-tree quality. More small seed trees are needed than large ones and, more seed trees are needed with decreasing site fertility. The seeding capacity of the neighbouring stands is also taken into consideration.

– Site preparation to expose the mineral soil, mainly as disc ploughing or patch scarification, is necessary and should be carried out in the summer following felling when the seed trees are retained. The exposed mineral soil surface, evenly spread out, should be equivalent to at least 20% of the area of the regeneration site. The need for site preparation increases as the preconditions for restocking, based on natural seeding, deteriorate, e. g. due to the small size of the seed trees. Site preparation should be timed to precede a good seed-crop year.

– The seed trees should be removed immediately or no later than 5 years after the emergence of sufficient restocking.

– Aesthetic viewpoints and exposure to wind should be taken into consideration when determining the location of the seed trees.

Natural regeneration of spruce

The first stage in the natural regeneration of spruce is to check whether there is advance growth on the site (Leikola 1985). If this is lacking, natural regeneration should be rejected. However, if there is advance growth, natural spruce regeneration can be achieved either by the shelterwood method or by strip clear-felling, which relies on seeding from the adjacent stand (Luonnonläheinen... 1994, Hokajärvi 1997). Compared to the case with pine, successful spruce regeneration using the shelterwood method requires several, correctly timed measures to obtain young growth and to release the existing advance growth. The silvicultural expertise required by this method is primarily reflected by its suitability for the regeneration of managed stands of spruce on fertile sites (Kalela 1961).

In spruce regeneration the shelterwood method involves the creation of a spruce understorey under the parent storey. In the first stage, the spruce stand is reduced to a density of 300–500 overstorey trees per hectare, and the understorey trees are removed. When enough new young growth has emerged, the spacing of the overstorey is widened to the shelterwood state of 100–300 trees/ha, at the same time favouring an admixture of birch and pine (Photo 8). Birch has an ameliorating effect on soil properties. Moreover, pine and birch promote the entry of light into the stand and to the forest floor, as well as reduce the amount of branch litter when the shelterwood trees are eventually removed. This is done when the young growth is able to cope with the competition from the ground vegetation, and before these young trees have become too large from the point of view of harvesting the overstorey (Photo 9). The time between felling aimed at thinning the overstorey to promote the intitiation of restocking, and final removal of the shelterwood trees, is about 15–20 years. The shelterwood trees are removed in several stages.

The shelterwood method has not been widely employed in the regeneration of spruce in Finland (Fig. 3). In addition to its greater time requirement, there are problems associated with poor restocking and difficulties in harvesting (Karppelin 1984, Leinonen et al. 1989). Poor restocking is an ecological issue because spruce contributes to the deterioration of the site, and causes the accumulation of a thick humus layer. These negative effects are even more pronounced in the cool, humid conditions of northern Finland (Sirén 1955). If the spruce stand is an unmanaged one, restocking is even more difficult to achieve because an understorey of pole-sized trees prevents the emergence of viable new growth. Another significant factor is the variation in the occurrence of good seed years on spruce. Poor seed years are relatively common on spruce even in southern Finland (Koski and Tallqvist 1978, Nieminen 1984) and, if a good seed year coincides with a dry sum-

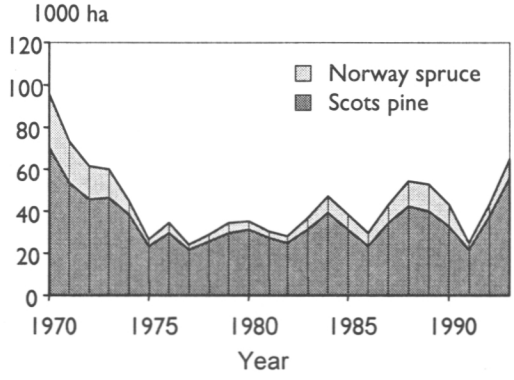


Figure 3. The total area treated with fellings and seed-tree and shelterwood retention during 1970–1994 (Finnish... 1998). The area covered by the former includes regeneration with Scots pine, while the latter includes regeneration with Norway spruce.

mer, even abundant new growth may be destroyed. Restocking is therefore most successful on grove-like and similar upland forest sites (Laiho 1987).

In addition to regeneration based on the shelterwood method, spruce can also be regenerated naturally through seeding from the neighbouring stands following clear-felling. This is called strip felling which, according to the Finnish forestry recommendations (Luonnonläheinen... 1994), is especially successful on fertile spruce-dominated mires or corresponding paludified upland forest sites, as well as moist or more fertile upland sites. On mineral soil sites, successful restocking requires site preparation to expose the mineral soil. Small-sized clear-cutting, combined with site preparation and a birch shelterwood, has also been proposed as an alternative to strip felling. The results obtained with seeding by the neighbouring stands are, however, so variable and depend on so many factors that the natural regeneration of spruce also needs to be reviewed.

Natural regeneration of birch

The basic precondition for successful natural regeneration of birch is, as the case with pine and spruce, mature seed and a sufficient seed crop. Studies on the seed crop (Sarvas 1952, Koski and Tallqvist 1978) have shown that there is considerable variation in the frequency of good and poor seed years, but even poor seed years do not necessarily mean that there will be no seed crop. Moreover, because birch seed has a good germination percentage, it has been estimated that the size of the seed crop does not limit the natural regeneration of birch (Savonen 1993). An abundance of seed is also obtained in northern Finland, although the seed crop is less than in southern Finland. The seed crop of silver birch is slightly smaller than that of downy birch.

On the average, downy birch starts flowering in southern Finland in the middle of May, while silver birch flowers about one week earlier (Sarvas 1952). Birch seed mature after about three months, which is also the point in time when the first seeds are shed. This continues into the following winter. From the point of view of natural regeneration it is essential that germinable seed is shed in southern Finland already at the beginning of August. Birch appears in great numbers on regeneration sites, apart from the most nutrient-poor sites, and in practice the growing of coniferous stands necessitates the removal of birch from young stands in one or more stages.

Owing to the capacity of birch for abundant natural restocking, there has been no particular need for the active application of natural regeneration, and the natural young growth of birch has not been exploited to any great extent in practice (Finnish... 1998). However, the latest silvicultural guidelines include this method (Luonnonläheinen... 1994, Metsän... 1996, Hokajärvi 1997) and there is experience of it both in the field of research (Raulo 1981) and in practice. The guidelines apply mainly to silver birch, but the natural regeneration of downy birch even, especially on cold, water-logged sites, is also mentioned as an alternative.

Two practical questions connected to the success of natural regeneration are the timing of felling, and the choice of the regeneration target. The best felling time is the winter preceding a good seed year. Selecting the correct felling time is difficult due to the fact that good seed years depend on a large number of factors, and predicting it on the basis of the seed crop has been difficult. The only certain feature is that an especially

good seed year is always followed by a poor seed year (Savonen 1990). The best regeneration targets are spruce stands growing on fertile sites that contain sufficient good birches to serve as seed trees. Restocking is most successful on these sites because the understorey in spruce stands is weak and does not deteriorate as rapidly as, for example, the understorey of pure stands of birch following felling of the overstorey.

Natural regeneration of birch requires 10–20 seed trees per hectare (Photo 10). If there are birches in the neighbouring stands, their seeding effect should be taken into account. Effective seeding extends to a distance of about 50 m from seed-bearing trees (Sarvas 1948, Saksa 1994). The seed trees are removed as soon as restocking has taken place unless they are left on the regeneration site for landscape reasons.

Good restocking presupposes efficient site preparation to expose the mineral soil. Birch regeneration on prepared sites is the better, the more mineral soil that is exposed (Raulo and Mälkönen 1976, Raulo 1981). The best time for site preparation is July, just before birch begins to shed its seed. When this is done, the seed shed in August will be able to germinate in freshly-exposed soil and the seedlings will not be overtaken by the ground vegetation. As a large number of seedlings usually emerge, the young stand should be cleaned no later than when the stand has reached a mean height of about three metres. This ensures that the stems have time to strengthen and can better withstand the snow load during winter.

Development prospects of natural regeneration

The popularity of natural regeneration has varied in Finland over the course of time. Before artificial regeneration became widespread, the forests were mainly regenerated naturally or left to regenerate without any specific measures being applied following dimension felling. In those days the sites treated with such fellings were sparsely stocked compared to the situation today, and it was common for trees in the understorey to develop and become the dominant storey (Mikola 1966).

Individual stand-based silviculture is far more comprehensive compared to silviculture of the past, and drawing a line between natural and artificial regeneration is nowadays far more precise. The development of soil amelioration methods has opened up new opportunities to regulate the soil water condition, as well as to choose the most appropriate soil preparation method according to the site properties. On the other hand, wood production that favours biodiversity and rapidly introduces new methods (New... 1998) imposes fresh challenges on the study of natural regeneration. The further development of natural regeneration is justifiable for a number of reasons; this is especially so in the light of the criteria set for ecological, economic and socially sustainable forestry (Criteria... 1997).

When viewed from the wood production standpoint, development and research needs (Nygren et al. 1997) will continue to be focused on solving the problems associated with the utilisation of the best seed years and restocking. Seed-crop forecasts should be drawn up for smaller areas than is currently the practice. This is a challenging but feasible task, given present-day technology. Promoting the emergence of young growth under a parent overstorey, achieving admixtures of broadleaves already at the restocking stage, and how to tend the young stands, are all research topics of interest. This kind of research would serve to speed up and improve certainty in the choice of targets for natural regeneration, as well as the implementation of regeneration itself.

REFERENCES

Appelroth, E., Heikinheimo, O., Kalela, E.K., Laitakari, E., Lindfors, J. & Sarvas, R. 1948. Julkilausuma. Metsätal. Aikakausl. 11: 1–2.

Criteria and indicators for sustainable forest management in Finland. 1997. Ministry of Agriculture and Forestry. 70 p.

Finnish statistical yearbook of forestry 1998. Finnish Forest Research Institute. Gummerus Kirjapaino Oy. Jyväskylä. 344 p.

Heikinheimo, O. 1932. Metsäpuiden siementämiskyvystä. I. Referat: Über die Besamungsfähigkeit der Waldbäume. I. Commun. Inst. For. Fenn. 17.3. 161 p.

Heikinheimo, O. 1937. Metsäpuiden siementämiskyvystä. II. Referat: Über die Besamungsfähigkeit der Waldbäume. II. Commun. Inst. For. Fenn. 24.4. 67 p.

Heikinheimo, O. 1948. Suomen oloihin sopivat uudistushakkausmenetelmät. Metsätal. Aikakausl. 11: 317–319.

Henttonen, H., Kanninen, M., Nygren, M. & Ojansuu, R. 1986. The maturation of Pinus sylvestris seeds in relation to temperature climate in northern Finland. Scand. J. For. Res. 1: 243–249.

Hokajärvi, T. 1997. Metsänhoito-ohjeet. Metsähallituksen metsätalouden julk. 10: 1–58.

Kalela, E.K. 1961. Metsät ja metsien hoito. WSOY. Porvoo. 367 p.

Karppelin, S. 1984. Kuusen luontainen uudistaminen edelleen ongelma – menetelmän käyttömahdollisuuksiin vaikuttavat monet tekijät. Metsä ja Puu 9: 20–21.

Kinnunen, K. 1993. Männyn kylvö ja luontainen uudistaminen Länsi-Suomessa. Abstract: Direct sowing and natural regeneration of Scots pine in western Finland. Metsäntutkimusl. tied. 447. 36 p.

Kinnunen, K. & Mäki-Kojola, S. 1980. Männyn luontaisesta uudistumisesta Pohjois-Satakunnassa. Summary: Natural regeneration of Scots pine in western Finland. Folia For. 449. 18 p.

Koski, V. & Tallqvist, R. 1978. Tuloksia monivuotisista kukinnan ja siemensadon määrän mittauksista metsäpuilla. Summary: Results of long-time measurements of the quantity of flowering and seed crop of forest trees. Folia For. 364. 60 p.

Kubin, E. 1998. When to remove Scots pine seed trees. In: Proceedings of a Nordic Symposium. New stand types in boreal forestry - ecological features and silvicultural consequences. Finnish Forest Research Institute. Research Papers 714: 45–53.

Laiho, O. 1987. Kuusen luontainen uudistaminen. Metsäntutkimusl. tied. 270: 24–37.

Lehto, J. 1956. Tutkimuksia männyn luontaisesta uudistumisesta Etelä-Suomen kangasmailla. Acta For. Fenn. 66.2. 106 p.

Lehto, J. 1969. Tutkimuksia männyn uudistamisesta Pohjois-Suomessa siemenpuu- ja suojuspuumenetelmällä. Summary: Studies conducted in northern Finland on the regeneration of Scots pine by means of the seed tree and shelterwood methods. Commun. Inst. For. Fenn. 67.4. 140 p.

Leikola, M. 1985. Kuusen luontainen uudistaminen on ongelma. Metsä ja Puu 4: 12–13.

Leikola, M. 1986. Metsien luontainen uudistaminen I. Harsintahakkuiden ajasta harsintajulkilausumaan (1830–1948). Helsingin yliopiston metsänhoitot. lait. tied. 57. 202 p.

Leikola, M. 1987. Metsien luontainen uudistaminen II. Harsintajulkilausumasta nykyhetkeen (1948–1986). Helsingin yliopiston metsänhoitot. lait. tied. 60. 198 p.

Leinonen, K., Leikola, M., Peltonen, A. & Räsänen, P.K. 1989. Kuusen luontainen uudistaminen Pirkka-Hämeen metsälautakunnassa. Summary: Natural regeneration of Norway spruce in Pirkka-Häme Forestry Board District, southern Finland. Acta For. Fenn. 209. 53 p.

Luonnonläheinen metsänhoito. Metsänhoitosuositukset 1994. Metsäkeskus Tapio. 67 p.

Metsän uudistaminen. 1996. UPM-Kymmene Metsä. 64 p.

Mielikäinen, K. 1997. Metsän kasvattaminen. Metsälehti Kustannus. 496 p.

Mikola, P. 1956. Hakkuu – asento – uudistamismenetelmä. Metsätal. Aikakausl. 8: 243–247.

Mikola, P. 1966. Alikasvosten merkitys metsien uudistumisessa. Metsätal. Aikakausl. 1: 4–7, 16.

Moilanen, M. & Saksa, T. (eds) 1998. Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus. 123 p.

New stand types in boreal forestry - ecological features and silvicultural consequences. 1998. Proceedings of a Nordic Symposium. Finnish Forest Research Institute. Research Papers 714. 164 p.

Nieminen, J. 1984. Metsäpuiden siemensato uudistamisen lähtökohtana. Metsäntutkimusl. tied. 129: 4–16.

Norokorpi, Y. 1983. Männyn luontainen uudistaminen Lapissa. Metsätal. Aikakausl. 105: 57–71.

Nygren, M., Ahonen, M., Koskinen, R., Kubin, E. & Mälkönen, E. 1997. Monimuotoinen metsänuudistaminen – Uudistamismenetelmien perustan tarkastelua. Metsäntutkimusl. tied. 636. 40 p.

Oinonen, E. 1956. Männiköiden luontaisen uudistumisen edellytyksistä Lapin kangasmailla eräiden taimivaroja selvittävien inventointien valossa. Metsätal. Aikakausl. 6–7: 225–230.

Pohtila, E. & Valkonen, S. 1985. Varttuneiden viljelytaimikoiden tila Lapin piirimetsälautakunnan alueen yksityismetsissä. Summary: Development and condition of artificially regenerated pine and spruce sapling stands in the privately owned forests of Finnish Lapland. Folia For. 631. 19 p.

Räsänen, P., Pohtila, E., Laitinen, E., Peltonen, A. & Rautiainen, O. 1985. Metsien uudistaminen kuuden eteläisimmän piirimetsälautakunnan alueella. Vuosien 1978–1979 inventointitulokset. Summary: Forest regeneration in the six southernmost Forestry Board Districts of Finland. Results from the inventories 1978–1979. Folia For. 637. 30 p.

Raulo, J. & Mälkönen, E. 1976. Koivun luontainen uudistuminen muokatulla kangasmaalla. Summary: Natural regeneration of birch (Betula verrucosa Ehrh. and B. pubescens Ehrh.) on tilled mineral soil. Folia For. 252. 15 p.

Raulo, J. 1981. Koivukirja. Gummerus Kirjapaino Oy. Jyväskylä. 131 p.

Ryynänen, M. 1982. Individual variation in seed maturation in marginal populations of Scots pine. Silva Fenn. 16(2): 185–187.

Saksa, T. 1987. Männyn taimikoiden kehitys auratuilla ja äestetyillä istutusaloilla Keski-Suomessa. Abstract: Development of Scots pine plantations in ploughed and harrowed reforestation areas in Central-Finland. Folia For. 702. 39 p.

Saksa, T. 1994. Rauduskoivun luontainen uudistaminen. Metsäntutkimusl. tied. 491: 9–12.

Sarvas, R. 1948. Tutkimuksia koivun uudistumisesta Etelä-Suomessa. Summary: A research on the regeneration of birch in South Finland. Commun. Inst. For. Fenn. 35.4. 91 p.

Sarvas, R. 1949. Siemenpuuhakkuu männikön uudistushakkuuna Etelä-Suomessa. Summary: Seed-tree cutting as a regeneration method in Scots pine forests of southern Finland. Commun. Inst. For. Fenn. 37.6. 43 p.

Sarvas, R. 1952. On the flowering of birch and the quality of seed crop. Commun. Inst. For. Fenn. 40.7. 38 p.

Sarvas, R. 1962. Investigations on the flowering and seed crop of Pinus silvestris. Commun. Inst. For. Fenn. 53.4. 198 p.

Savonen, E.-M. 1990. Siemensadon määrään ja laatuun vaikuttavia tekijöitä sekä siemensadon ennustaminen. Metsäntutkimusl. tied. 369: 4–14.

Savonen, E.-M. 1993. Koivun siemensato ja siementen käsittely. Metsäntutkimusl. tied. 470: 21–27.

Sirén, G. 1955. The development of spruce forest on raw humus sites in northern Finland and its ecology. Acta For. Fenn. 62.4. 408 p.

Tertti (Hertz), M. 1938. Metsien luontaisen uudistumisen edistämisestä. Metsänhoitajien jatkokurssit I. Silva Fenn. 37: 87–96.

Vaartaja, O. 1951. Alikasvosasemasta vapautettujen männyn taimistojen toipumisesta ja merkityksestä metsänhoidossa. Summary: On the recovery of released pine advanced growth and its silvicultural importance. Acta For. Fenn. 59.3. 133 p.

Valtanen, J. 1984. Männyn luontaisen uudistamisen mahdollisuudet. Metsäntutkimusl. tied. 158: 37–50.

Valtanen, J. 1998. Männyn luontainen uudistaminen siemenpuumenetelmällä. Metsäntutkimusl. tied. 693. 77 p.

THE ROLE OF CONIFEROUS UNDERSTOREY IN STAND FORMATION ON CLEAR-CUT AREAS IN THE TAIGA ZONE OF THE RUSSIAN NORTHWEST

A.D. Volkov, V.I. Sokovets and V.A. Ananiev

Forest Research Institute, Karelian Science Centre of the Russian Academy of Sciences, Pushkinskaya 11, Petrozavodsk, 185610, Russia

Quantity of understorey

Retention of the understorey during the harvesting of forests in the taiga zone is a common and effective means of promoting the natural regeneration of coniferous species on clear-cut areas.

In the Republic of Karelia, the first trials with understorey retention were initiated in the early 1950's following the increasing concentrated clear-cuts. It proved to be practically impossible to establish forest plantations on the annually clear-cut area. In the 1970's and 1980's, which was the most favourable period in the recent history of forestry, as much as 35% of the forest plantations were established on clear-cut areas. Since then, the figure has fallen to the current level of 25%. Around 50% of the clear-cut areas is reforested by retaining the understorey in connection with logging.

A considerable proportion of the primary forest stands in commercial forests contain viable coniferous understorey. The pine forests in Karelia currently have 5 000 to 15 000 trees/ha in the understorey (Photo 11). The understorey has the highest density (10 000 to 15 000 trees/ha) in old-growth pine forests of Pinetum cladinosum type, from 1 000 to 5 000 in forests of P. vacciniosum type, and only between 500 to 1 500 in P. myrtillosum type forests (Зябченко and Виликайнен 1974). Viable trees up to 1.5 m in height dominate in the pine understorey, and the age of the understorey ranges from 5 to 80 years.

The amount of spruce understorey in primary spruce stands varies, depending on the site conditions, from 2 000 to 6 000 trees/ha, with an average of 2 000 to 3 000. There is a clear trend for understorey density to increase on moving southwards. For instance, the average of 2 000 to 3 000 trees/ha in northern Karelia rises to 4 000–6 000 trees/ha in the southern parts of the region.

Stipulations concerning the retention of understorey are given in the "Regulations for final cuttings in the Republic of Karelia" (Правила... 1995). The minimum number of understorey trees, depending on their size and viability, to be retained under the forest canopy are specified in the "Guidelines for reforestation of state-owned forests in the Republic of Karelia" (Руководство... 1995), which bind logging companies to take every measure to retain young growth. The statutory documents for managing Karelian forests have been developed by the Forest Research Institute of the Karelian Science Center, Russian Academy of Sciences (Table 1).

Research and field trials have demonstrated that it is possible to retain 60 to 70% of the understorey trees growing under the canopy of trees to be felled.

Table 1. Minimum number of understorey and young trees to be retained on clear-cutting areas in the Republic of Karelia.

Species	Forest site type	Taiga sub-zones	Number of understorey trees depending on the size class, trees/ha			Understorey in groups, number of groups per hectare
			Small, 0.1–0.5 m	Medium, 0.6–1.5 m	Large, over 1.5 m	
Scots pine	Pinetum cladinosum and callunus	Middle taiga	3200	2400	1600	–
		Northern taiga	2800	2100	1400	
	P. vacciniosum	Middle taiga	2000	1600	1200	400
		Northern taiga	1800	1400	1000	350
	P. oxalidosum and myrtillosum	Middle taiga	2400	1600	1200	320
		Northern taiga	2100	1400	1000	280
	P. polytrichosum and sphagnosum	Middle taiga	1600	1200	1200	240
		Northern taiga	1400	1000	1000	210
Norway spruce	Piceetum oxalidosum and myrtillosum	Middle taiga	2400	1200	1200	320
		Northern taiga	2100	1000	1000	280
	Piceetum polytrichosum and sphagnosum	Middle taiga	1600	1200	800	280
		Northern taiga	1400	1000	700	250

Stand development

The change in growing conditions after clear cutting has a major effect on the survival and condition of the understorey. The highest mortality occurs during the first five years after logging. In Piceetum myrtillosum spruce forests (0spruce understorey) it reaches 6.0%, but in Pinetum vacciniosum pine forests (pine understorey) it is 13% and even 37% for small trees on some sites. The high die back rate is due to the extended exposure of small pine trees to a thick snow cover and damage by pine-leaf cast (*Phacidium infestans*). A damage survey of logging sites confirmed the resistance of spruce understorey to pests and parasitic fungi. Bark beetles and pine sawyers had infested a heavily suppressed understorey. The spruce understorey on 14% of the clear-cut sites was occasionally damaged by late spring frosts during the first 15 years after removal of the shelter canopy. Unlike pine understorey, a spruce understorey is distributed heterogeneously throughout the stand, and is of lower density (19–57%).

Studies on tree growth on the Piceetum myrtillosum clear-cut sites after the removal of spruce stands have shown that when over 1 000 trees/ha are left after felling, mixed plantations of medium and high density, containing at least 50% conifers, will be formed within 25 to 40 years (Table 2). The stands formed from the understorey have good growth. The current increment of the basal area and standing volume 30 years after felling equals 5.8 and 7.5%, respectively, which is 2.4-fold and 1.4-fold higher than in an artificially regenerated stand. When this is compared with spruce stands established by sowing, the average height and diameter are 40 to 50% greater. The standing volume in spruce stands develops mainly on the bases of medium, (with the height of 0.5–1.5 m) and large (1.5–3.0 m) understorey, which account for up to 70–90% of the stand volume. Spruces of small diameter only play a significant role in the accumulation of standing volume when

Table 2. Characteristics of Norway spruce stands formed from the understorey in clear-cut areas of the Piceetum myrtillosum forest type.

Plot No.	Time after felling, a	Composition	Site quality class	Average for spruce		Density	Standing volume, m^3/ha		Density, trees/ha		Occurrence, %
				D, cm	H, m		Total	Incl. spruce	Total	Incl. spruce	
3	27	$10S_{50}pcsP$	III	9.3	6.5	0.7	43	42	1690	1380	19
22	31	$10S_{35}pcsP$	II	9.6	7.6	1.0	82	79	2870	2180	51
9	32	$7S_{70}2B_{50}1P_{50}$	II	10.3	7.8	1.1	92	68	2450	1630	48
10	33	$10S_{70}$+P,B	III	9.3	6.9	1.0	70	65	2870	1960	57
19	41	$6S_{70}4B_{60}$	III	9.6	8.0	1.3	95	59	4210	1620	48
21	41	$5S_{30}2P_{30}2B_{20}$ $1Sdp_{20}$	II	10.5	8.5	1.0	93	44	2860	960	33
	41	Crown layer 1 $7B3Sdp_{40}$	II	14.0	9.5	1.1	178	–	2570	–	plantations sown spruce year 1939
		Crown layer 2 $10S_{40}$		4.8	5.5	1.0	42	42	2100	2100	

S = spruce, P = pine, B = birch

their proportion out of the number of trees in the stand is at least 50%.

The spruce understorey in Pinetum cladinosum, callunus, and vacciniosum forest types has a lower growth rate than a pine understorey. Retaining a spruce understorey in these types of forest will tend to lower forest productivity.

The results of studies carried out on the regeneration of clear-cut areas in dry upland forests (Pinetum vacciniosum, cladinosum, and callunus types) have shown that, when about 4 000 to 5 000 pine trees/ha are retained in the understorey (up to 1.5 m high), a pure pine stand is formed within 25–30 years with a density of 0.5 to 0.6 and, if large trees are present in the understorey, the density of the new stand increases by 0.2–0.3.

When evaluating reforestation methods used on clear-cut sites on drained peatlands, both the quantity and condition of the understorey left after logging and their connections with environmental changes (temperature, water conditions, snow melting, and freezing and thawing of peat soil) have to be taken into account. These aspects of reforestation, however, require more detailed research.

A study on natural regeneration has shown that the number of understorey trees growing under the canopy on drained sites varies from 2 000 to 17 000 per hectare. 85 to 92% of the understorey trees were viable individuals. As a rule, small spruce trees in the understorey (up to 0.5 m in height and 11 to 15 years old) predominate in spruce stands, accounting from 42 to 95% of the total number. The number of medium-sized trees in the understorey (0.5 to 1.5 m in height and 20–30 years old) ranges from 300 to 2 500 per hectare. The number of large understorey trees (over 1.5 m, 30 to 65 years old) was up to 1 600 trees/ha on some sites. Logging in tree stands with at least 1 000 trees/ha, distributed evenly throughout the stand, must be carried out

carefully in order to retain the understorey. As has been found in commercial pilot logging operations, retention of the understorey during winter felling accounted for 77% (69–91%) of the total number present before logging.

Studies on natural regeneration after final logging of spruce stands on mesotrophic drained peatland has shown that, on sites where the understorey had been retained while felling for subsequent reforestation, there were a sufficient number (5 100 to 6 500 trees/ha) of understorey conifers to stimulate stand formation within 6–8 years. The coniferous present after final logging on peatlands was found to be in a satisfactory condition and viable. During the last three years, the spruce understorey (0.5 to 1.5 m in height) had an increment of 51 cm, while the pine increment was even more at 69 cm. The mortality was insignificant, only 2–5%.

Studies on the regeneration of 17- to 20-year-old clear-cut, drained sites with pine and pine-birch sedge-sphagnosum and grass-sphagnosum stands show that the viability of understorey in narrow strip cuttings on transitional peatlands at a density of 3 000 to 3 500 trees/ha, followed by two tending operations of the young stand, produce coniferous forest with the density of 0.7. If, after felling, natural regeneration is promoted then the density of the stand increases up to 0.9 or even more. The young stand developing from the retained understorey on transitional peatlands has increased growth. The proportion of the current increment of basal area and stand volume varies between 6.3 and 10.7%. The current annual increment of the stand is relatively high, and amounts 5.3–5.9 m^3/ha. This increment rate is exhibited in Pinetum myrtillosum pine forests on upland mineral soils of III site class.

When the number of understorey trees retained after cutting is insufficient, other measures are needed to promote regeneration of a full forest cover. One of the key measures promoting natural regeneration on clear-cut sites is the retention of seed sources on the clear-cut areas. This includes individual seed trees, seed groups, forest seed blocks, belts, and adjacent dense forest if it contains seed trees.

According to Karelian forestry regulations, the adjacent forest stands containing seed trees act a source of coniferous seed in cutting areas (under 100 m wide). If the clear-cutting blocks are wider, or if there are no seed trees of target species, then wind-resistant seed trees are left standing in small groups, blocks or belts in the cutting area.

Seed trees are left standing in groups of three to five, with a total of 40 to 100 trees/ha in Pinetum cladinosum and callunus pine stands, 60 to 120 trees/ha in P. vacciniosum pine stands, and 80 to 150 trees/ha P. myrtillosum pine stands. Trees of height classes I and II are selected as seed trees. Groups of seed trees are arranged in rows across a cutting site in order to allowing the deposition of seed from adjacent forest located at a maximum distance of 100 m. In moist Pinetum myrtillosum and polytrichosum pine stands, the remaining seed blocks should be not less than 0.2 to 0.25 ha (40x50 m, 50x50 m) in size, with a distance of 200 to 250 m between them. Because of the risk of windfall in spruce stands, seed blocks of 0.25 to 0.5 ha in area are left at a distance of 200 to 250 m from each another. Seed blocks are left primarily among middle-aged and mature tree stands of key species in elevated areas.

When seeding sources are retained, clear-cut areas become regenerated within five years after logging. Stands dominated by pine are formed on nutrient-poor sandy

soils. On fertile soils there is a change of tree species, coniferous species very often being replaced by deciduous ones.

Long-term studies on the growth patterns and formation of spruce and pine stands from understorey stands of varying density, age, and size, have shown that retention of the understorey promotes the growth and formation of stands with good productivity, shortens the time required for valuable coniferous species to be grown, and promotes their genetic diversity and environmentally important role of forests.

REFERENCES

Зябченко, С.С. & Виликайнен, М.И. 1974. Рубки и восстановление сосновых лесов. In: Сосновые леса Карелии и повышение их продуктивности. Petrozavodsk. p. 84–189.

Правила рубок главного пользования в лесах Республики Карелия. 1995. Petrozavodsk. 37 p.

Руководство по лесовосстановлению в Гослесфонде Республики Карелия. 1995. Petrozavodsk. 85 p.

FINNISH EXPERIENCES IN MAKING USE OF THE UNDERSTOREY

M. Moilanen

Finnish Forest Research Institute, Muhos Research Station, Kirkkosaarentie 7, FIN-91500 Muhos, Finland

Background

The occurrence of understoreys was a subject of intensive research in Finland in the early 1900's. However, after forestry based on artificial regeneration became common in the 1960's, interest in utilising the understorey diminished. This even went as far as belittling their value, and regarding them as waste to be cleared from the regeneration site in order to promote site preparation and forestation. The main reason for such a critical attitude was the lack of detailed knowledge of the factors influencing the capacity of trees forming the understorey to recover. Professional foresters were concerned about the inferior appearance of these suppressed trees, their great height variation and group-wise occurrence. Furthermore, there was doubt as to the suitability of the site for the tree species forming the understorey, and their chances of not being destroyed during the harvesting of the overstorey.

Nowadays, environmental and nature-related considerations play a more important role in the way that forests are managed. The purpose of the new forestry legislation and silvicultural recommendations emphasising biodiversity is to promote nature-emulating silviculture and forest regeneration. Consequently, the role of understoreys is being reassessed (e.g. Laiho 1985, Parviainen and Seppänen 1994).

The occurrence of understoreys

Being a shade-tolerant tree species, spruce has the best chances of regenerating under an overstorey. Spruce understoreys emerge especially in stands where the dominant storey consists of birch or pine, but fully-stocked spruce stands offer relatively little space for such advance growth.

The most typical understoreys are those formed by spruce on fertile sites under overstoreys of birch and pine, and by pine on infertile upland sites under a pine overstorey. Spruce understoreys are more common in southern Finland, while pine understoreys are more common in northern Finland, (Tikka 1928, Pöntynen 1929, Sarvas 1937, 1950, Sirén 1951, Vaartaja 1952, Mikola 1966).

Drainage for forestry has promoted the natural emergence of young stands on peatland sites in recent decades. Habitats favourable for the development of understoreys are mires of above-average fertility; these retain their capacity to become restocked for several years after drainage. This is especially demonstrated by the understorey that develops on spruce-dominated mires, and on sites initially classified as herb-rich and sedge-rich pine- and birch-dominated pine mires (Seppälä and Keltikangas 1978, Keltikangas et al. 1978, 1986).

Spruce spreads readily to sites which are too infertile for it. On sites inferior to tall-sedged mire or *Myrtillus* upland site type,

the long-term yield of spruce is less than that of pine.

The ability of pine and birch as advance growth to compete against shading and root competition is inferior to that of spruce (e.g. Kellomäki 1991). Pine understoreys on dry or dryish upland pine forest sites are usually worth growing if they are sufficiently dense. The understoreys on drained pine mires with overstoreys of pine and birch are also worth growing, especially when the overstorey has been grown at a wide spacing. Between 0.5–3 m in height, these understoreys have not really been utilised, nor are the landowners fully aware of their growth potential. Nevertheless, more consideration could be given to making more use of established pine understoreys than is the case at present. Positive experiences have been reported, for instance, in releasing the short-lived young growth on pine-dominated peatland sites.

So far there has been little experience in utilising birch understoreys, and insufficient research has been carried out on their development potential. The occurrence of birch understorey is confined to forest clearings, shoreline forests, the edge zones of forest stands, and the banks of drainage ditches. An understorey of downy birch may also develop in sparsely-stocked pine stands on mires treated with fellings and fertilisation.

The dominant storey in a forest stand is usually older than the understorey, but sometimes (especially when the dominant storey and understorey are of different tree species) they may have emerged simultaneously. The understorey can emerge rather rapidly even from one year's seed crop, or it may develop slowly over several decades. Pine and spruce understoreys that are almost 100 years old have been reported on infertile sites (Pöntynen 1929, Vaartaja 1952). Restocking can be promoted by means of preparatory fellings carried out towards the end of the rotation (Kalela 1950, Vaartaja 1952).

According to the results of the Finnish National Forest Inventories, the frequency of understorey occurrence has remained at approximately the same level since the 1930's. In the 1980's, viable understoreys covered almost 300 000 ha of forest (more than 5% of the forest area) in southernmost Finland. Two-thirds of the understoreys were spruce-dominated, about one quarter pine-dominated, and less than 10% had a predominance of broadleaves. The proportion of understoreys varied on moving northwards. Viable understoreys in central Finland represented only 1% of the forest area in the early 1980's, while in Finnish Lapland it was 6%.

Our present knowledge concerning understoreys is based on research conducted mainly before the 1960's, and is thus in many respects outdated. Present-day forests are structurally dissimilar to the forests of the 1920's or the 1940's; stands are nowadays denser, and timber felling, site preparation, drainage and fertilisation have altered the soil over vast areas of forests, and these practices have also influenced the circumstances under which understorey develop.

Development of an understorey under an overstorey

Due to the competition derived from the overstorey, the height development of trees forming the understorey declines already at an early age. Trees belonging to the understorey grow slower than those growing unrestricted and with plenty of light; this becomes even more evident over time in the phenotype of the trees. They adapt their crowns and foliage structure to the shady environment in order to make maximum use

of the little light available. As a result of the intensive shading and root competition of the dominant storey, the height growth of the stem of understorey spruces is less than that of the length growth of the branches, and they adopt an umbrella-like form; i.e. the crowns become short and flat, the needles are flat and folded tightly against the stem of the shoot. Crown development is asymmetric. Pine understoreys are characterised by a decrease in the number of needles as the degree of shading increases (e.g. Pöntynen 1929, Vaartaja 1952).

The growth of understorey trees varies according to the degree of light and root competition which, in turn, depend on the age, species and density of the overstorey. The growth of understorey trees in a spruce stand composed of large trees approaching felling maturity growth may be almost non-existent in extreme cases. When growing on a fertile site under a relatively sparse overstorey, especially of birch, a spruce understorey can retain its vigour and develop relatively normally. A young, dense, fast-growing stand of silver birch is clearly a stronger competitor for understorey spruces than an old, slow-growing stand of downy birch (Mielikäinen and Valkonen 1995).

The understorey also restricts the development of the overstorey to some extent because both compete for the same growth resources. The denser, taller and faster growing the understorey, the greater is the proportion of the resources it consumes. The significance of root competition by the understorey has been reported in stands of grey alder (*Alnus incana* (L.) Moench) (e.g. Kalela 1936). The growth loss of the overstorey may be considerable. For instance, a dense, 1 m high spruce understorey reduced the growth of 60-year-old pine hold-overs by an average of $1 m^3$/ha over a period of 25 years on an *Oxalis-Myrtillus* site type) (Isomäki 1979). In spite of competition, there is often justification for growing a two-storeyed mixed stand. The total yield of a mixed stand comprising two tree species (birch-pine or birch-spruce) can be superior to that of a pure stand (Mielikäinen 1980, 1985). This is probably due to a number of reasons, e.g. the different depth distribution of the roots, the utilisation of nutrients and soil water, and the soil-ameliorating effect of birch litter.

Reaction of understoreys after release

The removal of hold-overs results in strong, partly positive and partly negative changes in the growing environment of the understorey. These changes are the stronger, the greater the shading and root competition caused by the overstorey. In addition to changes in light and nutrient conditions, the temperature, moisture and wind conditions are also changed (Fig. 1). The soil moisture content increases following the cessation of evapotranspiration by the overstorey and the proportion of precipitation reaching the soil increases. On drained mires the groundwater level often rises (even excessively) after felling if the ditches are not functioning properly (Päivänen 1982).

Following the removal of hold-overs, there is more room for root growth of the understorey trees, resulting in a decrease in the competition for water and nutrients. However, the roots of understorey trees are often structurally and functionally reduced, and they require time to grow and spread out. The trees also have to produce foliage that is adapted to the changed conditions.

Removal of the overstorey may increase the risk of damage to the released understorey. For instance, stronger insolation and larger temperature variations mean a greater risk of frost damage (Multamäki 1942, Leikola and Rikala 1983). Direct sunlight

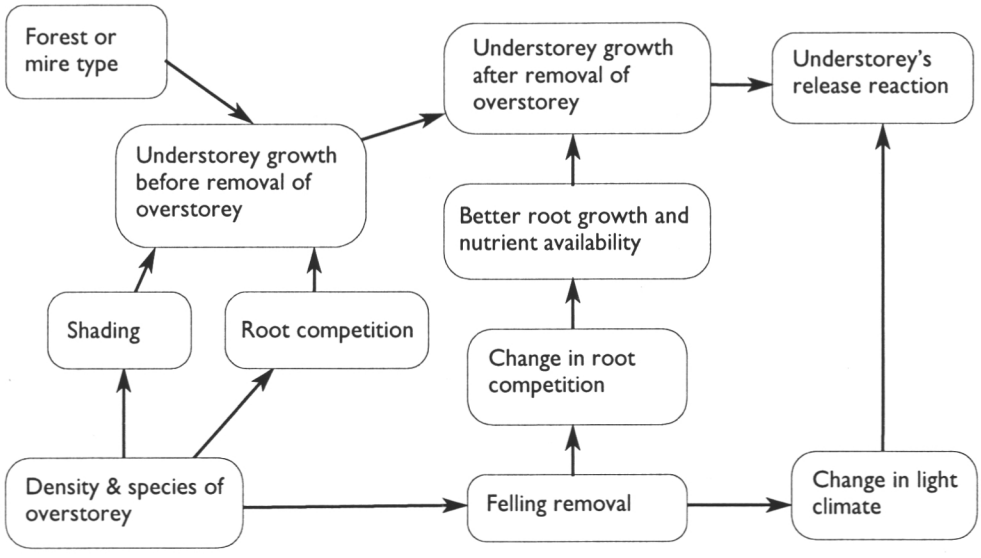


Figure 1. The factors influencing recovery of the understorey (Valkonen et al. 1998).

and the associated variations in temperature can damage the foliage, as well as the cambium and phloem of released understorey trees.

On peatland sites there is rather frequent a lack of potassium and boron. Potassium deficiency is mainly a problem in stands that have emerged on thick-peated, initially swampy and nitrogen-rich mires following drainage. In some cases, the potassium concentration of spruce needles on drained peatland sites has fallen following the removal of the overstorey, and this has deteriorated the ratio between nitrogen and potassium for tree growth. Nutrient imbalances can be corrected on such sites by PK fertilisation (Saarinen 1995, 1996).

Following their release, the growth of understorey trees initially remains unchanged or may even be retarded. The length of the recovery period depends on the site, tree species, growth status, and the density of the removed overstorey. Healthy, viable trees have been reported to require 2–7 years (spruce) and 1–4 years (pine) to recover their growth. On infertile upland, spruce understoreys suppressed by an overstorey for lengthy periods of time may "stagnate" for rather a long time. Cases have been reported where the reaction of the understorey to release has been negligible (Koistinen and Valkonen 1993, Mielikäinen and Valkonen 1995, Niemistö 1995).

There is often also great variation between the trees forming the understorey, since some trees recover faster than others. Spruces growing on a fertile site under a birch overstorey are often so vigorous that release does not result in essential changes in their growth rhythm (Cajander 1934, Vaartaja 1952, Koistinen and Valkonen 1993, Mielikäinen and Valkonen 1995).

Following the recovery stage, growth of the understorey improves and becomes more vigorous. The recuperation stage lasts until the understorey trees are growing as fast as similar-sized, free-growing trees on a corresponding site. A high crown ratio indicates a large and often vigorous crown that enables the tree to recuperate faster than one with a small crown. A fast growth rate before release also means rapid recuperation. Small trees take longer to recuperate than medium or large trees. Other parameters predicting understorey survival and rapid recuperation are young age, growth acceleration prior to release, and a good state of health (Koistinen and Valkonen 1993). In the case of spruce especially, the recuperation reaction is often very marked after an initial lag period: several years of stagnation can be followed by a multiple increase in height growth within a short period of time (Fig. 2).

A young and vigorous understorey of spruce or pine released from under a conifer overstorey, and at least 0.5 m in height, can (following a recuperation stage) achieve as fast a rate of growth as plantation established at the same time (Koistinen and Valkonen 1993). Spruce understorey members more than 1.5 m in height on sites resembling an *Oxalis-Myrtillus* site type or more than 1 m in height on a *Myrtillus* site type are considered superior to the dominant individuals in spruce plantations in terms of height growth (Koistinen and Valkonen 1993). The trees forming old understoreys which have been suppressed for a long time the trees must be clearly over the aforementioned heights indicated in order to be able to develop at the rate of planted trees because their recuperation stage is considerably longer.

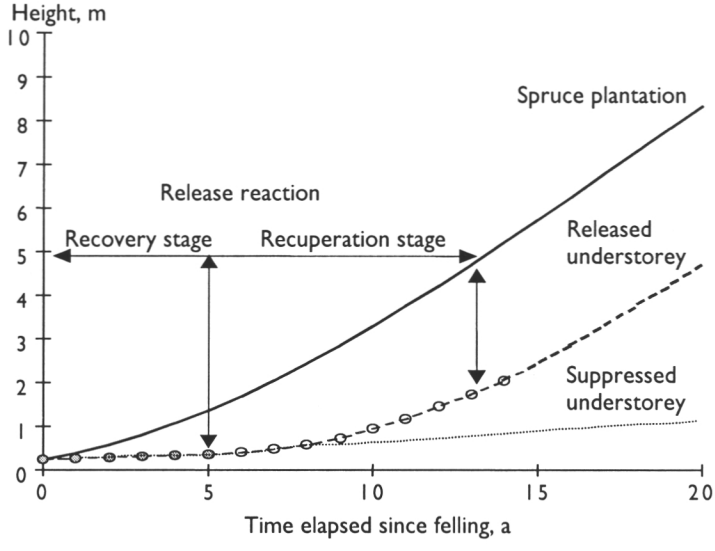


Figure 2. The stages in the release of an understorey. The age of a normal plantation of the same age at the moment of release is 5 years. In this example, the recovery stage lasts for 5 years and the recuperation stage for 9 years. The time span of the release reaction is 14 years in all. The former understorey trees subsequently develop according to the same growth rhythm as planted spruces (Valkonen et al. 1998).

Understorey damage when removing hold-overs

Releasing an understorey from overstorey suppression should not be postponed indefinitely as the overstorey will hamper the development of the young stand already at an early stage. Leaving the hold-overs unharvested for years increases the formation of gaps in the young stand and leads to within-stand variation in height. However, there are grounds for postponing the release operation and for allowing the advance growth to reach a height of 1–2 m on sites where there is risk of frost, and in northern Finland where the harshness of the climate, especially at the timberline, is a risk factor affecting regeneration.

Hold-overs are usually removed at the same time to save timber-harvesting costs and to minimise the risk of damage. However, if an understorey of spruce has developed under a dense tree stand, the removal of hold-overs must be performed in two stages. This gives the understorey time to adapt sufficiently to the increasing light conditions before final release, and thereby avoid the damage and loss of growth caused by the "shock effect". It is also a good idea to remove hold-overs in stages when the aim is to grow two tree storeys for a longer period, e.g. an advanced stand of birch over a young stand of spruce.

The positive effects of removing hold-overs include increasing space for growth of the understorey, improved availability of nutrients and light, and less root competition. The negative effects include damage to the understorey trees (stem and root damage), and under-stocking caused by the gaps formed in the understorey. The increasing grouping of trees and gaps in the understorey stand and the variation in tree size lead to changes in the quality and growth of the trees, and affect the long-term yield of wood and the profitability of growing the tree stand. Small trees will be damaged in connection with felling as well as forest haulage when the overstorey is being harvested. Damage is usually caused by the crowns of trees as they are felled, small trees crushed under logging residue, the clearance of extraction tracks, and trees being run over by wood harvesting machines (Maukonen 1987, Harstela and Rantonen 1988, Niemistö 1995, Hyppönen and Niemistö 1998).

The damage per cent (the proportion of trees damaged in various ways out of the total number of trees) when removing hold-overs from above pine advance growth has averaged 15–20%. In the case of spruce advance growth the damage per cent is usually higher, averaging 30% (Maukonen 1987, Peltoniemi 1991, Hyppönen and Niemistö 1998).

The number of damaged trees varies greatly. Hold-over removals carried out in central Finland in the mid-1980's resulted in damage percentages of between 4 and 57 in young pine stands. The situation in young spruce stands varied between 12% and 74%. In the removal of pine hold-overs on non-industrial private forest holdings in Finnish Lapland in the early 1990's, the range of variation was 4–45%. In the removal of hold-overs in mixed stands the damage per cent varied between 5% and 26% (Maukonen 1987, Peltoniemi 1991, Mäkelä 1992).

The logging trace in the removal of hold-overs can be improved through careful planning and correct timing of the harvesting. The overstorey above small young stands can be removed either when there is no snow (when the trees forming the advance growth are visible and can be avoided) or when a thick cover of snow protects the trees both from felling and forest haulage damage. Removal of hold-overs

should be avoided when the temperature is very low due to the greater risk of damage to the understorey. On soils with good bearing capacity release of the understorey should be carried out when the soil is not frozen, but on soils with poor bearing capacity during mild winter days. Summer harvest should be avoided on mineral soils and mires with poor bearing capacities (Hyppönen and Niemistö 1998).

Heartwood decay sometimes occurs even in groups of rather young trees that have developed in gaps in old spruce stands infected by the root-rot fungus (*Heterobasidion annosum*) (Kangas 1952, Tamminen 1985, Piri 1996). While more information is needed about the risk of decay and the frequency of decay damage, it is nevertheless best to carry out wood harvesting during the winter as a means of avoiding logging damage. The spread of decay fungi into the freshly cut stumps when the soil is not frozen can be prevented by means of biological control agents or with urea treatment. Spruce understoreys under pine and birch are as susceptible to decay, however.

Choosing the appropriate wood harvesting method is important. The use of telescopic lifting devices when loading timber allows wider strip road spacing and reduces the risk of damage to the remaining stand. Good planning and implementation of harvesting work is equally important in the removal of hold-overs as in thinning. Both motor-manual and harvester-based logging methods can be used in harvesting hold-overs with relatively minor damage to the remaining stand, even when large harvest volumes are extracted (Roiko-Jokela 1983).

Potential of understoreys

Understoreys are of considerable significance in forest regeneration. For example, a considerable proportion of the spruce and pine understorey that were earlier deemed non-viable in the National Forest Inventories have subsequently been estimated to have been viable (Mikola 1966). Almost half of the young stands formed under pine hold-overs in Lapland have developed without having to resort to regeneration cutting. The natural regeneration of spruce is also largely based on understoreys: 60–85% of the restocking material in spruce stands in southern Finland regenerated by the shelterwood system were present already before regeneration cutting (Hänninen et al. 1972). In the case of strip felling, too, the existing advance growth of wildlings under the overstorey often forms the starting material for the future tree generation. Regeneration in all-aged forestry is also based almost entirely on utilisation of the understorey. Together with other natural restocking material, understoreys also play a significant role in filling in the gaps in young plantations (Räsänen et al. 1985, Leinonen et al. 1989).

Understoreys can also be used to fill gaps in plantations and naturally regenerated stands. Although part of the understorey is destroyed during removal of hold-overs and in clear-cutting, and in the associated site preparation, especially spruces remain viable on the regeneration sites and supplement the future young stand. The majority of the natural stock of spruce may have emerged before site preparation on lightly scarified sites where pine is planted. As understorey material tends to supplement plantations in a random fashion, little attention is paid to this material when planning and implementing regeneration measures. The present felling instructions, which emphasise the conservation of biodiversity, will undoubtedly lead to an increase in the proportion of understoreys in the following tree generations.

The advantage of regeneration based on utilisation of the understorey material over other regeneration methods is based on several factors (Aarnio et al. 1998). First of all, utilising the understorey usually means a saving in time relative to the other alternatives, despite the recovery and recuperation stages. Understorey trees have grown under an overstorey for a varying period of time and they are often initially larger than the planting stock. When the overstorey is removed, the presence of an understorey means that the young stand is ready on the site, which is not the case when planting is used. However, it is also true that in certain situations understorey utilisation can lead to a loss of time because a short, stunted understorey can fall behind a plantation in growth.

The utilisation of understoreys saves costs because there are usually no actual regeneration costs involved. Natural regeneration and artificial regeneration necessitate several measures such as clearing of the regeneration site, site preparation, and sowing or planting. In contrast, these are not needed with understorey-based regeneration. However, the harvesting of holdovers may be more expensive because damage to the understorey has to be avoided. An understorey composed of small trees may also have to be supplemented by artificial means (planting). Avoiding damage to the understorey also means increased costs in both mechanised and motor-manual logging and in forest haulage, but with small harvest volumes (below 100 m^3/ha) the extra harvesting costs remain at a reasonable level.

Regardless of the risks of impaired recuperation, retaining small groups of understorey trees on the regeneration site is justifiable also from the viewpoint of biodiversity, the environment and the landscape. In addition to groups of understorey trees, individual trees, snags, decayed stems of broadleaved trees and fallen trees should also be left on regeneration sites, irrespective of whether the sites are planted or naturally regenerated. The presence of tree groups and retention trees make the regeneration sites look smaller, offer shelter to wildlife and add to the biodiversity of commercial forests.

When assessing the usability of understoreys, technical, economical and socio-economic factors should also be taken into consideration as well as the biological factors (Saksa et al. 1998). Is the tree species that the understorey is composed of suitable for the site? Is the density of the understorey sufficient? What is the recovery ability, state of health and quality of the plants? The harvest damage caused by the removal of the overstorey and the profitability of understorey-based regeneration relative to other regeneration options, should also be taken into account.

Understoreys are a challenge also to forest research. More reliable information is needed about the recuperation reaction and subsequent development of understoreys on different sites. Neither do we have sufficient knowledge about the preconditions for the emergence and growth of understoreys in present-day commercial forests. This is especially applicable to drained mires. Similarly, more research is needed on the effects of understoreys on biodiversity.

REFERENCES

Aarnio, J., Hyppönen, M. & Valkonen, S. 1998. Alikasvosten hyödyntämisen talous. In: Moilanen, M. & Saksa, T. (eds) Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus ja Metsäntutkimuslaitos. ISBN 952–5118–19-3.

Cajander, E.K. 1934. Kuusen taimistojen vapauttamisen jälkeisestä pituuskasvusta. Referat: Über den Höhenzuwachs der Fichtenpflanzenbestände nach der Befreiung. Commun. Inst. For. Fenn. 19.5. 59 p.

Harstela, P. & Rantonen, H. 1988. Ylispuuhakkuun taimikoille aiheuttamat vauriot. Metsäntutkimusl. tied. 286:18–22.

Hyppönen, M. & Niemistö, P. 1998. Ylispuuhakkuut ja taimikkovauriot. In: Moilanen, M. & Saksa, T. (eds) Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus ja Metsäntutkimuslaitos. ISBN 952-5118-19-3.

Hänninen, T., Räsänen, P. & Yli-Vakkuri, P. 1972. Männyn ja kuusen luontaisen uudistamisen antamista tuloksista Etelä-Suomen kangasmilla. Helsingin yliopiston metsänhoitot. lait. tied. 7.

Isomäki, A. 1979. Kuusialikasvoksen vaikutus männikön kasvuun, tuotokseen ja tuottoon. Folia For. 392. 13 p.

Kalela, E.K. 1936. Tutkimuksia kuusi-harmaaleppä-sekametsiköiden kehityksestä. Referat: Untersuchungen über die Entwicklung der Fichten-Weisserlen-Mischbestände in Ost-Finnland. Acta For. Fenn. 44.2. 198 p.

Kalela, E.K. 1950. Ecological character of tree species and its relation to silviculture. Acta For. Fenn. 57.1. 35 p.

Kangas, E. 1952. Maannousemasienen (Polyporus annosus Fr.) esiintymisestä, tartunnasta ja tuhoista Suomessa. Referat: Über Auftreten, Infektion und Schäden des Wurzelschwamms (Polyporus annosus Fr.) in Finnland. Commun. Inst. For. Fenn. 40.33. 34 p.

Kellomäki, S. 1991. Metsänhoito. Silva Carelica 8. 403 p.

Keltikangas, M., Laine, J., Puttonen, P. & Seppälä, K. 1986. Vuosina 1930–1978 metsäojitetut suot: ojitusalueiden inventoinnin tuloksia. Summary: Peatlands drained for forestry during 1930-1978: Results from field surveys of drained areas. Acta For. Fenn. 193. 94 p.

Koistinen, E. & Valkonen, S. 1993. Models for height development of Norway spruce and Scots pine advance growth after release in southern Finland. Silva Fenn. 3: 179–194.

Laiho, O. 1985. Alikasvosten elpyminen ja niiden hyväksikäyttö. Metsäntutkimusl. tied. 182: 39–50.

Laiho, O., Lähde, E., Norokorpi, Y. & Saksa, T. 1997. Undergrowth as a regeneration potential on Finnish peatlands. In: Trettin, C.C., Jurgensen, M.F., Grigal, D.F., Gale, M.R. & Jeglum, J.K. (eds) Northern Forested Wetlands: Ecology and Management. CRC Press Inc.; Lewis Publishers. p. 121–131.

Leikola, M. & Rikala, R. 1983. Verhopuuston vaikutus metsikön lämpöoloihin ja kuusen taimien menestymiseen. Folia For. 559.

Leinonen, K., Leikola, M., Peltonen, A. & Räsänen, P.K. 1989. Kuusen luontainen uudistaminen Pirkka-Hämeen metsälautakunnassa. Summary: Natural regeneration of Norway spruce in Pirkka-Häme forestry board district, southern Finland. Acta For. Fenn. 209. 53 p.

Mäkelä, M. 1992. Ylispuiden poistohakkuiden korjuutekniikka. Metsätehon katsaus 6.

Maukonen, A. 1987. Ylispuuhakkuun taimikolle aiheuttamat vauriot. Metsäntutkimusl. tied. 244. 30 p.

Mielikäinen, K. & Valkonen, S. 1995. Kaksijaksoisen kuusi-koivu-sekametsikön kasvu. Folia For. 2: 81–97.

Mielikäinen, K. 1980. Mänty-koivu-sekametsiköiden rakenne ja kehitys. Summary: Structure and development of mixed pine and birch stands. Commun. Inst. For. Fenn. 99.3. 82 p.

Mielikäinen, K. 1985. Koivusekoituksen vaikutus kuusikon rakenteeseen ja kehitykseen. Summary: Effect of an admixture of birch on the structure and development of Norway spruce stands. Commun. Inst. For. Fenn. 133. 79 p.

Mikola, P. 1966. Alikasvosten merkitys metsien uudistamisessa. Metsätal. Aikakausl. 1: 4–7.

Multamäki, S.E. 1942. Kuusen taimien paleltuminen ja sen vaikutus ojitettujen soiden metsittymiseen. Referat: Das Erfrieren der Fichtenpflanzen (Picea excelsa Link) in seiner Wirkung auf die Bewaldung der entwässerten Moore. Acta For. Fenn. 51.1. 352 p.

Niemistö, P. 1995. Turvemaan hieskoivikon tiheyden vaikutus alikasvoskuusikon tiheyteen. Metsäntutkimusl. tied. 552: 87–103.

Parviainen, J. & Seppänen, P. 1994. Metsien ekologinen kestävyys ja metsänkasvatusvaihtoehdot. Metsäntutkimusl. tied. 511. 110 p.

Peltoniemi, T. 1991.Ylispuiden poisto konetyönä, miestyönä ja niiden yhdistelmänä. Metsätehon katsaus 18.

Piri, T. 1996. The spreading of the S type of Heterobasidion annosum from Norway spruce stumps to the subsequent tree stand. Eur. J. For. Path. 26: 193–204.

Päivänen, J. 1982. Hakkuun ja lannoituksen vaikutus vanhan metsäojitusalueen vesitalouteen. Folia For. 516. 19 p.

Pöntynen, V. 1929. Tutkimuksia kuusen esiintymisestä alikasvoksina Raja-Karjalan valtionmailla. Referat: Untersuchungen über das Vorkommen der Fichte (Picea excelsa) als Unterwuchs in den finnischen Staatswäldern von Grenz-Karelien. Acta For. Fenn. 35. 235 p.

Roiko-Jokela, P. 1983. Taimikoiden kunto ylispuiden poiston jälkeen. Metsäntutkimusl. tied. 105: 72–82.

Räsänen, P.K., Pohtila, E., Laitinen, E., Peltonen, A. & Rautiainen, O. 1985. Metsien uudistaminen kuuden eteläisimmän piirimetsälautakunnan alueella. Vuosien 1978–1979 inventointitulokset. Folia For. 637. 30 p.

Saarinen, M. 1996. Effects of removal of shelterwood on the foliar nutrient concentrations of Norway spruce (Picea abies (L.) Karst.) on drained peatlands. Suo 3: 95–102.

Saksa, T., Hyppönen, M. & Valkonen, S. 1998. Miten suhtautua alikasvoksiin. In: Moilanen, M. & Saksa, T. (eds) Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus ja Metsäntutkimuslaitos. ISBN 952-5118-19-3.

Sarvas, R. 1937. Kuloalojen luontaisesta metsittymisestä. Pohjois-Suomen kuivilla kankailla suoritettu metsäbiologinen tutkielma. Referat: Über die naturliche Bewaldung der Waldbranflächen. Eine waldbiologische Untersuchung auf den trockenen Heideböden Nord-Finnlands. Acta For. Fenn. 46.1. 146 p.

Sarvas, R. 1950. Tutkimuksia Perä-Pohjolan harsimalla hakattujen yksityismetsien uudistamisesta. Summary: Investigations into the natural regeneration of selectively cut private forests in Northern Finland. Commun. Inst. For. Fenn. 38.1. 95 p.

Seppälä, K. & Keltikangas, M. 1978. Alikasvostaimistot Pohjanmaan ojitusalueiden hieskoivikoissa. Suo 1: 11–16.

Siren, G. 1951. Alikasvoskuusten biologiaa. Summary: On the biology of undergrown spruce. Acta For. Fenn. 58.2. 90 p.

Tamminen, P. 1985. Butt-rot in Norway Spruce in Southern Finland. Commun. Inst. For. Fenn. 127. 52 p.

Tikka, P.S. 1928. Havaintoja kuusen esiintymisestä ja kehityksestä Pohjois-Suomen kuivissa kangasmetsissä. Referat: Über das Vorkommen und die Entwicklung der Fichte in den trockenen Heidewäldern von Nord-Finnland. Silva Fenn. 10. 83 p.

Vaartaja, O. 1952. Alikasvosasemasta vapautettujen männyn taimistojen toipumisesta ja merkityksestä metsänhoidossa. Summary: On the recovery of released pine advance growth and its silvicultural importance. Acta For. Fenn. 59.3. 133 p.

Valkonen, S., Saksa, T., Saarinen, M. & Moilanen, M. 1998. Alikasvos vapauttamisen jälkeen. In: Moilanen, M. & Saksa, T. (eds) Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus ja Metsäntutkimuslaitos. ISBN 952-5118-19-3.



J. Olkkonen

1. Old-growth Scots pine stand in the northern taiga sub-zone near Kostomuksha, the Republic of Karelia.



M. Turtiainen

2. Old-growth Norway spruce stand in the southern taiga sub-zone in the Vodlozero National Park, the Republic of Karelia.



3. Hauling full-length trees by caterpiller.

J. Olkkonen



4. The first cutting stage of combined felling in a deciduous forest with a Norway spruce understorey. The second cutting stage will be done after 10 years.

J. Olkkonen



5. Selection cutting using Finnish harvesting technology.

J. Olkkonen



E. Oksanen

6. In planning regeneration sites the quidelines of environmental protection and forest regeneration must be observed.



P. Savilampi

7. A view in winter 1999 of the field experiment for monitoring natural regeneration of Scots pine in the Muhos research area of the Finnish Forest Research Institute. The seed-tree stand was prepared in 1985, and soil preparation using disc ploughing was carried out in 1986. The seed trees were removed from the disc-ploughed plot (left) in winter 1996, but retained on the untreated plots.



E. Oksanen

8. A shelter tree stand of Norway spruce with a birch admixture.



P. Savilampi

9. The shelter trees should be removed at an early stage to avoid harvest damage to the young growth. In this stand the removal of shelter trees is already delayed.



E. Oksanen

10. A seed-tree stand of silver birch.



E. Oksanen

11. Viable understorey in an old Scots pine stand on a dry site.



E. Oksanen

12. Intensive flowering of Norway spruce.



E. Oksanen

13. A Scots pine seed crop observation stand in Punkaharju, southwestern Finland.



E. Oksanen

14. Abundant cone crop of Norway spruce.



E. Oksanen

15. Plus trees in natural forests form the basic material for tree breeding.

16. Scots pine seed orchard in Punkaharju, southwestern Finland.



E. Oksanen

17. Measuring the growth of containerised seedlings in a greenhouse of Suonenjoki Research Station, the Finnish Forest Research Institute.



R. Rikala

18. Bare-rooted seedling production in Kondopoga, the Republic of Karelia.



M. Turtiainen



19. New greenhouses for the production of planting material in Petrozavodsk, the Republic of Karelia.

M. Turtiainen



E. Oksanen

20. Growing conditions on mounds are favourable for transplants.



A. Rummukainen

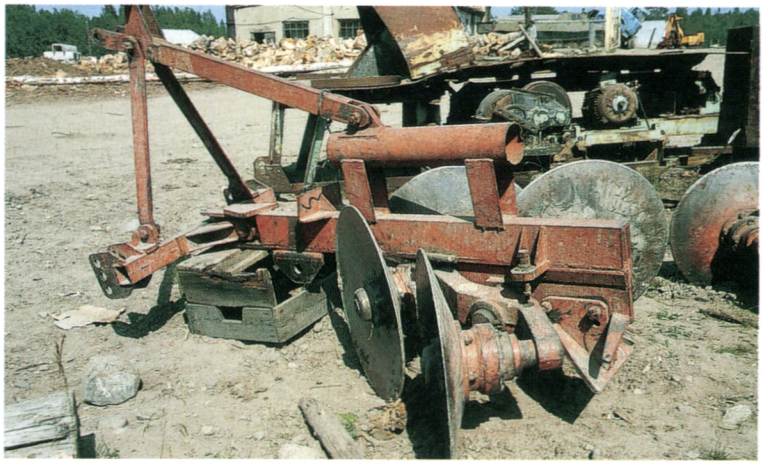
21. TTS-Delta disc plough and TTS-Sigma sowing device.



A. Rummukainen

22. Ilves planter.

23. Disc scarifier developed in the Republic of Karelia.



M. Turtiainen

24. Forest regeneration area prepared by a disc scarifier for planting in Kostomuksha, the Republic of Karelia.



M. Turtiainen



M. Turtiainen

25. Training a planting crew on a forest regeneration area in the Republic of Karelia.



J. Olkkonen

26. Vigorously developing Norway spruce plantation in the Republic of Karelia.



T. Kurkela

27. Scots pine sapling stand damaged by *Phacidium infestans*.



P. Savilampi

28. Logging residue contains a considerable proportion of the nutrient reserves in a forest stand.



E. Kubin

29. Pioneer ground vegetation species soon become established in regeneration areas. This experimental area was clear-cut in 1981, and prescribed burning, ploughing and planting of Scots pine were carried out in 1983. The photo was taken on September 30th , 1985.



J. Eskelinen

30. A mire provides a suitable overland-flow field for flood water from a deep sedimentation ditch.

4. SEED CROPS AND SEED ORCHARDS

SEED CROPS AND SEED CROP FORECASTS FOR A NUMBER OF TREE SPECIES

T. Hokkanen
Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN–01301 Vantaa, Finland

Introduction

Professional foresters and researchers have been interested in the annual fluctuation of the seed crop of forest trees for as long as timber has been harvested on a commercial scale. The abundance of the seed crop has been monitored and measured using a number of methods in order to forecast the occurrence of good seed-crop years.

Finland has a long tradition of assessing the seed crop of a number of tree species. As a result of the pioneer work carried out by two professors of silviculture, Olli Heikinheimo and Risto Sarvas, our longest continuous seed crop series extends over a period of more than 70 years. As a result, the size of the seed crop of a number of tree species, as well as the occurrence frequency of good seed years, are relatively well known in Finland.

A number of countries (e.g. Germany and Russia) started studying the abundance and fluctuation of the seed crop of forest trees before Finland. Studies were carried out by Ogiyevsky, Sobolev and Fomitchev on seed crops in Russia already during the 19th century (Heikinheimo 1932). The results of these studies encouraged Finnish researchers to start their own research on this topic.

A number of approaches have been used in forecasting seed crops:

1) Because cyclic trends have been detected in some observation series, it has been assumed that the internal rhythm of the trees, or cosmic radiation associated with sunspot activity, may be the reason for the variation.

2) Abundant flowering is often preceded by an unusually warm growing season, whereas flowering in the next year is usually poor after a cold summer. This observation has led to the assumption that external factors govern the formation of flower primordia.

3) Apart from certain exceptions, it takes a minimum of one year from the formation of the flower primordia to seed fall. From the point of view of forestry, pine is the most interesting species in this respect because the time span is nearly three years. A prognosis of the size of the seed crop can be made on the basis of observations on the number of flower buds, pistillate flowers and cones.

Methods used in Finland for assessing and measuring seed crops

The Finnish Forest Research Institute has used three methods in monitoring seed crops. A cone crop survey was carried out

annually during 1950–1993. The survey was scientifically rather unreliable, and was based on annual questionnaires sent to various forestry organisations and professional foresters, located in different parts of the country, who were asked to estimate the regional size of the cone crops. Four size categories, based on the number of cones on dominant trees, were used in the assessment.

At the end of the 1950's Prof. Sarvas established a nation-wide network to monitor the flowering and seed crops of trees. At its most extensive, the network included more than 170 plots, with eight plots in the Scandinavian countries and Central Europe. 24 tree species, in addition to the four main tree species in Finland (Scots pine, Norway spruce, silver birch and downy birch), were monitored (Koski and Tallqvist 1978). The emphasis in Sarvas' research gradually switched to investigating the reasons for fluctuations in the seed crop. He was particularly interested in the flowering of forest trees and research on the temperature sum (Photo 12). Our knowledge of the reproduction biology of trees increased substantially as a result of these thorough studies, although their effect on practical forest regeneration was perhaps less noticeable.

Each sample plot usually has about ten funnel-shaped litter collectors, and are used to monitor the amounts of seed and litter falling from the trees (Photo 13). The longest continuous time series recorded by this method covers nearly 40 years (Fig. 1). The seed crop of an individual stand can be determined with great precision by this method. However, one disadvantage is the large amount of work involved in collecting and handling the material, and the fact that the data collected apply only to the stand, and not to individual trees. Because the monitoring of the seed crop is based on the seed fall, the method cannot be directly applied to forecasting seed crops.

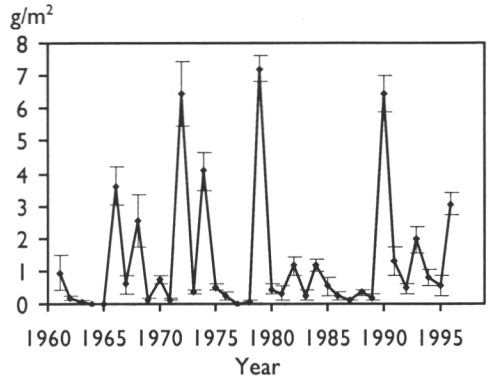


Figure 1. Variation of the spruce seed crop in Siilinjärvi during 1961–1996 according to seed fall years. The bars depict the standard error of the mean of each collector.

A third monitoring method, developed specifically for seed crop forecasts, is observation of the flowering and seed crop of the trees in special seed-crop observation stands. This was initiated by the Finnish Forest Research Institute in 1979. A description of the method is given in conjunction with the seed crop forecasts.

Factors regulating the size and quality of the seed crop

A number of factors influence the seeding of a cutting area in natural forest regeneration. These factors can be depicted by means of a seed crop concept model (Fig. 2). The model illustrates the complexity and multi-phased nature of the ecological process resulting in a seed crop. The most important factors influencing the abundance and quality of the seed crop include variations in the climatic and weather conditions, and the internal anatomical, physiological and genetic characteristics of the trees. The weather conditions during the growing season preceding flowering, especially in June, July and August, are the

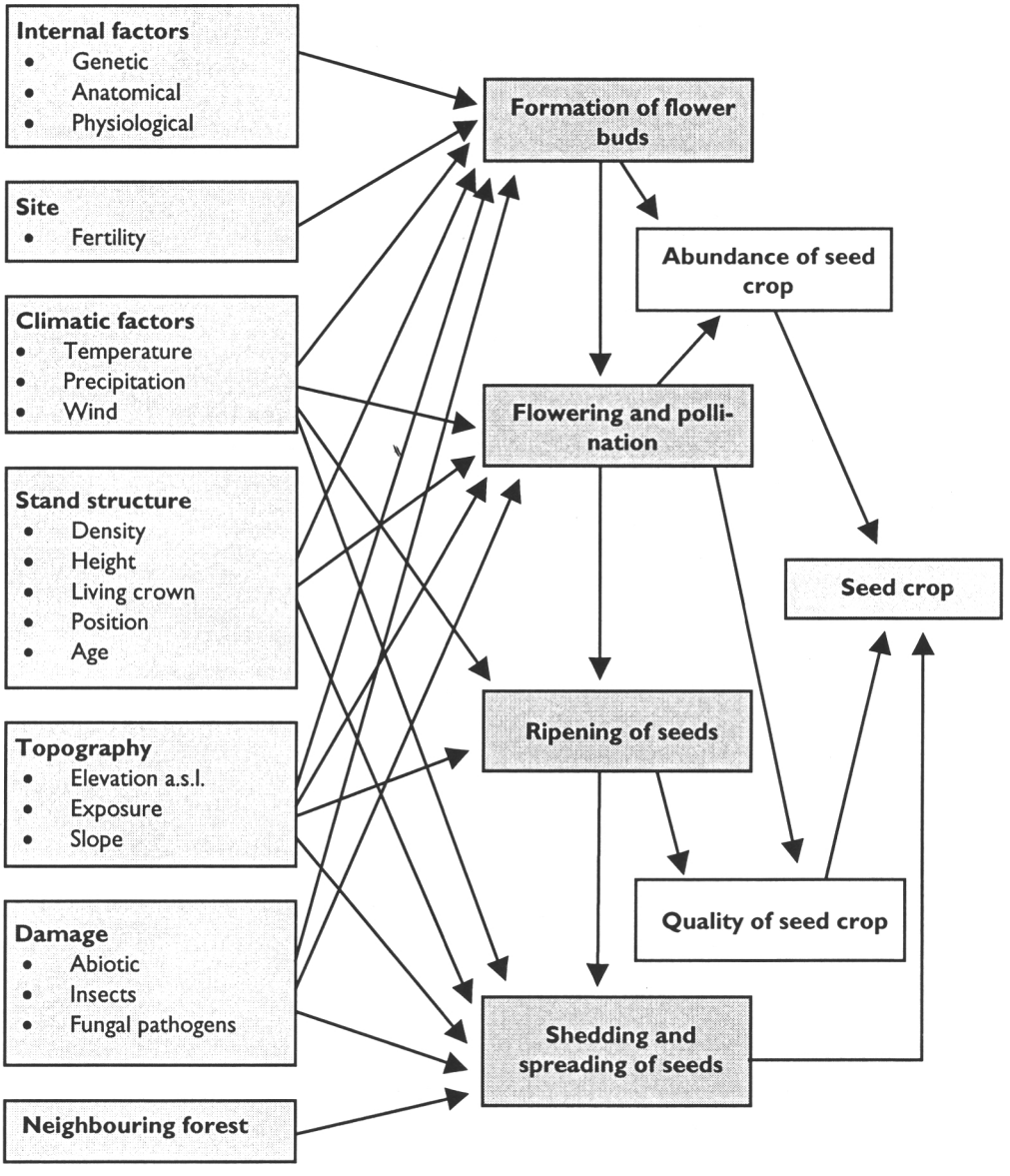


Figure 2. Concept model for seed crops. The model describes the most important factors affecting the quantity and quality of the seed crop from the generation of the flower buds to the seed fall.

most important factors. High temperatures increase the production of seed, whereas cold weather, abundant rainfall and cloudiness decrease it. The temperature conditions during the summer preceding flowering are less important for spruce than for pine (Leikola et al. 1982). The most important site factors include fertility and, especially in northern Finland, the elevation above sea level and the topography. According to Sarvas (1962), the average annual seed crop in adult, normally pollinated pine forests of the *Myrtillus* site type is

about double that of pine forests of the *Calluna* site type.

The most important stand parameters influencing the seed crop are the age, density, height and living crown. The structure of the tree stand can be regulated through silvicultural measures, e.g. by cutting the stand into a seed-tree position in order to increase seed production. The stocking with pine seedlings is at the optimum level in southern Finland when the density of seeding trees is 100 to 200 stems/ha. If the conditions favour regeneration, adequate seeding can be achieved over a range of 20 to 200 stems/ha (Lehto 1956). The present Finnish silvicultural recommendations, which also take into account the economic factors and modern harvesting methods, give a desired density for pine seed trees of 40 to 100 stems/ha

The seed production of mature spruce stands is directly linked to the stand density. Koski and Tallqvist (1978) have calculated that an increase from 200 to 500 stems/ha means that the seed production capacity of spruce will increase threefold. In the case of pine and birch, the dominant height of the stand has a direct effect on seed production. The capacity is doubled when the dominant height increases from 15 to 30 m (Koski and Tallqvist 1978). Capacity means the highest possible level of flowering and seed crop. For pine and especially birch, excessive reduction of the crown may significantly decrease the size of the seed crop. Therefore a preparatory cutting should always be made prior to creating the actual seed-tree position in denser pine and birch stands. Seed and cone pests may also have a significant effect on the size and quality of spruce seed production in certain years.

Seed crops of different tree species in Finland

Scots pine (*Pinus sylvestris* L.) produces an abundant seed crop in southern Finland on an average three times every decade. The annual variation is smaller than that for other tree species, and there are no years of total seed crop failure (Fig. 3, Table 1). The annual variation in northern and southern Finland do not necessarily follow the same pattern. In Lapland, the pine seed crop is abundant and good at the most once every ten years. Therefore, cone harvesting during good seed years is of utmost importance in the north.

On the basis of long-term observations made in seed crop stands, the average annual pine cone crop throughout the whole country is about 35 cones/tree. The seed crop of an open pine stand is usually greater than that of a dense stand. Based on the publications of Heikinheimo (1932, 1937, 1948), Sarvas (1962) and Koski and Tallqvist (1978), Kellomäki (1987) has estimated the average annual seed crop of pine to be 50 to 150 seeds/m^2, or 1.8 to 2.5 kg/ha. Recent long-term measurement series have given more precise information, and the annual pine seed crop is about 3.5 kg/ha in southern Finland and about 1 kg/ha in Lapland. About 15 kg/ha of seed have been harvested in southern Finland in peak years. The percentage of empty seeds is around 20 to 30% of the total number of pine seeds (Sarvas 1962).

There is great annual variation in the seed crop of Norway spruce (*Picea abies* (L.) Karsten) (Figs. 1 and 4, Table 2). There are three to four good cone years every decade, but even an abundant crop can be destroyed by seed pests. Total failures or very poor seed crops occur about five times every ten years (Photo 14). There may be several bad years in succession.

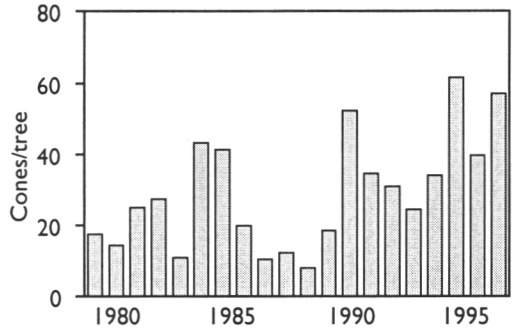


Figure 3. Variation in the Scots pine cone crop in southern Finland during 1979–1998 based on observations in seed-crop observation stands. A year in this context is the year of cone formation, i.e. that the seed fall occurs in the following spring. The material contains only those plots that have been actively monitored throughout the study period.

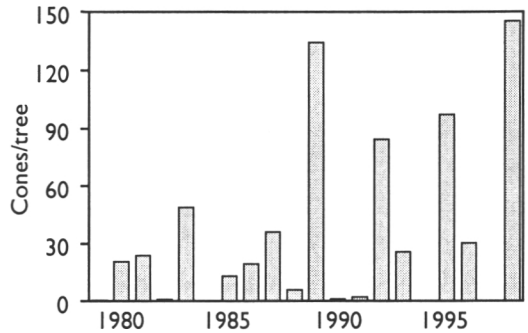


Figure 4. Variation in the Norway spruce cone crop in southern Finland during 1979–1998 based on observations in seed-crop observation stands. A year in this context is the year of cone formation.

Table 1. Average annual cone crop in Scots pine seed-crop observation stands in 1979–1998. sd = standard deviation, N1 = number of observation stands, N2 = number of observation trees.

Year	Cones	sd	N1	N2
1979	17.6	14.5	41	2 040
1980	18.9	17.8	37	1 845
1981	25.4	16.0	42	2 088
1982	36.5	27.5	47	2 335
1983	10.8	7.9	46	2 271
1984	33.3	27.5	44	2 160
1985	43.2	28.0	34	1 668
1986	23.7	15.8	37	1 765
1987	13.2	10.8	35	1 681
1988	23.3	28.1	26	1 235
1989	10.0	6.1	45	2 178
1990	19.1	12.5	45	2 205
1991	49.0	31.9	41	2 004
1992	31.7	17.6	36	1 774
1993	30.9	26.1	44	2 195
1994	28.9	32.6	64	3 219
1995	22.6	17.0	87	4 258
1996	71.0	35.5	78	3 777
1997	52.8	41.6	79	3 747
1998	65.0	48.4	88	4 222

Table 2. Average annual cone crop in Norway spruce seed-crop observation stands in 1979–1998. sd = standard deviation, N1 = number of observation stands, N2 = number of observation trees.

Year	Cones	sd	N1	N2
1979	2.9	7.8	25	1 242
1980	23.6	28.1	32	1 574
1981	25.4	21.9	32	1 573
1982	1.2	3.0	35	1 694
1983	52.0	44.6	35	1 694
1984	1.6	4.1	23	1 110
1985	10.9	12.9	32	1 568
1986	29.6	31.9	32	1 537
1987	29.8	36.6	35	1 674
1988	7.0	10.7	35	1 700
1989	141.6	83.8	35	1 680
1990	1.8	3.0	34	1 658
1991	5.9	12.5	33	1 600
1992	70.4	70.7	34	1 646
1993	21.3	15.1	36	1 768
1994	6.5	18.9	52	2 717
1995	98.5	67.6	71	3 412
1996	25.4	38.5	61	2 961
1997	3.6	11.0	61	2 855
1998	126.9	75.7	71	3 349

During the 1990's, bad cone years occurred in southern Finland in 1990, 1991, 1994 and 1997 (Fig. 4). It is very seldom that the spruce seed crop is abundant in two years in succession.

The average long-term spruce cone yield in seed crop observation stands has been about 40 cones/tree. According to a summary compiled by Kellomäki (1987) from a number of publications, the average annual seed fall is 3 to 4.5 kg/ha. The most recent measurement series indicate that the long-term spruce seed crop in Lapland falls within this abundance category, whereas in southern and central Finland the average crop on fertile sites may be as high as 10 to 20 kg/ha. In four observation stands where the seed crop has been monitored with litter funnels for more than 35 years, the average spruce seed crop varied from 10.5 to 18.3 kg/ha. In a peak year the seed crop may be as high as 120 kg/ha.

The largest spruce seed crop in Finland was recorded in 1990, when an average of 4 100 seeds/m^2 was counted in the Aulanko nature reserve. No seeds are produced in bad years. The spruce seed crop in southern Finland in autumn 1998 appears to have been the best in 50 years but, owing to the prevalence of insect pests and fungal pathogens, the quality of the crop was poor. Thus, a peak yield in terms of quantity does not always guarantee good restocking of the regeneration area. The average proportion of empty seeds is 67%, and the annual variation range 20–100% (Sarvas 1986). The proportion of empty seeds is highest in bad, and smallest in good seed years.

On an average, silver birch (*Betula pendula* Roth.) and downy birch (*B. pubescens* Ehrh.) have good seed years at 2- to 3-year intervals in southern Finland. The annual variation is considerably high (Fig. 5, Table 3). According to the latest results from the seed crop observation stands, the flowering of birch can be negligible in certain years even in southern Finland.

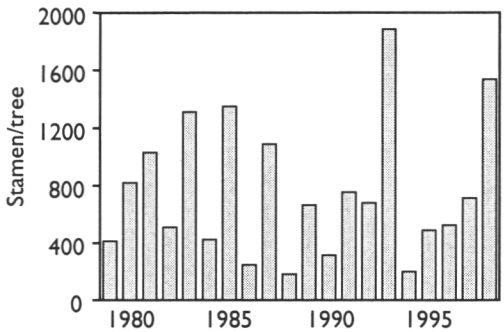


Figure 5. Variation in staminate flowering of birch in southern Finland during 1979–1998 based on observations in seed-crop observation stands.

Table 3. Average number of staminate catkins of birch in seed-crop observation stands in 1979-1998. sd = standard deviation, N1 = number of observation stands, N2 = number of observation trees.

Year	Cones	sd	N1	N2
1979	424	409	30	1 371
1980	712	816	35	1 584
1981	1 206	1 114	35	1 596
1982	396	435	34	1 548
1983	1 039	718	36	1 598
1984	345	363	35	1 633
1985	1 287	800	35	1 586
1986	394	629	37	1 666
1987	796	792	34	1 561
1988	168	164	39	1 782
1989	620	865	36	1 617
1990	248	368	40	1 815
1991	588	722	40	1 820
1992	496	618	37	1 702
1993	1 521	880	38	1 662
1994	155	130	40	1 776
1995	386	484	63	2 940
1996	447	660	59	2 724
1997	590	667	62	2 737
1998	1 320	1 023	65	2 802

Birches in southern Finland produce an average of 700 to 800 staminate catkins per tree. The largest measured annual seed crop of a downy birch stand in Finland is as high as 260 000 seeds/m^2 (Koski and Tallqvist 1978). The seed crop decreases gradually on moving northwards. Birch seeds remain viable in the ground and are able to germinate in future years. The proportion of empty seeds in both birch species is relatively high, from 40 to 80% (Sarvas 1955).

The seed crops of grey alder (*Alnus incana* (L.) Moench) and common alder (*A. glutinosa* (L.) Gaertner) are relatively abundant and recurring. The seed crops of both species have been 60 kg/ha in the best seed years (Raulo and Hokkanen 1989).

Larch is of minor economic importance in Finland because it is not an indigenous species. Larch plantations mainly consist of Siberian larch (*Larix sibirica* Ledeb.). In long-term (1959–1995) measurements carried out at Punkaharju in southeastern Finland, the average larch seed crop has been around 450 seeds/m^2. In the peak year of 1979, the seed fall was 2 000 seeds/m^2.

Seed crop forecasts

Successful natural regeneration can be significantly promoted by timing regeneration felling and site preparation to coincide with the ripening of an abundant seed crop. Reliable seed crop forecasts drawn up at a sufficiently early stage provide an important tool for decision-making concerning regeneration. In addition to using the prognoses for timing the regeneration felling and site preparation, they can also be helpful in selecting the method of regeneration and determining the planting density when the aim is to use natural seedlings on the planting or sowing site. In addition, the forecasts provide important information for the planning and implementation of cone harvesting. There is also a lot of general interest in the prognoses and records of seed crops, because the flowering and cone crop of forest trees, with their large annual variation and many repercussions, such as heavy migration of seminivorous birds and dynamics of the squirrel population, are highly visible natural phenomena.

The seed crop prognoses can be based on microscopic analysis of the buds, on visual observations of flowering and the cone crop, or on computer models. In Finland, models for forecasting the seed crop of spruce and pine have been developed on the basis of long-term seed crop series (Leikola et al. 1982, Pukkala 1987). However, several uncertainties affect the use of the models. At present, the models for the rest of Finland are better than those for Lapland, and the models for pine are better than those for spruce. The models can explain only 37 to 40% of the variation in the seed crop, but they can usually identify good and bad seed years correctly (Pukkala 1987).

Prediction method developed by the Finnish Forest Research Institute

The Finnish Forest Research Institute started to develop a new, more reliable method for forecasting seed crops in 1993. Since 1994, national and regional prognoses for pine, spruce and silver and downy birch have been drawn up. In this method, the prediction for conifers is produced in three phases. The first preliminary forecast of the flowering abundance during the following summer is based on microscopic analysis of bud samples in late autumn. The second forecast is based on on-site flowering observations in the designated seed crop observation stand, and the final forecast on the estimation of the number of cones on the same trees in late summer. Thus, the accuracy of the forecasts increases as the time of seed fall approaches. The forecasts for

birch are based on observations of staminate catkins in the autumn. The local accuracy of the predictions depends on the density of the test plot network.

Early prognosis provides sufficient time for planning the regeneration. The seed crop forecasts for birch can cover almost one year, for spruce 1.5 years and for pine as much as 2.5 years into the future. The ability to give a reliable forecast of the best and the worst seed years is the most important precondition for successful regeneration.

Seed-crop observation stands

The Finnish Forest Research Institute has set up about 280 seed-crop observation stands extending from the south coast to the forest line in the north for observing and forecasting seed crops (Fig. 6). Fifty trees with dominant crowns have been permanently numbered for annual binocular observation of the number of flowers and cones on the individual trees.

The observer counts or estimates the number of flowers or cones on each of the numbered trees in the observation stand, and classifies the tree according to an abundance category. There are six or seven categories depending on the tree species. The following abundance classification system is used in the estimation:

Abundance category	Birch staminate catkins/tree	Pine and spruce pistillate flowers or cones/tree
1	0	0
2	1–20	1–20
3	21–200	21–50
4	201–1 000	51–100
5	1 001–5 000	101–200
6	> 5 000	201–500
7		> 500

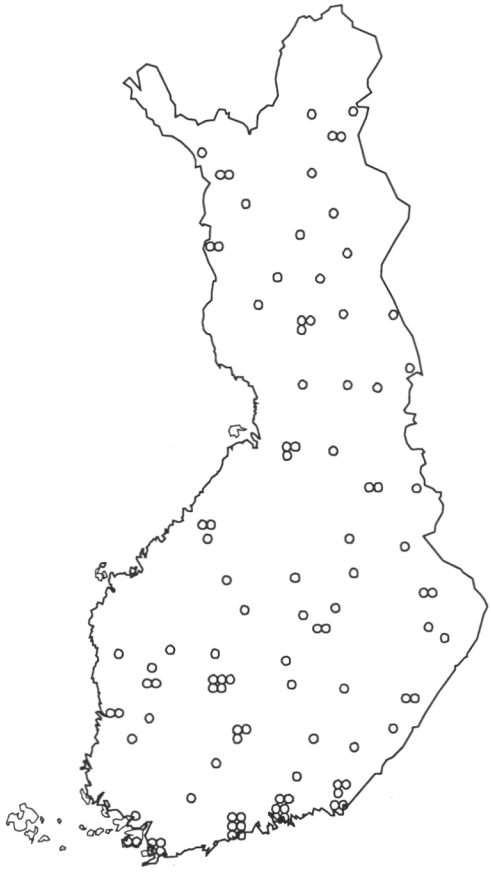


Figure 6. Map of the locations of pine seed crop observation stands in Finland.

The observations on birch focuses on staminate catkins, and their abundance is estimated in the autumn (October-November) soon after the leaves have fallen. Counting pistillate flowers on birches is not possible because they become visible only when the birch comes into leaf in the spring. The observation of pistillate flowers on spruce is performed during the flowering period in late May or June, and the estimation of cones in July. The observation of pistillate flowers on pine is performed during flowering in June, and the estimation of cones in July or August. The

peak in spruce flowering in southern and central Finland lies between the effective temperature sum values of 130–150 °C·d (threshold value +5°C) and of pine between 220–240 °C·d (Sarvas, 1962, 1968 and Kellomäki 1987).

In addition to the field personnel of the Finnish Forest Research Institute, several other bodies representing the state forest administration (Finnish Forest and Park Service), private forestry (Forestry Development Centre Tapio), educational forestry and agricultural institutes and private corporations in the forestry sector (A. Ahlström Oy, Stora Enso Oyj and UPM-Kymmene Oyj), co-operate in the observation work. About one half of all the observations of flowering and cones are made by these bodies.

Study of buds

The forecasts made on the basis of the observation stands can be supplemented with bud studies. These speed up the preliminary prognosis of the expected spruce and pine seed crops by about six months compared to a prognosis based on flowering observations. The study of buds is initiated in October when sample branches are collected for microscopic bud study from felled conifers in cutting areas. The sample trees should be fairly mature and of the dominant crown class, i.e. preparatory or final cutting stands are suitable. 30 sample trees are chosen from each stand fairly soon after cutting, since the buds on felled trees dry rather quickly in the early autumn. Samples can be collected from trees felled in September or October only during two weeks after cutting, but during the whole winter from trees felled at a later date.

The sample branches are collected from the crown, no less than two metres from the tree top. Ten branches per tree are collected from pine, whereas three to five spruce branches constitute a sufficient sample, provided that the number of end buds is at least ten on each branch. The end buds from the sample branches are studied under the microscope, and the total number of pistillate flower primordia and cones of various ages are counted. The method is rather laborious and time-consuming, which means that large-scale studies cannot be performed. Usually, four or five sample stands for each tree species are enough to make a regional prognosis if the area in question is a forest centre or a smaller area.

Ripening of the seed crop

In addition to the abundance of the seed crop, the forecasts cover seed ripening, the prevalence of insect pests and fungal diseases and the risks they pose to the cone crop. An abundant, good-quality pine seed crop requires three consecutive, relatively warm growing seasons. In northern Finland, the ripening of seeds is often the minimum factor for pine regeneration. If the weather conditions during the ripening summer are cold and wet, the germination percentage of the seeds is low. In such circumstances it is not feasible to use even an abundant seed crop for regeneration or cone harvesting. Therefore, information about the seed germination percentage, based on accumulated local temperature sums, is also included in the prognoses. In addition, the Finnish Forest and Park Service and the seed centre of Tapio, which are responsible for the seed supply of forest trees in Finland, assist in determining the quality of the seed crop by providing the results of x-ray tests and germination percentage tests for use in the forecasts.

The proportion of ripened seeds begins to increase steeply above the threshold value of 600–700 °C·d (effective temperature sum). The maximum values for ripened

seeds are usually obtained in the range of 900–1 100 °C·d (Henttonen et al. 1986). According to Sarvas (1967), 50% of the seeds will ripen if the accumulated temperature sum is at least 85% of the average temperature sum for the area.

Seed damage

Seed and cone pests and rust fungi can cause extensive damage to the seed crop in certain years. In Finland, monitoring is focused on the seed and cone insects occurring on spruce. The significance of insect pests for pine is considerably less. The most important insect pests for spruce cones are *Cydia strobilella, Dioryctria abietella* and *Lasiomma anthracina.* Considerable damage is also done by *Plemeliella abietina* and *Megastigmus strobilobius*, which penetrate into spruce seeds. It is difficult to predict the damage, since many damaging insect species can remain in diapause for several years, waiting for the next more abundant seed crop.

Damage prediction requires good knowledge of the population dynamics of insect pests and the various factors affecting it. The cone damage caused by insects can be predicted with sufficient reliability for the needs of practical forestry by constantly monitoring the annual size of the cone harvest, and by taking random samples of possible damaging insects in July or August. The seed crop is of the best quality when, after two or more bad cone crops, there is abundant spruce flowering (Rummukainen 1960, Annila 1979, 1981).

The most important fungal diseases affecting spruce are *Thekopsora areolata* and *Chrycomyxa pyrolatum*, which are especially prevalent in wet summers. The rust fungi infect the pistillate flowers in late May – early June when spruce is in flower. *Thekopsora areolata* occurs especially on fertile sites, along fields and grazing areas where bird cherry (*Prunus padus*) is abundant. According to Rummukainen (1960), a medium-size cone infected by *Thekopsora areolata* produces about 600 million rust spores. *Chrycomyxa pyrolatum* causes seed withering or completely empty cones. A high rust fungus population considerably reduces the seed production of spruce, especially at northern latitudes.

As a whole, the seed quality issues complicate and delay forest regeneration decisions, since seed quality can only be conclusively determined in the autumn preceding seed fall.

REFERENCES

Annila, E. 1979. The life cycles of the cone-infesting Dioryctria species (Lepidoptera, Pyralidae) in Finland. Notulae Ent. 59: 69–74.

Annila, E. 1981. Kuusen käpy- ja siementuholaisten kannanvaihtelu. Summary: Fluctuations in cone and seed insect populations in Norway spruce. Commun. Inst. For. Fenn. 101. 32 p.

Heikinheimo, O. 1932. Metsäpuiden siementämiskyvystä I. Referat: Über die Besamungsfähigkeit der Waldbäume I. Commun. Inst. For. Fenn. 17.3. 61 p.

Heikinheimo, O. 1937. Metsäpuiden siementämiskyvystä II. Referat: Über die Besamungsfähigkeit der Waldbäume II. Commun. Inst. For. Fenn. 24.4. 67 p.

Heikinheimo, O. 1948. Metsäpuiden siementämiskyvystä III. Summary: On the seeding capacity of forest trees III. Commun. Inst. For. Fenn. 35.3. 15 p.

Henttonen, H., Kanninen, M., Nygren, M. & Ojansuu, R. 1986. The maturation of Scots pine seeds in relation to temperate climate in northern Finland. Scand. J. For. Res. 1: 243–249.

Kellomäki, S. 1987. Metsäekologia. Silva Carelica 7. 297 p.

Koski, V. & Tallqvist, R. 1978. Tutkimuksia monivuotisista kukinnan ja siemensadon määrän mittauksista metsäpuilla. Summary: Results of longtime measurements of the quantity of flowering and seed crop of forest trees. Folia For. 364. 60 p.

Lehto, J. 1956. Tutkimuksia männyn luontaisesta uudistumisesta Etelä-Suomen kangasmailla. Summary: Studies on the natural reproduction of Scots pine on the upland soils of southern Finland. Acta For. Fenn. 66.2. 106 p.

Leikola, M., Raulo, J. & Pukkala, T. 1982. Männyn ja kuusen siemensadon vaihteluiden ennustaminen. Summary: Prediction of the variations of the seed crop of Scots pine and Norway spruce. Folia For. 537. 43 p.

Pukkala, T. 1987. Kuusen ja männyn siemensadon ennustemalli. Abstract: A model of predicting the seed crop of Picea abies and Pinus sylvestris, Silva Fenn. 2: 135–144.

Raulo, J. & Hokkanen, T. 1989. Harmaa- ja tervalepän karikesato. Summary: Litter fall of Alnus incana and Alnus glutinosa. Folia For. 738. 25 p.

Rummukainen, U. 1960. Kuusen siementuhojen runsaudesta ja laadusta. Referat: Über Reichlichkeit und Art der Samenschäden bei der Fichte. Commun. Inst. For. Fenn. 52.3. 83 p.

Sarvas, R. 1952. On the flowering of birch and quality of seed crop. Commun. Inst. For. Fenn. 40.7. 38 p.

Sarvas, R. 1962. Investigations on the flowering and seed crop of Pinus silvestris. Commun. Inst. For. Fenn. 53.4. 198 p.

Sarvas, R. 1967. The annual period of development of forest trees. Proceed. Finnish Academy of Science and Letters 1965. p. 211–231.

Sarvas, R. 1968. Investigations on the flowering and seed crop of Picea abies. Commun. Inst. For. Fenn. 67.5. 84 p.

SCOTS PINE PROVENANCE TRIAL IN THE REPUBLIC OF KARELIA

B.V. Rayevsky

Forest Research Institute, Karelian Science Centre of the Russian Academy of Sciences, Pushkinskaya 11, Petrozavodsk, 185610, Russia

Introduction

During the 1960's and 1970's large-scale IUFRO co-ordinated international programmes were implemented for the establishment of geographical plantations of the main forest-forming species in the European industrialised countries. The Soviet Union did not participate in these trials, although it did implement its own similar programmes. During 1974–1977, for instance, a series of geographical plantations were established with Scots pine (*Pinus sylvestris* L.) on 33 testing sites located throughout the former USSR (Shutyaev and Giertych 1997). The series included 113 provenances. Two geographical pine plantations were established in Karelia: in the northern taiga sub-zone (Ambarny forest district of the Chupinsk leskhoz, with 29 provenances and a total area of 12 ha), and in the middle sub-zone (Kumsa forest district of the Medvezhyegorsk leskhoz).

This paper presents data on the survival and growth of the Scots pine provenances on plot No. 5 of the above series, located near the town of Medvezhyegorsk (63°00' N, 34°03' E, 100 m a.s.l.).

The plantations were established in 1977 under the scientific and methodological guidance of staff from the Forest Research Institute on the site of a clear-cut pine forest (Pinetum calluno-vacciniosum type, site class IV). The soil was not prepared, except for stump extraction and prescribed burning in 1976. The plantation area consists of 15.2 ha, of which 13.9 ha is covered by newly planted trees. Two-year-old seedlings grown in the open were planted in patches with a spacing of 0.8x2.5 m and a density of about 5 000 seedlings/ha on 0.10 and 0.15 ha plots. A total of 45 provenances ranging from Monchegorsk (67°51' N) to Smolensk (54°00' N) and from Estonia (26°28' E) to Yakutia (130°00' E) (Table 1, Fig. 1) were planted in triplicate. Chemical soil analyses and forest pathology surveys were made during the study period (Марьин 1979, Крутов 1981). Survival and biometric measurements were carried out annually up until 1989, and subsequently at five-year intervals (Малышев and Щербакова 1993). The plantation was measured according to the methods of the All-Union Research Institute for Silviculture and Mechanisation of Forestry (Проказин 1972). The statistical data were processed using correlation, regression and dispersion analyses (Плохинский 1970).

Survival, growth and development of the plantations were analysed separately by provenances and by groups of provenances used for plantation establishment. Individual provenances were compared with alternative 14, which was the local one (Medvezhyegorsk raion), and groups of provenances with group II, taken as the check alternative. This group represents the middle sub-zone of the taiga of the Russian European North. The plantation was established on the border of the northern and

Table 1. The groups of Scots pine provenances of the geographical plantation in the Medvezhyegorsk leskhoz.

Provenance group No., subspecies	Provenance No.	Zone	Geographical coordinates	
			Northern latitude	Eastern longitude
I *lapponica*	1,2,3,12,18	Northern taiga sub-zone of European Russia	67°51'–64°45'	34°30'–33°00'
II *sylvestris*	4,9,14,15,16,17	Central taiga sub-zone of European Russia	62°54'–60°00'	43°00'–30°28'
III *sylvestris*	19,21,22,23,24	Southern taiga sub-zone of European NW of Russia	60°00'–56°23'	32°28'–26°28'
IV *sylvestris*	8,41,42,43,44,45, 47,48	Central regions of European part of Russia	59°20'–54°00'	44°28'–33°00'
V *sylvestris*	10,13,67,68,73,74	NE of European part of Russia, northern and central Ural	64°40'–57°03'	57°00'–50°06'
VI *sibirica*	77,78,81,82,88,91	Western Siberia	61°25'–52°50'	84°27'–60°24'
VII *sibirica*	93,94,102,103, 104,109,117,118	Middle and eastern Siberia	66°00'–58°00'	130°00'–88°00'

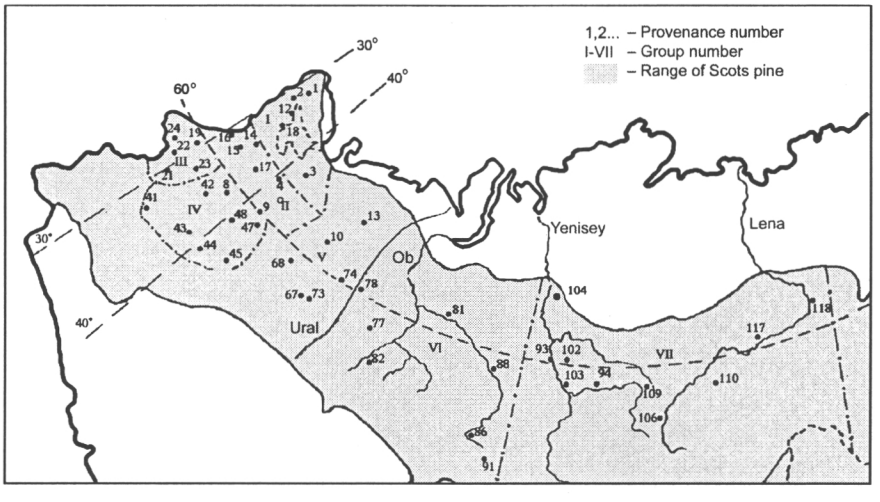


Figure 1. Scots pine provenances in the geographical plantation.

middle taiga sub-zones (running across Karelia in the area of Medvezhyegorsk).

The sites burned after felling and covered with heather are characterised by relatively infertile soil, poor water-holding capacity, and considerable daily variation in the temperature at the soil surface. Planted

seedlings are subjected to extreme soil and hydrological conditions.

Results and discussion

The average survival rate of the plantations in the planting year was 70.1%. Check group II ranked only fifth (71.1%) and the local provenance (14) ranked twentieth (74.4%). Groups III and IV (the southern taiga sub-zone of the northwestern part of the Russian Federation and central Russia) had the lowest survival. Groups V, VII, I and VI, which originated from the north-eastern part of European Russia and from Siberia, i.e. regions with a continental climate and distinct drought period, had the highest survival. Group I was the only exception (Fig. 2).

According to results presented by Krutov (1981), insect attack (55% of the total mortality) was the main cause of the extensive die back in all the provenances in the plantations during the following three-year period. Most of the seedlings were killed by *Melolontha hippocastani* Fabr. or the pine weevil (*Hylobius abietis* L.), which accounted for 90–95% of the die back caused by insects. Snow pine-leaf cast (*Phacidium infestans*) was responsible for 22% of the total die back. Groups III and IV were affected the most by these damaging agents - 27.7 and 29.3%, respectively, of the total mortality. The provenances in other groups were 2 to 3 times more resistant. Other agents, mainly abiotic ones, accounted for 23% of the total die back. By the fifth year, insects and fungal pathogens played a minor role in die back in the plantations.

During the first five years there were no clear changes in the survival of the provenances, although certain trends were apparent (Fig. 2). The mortality rate in most of the provenances in the plantation was 2–3% annually, and in some provenances 5–7%. On the whole the ranking according to survival ability at the present time levelled out at the age of 15 and it is not likely to change radically in the future.

The provenance 14, grown from locally collected seed, had relatively good survival (53.5%) at the age of 18. At this age only eight alternatives had better survival. Check group II, with a survival rate of 42.6%, ranked second to group I provenance from the northern taiga sub-zone, the difference

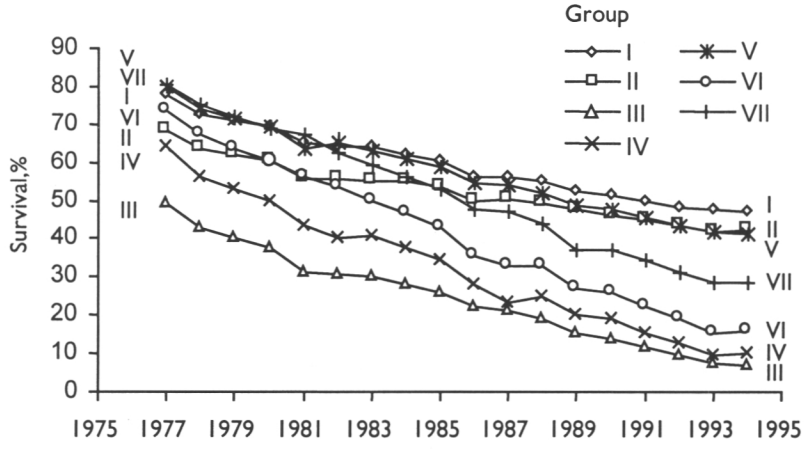


Figure 2. Survival of Scots pine provenance groups.

being 4.6%. These two groups gradually became the leaders owing to their lower share in the annual mortality. The reference group was followed by group V (41.3%) with almost the same survival rate. Groups III, IV and VI (the southern taiga sub-zone of the northwest part of the Russian Federation, the central regions of European Russia, and western Siberia) had the lowest survival rate. The provenances from eastern and middle Siberia were intermediate in this respect (Fig. 2). Overall, the survival rate of the provenances was 26.3% in 1994 (70.1% in 1977) which corresponds to a decrease of over 50% during the period. The different survival levels were clearly due to geographical factors. As expected, the provenances from the northern and middle taiga sub-zones of European Russia proved the most tolerant and adaptable, and certain northern provenances of the *lapponica* subspecies (Murmansk Region, the north of Arkhangelsk Region, northern Karelia) even had survival rates higher than the check alternative established using local seed.

Strong positive correlation was found between the latitude of seed collection and the survival rate of the different provenances (r = 0.92), while there was no correlation between the longitude of the provenance and the survival rate (Fig. 3). Thus, the results obtained from the plantation concerning the survival rate are, in principle, in relatively good agreement with the existing forest seed zoning system (Лесосеменное... 1982). They also confirm that the region located between latitudes 60–68° N in European Russia can be used as a source of seed for the Central Karelian seed sub-region of the Karelian seed region (63°–64°30' N, Karelia). Moreover, the use of pine seed from localities above latitude 63° N in the northern taiga sub-zone (e.g. 63°–66°40' N) will increase the survival rate of provenances at the most by 13.6%, while the use of seed from the south of latitude 63° N (e.g. 63°–60°40' N) will reduce the rate by 17.8%. Thus, the transfer of seed stock in a latitudinal direction within the Republic of Karelia even (60°40'–66°40' N) can substantially change the rate of survival.

Analysis of height growth in the plantation by the groups of provenances (Fig. 4) gives a picture that is almost opposite to the

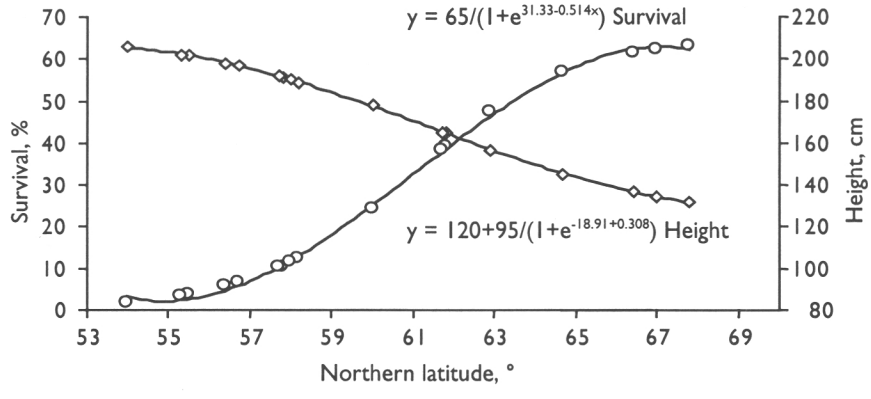


Figure 3. Geographical plantation of Scots pine. Regressions of survival and height of provenances on the latitudinal gradient.

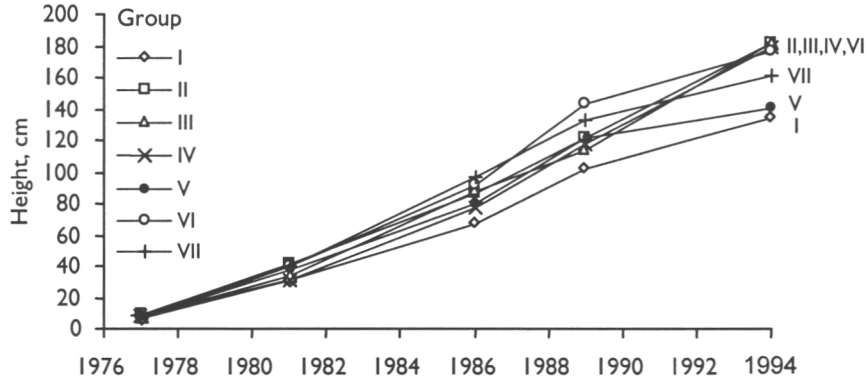


Figure 4. Height development of Scots pine provenance groups in the geographical plantation.

dynamics of survival. The northern provenance groups (I and V) are among the most slowly growing ones. Climotypes have rearranged for this indicator until recently, and hence the final picture had not been formed at the age of 15. Provenances from the middle taiga sub-zone (check group II) had relatively good survival and growth compared to the other groups. However, it should be pointed out that the growth parameters of the individual provenances in the trials differed considerably. Comparison of the partial average sets in the single-factor dispersion showed that the height of 29 provenances differed significantly from that of the local provenance (14), but only two had a greater stem diameter at root collar – provenances 24 and 9, respectively Genotype accounted for about 13% of the total variation in all the growth parameter. The height and diameter of check group II were significantly greater than in groups I, V and VII, but not in height compared to groups III, IV and VI. The provenances from the northern taiga sub-zone (group I) proved to be the most slowly growing ones. They had smaller height and diameter compared to the provenances of group II - 31.3 and 21.4%, respectively. The development success of the provenance groups was expressed by multiplying the survival rate (A) by the average height (B) (Table 2).

Check group II (rank 1) was clearly the best, followed by group I (the northern taiga sub-zone). Groups III and IV were the worst owing to their poor survival, although the growth indicators of these two groups were close to those of the reference group.

In these plantations there was no correlation between the provenances studied for height growth and the longitude of the provenance. However, there was strong negative correlation between the rate of height growth and the latitude gradient (r =

Table 2. Ranking at Scots pine provenance groups according to survival and height.

Group No.	Survival (A)	Height, cm (B)	A·B	Rank
I	0.47	134	63.0	2
II	0.39	181	70.6	1
III	0.07	182	12.7	7
IV	0.09	181	16.3	6
V	0.36	142	51.1	3
VI	0.17	177	30.1	5
VII	0.28	161	45.1	4

-0.67) (Fig. 3). According to the regression model, the transfer of pine seed from the northern part of Karelia to latitude 63° N may reduce the average height of the plantations by 13.1%, and transfer from the southern part to latitude 63° N increase this parameter by 10.6% compared to the reference.

Thus, opposite tendencies were determined in the plantations of Scots pine for survival and growth. If moved southward, pine provenances from the northern taiga sub-zone have a better survival rate but slower growth than the local provenances. The situation is the opposite for provenances originating from areas to the south of the trial location. On dry, relatively infertile sandy and sandy loam soils (Pinetum vacciniosum forest type) in the Central Karelian seed sub-region of the Karelian seed region (64°30'–63°00' N), where Scots pine does not normally suffer from competition from other coniferous and deciduous species but the hydrological conditions are not the most favourable for Scots pine, preference should be given to local seed collected from trees growing in similar conditions. It also should be recognised that seed from the Northern Karelian seed sub-region of the Karelian seed region (Karelia north of 64°30' N), i.e. the range of latitudes 63–66° N, can be used in this area. The positive effect of higher survival may compensate for their somewhat retarded growth rate. It is not recommended to use pine seed from the southernmost regions (south of 62° N) of Karelia, although the regulations currently in force do permit this.

In the middle and northern taiga subzones, especially in conditions where rapid growth of the trees is assured, evaluation of the survival of the plantations should be carried out at the age of 15–18 at least. As regards intra-species genetic variation in Scots pine, the data obtained from a single trial make it possible solely to point to the statistically confident difference in growth variables of most of the provenances and of their groups and the reference plots, the presence of the statistically substantial genotype component in the dispersion of the studied characters. Northern provenances (group I) were clearly differentiated in the plantations. This is in agreement with the large amount of experimental data verifying the existence of ssp. *lapponica*. We believe that the southern border of the distribution of this geographic race in the territory of Karelia should run somewhere between 64–65° N.

Conclusions

According to Shutyaev and Giertych (1997), the latest scientific reports on the trials of geographical plantations were forwarded by the participating organisations to the co-ordination centre (the Central Research Institute of Tree Breeding and Selection, in Voronezh) in 1990. This means that the large-scale trial is no longer being financed by the State. Of course the bulk of the information from the plots has already been collected. However, these studies need to be continued. It would be interesting to establish 3–4 new experiments, for instance between latitudes 60–67° N in the territory of Karelia, in order to test 20–40 pine provenances from the taiga zone of the Ural region of European Russia without attempting to include the entire natural growing area of Scots pine. Such tests would make it possible to study the intra-species structure of this species in greater detail.

REFERENCES

Крутов, В.И. 1981. Влияние лесопатологических факторов на приживаемость и сохранность географических культур сосны в Карельской АССР. In: Всесоюзное совещание по вопросам адаптации древесных растений к экстремальным условиям среды. Тез. докл. Petrozavodsk. p. 68–70.

Лесосеменное районирование основных лесообразующих пород в СССР. 1982. Moscow. 368 p.

Малышев, И.И. & Щербакова, М.А. 1993. Сравнительная оценка экотипов сосны и ели разного происхождения и выделение из них наиболее перспективных для Карелии. In: Селекция и лесное семеноводство в Карелии. Petrozavodsk. p. 5–26.

Марьин, Е.М. 1979. Географические культуры сосны обыкновенной в Карелии. In: Селекция и лесное семеноводство в Карелии. Petrozavodsk. p. 47–59.

Плохинский, Н.А. 1970. Биометрия. Moscow. 367 p.

Проказин, Е.П. 1972. Изучение имеющихся и создание новых географических культур. Pushkino. 52 p.

Shutyaev, A.M. & Giertych, M. 1997. Height growth variation in a comprehensive Eurasian provenance experiment of Pinus sylvestris L. Silvae Genetica 46(6): 332–348.

EXPERIENCES IN THE ESTABLISHMENT OF SCOTS PINE SEED ORCHARDS IN THE REPUBLIC OF KARELIA

A.A. Mordas

Forest Research Institute, Karelian Science Centre of the Russian Academy of Sciences, Pushkinskaya 11, Petrozavodsk, 185610, Russia

Establishment of seed orchards

Scots pine (*Pinus sylvestris L.*) is one of the most important and valuable forest-forming tree species. In Karelia, pine-dominated stands occupy some 60% of the total forest area, making it the predominant species used in reforestation. However, the demand for seed of local provenance (to be collected in highly productive natural pine stands) cannot be satisfied because of year-to-year variation in the cone crop and the low quality of seed resulting from the extreme climatic factors, especially within the northern taiga sub-zone. This situation has compelled us to use imported seeds, which frequently violates the principles of forest seed zoning and has resulted in the extensive spread of fungal pathogens and the death of pine plantations (Крутов and Шубин 1983).

Since 1982, the geographical and ecological transfer of forest seed for forest-growing purposes has been regulated by the document "Forest seed zoning ..." (Лесосеменного... 1982). In compliance with this document, the Karelian forest seed zone was subdivided into three sub-zones: North Karelia (north of latitude 64°30′ N), Central Karelia (between 63° and 64°30′ N) and South Karelia (south of 63° N).

In order to achieve large-scale production of seed with valuable genetic properties and high seed quality, permanent seed-supply areas have been created in Karelia since the early 1970's. This is mainly based on grafted seed orchards (Воробьев 1981), which is in line with recent trends in forest seed production.

The first experimental, grafted pine seed orchard covered 4 ha and was established by the Forest Research Institute of in the early 1960's. At that time, some 90 plus trees were selected, and the criteria to be used in their evaluation were defined (Щербакова et al. 1979). The intraspecific diversity of Scots pine was studied by distinguishing between geographical races (subspecies), varieties and biological forms (Козубов 1962).

The first commercial seed orchards were established in 1975 on the basis of the project carried out by the Institute "Soyuzgiproleskhoz" in the South-Karelian forest seed zone (Zaonezh, Lakhdenpokhya, Olonets and Petrozavodsk forest management units, leskhoz) where stable maturation of seed occurs (Лаур and Щурова 1987). The selection of plus trees and stands, and the vegetative propagation of plus trees, were first performed. The intensive selection of plus trees was carried out by the Petrozavodsk and Olonets Seed-Farming Stations, as well as by the Institute "Soyuzgiproleskhoz", on forests of the Pinetum myrtillosum (75%), P. vaccinio-sum (17%) and P. oxalidosum (6%) types. A number of plus trees (2%) were selected from less productive (Pinetum polytricho-sum and P. cladinosum) types (Щурова 1998).

According to the State Forest Committee of the Republic of Karelia, 1 451 plus trees and 395 ha of plus stands were selected for forest-breeding inventory purposes (as of January 1, 1996). 421.5 ha of grafted pine seed orchards were established, of which 204.5 ha were certified and included as permanent forest seed areas; 139.4 ha of grafted seed plantations of other species (Norway spruce, Karelian birch, larch, Siberian cedar pine) (Царев et al. 1996).

The reproductive properties of the grafted transplants were investigated as a joint effort by the Forest Research Institute (Karelian Science Centre, RAS) and the Petrozavodsk Forest Experimental Station (St. Petersburg Forestry Research Institute). The research was conducted in a representative first-generation pine seed orchard that had been established in the South-Karelian forest seed zone (Olonets), chosen on the basis of its site, soil and climatic conditions.

Results and discussion

As is generally known, the synchronous flowering of geographically and ecologically isolated clones in "synthetic" populations is a prerequisite for cross-pollination. We have not observed any phenological obstacles as regards the flowering periods of northern and southern ecotypes cultivated in South Karelia, thus making spontaneous intraspecific hybridisation possible. We have found comparatively early- and late-flowering clones (characterised by a short and long period in the development of macro- and microstrobiles) among the representatives of pine populations from North, Central and South Karelia and, therefore, it is the combination of these two features that ensures relatively favourable pollination throughout the entire flowering period.

Flowering in the pine seed orchards generally starts when the effective temperature sum (threshold value +5°C) reaches 180–190 °C·d. This usually occurs in late May – early June. When the weather is dry and warm, the development of female strobiles (starting from dehiscence of the seed scales and continuing up until their closure) lasts 10 to 12 days, and pollen production from male flowers is observed everywhere for 3 to 4 days. Unfavourable weather conditions (rain, frost etc.) often have a considerable influence on the regular development of the reproductive processes (i.e. their start and duration), sometimes resulting in the extensive death of inflorescences and ovaries.

The year-to-year variation in flowering and seed production, which is a normal occurrence in natural stands, can also be seen in seed orchards. However, seed years occur more frequently in the latter case and, even during intermediate periods, there is never any complete absence of seed. During eight years' observation in a plot comprising southern clones, abundant female flowering (averaging 3.5–4 points on a six-point scale) was reported every three years. Significant interclonal differences in the flowering abundance usually continue for several years in a row. However, we have found that some poorly flowering clones start to flower more abundantly 15 years after planting.

The reproductive activity of seed trees is highly dependent on their genetic characteristics. The genotype determines 30–40% and 37% of the abundance of female and male flowering, respectively, and varies only slightly between years. The variation is mainly dependent on seed periods, weather conditions and other factors. The high degree of inheritance of these characteristics makes it possible to apply them as criteria in the selection of high-yield clones.

Female flowering is predominant in the newly established seed orchards and the absence of external pollen is influencing seed production especially in the northern ecotypes. In our study, artificial supplementary pollination resulted in a 16–20% increase in the level of ovary preservation. A balance between female and male flowering, as well as favourable pollination conditions, were observed at the beginning of the second decade after planting; since then, cone formation has taken place regularly. At this age, the interclonal differences become stable with regard to flowering type, cone formation, seed yield, intervals between seed years, shape and structure of the crowns etc.

The highest seed productivity in one seed year, amounting to 18.3 kg/ha, occurred on a plot in a 15-year-old plantation. This accounted for 58% of the yield harvested from the four most productive clones (the total number of clones was 15). Since then, the seed production on this plot has dropped significantly due to increased canopy density. The reason for this was a comparatively high initial planting density (5x5 m), die back of the lower branches, and restriction of female flowering exclusively to the upper third of the crown. The average yield from 12–16-year-old plantations ranges from 2.3 to 9.3 kg/ha between seed years, depending on the composition and provenance of the clones, trees density, thinning regularity etc.

In data collected on the growth and development of 7- to 11-year-old, geographically isolated ecotypes, there was negative correlation between site latitude and growth parameters ($r_{height} = -0.73$; $r_{diam.} = -0.66$), and stronger positive correlation ($r = 0.99$) between latitude and the average fruit bearing index (Table 1). These data corroborate the well-established fact that an increase in the ambient temperature by several degrees above the normal value during the formation of generative buds results in more intensive flowering of Scots pine and a sharp improvement in seed germination.

The average seed yield of the northern clones surrounded by southern ecotypes amounted to 1.9–2.1% of the cone mass, and the proportion of empty seeds to 4.8–3.1% of the total number of seed. In natural pine stands in the northern taiga sub-zone the values are different: 0.4–0.6% and 20–50%, respectively (Волков and Зябченко 1966). It can be assumed that the natural pollination of northern clones by the pollen of southern clones should result in seed progeny that are more adapted to growing in northern regions than those from southern clones. This hypothesis is based to a certain extent on the fact that hybrids are

Table 1. Growth parameters and the reproductive capacity of 11-year-old climatic ecotypes of Scots pine in South Karelia.

Forest seed zone, subzone	Height, cm	Diameter at breast height, cm	Crown diameter, m	Flowering[1]		Fruit bearing[1]
				Female	Male	
North Karelia	341	5.7	1.8	4.8	1.1	3.2
Central Karelia	422	7.9	2.4	3.8	1.4	2.6
South Karelia	453	8.5	2.7	3.5	2.3	2.2
Moscow forest seed zone	523	9.3	2.8	1.0	3.1	0.6

1) according to a six-point scale

less sensitive to soil and climatic conditions because of their higher adaptability. However, the latter assumption needs to be verified experimentally.

The actual breeding value of the plus trees and seed from the seed orchards was tested using 8- to 15-year-old Scots pines on three experimental plots (total area 19 ha). 39% of the 31 families (half-sib progenies) had high growth, half (45%) showed similar growth to the reference plot, and the remainder (16%) had poorer growth. Depending on the age of the plantations and site quality, the number of relatively fast-growing progenies (breeding effect) ranged from 5 to 22%. The families belonging to this group have high vigour under different growing conditions due to their high adaptability (response standard). In order to improve the efficiency of artificial regeneration, these progenies should first be used in establishing forest plantations. However, seed from mother trees whose progeny have exhibited slow growth in the very beginning of our preliminary tests should not be rejected, because growth may drastically increase in the next stages of ontogenesis. Moreover, the results of controlled crossings have shown that pollen from mother trees can sometimes lead to pronounced heterosis in the hybrid progenies of the first-generation.

Thus, the Scots pine seed orchards can serve as a stable source of high-quality, genetically improved seeds for reforestation purposes in the Republic of Karelia, including its northern areas. However, the area of the seed orchards established so far is not sufficient to meet the seed requirements.

In addition to its main function, the establishment of seed orchards should be regarded as a significant element among measures aimed at conserving the valuable genetic potential of local, forest-forming species and promising introduced species.

One of the major forthcoming tasks is the improvement of the breeding effect and productivity of the pine seed orchards and the transition to a new qualitative stage of seed production by establishing second generation seed orchards. To implement this task, we should continue to assess and select the most promising clones in the existing seed orchards, carry out studies in the experimental plantations, and establish new seed orchards in areas where the mother (plus) trees are available.

The mechanisation of cone harvesting is still an urgent problem in practical seed collection considering the increasing age and size of trees. The lack of suitably designed lifting equipment means that all the seed cannot be collected from the trees.

Occasionally there are problems in the seed orchards caused by insects (banded pine weevil, large pine weevil, beetles, etc.), fungus diseases (pine twisting rust), small rodents (voles) and elk.

Conclusions

The establishment and utilisation of the permanent forest seed areas are implemented on the basis of tree breeding principles, and in accordance with the norms and regulations presented in the following recommendations and regulations: "Principal regulations for forest seed-farming in the Russian Federation" (1993), "Forest seed production zoning of the main forest-forming species in the USSR" (1982), "Regulations for allocation and conservation of the gene resources of wood species in the USSR forests" (1982), "Recommendations for establishing of the permanent forest seed orchards based on tree breeding principles" (1986), "Recommendations for selection and recording of forest seed areas

in the Russian Federation" (1995). Standards, rules and regulations in force should be taken into account.

In addition, the following practical and methodological recommendations have been published with regards to the regional problems under consideration: "Growing of improved planting stock in main forest nurseries of Karelia" (1977), "Coniferous seed orchards in the North of European Russia" (1984), "Methodological guidelines for forest seed production in the North of European Russia" (1985), "Establishing of seed orchards for the northern ecotypes of pine" (1986).

The Karelian Breeding and Seed Centre, State Forest Committee of the Republic of Karelia, is responsible for verifying the quality of the best trees and permanent seed orchards.

REFERENCES

Волков, А.Д. & Зябченко, С.С. 1966. О вызревании семян сосны в условиях Севера. In: Сборник научно-исследовательских работ по лесному хозяйству. Moscow. Вып. 10: 298–312.

Воробьев, Г.И. 1981. Генетика, селекция и семеноводство как основа создания высокопродуктивных лесов. In: Научные исследования для лесов будущего. Moscow. p. 6–14.

Козубов, Г.М. 1962. Внутривидовое разнообразие сосны обыкновенной (Pinus silvestris L.) в Карелии и на Кольском полуострове. Автореферат диссерт. канд. с.-х.н. Leningrad. 16 p.

Крутов, В.И. & Шубин, В.И. 1993. О районировании семян в северной подзоне тайги. In: Селекция и лесное семеноводство в Карелии. Petrozavodsk. p. 26–33.

Лаур, Н.В. & Щурова, М.Л. 1987. Лесосеменные плантации Карелии. In: Селекционно-генетические исследования древесных пород в Карелии. Petrozavodsk. p. 130–134.

Лесосеменное районирование основных лесообразующих пород в СССР. 1982. Moscow. 368 с.

Царев, А.П., Лаур, Н.В. & Щурова, М.Л. 1996. Состояние и проблемы развития постоянной лесосеменной базы в Республике Карелия. In: Труды лесоинженерного факультета Петр.ГУ. Petrozavodsk. Вып. 1: 100–103.

Щербакова, М.А., Ермаков, В.И. & Малышев, И.И. 1979. Из опыта отбора плюсовых деревьев сосны и создания первой в Карелии прививочной лесосеменной плантации. In: Селекция и лесное семеноводство в Карелии. Petrozavodsk. p. 59–70.

Щурова, М.Л. 1998. Отбор плюсовых деревьев сосны в Карелии. In: Научные основы селекции древесных растений Севера. Petrozavodsk. p. 143–147.

THE ESTABLISHMENT OF SECOND-ORDER SCOTS PINE SEED ORCHARDS

V.Ya. Popov and D.Kh. Faizulin
Northern Research Institute of Forestry, Nikitov str. 13, Arkhangelsk, 163062, Russia

Introduction

The genetic properties and quality of seed are crucial factors in the success of artificial reforestation. Therefore, a task of high priority in forest management is the establishment of high-yield, second-order seed orchards, producing seeds with valuable hereditary properties.

Phenotype-based selection of plus trees is only the first phase in the chain of breeding activities aimed at enhancing the yield of man-made forest stands. Numerous studies have shown that highly productive "parents" do not always produce good progenies. Our data (Попов et al. 1985) show that only 30% of plus trees belong to the elite, whereas the remaining 50% and 20% are average and unsatisfactory, respectively, in terms of their hereditary properties. The breeding effect is relatively low (5–8%) in orchards established with cuttings from plus trees, the heredity properties of which have not been checked.

It is essential, in order to raise the efficiency of seed orchards, to use plus trees with a high combining ability and good propagation potential. It is normally recommended to assess the hereditary properties of plus trees, such as the growth rates of the progeny, on the basis of long-term observations in trial plantations. However, scientists and practical foresters have to look for ways of overcoming the problems associated with the long duration of trials, the probability of errors in assessing the heredity properties of plus trees, and defining the growth rates of their progenies due to variation in soil conditions and other factors. Early diagnostic methods are being developed and applied to overcome these problems.

Trial plantations

It would be extremely important to find early diagnostics methods that are technically accessible, unbiased and highly productive. An early diagnostics method, based on the number of seed lobes, has been developed at the Northern Research Institute of Forestry (SevNIILKh) (Попов and Жариков 1973, 1978). The progenies of individual trees and populations are classified according to the relationship between the number of seed lobes in the germs (seeds) and the growth of the progenies during their first 10 years. At the present time the trial plantations include 20- to 29-year-old Scots pine trees with different numbers of seed lobes. The growth and development characteristics of heterolobed pine individuals (i.e. trees with different numbers of seed lobes) have been determined in this study. This has enabled us to make a reliable estimate of the potential of trees with 4, 5, 6, 7 and 8 seed lobes, and to obtain objective information on the genetic properties of plus trees.

Trial plantations with Scots pine were established in 1972, 1976, 1977 and 1979 in the middle and southern taiga sub-zones of European Russia. They were planted on cutover sites, previously occupied by pine,

of the Pinetum oxalidosum, vacciniosum, myrtillosum and callunus forest site types. The total area of the plantations is 11 ha. The planting stock comprised 2- to 3-year-old seedlings grown from seed collected in 1965, 1966, 1973, 1974 and 1976. The seed was collected from local populations and permanent forest seed areas (PFSA). There were 2 to 4 replications.

In all the trial plantations, established with progenies of different provenances (local population, PFSA) and progenies from different ecological conditions, the trees of the 6–8-lobed lines still have the most vigorous growth. At the age of 20 to 29 years the stem volume exceeded that of the 4- to 5-lobed lines by an average of 15–38% (Table 1).

The stable growth and superior development of the 6- to 8-lobed trees compared to the 4- to 5-lobed trees is due to the rapid and simultaneous germination of the seeds, and better development of the assimilation organs, root system and resin system of the needles and phloem. In the second year the 6- to 8-lobed trees already have more fascicles with 2 and 3 needles, a greater number of individuals with the three-needled trait, and a higher needle density per cm of axial shoot. The 6- to 8-lobed trees were superior to the 4- to 5-lobed trees in this respect by 6–19%, depending on the year. The needles and phloem of their axial shoots had a higher number of resin ducts (Table 2). This indicates that the number of seed lobes is genetically determined, and could therefore be used in the early diagnosis of the hereditary properties of plus trees and populations of Scots pine.

In the progenies of individual coniferous trees, the trait of seed lobe number is a function of the genotypes of the mother and father trees. The mother genotype plays a central role in determining this trait. In spite of the certain effect of pollinators, the ranking of the mother trees as regards this trait within the population remains the same in every reproductive year (Попов and Жариков 1978, 1990). Hence, if we determine the number of 6- to 8-lobed pine trees in the progenies of the trees and population, we can determine with a high degree of confidence the standing of the trees within the population in terms of this trait.

Pine trees with good hereditary properties include individuals whose progenies have 13% or more 6–8-lobed germs than progenies of the same reproduction populations. The seed collected from such trees is classified as certified seeds. This hybrid group of trees comprises 10–12% of the populations.

This method for the early diagnosis of hereditary properties, based on the number of seed lobes and the growth of heterolobed individuals and their resistance to unfavourable environmental factors, can be used to assess, already during the first year with a high seed yield, the hereditary properties of plus trees without having to establish trial plantations. Forest seed orchards could then be established to produce progenies with a productivity 15–20% higher than that of natural stands (Попов and Жариков 1978).

It is known (cf. Basic Regulations on Forest Seed Breeding in the Russian Federation (Основные... 1994)) that the genetic value of plus trees is determined by their combining ability, i.e. the ability to maintain selected traits (properties) in their seed progenies. Plus trees of high combining ability are defined as elite individuals.

However, we consider such a definition to be one-sided. Elite individuals should encompass trees which, as well as a high-combining ability, also possess good inheritance in terms of seed yield. Second-order pine orchards, established with veg-

Table 1. Dimensions of Scots pines grouped according to the number of seed lobes in trial plantations established during 1972–1979 in the middle and southern taiga sub-zones of European Russia.

Year of establishment	Former forest site type	Seed source	Year of seed production	Tree age, a	Number of seed lobes					
					4–5			6–7		
					Height, m	Diameter, cm	Volume, m^3	Height, m	Diameter, cm	Volume, m^3
Middle taiga sub-zone										
1972	Pinetum myrtillosum, IV site class	Population	1965	29	6.9±0.08	8.6±0.18	0.0247	7.4±0.19	9.3±0.37	0.0304
		PFSA[1]	1966	29	7.0±0.27	8.7±0.53	0.0255	7.8±0.15	9.8±0.40	0.0351
Southern taiga sub-zone										
1976	P. oxalidosum, II site class	Population	1973	23	9.4±0.11	13.0±0.09	0.0741	9.8±0.07	13.5±0.01	0.0850
1977	P. vacciniosum, III site class	Population	1974	23	9.3±0.19	10.1±0.13	0.0429	10.0±0.17	10.5±0.15	0.0492
		PFSA	1974	23	9.5±0.14	10.2±0.16	0.0436	10.1±0.15	10.6±0.19	0.0505
1979	P. callunus, IV site class	Population	1976	20	6.9±0.08	7.6±0.07	0.0193	7.1±0.09	8.1±0.05	0.0224

1) PFSA = permanent forest seed area.

Table 2. Development of 2- to 23-year-old heterolobed Scots pines in trial plantations, 1976.

Characteristic	Number of seed lobes			
	4	5	6	7
	2-year-old seedlings			
Number of fascicles with 2 needles	37±4.2	46±2.1	58±2.8	62±3.7
Number of fascicles with 3 needles	0.6±0.2	1.2±0.2	1.8±0.3	2.1±0.3
Needle length in two-needled fascicles, mm	41±2.8	45±1.2	63±1.9	61±1.7
Three-needled seedlings, %	40	46	59	57
	8-year-old trees			
Three-needled trees, %	50	62	68	84
	11-year-old trees			
Area of assimilation surface, dm^2		930	1130	1230
	23-year-old trees			
Number of needles/cm of axial shoot in 1994	8.3±1.0	9.8±0.4	10.5±0.5	10.6±0.4
Number of needles/cm of axial shoot in 1995.	9.4±1.1	9.9±0.5	10.3±0.5	10.4±0.6
Three-needled fascicles on the axial shoot, 1994, %	29	40	45	60
Three-needled fascicles on the axial shoot, 1995, %	8	26	29	37
Trees with 50 and more three-needled fascicles on the axial shoot, 1995, %	12	38	50	65
Number of resin ducts in the needles, 1994	14.1±0.1	14.3±0.1	14.8±0.1	15.2±0.1
Number of resin ducts in the needles, 1995	14.9±0.1	15.2±0.1	15.7±0.1	16.3±0.1

etatively propagated progenies of elite trees, should have high seed yields.

Individual variation in the seed yield of coniferous trees is largely due to differences in inherited characteristics such as cone abundance and the yield of fully-formed seed. As a rule, these hereditary characters are independent, and the value of one cannot serve as a reliable indicator of the other. Therefore, two characters should be used to assess the seed production of trees, and namely: the abundance of cones and the of full-grained seeds (Попов and Тучин 1982, Тучин and Попов 1982).

In years with a high seed yield the seed production of plus trees and clones can be estimated directly, whereas in years with a low seed yield the estimates are based on branch angle, which is an indirect indicator. On trees with a high seed production potential the angle between the stem and the first-order side shoots is usually equal or close to 90° (Попов et al. 1994).

Direct estimation of the seed production of plus trees is based on visual counts of the number of cones on the plus trees and on 40–50 control trees surrounding them. The

average number of cones per fruiting tree in the stand is then calculated. If a plus tree has at least 1.5 times more cones than the average for the stand, the plus tree is classified as abundantly fruiting (Попов and Тучин 1982).

Branch angle is the most suitable character for estimating the pine seed production potential in years with a low seed yield. Studies carried out over many years have demonstrated that trees with a branch angle of 90° (right angle) typically reach the reproduction phase at an earlier age and have more abundant flowering and fruition than trees with a branch angle of 75°, and even more so than trees with 60° (acute angle). Individuals with a branch angle of 90° bear larger cones and seed, and have the highest seed yields (Table 3).

The difference between right-angled and acute-angled trees with respect to flowering and fruition intensity in the middle taiga

Table 3. The seed-bearing dynamics of Scots pine with different branch angles permanent forest seed areas in the southern taiga sub-zone of European Russia.

Year	Branch angle			
	60°	75°	90°	Average
	Trees with cones, %			
1988	100	100	100	100
1989	69	76	100	77
1990	44	54	63	52
1991	75	97	100	94
1992	100	99	100	99
1993	100	100	100	100
1994	33	51	86	56
1995	93	97	100	97
	Number of cones per seed-bearing tree			
1988	41±8	57±8	77±20	56±7
1989	16±5	26±5	39±16	26±4
1990	17±6	31±8	47±36	29±7
1991	119±36	126±12	193±60	130±11
1992	141±30	165±14	241±45	167±12
1993	313±43	341±20	540±111	350±19
1994	18±5	20±3	29±4	21±3
1995	79±17	120±16	203±103	120±14
	Seed production of 15- to 20-year-old trees, g			
1988	4.96	6.35	9.08	6.38
1989	1.34	2.48	3.37	2.42
1990	0.77	1.45	2.41	1.34
1992	19.48	24.40	28.54	23.84
1993	44.32	48.07	55.11	48.67

sub-zone is greater than that in forest seed stands in the southern taiga zone. The intensity of male "flowering" is 2.7–5.0 times higher, and for female "flowering" and fruition 1.5–10.0 times and 2.3–4.2 times, respectively. This is due to the fact that normal pollination and seed ripening in the middle taiga sub-zone are often retarded by low temperatures. Under such conditions, the branches of trees with a branch angle of 90° are more exposed to sunlight and subsequently higher temperatures.

The flowering and fruition, number of cones and seeds and eventually the seed yield of right-angled trees are superior to those of acute-angled (60° and 75°). This superiority is determined by the distribution of shoots. The crowns of right-angled trees are more open than those of trees with other crown forms. This is explained by the greater amount of light reaching the female flowers, faster growth and better access to pollen.

If implemented, the SevNIILKh recommendations on direct and indirect (branch angle) indicator-based selection of abundantly seed-bearing plus trees and clones of pine will enable us to enhance the seed production of seed orchards by a factor of 1.5–1.7 (Попов and Тучин 1982, Тучин and Файзулин 1990).

Scots pine trees with different branch angles do not differ greatly as regards the proportion of fast-growing individuals in their progenies. This indicates that it is always necessary in Scots pine breeding to first breed for trees with productive progenies, and only then to breed for trees with a high seed yield.

Conclusions

Researchers at the Northern Research Institute of Forestry have determined regularities in inheriting economically valuable traits and properties of Scots pine, developed early diagnostic methods for the hereditary properties of plus trees with respect to the growth rate, seed yield and of the progenies; and worked out proposals concerning the selection of grafting scions of pine. These developments are allowing foresters to start establishing second-order pine seed orchards.

REFERENCES

Основные положения по лесному семеноводству в Российской Федерации. 1994. Moscow. 23 p.

Попов, В.Я. & Жариков, В.М. 1973.Методы отбора и ранней диагностики наследственных свойств плюсовых деревьев сосны и ели (Методические рекомендации). АИЛиЛХ. Arkhangelsk. 40 p.

Попов, В.Я. & Жариков, В.М. 1978. Ранняя диагностика наследственных свойств плюсовых деревьев сосны и ели (Методическое пособие). АИЛиЛХ. Arkhangelsk. 14 p.

Попов, В.Я. & Тучин, П.В. 1982. Методические рекомендации по селекционной оценке семенной продуктивности плюсовых деревьев сосны и ели. АИЛиЛХ. Arkhangelsk. 9 p.

Попов, В.Я., Тучин, П.В., Жариков, В.М. & Барболин, Н.А. 1986. Комплексная селекционная оценка плюсовых деревьев сосны и ели на Европейском Севере. Научно-исслед. работы за 1981–1985 гг. Лесная промышленность. Moscow. p. 101–106.

Попов, В.Я. & Жариков, В.М. 1990. Селекционные основы семеноводства на Европейском Севере. Селекция и семеноводство хвойных пород на Европейском Севере. АИЛиЛХ. Arkhangelsk. p. 3–17.

Попов, В.Я., Тучин, П.В. & Файзулин, Д.Х. 1994. Селекционные приемы повышения урожайности на плантациях и постоянных лесосеменных участках сосны обыкновенной. Антропогенное вляние на Европей-

ские таежные леса России. АИЛиЛХ. Arkhangelsk. p. 123–137.

Тучин, П.В. & Попов, В.Я. 1982. О взаимовлиянии маточников и опылителей на выход полнозернистых семян сосны обыкновенной. Материалы научной сессии по итогам научно-исслед.работ за 1981 г. АИЛиЛХ. Arkhangelsk. p. 47–49.

Тучин, П.В. & Файзулин, Д.Х. 1990. Динамика плодоношения сосны на плантациях вегетативного и семенного происхождения. Селекция и семеноводство хвойных пород на Европейском Севере. АИЛиЛХ. Arkhangelsk. p. 18–23.

UTILISATION AREAS OF SEED SOURCES

V. Koski
Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

Artificial regeneration aims at the formation of stands with a fast growth rate and good quality. A good combination of two main factors, namely genetics and silviculture, is a precondition for achieving such a result (Photo 15). The importance of this basic principle can be illustrated as follows:

Genetical quality	Silvicultural measures	
	adequate	inadequate
High	Good	Poor
Low	Poor	Failure

Silviculture, in its broad sense, includes all choices and measures extending from site selection up to thinnings. However, the scoring of genetical quality and silvicultural measures is not based on two categories "good" and "bad". Both factors can have any value from 0 (zero) to 1. The connection between genetics and silviculture can be expressed as:

$$P = G \times S$$

where P = yield, G = genetical quality, and S = silvicultural quality.

According to the rule of multiplication, the product is always small if any of the factors is close to zero. In other words, a low score in one factor is not compensated by extra input from another one.

The selection of geographical origin is of primary importance in genetical issues. Adaptation to the local climate is the focal point in the boreal zone. All other traits are subordinated to adaptation.

Local (autochthonous) seed source is a spontaneously emerging alternative, which is currently often mentioned as the only acceptable choice in the name of faithfulness to nature. Local origin in this connection is understood in a very narrow sense; limited to few kilometres. However, such a restriction does not work on a practical scale. Real local seed is seldom available. Seed procurement and nursery production would meet insurmountable difficulties, if hundreds of small seed and seedling lots had to be produced and kept apart, as well as their documented identity. All studies on population genetics and provenance trials have revealed that in fact local origin must be defined more broadly. In conditions like those in Finland, the range is approximately ±1° latitude and ca. 500 km in the east-west direction.

A solid set of rules for seed transfer has been obtained from a series of provenance trials established since the beginning of the 20th century. A comprehensive series of field trials has been established more recently with seed orchard material. Climatic adaptation does not set as stringent boundaries in the temperate zone, e.g. in Central Europe, as it does in the boreal zone.

Finnish implications

Traditional rules for seed transfer (Heikinheimo 1949) state that local seed should be used for Scots pine (*Pinus sylvestris* L.), and seed of 2 to 3 degrees more southerly origin for Norway spruce (*Picea abies* (L.) Karsten). During the last few years, how-

ever, southward transfer of Scots pine has been promoted in the northern part of Finland.

Seed for sowing, especially in the nurseries, have mainly been collected from seed orchards during the past ten years (Photo 16). Seed orchards are artificial populations, and the utilisation areas of respective seed crops are therefore not determined in the same way as those of natural stands. Each seed orchard consists of numerous clones whose ortets (plus trees) originate from a fairly large zone. Seed orchards were often established in a climatically more favourable zone in order to enhance seed production. A transfer to the south has caused undesirable hybridization between climatic ecotypes as a result of heavy pollen contamination in seed orchards. The provenance hybrid has superior performance in the central area of the plus tree origins and at the seed orchard location.

All the above factors are taken into account when calculating the utilisation area for each orchard. The average effective temperature sum (above +5°C) of the growing season is used as the climate parameter. The formula contains the following factors:

1. Temperature sums of the original sites of the respective plus trees.
2. Number of ramets per clone.
3. Temperature sum at the seed orchard.

Nikkanen and Karvinen (1999) have developed algorithms containing the following terms:

Z = utilisation area in terms of temperature sum,

TS_A = the average temperature sum of the plus trees, weighted by the number of ramets,

TS_B = temperature sum of the seed orchard location,

C = northern restrictor (if $TS_A > 1\,100$ °C·d, $C = 0$), and

$TS_M = 0.75 \times TS_A + 0.25\ TS_B + C$ = characteristic of the seed crop.

Owing to their different response to transfer, pine and spruce have their own variables:

Scots pine

$Z = TS_M - 100$ °C·d $\leftrightarrow TS_M + 100$ °C·d /maximal transfer

Norway spruce

$Z = TS_M - 130$ °C·d $\leftrightarrow TS_M + 70$ °C·d

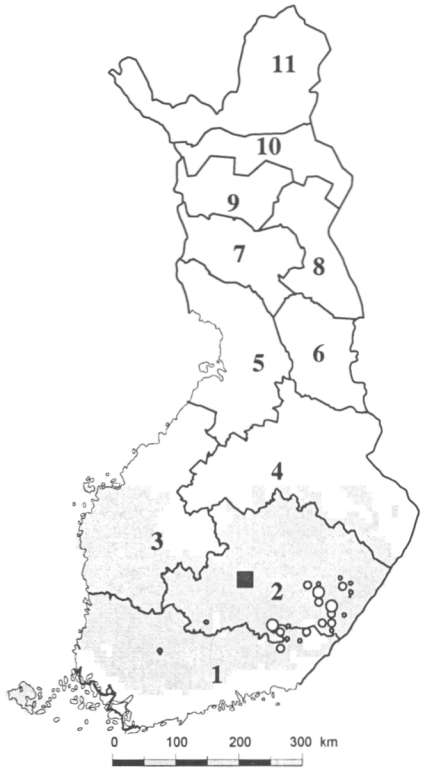
The result of the calculations is illustrated with some examples from the catalogue in Fig. 1.

Future trends

During the past few decades the rules of seed transfer and utilisation areas for seed orchards have been based on a rather scanty knowledge of genetic factors, and have often been rather over-optimistic. Since then, research on forest genetics has generated a large amount of useful information. Advanced statistical analyses carried out on powerful computers have produced more comprehensive, new information from the mature provenance trials. The following examples illustrate findings that will influence selection of the origin of reforestation material.

The impact of geographical transfer on performance is not a consistent function of distance, but depends on latitude (Beuker 1994, Persson 1994, 1998). This phenomenon is significant to the north of latitide 60°, and increasingly important north of latitude 65°. Such a pattern is most probably connected to differences in the fluctuation of the photoperiod. Some experimental studies support this hypothesis (Partanen et al. 1999).

Seed orchard No. 61 Huhtapuro



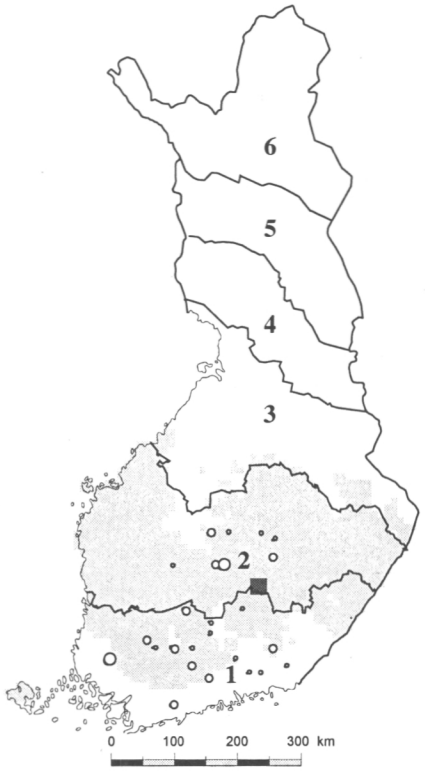
Tree species: Scots pine
Pinus sylvestris
Owner: Finnish Forest and Park Service
Established: 1967
Location: Toivakka
62°02′ N, 26°14′ E, 160 m a.s.l.

Temperature sum:

Seed orchard location	1125 °C·d
Plus tree sites	1224 °C·d
Utilisation area	1090–1290 °C·d

Area:	8.7	ha
Number of clones:	73	
Number of ramets:	1248	
Density:	143	trees/ha
Planting spacing:	5x5	m

Seed orchard No. 111 Leppäniemi



Tree species: Norway spruce
Picea abies
Owner: Forestry Development Centre Tapio
Established: 1966
Location: Kangasniemi
61°56′ N, 26°41′ E, 100 m a.s.l.

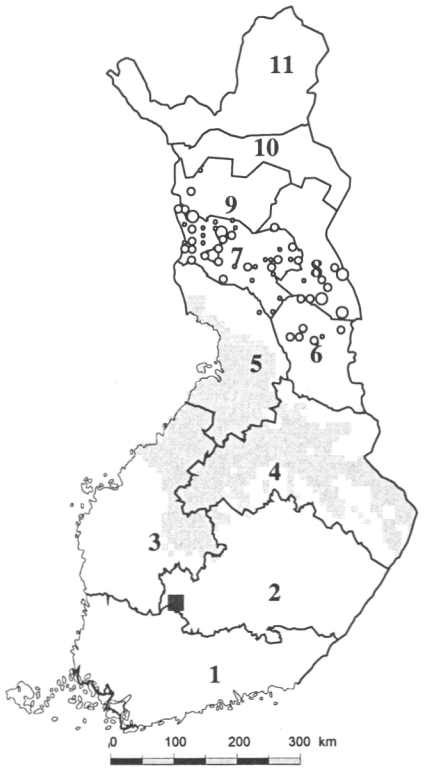
Temperature sum:

Seed orchard location	1184 °C·d
Plus tree sites	1199 °C·d
Utilisation area	1060–1260 °C·d

Area:	9.8	ha
Number of clones:	57	
Number of ramets:	3231	
Density:	330	trees/ha
Planting spacing:	5x5	m

Figure 1. Examples of the utilisation areas for Scots pine and Norway spruce seed orchards. One case is shown for each species in which the seed orchard is located within the utilisation area (pine No. 61, spruce No. 111), and another one in which the seed orchard is located considerably south of the origin of the plus trees (pine No. 125, spruce No. 365). Seed orchard location is marked with a square, origins of the plus trees with solid circles, and the utilisation area is shaded. Respective breeding zones are indicated by borderlines and numbers (See next page).

Seed orchard No. 125 Ristaniemi



Tree species: Scots pine
Pinus sylvestris
Owner: Forestry Development Centre Tapio
Established: 1973
Location: Orivesi
61°42′ N, 24°15′ E, 160 m a.s.l.

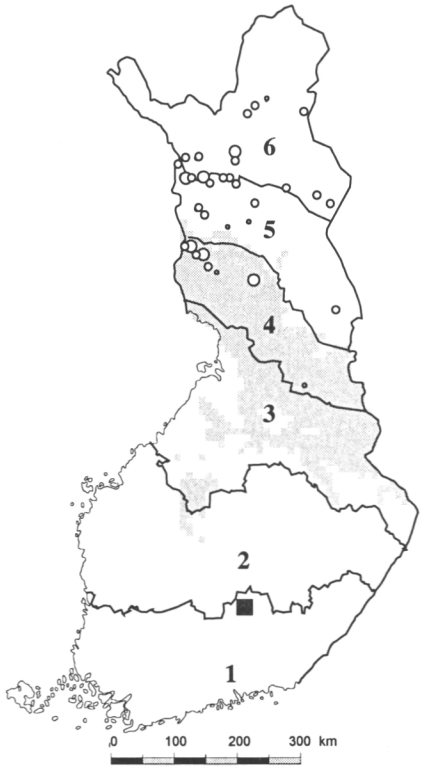
Temperature sum:

Seed orchard location	1169 °C·d
Plus tree sites	838 °C·d
Utilisation area	970–1080 °C·d

Area:	22	ha
Number of clones:	173	
Number of ramets:	6380	
Density:	290	trees/ha
Planting spacing:	5x5	m

■ Seed orchard
Utilisation area
• Plus tree
o 2-5 plus trees
O > 5 plus trees
1–11 Breeding zones

Seed orchard No. 365 Paronen



Tree species: Norway spruce
Picea abies
Owner: Finnish Forest and Park Service
Established: 1970
Location: Joutsa
61°39′ N, 26°17′ E, 130 m a.s.l.

Temerature sum:

Seed orchard location	1217 °C·d
Plus tree sites	820 °C·d
Utilisation area	850–1030 °C·d

Area:	28.3	ha
Number of clones:	122	
Number of ramets:	9001	
Density:	318	trees/ha
Planting spacing:	3.5x7	m

■ Seed orchard
Utilisation area
• Plus tree
o 2-5 plus trees
O > 5 plus trees
1–6 Breeding zones

In the case of Scots pine, the origin of the seed has a large impact on stem and wood quality (Ståhl 1998). A southern origin produces more pulp wood, but the stem form, branchiness, and wood density are poor. A northern origin yields less in volume, but the proportion of high-quality stems is high. The type of origin chosen depends on the aim of forest cultivation.

The idea that the adaptive traits of forest trees are narrow and static has proved to be erroneous. Trees possess a large acclimation potential, as displayed in provenance trials. However, there are conspicuous differences among species and origins. Furthermore, genetic change, i.e. adaptation, can be significant even in one generation. A spruce stand whose first generation grew in a new environment produced offspring different from those growing at the original site (Skrøppa and Kohmann 1997). One very surprising finding is that the location of the seed orchard and the weather conditions during reproduction have an impact on the annual rhythm of the offspring of Norway spruce, and consequently on their hardiness (Jonsen and Skrøppa 1996,1997, Johnsen et al. 1996, Skrøppa and Kohman 1997). The biological mechanism behind these phenomena is still obscure.

Conclusions

In conclusion, proper choice of seed source is always a fundamental element of successful forest cultivation. Seed orchard material has the advantage that the utilisation areas have to be defined. The utilisation area is the geographical zone within which field survival is at least as good as that of the local origin. Further elaboration of the methods for delineating utilisation areas and seed transfer is still needed. Intensified research co-operation based on Finnish, Scandinavian, and Russian provenance trials, would broaden the scope and promote the theoretical and practical aspects of geographical variation.

REFERENCES

Beuker, E. 1996. Implications of climate adaptability in provenance trials with Scots pine and Norway spruce in Finland for the possible effects of climate warming. Dissertation. University of Joensuu, Faculty of Forestry. 33 p. ISBN 951-708-400-5.

Heikinheimo, O. 1949. Tuloksia kuusen ja männyn maantieteellisillä roduilla suoritetuista kokeista. Summary: Results of experiments on the geographical races of spruce and pine. Commun. Inst. For. Fenn. 37.2. 44 p.

Johnsen, Ø. & Skrøppa, T. 1996. The adaptive properties of Picea abies progenies are influenced by environmental signals during sexual reproduction. Euphytica 92: 67-71.

Johnsen, Ø., Skrøppa, T., Junttila, O. & Daehlen, O.G. 1996. Influence of the female flowering environment on autumn frost hardiness of Picea abies progenies. Theor. Appl. Genet. 92: 797-802.

Johnsen, Ø. & Skrøppa, T. 1997. Parents of Norway spruce adjust the performance of their progeny according to changes in climate and weather during female flowering. In: Mohren, G.M.J. et al. (eds) Impact of global change on tree physiology and forest ecosystems. p. 159-163. Kluwer. Dordrecht.

Nikkanen, T. & Karvinen, K. 1999. Männyn ja kuusen siemenviljelykset Suomessa. Manuscript. Finnish Forest Research Institute.

Partanen, J. & Beuker, E. 1999. Effects of photoperiod and thermal time on the growth rhythm of Pinus sylvestris L. seedlings. Scand. J. For. Res. 14: 487–497.

Persson, B. 1998. Will climate change affect the optimal choice of Pinus sylvestris provenances? Silva Fenn. 32: 121-128.

Skrøppa, T. & Kohmann, K. 1997. Adaptation to local conditions after one generation in Norway spruce. Forest Genetics 4: 165-171.

Ståhl, E. 1998. Changes in wood and stem properties of Pinus sylvestris caused by provenance transfer. Silva Fenn. 32: 163-172.

5. PLANTING STOCK PRODUCTION

SEEDLING PRODUCTION FOR REFORESTATION

R. Rikala
Finnish Forest Research Institute, Suonenjoki Research Station, FIN-77600 Suonenjoki, Finland

Introduction

The task of forest nurseries is to produce seedlings that meet predetermined morphological and physiological criteria at moderate cost within a specific timetable. The ultimate indicator of the quality of the entire chain from nursery to planting site is the success of planting-out. From the point of view of plant quality and subsequent changes in quality, the chain can be divided into three parts: 1) growing the seedlings at the nursery, 2) transferring the seedlings and planting out, and 3) acclimation of the seedlings to the planting site (Fig. 1).

Seedling quality at the nursery is the result of the combined effect of the genotype of the seed and the propagation environment, which includes the geographic location, propagation facilities and cultivation practices used to raise the seedlings. The purpose in regulating the propagation environment and in the choice of cultural practices is to steer the seedling characteristics in the desired direction. Following the growing stage, the transportation, storage and planting-out phases have crucial impacts on the out-planting performance. The seedlings have to be able to withstand the stresses they are subjected to during transportation and storage, and then acclimate quickly to the conditions of the planting site.

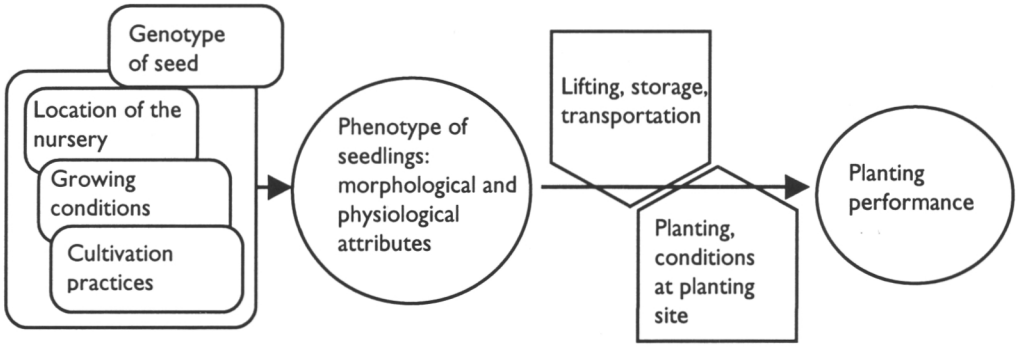


Figure 1. Schematic diagram of the factors influencing seedling attributes and the planting performance.

Development of seedling production methods

Up to the end of the 1950's, the practices used in the production of seedlings for reforestation in Finland were based on Central European trends. From the 1930's onwards production was mainly concentrated on the production of spruce planting stock, but in the 1950's there was a strong increase in the proportion of pine seedlings. Annual production reached a peak of about 250 million seedlings in the early 1970's (Fig. 2). Birch production started in the 1970's. In 1997, the distribution of forestry planting stock produced in Finland was as follows: Scots pine 38%, Norway spruce 45%, birch 13%, and other species 3% (mainly larch and lodgepole pine).

Forest tree nurseries increased in size, and the mechanisation of bare-rooted stock production began in the 1950's. Transplanting machines, root pruning machines and lifting machines were developed for this line purpose. Production in greenhouses was introduced in the 1960's, and the use of irrigation systems, horticultural peat and fertilisers increased strongly. The aim was to rationalise and automate seedling production because of the rise in labour costs, the reduced availability of labour, and the need to level out peaks in labour requirements. The great speed at which these changes were introduced in Finland is demonstrated by the fact that the proportion of containerised seedlings out of the total seedling production in 1976 was 26%, and 20 years later it was 86%. The proportion of bare-rooted stock continues to be high in Central Europe and in the United States, indicating that this production method is still competitive under certain conditions. There are considerable differences between bare-rooted stock and containerised stock as regards their production requirements, methods, and the way the seedlings are used, and these factors deserve careful consideration when designing new seedling production (Table 1).

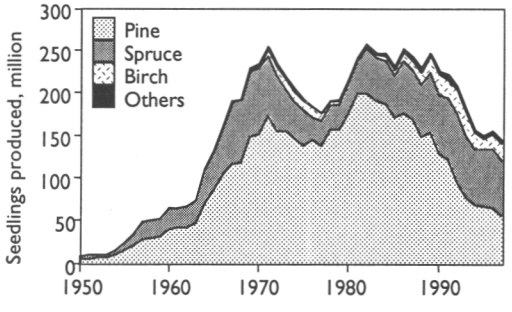


Figure 2. Development of forest tree seedling production in Finland by tree species during the period 1950–1997. The tree species distributions presented for the years 1953–1964 are estimates.

Seed, seed treatment and seed germination

Seed treatment before sowing

Rapid, uniform seed germination is an important aspect in achieving even seedling development. Pre-treatment of the seed is sometimes used even in the production of bare-rooted stock; for instance, stratification improves the germination rate in the field. In containerised seedling production it is nowadays even more important that every seed germinates. However, all the seed do not germinate within a reasonable time even though they may be viable. Such seeds are still in a state of dormancy. There are a number of reasons for seed dormancy. The germination capacity and germination rate of the seed can be promoted by removing the non-germinated seeds, or by shortening the germination time of individual seeds by breaking seed dormancy by physical and physiological means. One ex-

Table 1. Comparison of the production of containerised and bare-rooted seedlings (modified from Landis et al. 1995).

Factor	Production of containerised seedlings (CP) compared to the production of bare-rooted seedlings (BP)
Length of the growing period and location	CP is better for areas with a short growing season (northern or high altitude regions): high elevation or high latitudes
Space requirement and soil quality	Less growing space is needed and soil quality is less important in CP than in BP
Initial investment	CP requires more expensive structures and equipment than BP, where the costs vary according to the degree of mechanisation
Amount and quality of water	CP requires less water than BP, and the quality can be chemically controlled; good quality essential in BP production
Labour	In CP the labour requirements are smaller and the work peaks lower, more expertise (depends on the degree of mechanisation) is needed
Structures, machinery and equipment	In CP this ranges from open growing areas to sophisticated structures, devices and automation
Seed-use efficiency	In CP high efficiency (close to 100%) with seed pre-treatment, whereas in BP only 10%–30%
Length of crop rotation and plant size	In CP shorter (3 months to 2 years) rotation, smaller plants and size variation than in BP, in which the rotation is longer (2–4 years), tall plants and larger variation
Suitability of tree species	CP: small seed, weak germination, slow-growing, tap-root dominant tree species; BP: broadleaved plants requiring plenty of growing space
Pests	In CP smaller pest risk due to sterile medium, but a risk of abiotic injury due to enclosed structures and shorter rotation time
Winter storage	In CP roots are susceptible to injury if stored outdoors. When kept in cold storage requires more storage space than bare-rooted plants
Handling of seedlings	CP is more tolerant of physical damage or exposure than BP
Transport	CP take up more space and are heavier than BP, but need no short-term, cold-storage
Out-planting site conditions	CP suffer less planting shock than BP
Planting season, site preparation	CP have wider planting windows than BP. Site preparation is more important for CS than for BP
Planting work	CP quicker to plant and less prone to faults in planting
Planting performance	On average, the differences are small, but can also be great depending on the site

ample of the physical methods is mass-and-size based grading. The separation of viable and non-viable seeds by the Prevac and IDS methods, developed and introduced in Sweden, is based on their different water-retention capacities. Physiological methods include stratification and light and hormone treatments (e.g. Bonner et al. 1974).

Germination and germination conditions

Moisture and temperature are the primary factors initially affecting seed germination. The process of water absorption can be divided into three stages. In the first stage, immediately after sowing, seeds absorb plenty of water and it is important to keep

them moist. Under optimum conditions, this stage lasts for 12–24 hours in pine seed, and is a reversible process. The second stage (duration 3–5 days) involves the initiation of enzymatic and metabolic functions, which require oxygen in addition to water. This stage is irreversible, i.e. if the seed dries out, it will also die. In the third stage, cell division begins and the point of the primary root breaks through the seed coat. Under nursery conditions, birch takes less than one week to germinate, pine takes 1–1.5 weeks, and spruce 1.5–2 weeks.

Seeds are usually sown in the spring in the open when the soil temperature has risen to +10°C. Depending on the tree species and seed provenance, the temperature in the greenhouse during seed germination is kept at 20–25°C (Landis et al. 1992). At this stage, the germlings are sensitive to both low and high temperatures. Even brief periods of low temperatures (<5°C) can arrest seedlings growth for a considerable time. On the other hand, it is recommended that spruce stock be irrigated if the temperature at the soil surface rises above 27°C.

Fertilisation

Effect of fertilisation on seedlings

Fertilisation has a marked effect on seedling quality. It generally increases seedling size, dry mass, nutrient concentrations and the allocation ratios (e.g. root/shoot ratio) (Duryea 1984) (Fig. 3). Excessive fertilisation can lead to growth abnormalities, e.g. lammas growth (Rikala 1992). Also, the nutrient status of the seedlings affects their frost-hardiness (e.g. van den Driessche 1991). A poor nutrient status in pine seedlings impairs their frost-hardiness during hardening (Rikala and Repo 1997). In general, fertilisation does not appear to have a clear effect on the post-planting survival of

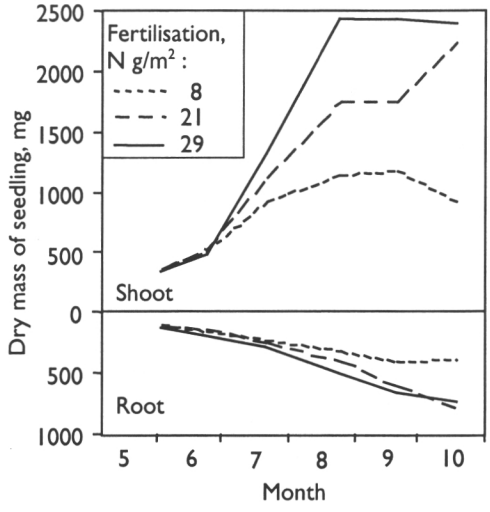


Figure 3. The development of the dry masses of the shoots and roots of container pine seedlings during the second growing period by different fertilisation treatments (Rikala and Huurinainen 1990). The seedlings were fertilised using multi-nutrient fertiliser solutions.

seedlings, but high nutrient concentrations, especially a high nutrient content, accelerates height increment (e.g. Rikala and Huurinainen 1990).

Determining the need for fertilisation

The need for fertilisation depends on the amount of nutrients taken up by the seedlings, the amount of nutrients immobilised in the soil, the amounts leached from it, and the amounts possibly taken up by weed plants. In practice, the following questions usually arise with respect to fertilisation: how much, in what proportions, in what form, and when?

Earlier, fertilisation was based on experience or on the average amounts of nutrients taken up by seedlings. A more reliable picture of the fertilisation requirement is obtained by carrying out soil and plant analyses. A common practice used to monitor the nutrient status of the substrate

in containerised seedling production is to measure the electrical conductivity (EC), the nutrient concentrations in the water in the growth medium, or the concentration of soluble nutrients in the growth medium. Reference values are available for this purpose (e.g. Landis 1989a). No matter what method is used, however, the samples that are taken must be representative of the seedling stock in question. Proper sampling is therefore extremely important (Youngberg 1984, Jalkanen and Rikala 1995).

Fertilisation methods

Nutrient addition is often divided into basic fertilisation, maintenance fertilisation and late-season fertilisation. Basic fertilisation refers to the mixing of nutrients, often including limestone, into the soil or growth medium before the seeds are sown or the seedlings transplanted (Donald 1991, Proe 1994). It is recommended that the need for basic fertilisation be determined on the basis of soil analysis, and that the nutrients be applied in a slow-release form.

Maintenance fertilisation is designed to maintain the nutrient status of the substrate; the nutrients are applied during the growing period in a fast-release form. They can be applied in liquid form in the irrigation water, as granular fertiliser spread onto the surface of the soil, or inserted into the soil between the seedling rows. The development of irrigation systems has made it possible to achieve more precise fertilisation that matches the nutrient requirements of the seedlings. In the Ingestad method, for example, the low-rate of nutrient application matches the rate of plant growth, the aim being to keep the nutrient concentrations in the plants at a balanced level throughout the growing season (Ingestad and Lund 1986). Maintenance fertilisation can also be carried out in a single dose using slow-release fertilisers. Urea derivatives and other slow-release nitrogen compounds, as well controlled-release multi-nutrient fertilisers, are available for this purpose.

Late-season fertilisation refers to the application of nutrients, usually nitrogen, after plant growth has slowed down or terminated. At that time the nutrient concentrations in the seedlings can rise without affecting seedling growth or the hardening process (Donald 1991). Late-season fertilisation has not earlier been used very much, but recent positive results are expected to promote this practice.

The practice in Finland in both bare-rooted and containerised seedling production has been to apply almost half of the nutrient requirements in basic fertilisation. Multi-nutrient fertilisers are usually used in maintenance fertilisation, the amount of nitrogen varying between 10 and 20 g/m^2. Calculated per plant, however, the differences are large and depend on both the production method and the tree species owing to the different growing densities used.

Production of bare-rooted seedlings

Preparing the seed beds and sowing

In the production of bare-rooted conifer seedlings, the transplant material grown in the open is usually 2-year-old stock, while in the greenhouse they are grown to the age of 1 year. The methods used in preparing and sowing the seed beds vary from nursery to nursery. Before the beds are formed, organic material, limestone and fertiliser can be mixed into the soil in order to achieve optimal growing conditions. Basic improvement also includes the levelling of raised areas and the turning of compacted areas (Warkentin 1984). The soil is mixed to make it homogenous and beds are then usually formed using a bed former that are raised above the surrounding ground; this is particularly necessary on poorly permeable

soils. The width of the seed beds is usually 1.0 to 1.3 m. Broadcast and band sowing are usually used in raising seedling material for transplanting, while drill sowing using a precision sowing machine is used if the roots are to be pruned in the later stages of growing.

In band sowing, the seeds are sown in 5–10 cm wide bands at intervals of about 15 cm. In broadcast sowing, the aim is to obtain 500–800 pine or 800–1 000 spruce seedlings/m^2. A method, based on the distributions of the morphological seedling characteristics and the proportion of culls, has been developed for calculating the growing density in drill sowing (Parviainen 1980). The usual target is to obtain between 40 and 60 plantable seedlings per row m.

Covering the seeds accelerates germination and reduces seed drifting caused by rain and irrigation. The rule of thumb in Canada is to cover seed to a depth equal to the seed length. Covering the seed to a depth of 2–5 mm with coarse sand (particle size range 2–3 mm) has given good results in Finland. Germination is impaired if the layer is thicker. The sown area can also be covered with thin gauze, which increases the temperature and humidity, thereby speeding up seedling development and reducing the risk of insect damage.

Transplanting and root pruning

Transplanting seedlings to give them more growing space, promotes the development of a fibrous root system and the seedlings become sturdier. The time for transplanting is either in the spring (before the onset of root growth) or after midsummer (when height growth has ceased). Transplanting beds are about 1 m wide. The spacing for transplanted pine is 5 cm, for spruce 6–7 cm, and for birch 10–15 cm. The row interval is 20–25 cm. Transplanted bare-rooted pine stock is usually grown to an age of 2+1-years, spruce to 2+2-years, and birch to 1+1-years. If the seedlings to be transplanted have been grown in a greenhouse, the time preceding transplanting is shortened by one year. A new practice in recent years has been to use small containerised seedlings, grown in the greenhouse, as transplanting stock (Hahn 1984). This seedling type is usually denoted as p+1 (plug+1). In addition to requiring a shorter production time, another advantage of the p+1 stock over bare-rooted, transplanted stock is that it usually has better root formation.

Pruning the roots of seedlings has been used to replace transplanting. Root pruning is less expensive than transplanting (Harstela and Tervo 1983), but it presupposes drill sowing. Root pruning induces the formation of new root tips, resulting in a more fibrous root system and better root structure than that of transplanted stock (Duryea 1984). However, the seedlings are not as sturdy as transplanted stock owing to the higher growing density of root-pruned seedlings (Parviainen 1980, Mason 1994). The roots can be pruned before height growth commences, when it reduces height growth, or it can be done after height growth has ceased, resulting in a decrease in needle growth and also an effect on the following summer's height growth (Parviainen 1980).

Production of containerised seedlings

Container types, growing density and growing schedule

Containerised seedlings are grown in a wide range of containers (Landis 1990a). Containerised seedling production in Finland started with paper pots and peat pots. Styrofoam block containers became common in the 1970's and are still popular in

Canada. Container trays made of rigid plastic are nowadays common in the Nordic countries (Photo 17). The walls of the cells in these containers have ribs and air slits in order to promote air pruning and inhibit root spiralling and deformation. The structure of the container is of prime importance from the point of view of root development. The Vapo method, which includes root pruning in the production chain, was developed to prevent root coiling and other forms of deformation (Parviainen and Tervo 1989). The seedlings are grown in a peat sheet and, once they have reached a sufficient height, the roots and the peat around each seedling are pruned vertically on four sides. This results in wall-less, cube-shaped "containers". The roots, which become more fibrous, bind the peat cube without an actual container being necessary.

Both the growing density and the container volume have a decisive effect on the costs of growing containerised seedlings in the greenhouse and on seedling quality (e.g. Landis 1990a). The stem diameter, sturdiness and dry mass of the seedlings increase and their physiological quality improves when they are given more space to grow in (e.g. Duryea 1984, Rikala and Aphalo 1998) (Fig. 4). The growing density and the length of the growing period have to be matched; if seedlings are allowed to grow to too tall with respect to their growing density, their survival after planting-out is poor. In Finland, the growing density used for containerised pine and spruce stock varies between 400 and 900 seedlings/m^2, and the container volume correspondingly between 70 and 180 cm^3 (Decision... 1992). In northern Finland, a growing density of as

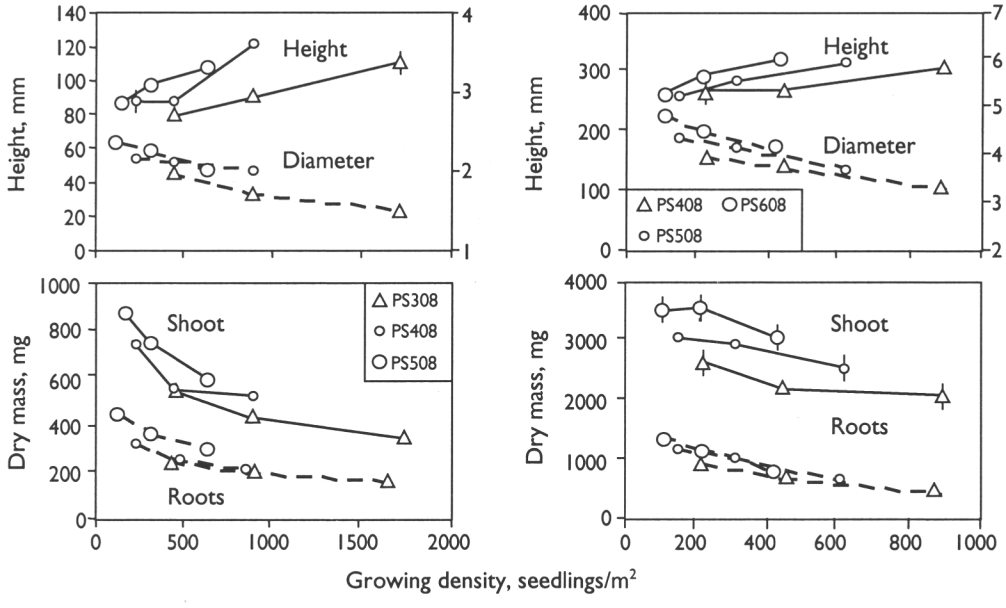


Figure 4. The dependence of the height, root-collar diameter, and the dry mass of the shoot and roots of pine and spruce on growing density and container volume during the second growing period (lines connect the individual density treatments of a particular container size). Sizes of the Ecopot cells: PS308 = 45 cm^3, PS408 = 75 cm^3 , PS508 = 103 cm^3, PS608 = 152 cm^3. Vertical lines represent the standard error of the mean.

high as 3 000 seedlings/m^2 can be used, with a container volume of at least 45 cm^3. Birch and larch are grown at a wider spacing (140–300 per m^2) in larger containers (230–400 cm^3). Moreover, the container trays for birch need to be set out at a wider spacing (15–20 cm apart) midway through the growing period so that the seedlings can become sturdier and there is sufficient ventilation between them to reduce the risk of plant diseases.

Containerised birch seedlings are usually grown for one growing period, pine for one or one and a half, and spruce for one or two. Depending on the germinability of the seed, 1–5 seeds are sown in each container, and a few weeks after sowing the seedlings are thinned, leaving one in each container. In addition to this direct sowing method, a method called prickling is also used, especially in the production of containerised birch seedlings; germlings grown at a high density are transplanted into containers when they are a few weeks old. This method results in a better yield from the available seed.

Substrate

Light, low-humified Sphagnum peat is the predominant substrate used in containerised seedling production in the Nordic countries. In North America, 20–30% of perlite, vermiculite or sawdust is often added to the peat to decrease the water-holding capacity and to improve aeration of the substrate (Landis 1990b). Mixing fine mineral material into the substrate improves the conductivity of water from the substrate to the seedlings (Örlander and Due 1986). However, so far there is no evidence to show that adding fine mineral material to peat would affect the rooting of seedlings following planting-out (Heiskanen and Rikala 1998).

Pine and spruce grow best in light Sphagnum peat when the pH is within the range 4–5. This can be achieved by adding 0.5–2.0 kg of limestone per m^3 of substrate (Rikala and Jozefek 1990). There is no corresponding optimum pH for birch, because birch grows almost as well over a wide pH range (3.5–8.0). Wood ash can also be used, instead of limestone, to neutralise the acidity of the peat. However, the nutrient composition of ash varies, and ash from industrial sources may contain substances that, even in low concentrations, are toxic to seedlings. How well the liming substances and fertiliser are mixed into the peat has an impact on the uniformity of seedling quality, particularly when they are grown in small containers (Landis 1990b). Fertilisers and limestone can be mixed in large industrial mixing units. In Finland, 0.8 kg of fertiliser and 2–3 kg of limestone are used per m^3 of peat. The use of basic fertilisers has been stopped in Sweden and Canada.

Growing environment and propagation facilities

The main aim in the production of containerised seedlings is to steer seedling development in the desired direction by regulating the environmental conditions. To achieve this, greenhouses can be equipped with ventilation, heating, lighting, blacking-out, irrigation and fertilising systems. Birch seedlings are grown in greenhouses for 1–2 months until they reach the height of 10–15 cm, and they are then moved out into the open. Pine seedlings are usually moved out towards the end of July as they harden best in low (+5°C) night temperatures (Dormling 1993). In the case of spruce, bud development requires sufficient warmth at the stage when they are sensitive to frost. Spruce seedlings are therefore often kept in the greenhouse until the autumn of the first

year. Containerised seedlings are grown in the open during the second year.

Greenhouses have to be equipped with ventilation and heating if successive crops of seedlings are to be grown during the same season. Efficient ventilation is needed to prevent the temperature and humidity from rising excessively and to keep the carbon dioxide concentration of the air constant. If an early start is made on growing the first crop, e.g. in March, photoperiodic lighting (to extend the natural photoperiod) may also be needed for spruce in order as to prevent the long dark period (night) from initiating bud formation after germination.

When growing seedlings in a greenhouse it is important to ensure that the irrigation is even because fertilisation is often carried out using the irrigation equipment. As the evaporation conditions in the greenhouse usually vary, being able to regulate the irrigating equipment is also important. Mobile irrigation booms distribute the water very evenly compared to fixed system pipes with sprinklers. In the production of containerised seedlings, the irrigation requirement can be determined either on the basis of evapotranspiration, e.g. by weighing the growing units (Landis 1989b), or by measuring the water content of the substrate with a TDR meter (Lambany et al. 1996). Weighing is an easy and cheap method: 5–10 seedling trays are selected at random in the greenhouse and are weighed weekly. The seedling trays are watered to the upper limit of the target mass range (corresponding to a peat water content of about 50% by volume) when their mass has dropped to the lower limit of the target mass range (corresponding to a peat water content of 35% by volume).

The materials used as the base of greenhouses and growing areas in the open include sand, crushed stone and asphalt. Containerised seedlings are being grown to an increasing extent on raised frames in order to prevent the roots from growing out of the containers. The trays are supported, 10–80 cm above the ground, on various types of support or on larger frames that serve as handling units. In order to achieve effective air-pruning of the roots, the containers have to be raised to a sufficient height and the structures must allow unrestricted air movement. For the winter, however, the seedlings must be lowered in order to prevent frost injury to the roots (Sutinen et al. 1996).

When seedling provenances representing a wide geographical area are grown at the same nursery, seedling growth cannot always be terminated and hardening initiated at the desired time. If the nursery is located further to the north than the origin of the seed, winter hardening of the seedlings especially will be delayed and autumn frost may damage the seedlings. Shortening the length of the day (number of daylight hours) to 8–12 h, depending on the provenance in question, for a period of three weeks will stop height growth and cause earlier hardening in several tree species, e.g. spruce, larch, birch. With pine, this short-day treatment speeds up hardening, but requires simultaneous low night-time temperatures. Pine seedlings are sometimes also subjected to the short-day treatment in order to induce the formation of double needles. Pine seedlings sown early in April and given the short-day treatment at the end of May or early June, produce a terminal bud that bursts within a few weeks, and the second period of height growth with double needles will occur during the same summer.

Nursery pests and pest management

Conditions that favour rapid seedling growth and high growing densities are also favourable to several pests (e.g. Sutherland et al. 1989, Lilja et al. 1997). The primary

damaging agents include damping-off, which is caused by several species of fungi, that kills the seeds and germlings of many tree species. Common grey mould (*Botrytis cinearea*) spreads readily among moist, dense vegetation, and is therefore a common problem when growing containerised seedlings. The most problematic of the fungi causing root die back in conifers are those belonging to the genus *Rhizoctonia.* Common diseases of pine are Scleroderris canker (*Gremeniella abietina*), pine twisting rust (*Melampsora pinitorqua*), pine needle cast (*Lophodermium seditiosum*), and snow blight (*Phacidium infestans*). The most serious birch diseases are those caused by birch rust (*Melampsoridium betulinum*) and various shoot and leaf lesions of birch caused by several fungi.

Good nursery hygiene (e.g. eliminating the sources of infection from the vicinity of the nursery and keeping seedling boxes and the base clean) often helps to prevent damage by fungi. Sufficient ventilation within greenhouses, avoiding too dense a seedling spacing and excessive irrigation, growing containerised seedlings above the ground surface, and removal of dead or diseased seedlings, are all important cultivation measures for preventing the spread of plant diseases. Excessive or unbalanced fertilisation that can make the seedlings susceptible to diseases. Some plant diseases can still only be controlled by chemical means. Biological control is being developed against fungal diseases, too (e.g. Gromovykh et al. 1997).

Invertebrates, e.g. aphids, bugs, weevils, mite and the larvae of several moths, can cause serious damage (Sutherland et al. 1989). As the occurrence of insects is sporadic, continuous monitoring (either by general observations or by means of traps such as glue traps) is important from the point of view of the timing of control operations. Birds and mammals can also cause serious damage in nurseries. Grouse eat buds and conifer needles, while smaller birds eat seeds. Voles can cause serious damage in seedling beds and among stored seedlings.

Weeds can also be a serious problem, especially in nurseries producing bare-rooted stock (Owston and Abrahamson 1984). Mechanical control is suitable for the eradication of certain weed plants, but this is often expensive and ineffective, especially when herbicides have to be used. However, efficient and safe control chemicals are not available for all weed species. One problem in containerised seedling production can be the growth of mosses, algae and liverworts on the surface of the substrate owing to its high moisture and nutrient levels. Control of these agents should be based primarily on preventative measures (washing and disinfecting of structures and seedling boxes), and on cultivation practice such as covering the seed with grit (2–4 mm) or some other rapidly drying material, correct irrigation and sufficient ventilation. Herbicides are nowadays available for suppressing mosses.

The main abiotic damaging agents are frost, excessive heat, water deficiency and excess water. The frost-hardiness of seedlings depends on the time of year. The most sensitive parts of a seedling are the roots, which can be damaged in the autumn already at temperatures of -5°C...-10°C, and in winter at -15°C...-25°C if the seedlings lack a snow cover (Lindström and Nyström 1987). The roots of containerised seedlings especially are susceptible to damage by low temperatures. The shoots may be damaged by frost episodes during the summer if their frost-hardiness is sufficient only down to temperatures of -2°C...-5°C. Dry and sunny weather in the spring, when the snow cover has partly melted but the soil is still frozen,

can cause desiccation in seedlings. Snow can bend or even break seedlings during the winter when the surface crust of the snow moves as it alternatively melts and freezes. In the summer, excessively high temperatures (> 45°C) can either kill seedlings directly or impair their growth (> 35°C) (Landis et al. 1992).

Seedling quality

Indicators depicting seedling quality and predicting their out-planting performance are needed when monitoring development during cultivation, and when sorting the stock for sale. Work has been carried out on determining the seedling attributes that best predict the planting performance in order to develop methods for assessing seedling quality (Duryea 1984). Seedling quality has been described by means of a large number of attributes that have been assessed in numerous literature reviews (Ritchie 1984).

Diameter and sturdiness are considered to be the best morphological characteristics for predicting planting performance (Duryea 1984). Although the morphological properties of seedlings are still considered reliable for depicting their quality (e.g. Puttonen 1997), performance attributes such as frost-hardiness and the growth potential of the roots have also found use in quality testing (Dunsworth 1997). Physiological attributes suitable for nursery use have not yet become widely accepted.

In Finland, seedling quality is regulated by official regulations (Decision... 1992), and adherence to the regulations is supervised by inspectors from the Ministry of Agriculture and Forestry in the form of random inspections carried out at nurseries in the spring. When selling the seedlings, the buyer has to be provided with information such as where the seedlings were grown, the area where the seedlings can be used, and the age and type of seedling. Seedlings for sale have to be healthy and vigorous. The regulations also set out the criteria for rejecting seedlings. In addition, pine, spruce and birch stock also have to meet certain size requirements based on the median height of the seedling batch. Bare-rooted stock have specific minimum height and diameter of individual seedlings according to the median height of the batch. The maximum permissible median height of a batch of containerised seedlings is determined by their growing density and the minimum height of an individual seedling determined on the basis of the median height of the batch. The culling of seedlings that are too small with respect to the median height of the batch is based on the assumption that the seedlings that have become suppressed by the surrounding seedlings may be genetically inferior, or that this is due to environmental factors. These seedlings are in any case considered too weak to withstand planting shock. These size requirements are based on seedling material that has been measured at nurseries and in connection with planting-out trials.

The quality requirements and supervision applied in Finland deviate from those in the other Nordic countries and in Canada. Once the EU directives come into effect in Finland, official supervision will probably cease and seedling quality will probably be a matter to be settled between the seller and the buyer.

REFERENCE

Bonner, F.T., McLemore, B.F. & Barnett, J.P. 1974. Presowing treatment of seed to speed germination. In: Seeds of woody plants in the United States. Washington, D.C: USDA, Forest Service. Agriculture Handbook 450: 126–135.

Decision of the Ministry of Agriculture and Forestry on the Trade of Forest Reproductive Material. 1992. 1533/92.

Donald, D.G.M. 1991. Nursery fertilization on conifer planting stock. In: van den Driessche, R. (ed.) Mineral nutrition of conifer seedlings. CRC Press Press. Boca Raton – Ann Arbor – Boston. p. 135–168.

Dormling, I. 1993. Bud dormancy, frost hardiness, and frost drought in seedlings of Pinus sylvestris and Picea abies. In: Li, P.H. & Christersson, L. (eds) Advances in cold hardiness. CRC Press. Boca Raton – Ann Arbor – London – Tokyo. p. 285–298.

Dunsworth, G.B.1997. Plant quality assessment: an industrial perspective. New Forests 13: 439–448.

Duryea, M.L. 1984. Nursery cultural practices: Impacts on seedling quality. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 143–164.

Gromovykh, T.I., Malinovsky, A.L., Gukasyan, B.M., Tulpanova, B.A. & Golovanova, T.I. 1997. The application of microbiological antagonism for biological control of damping-off in nurseries. In: James, R.L. (ed.) Proceedings of the third meeting of IUFRO Working Party S7.03–04 Diseases and insects in forest nurseries USDA Forest Service, Northern Region, Forest Health Protection, Report 97–4: 138–144.

Hahn, P.F. 1984. Plug+1 seedling production. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 165–181.

Harstela, P. & Tervo, L. 1983. Technology of the production of bare-root seedlings. Commun. Inst. For. Fenn. 110. 51 p.

Heiskanen, J. & Rikala, R. 1998. Influence of different nursery container media on rooting of Scots pine and silver birch seedlings after transplanting. New Forests 16: 27–42.

Ingestad, T. & Lund, A. 1986. Theory and techniques for steady state mineral nutrition and growth of plants. Scand. J. .For. Res. 1: 439–453.

Jalkanen, A. & Rikala, R. 1995. Foliar chemical composition and sampling intensity in bare-root Pinus sylvestris nursery crops. New Forests 10: 225–237.

Lambany, G., Robidas, L. & Ballester, P. 1996. Measurement of soil water content in a peat-vermiculite medium using time domain reflectometry (TDR): A laboratory and field evaluation. Tree Planters' Notes 47(3): 88–93.

Landis, T.D. 1989a. Mineral nutrients and fertilization. In: Landis, T.D., Tinus, R.W., MacDonald, S.E. & Barnett, J.P. The container tree nursery manual. Volume 4. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 1–67.

Landis, T.D. 1989b. Irrigation and water management. In: Landis, T.D., Tinus, R.W., MacDonald, S.E. & Barnett, J.P. The container tree nursery manual. Volume 4. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 69–118.

Landis, T.D. 1990a. Containers: Types and functions. In: Landis, T.D., Tinus, R.W., MacDonald, S.E. & Barnett, J.P. The container tree nursery manual. Volume 2. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 1–39.

Landis, T.D. 1990b. Growing media. In: Landis, T.D., Tinus, R.W., MacDonald, S.E. & Barnett, J.P. The container tree nursery manual. Volume 2. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 41–85.

Landis, T.D., Tinus, R.W., McDonald, S.E. & Barnett, J.P. 1992. Atmospheric environment. Vol. 3. The container tree nursery manual. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 145 p.

Landis, T., Tinus, R., McDonald, S. & Barnett, J. 1995. Nursery planning, development, and management. In: Landis, T.D., Tinus, R.W., MacDonald, S.E. & Barnett, J.P. The container tree nursery manual. Volume 1. Washington DC: USDA, Forest Service. Agriculture Handbook 674: 1–188.

Lilja, A., Lilja, S., Kurkela, T. & Rikala, R. 1997. Nursery practices and management of fungal diseases in forest nurseries in Finland. A Review. Silva Fenn. 31: 79–100.

Lindström, A. & Nyström, C. 1987. Seasonal variation in root hardiness of container-grown Scots pine, Norway spruce, and lodgepole pine seedlings. Can. J. For. Res. 17: 787–793

Mason, W.L. 1994. Production of undercut stock. In: Aldhous, J.R. & Mason, W.L. (eds) Forest nursery practice. The Forestry Authority. London HMSO. Forestry Commission Bulletin 111: 112–121.

Owston, P.W. & Abrahamson, L.P. 1984. Weed management in forest nurseries. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 193–201.

Parviainen, J. 1980. Juurten leikkaaminen männyn paljasjuuristen taimien kasvatusmenetelmänä. Zusammenfassung: Wurzelschnitt als Anzuchtsmethode bei wurzelnackten Kiefernpflanzen. Commun. Inst. For. Fenn. 98.2. 131 p.

Parviainen, J. & Tervo, L. 1989. A new approach for production of containerised coniferous seedlings using peat sheets coupled with root pruning. In: Mason, W.L., Deans, J.L. & Thompson, S. (eds) Producing uniform conifer planting stock. Forestry Supplement 62 VN: 87–94.

Proe, M.F. 1994. Plant nutrition. In: Aldhous, J. & Mason, W. (eds) Forest nursery practice. The Forestry Authority. London HMSO. Forestry Commission Bulletin 111: 37–65.

Puttonen, P. 1997. Looking for the "silver bullet" – can one test do it all? New Forests 13: 9–27.

Rikala, R. 1992. Taimitarhalannoituksen vaikutus männyntaimien jälkikasvuun ja istutuksen jälkeiseen menestymiseen. Summary: Effect of nursery fertilization on incidence of summer shoots and field performance of Scots pine seedlings. Folia For. 794. 19 p.

Rikala, R. & Jozefek, H. J. 1990. Effect of dolomite lime and wood ash on peat substrate and development of tree seedlings. Silva Fenn. 24: 323–334.

Rikala, R. & Huurinainen, S. 1990. Lannoituksen vaikutus kaksivuotisten männyn paakkutaimien kasvuun taimitarhalla ja istutuksen jälkeen. Summary: Effect of fertilization on the nursery growth and outplanting success of two-year old containerized Scots pine seedlings. Folia For. 745. 16 p.

Rikala, R. & Repo, T. 1997. The effect of late summer fertilization on the frost hardening of second-year Scots pine seedlings. New Forests 14: 33–44.

Rikala, R. & Aphalo, P. 1998. Kasvatustiheyden ja paakkukoon vaikutus taimien ominaisuuksiin taimitarhalla ja menestymiseen istutuksen jälkeen. In: Poteri, M. (ed.) Taimitarhatutkimuksen vuosikirja. Metsäntutkimusl. tied. 696: 21–35.

Ritchie, G.A. 1984. Assessing seedling quality. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 243–259.

Sutherland, J.R., Shrimpton, G.M. & Sturrock, R.N. 1989. Diseases and insects in British Columbia forest seedling nurseries. Forestry Canada, British Columbia Ministry of Forests. Victoria. FRDA Report 065. 85 p.

Sutinen, M-L., Mäkitalo, K. & Sutinen, R. 1996. Freezing dehydration damages roots of containerized Scots pine (Pinus sylvestris) seedlings overwintering under subartic conditions. Can. J. For. Res. 26: 1602–1609.

van den Driessche, R. 1991. Effects of nutrients on stock performance in the forest. In: van den Driessche, R. (ed.) Mineral nutrition of conifer seedlings. CRC Press. Boca Raton – Ann Arbor – Boston. p. 229–261.

Warkentin, B.P. 1984. Physical properties of forest-nursery soils: Relation to seedling growth. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 53–61.

Youngberg, C.T. 1984. Soil and tissue analysis: Tools for maintaining soil fertility. In: Duryea, M.L. & Landis, T.D. (eds) Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Junk Publishers, The Hague – Boston – Lancaster. Forest Research Laboratory, Oregon State University. Corvallis. p. 75–80.

Örlander, G. & Due, K. 1986. Location of hydraulic resistance in the soil-plant pathway in

seedlings of Pinus sylvestris L. grown in peat.
Can. J. For. Res. 16(1): 115–123.

PLANTING STOCK PRODUCTION AND INCREASING FOREST YIELD IN THE NORTH OF EUROPEAN RUSSIA

V.A. Mochalov
Northern Research Institute of Forestry, Nikitov str. 13, Arkhangelsk, 163062, Russia

Introduction

The yield from artificially regenerated forests and their economic management depend, for instance, on effective integration of the methods used in establishing the plantations, on a proper combination of silvicultural and amelioration methods, as well as on exploitation of the gains achieved through forest tree breeding. The plantations established by planting in the North of European Russia (Arkhangelsk Region, Vologda Region and the Republic of Komi) have been successful in a considerable proportion of the total area regenerated by planting.

The wide range of climatic and site conditions in the region presupposes the use of planting stock of various species and size. For instance, the growth and productivity of Scots pine are better than Norway spruce in plantations established on clear-cut areas in forests of the Pinetum hylocomiosum types. Larger planting material is required on clear-cut areas because they rapidly become covered with grasses, herbs and scrubs. This type of planting stock allows a decrease in the number of mechanical and silvicultural treatments required in the plantations, which is especially important in the northern taiga conditions where the road network is relatively undeveloped. The planting material must meet standard requirements and be of superior quality from the biological point of view in order to ensure rapid establishment and high vigour.

Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) seedlings are mainly produced in the region. Siberian spruce (*Picea obovata* Ledeb.) and Norway spruce x Siberian spruce hybrids are predominant in the northeastern part of the region. The planting stock comprises 15–20% pine and 79–83% spruce. Other species are Siberian larch (*Larix sibirica* Ledeb.), Sukachev larch (*L. sukaczewii* Djil) and Siberian cedar pine (*Pinus cembra* subsp. *sibirica* (Du Tour) Krylov).

The small area of pine and larch plantations is mainly due to an insufficient supply of seed although, according to the site conditions and the good growth of the above species, the area of pine plantations could be doubled or tripled, and the area of larch plantations increased considerably (Попов et al. 1992).

The planting material used in the region is produced either in nurseries in the open (88–92% of the seedlings and transplants) or in plastic greenhouses. Most (up to 90%) of the planting stock is seedlings, the remainder being transplants. Based on the silvicultural, ecological and economic conditions prevailing in the region, the proportion of larger-sized planting stock (transplants) could be increased to up to 20–30%. This would enable a considerable share of the costs incurred in treatment in the plantations to be transferred to stages such as transplant production and planting.

In recent years one of the forest management units (leskhoz) in the Arkhangelsk

Region has started producing planting stock by the containerised system using Finnish technology. However, a number of biological, technological and economic parameters will have to be tested before this technology can be applied on a more extensive scale.

Soil and climatic conditions

The climatic conditions in the region are harsh, with a short growing season, cool weather and even frost during summer. In the southern part of the region (Vologda) frost does not occur only in July, and in the northern part (Arkhangelsk) temperatures of below 0°C can occur at any time during the summer. According to observations made in 1998, temperatures ranging from -1.0 to -4.7°C occurred in every 10-day period during June, July and August in the nursery of the Arkhangelsk leskhoz (45 km from Arkhangelsk).

The soil in the forest nurseries ranges from sandy clay to loam. The organic matter content in the cultivated layer in most of the seedling beds is below 2%. Soil acidity is relatively low, with low concentrations of available nitrogen, phosphorus and potassium. The loamy soils are compact, and are water-logged in the autumn and dry in the summer. The moisture content of the sandy clays is unsatisfactory.

Long-term observations in the nurseries have shown that, even if there is sufficient precipitation during the growing season (100–200 mm during June to August), the precipitation is usually unevenly distributed. Almost every year there are 2- to 3-week periods with only 3–10 mm of precipitation, resulting in insufficient moisture for seed germination and seedling development. During such periods the nurseries require watering.

Seedling production in the open

Pine and larch seedlings are grown for 2–3 years, and spruce and cedar pine seedlings for 3–4 years in the open nurseries. The unfavourable soil and climatic conditions result in low seed germination in the ground, slower seedling growth, and losses in planting stock quality and yield. Seedlings grown loams and sandy clays with loamy layers close to the surface and a high water table, are susceptible to damping-off and frost heaving.

Techniques have been developed for preparing fallow fields and seedling production that ensure optimal physical and chemical soil properties, good seed and seedling survival, and intensive growth and balanced development of the plants (Мочалов et al. 1991).

In order to reduce seedling mortality due to abiotic factors (water-logging, frost heaving), the surface of the fields is levelled, and ditches dug on loamy soils in order to ensure the runoff of excess water in the autumn and spring. Without these measures, seedling mortality caused by frost heaving and dying-off can be as high as 50 to 90% in depressions, and growth can be reduced to one quater at the most (Мочалов 1988).

Optimal conditions for seedling growth and development are obtained soils when the bulk density of the cultivated layer is not more than 1.2 g/cm^3, there is high soil porosity and aeration throughout the whole production period, and the organic matter content is at least 3%. Our studies have shown that this can be achieved by applying a large (100–500 t/ha) dose of well decomposed peat that is evenly mixed into the cultivation layer (Мочалов and Мочалова 1996). The bulk density, porosity and aeration are still optimal even after three years' growing. Moreover, properties such as the

water capacity of the soil and water absorbing quality, active moisture range and wilting moisture increase while, at the same time, there is an increase in the water deficit of the soil and watering has to be increased. Improving the hydrological properties of the soil and increasing the organic matter content alone increased the height growth of the seedlings by 20 to 50 %, and the output of standard material by 10 to 40% (Мочалов 1988).

In order to improve the fertility of the soil and to supply the seedlings with nutrients, timing of application and doses have been determined for mineral fertilisers and composts consisting of peat or coniferous tree bark chips, mixed with chicken manure. Applications of 25–75 t/ha of compost have increased the size of the seedlings by 20 to 40%, the output of standard seedlings by 30 to 37%. The concentration of exchangeable elements in the soil following compost application has been higher at the end of the rotation than with mineral fertilisers.

The timing and techniques used in mulching sown areas, the amount and timing of watering and mineral dressing and other treatments and disease control by fungicides have been developed and tested in order to ensure good seedling survival and maximum growth (Мочалов et al. 1991). The herbicides "roundup", "fosulen", "arsenal" and "landmaster" for fallow areas, and "goal" on sown beds have proved to be effective for weed control. However, these treatments have not completely eliminated the weed problem, and a combination of mechanical and chemical measures is needed. However, the structure and fertility of the soil should be maintained, and adverse effects on the environment must be kept to a minimum.

Pine and spruce transplant production

Soil preparation measures are not necessary when plantations are established with larger-sized planting stock (transplants). This means that a considerable portion of the total costs of stand growing is transferred from the plantations to the nurseries, as well as to the initial stage of the growing process. During the transplant growing stage when the plants start to differentiate in size, it is also possible to select the fast-growing individuals and to distribute the transplants, which will later form the first storey of a stand, evenly throughout the planting area.

The studies on transplant production technology (Photo 18) were carried out in nurseries with loams and sandy clays in the northern and middle taiga sub-zones of the Arkhangelsk Region. In years with periods of cold weather and frost in summer, the height increment of the transplants decreased by 30–60% and the increment was ca. 50% less in the northern taiga sub-zone compared to that in the middle sub-zone. As a result, the transplant growing period in some of the rotations had to be extended from 2–3 to 3–4 years in order to obtain standard, large-sized planting stock.

Analysis of the combined and separate effects of the physical and chemical soil properties, as well as the size of the seedlings used, on the growth of the transplants has shown that the soil density and hydrological factors of the cultivated layer are the most important. A decrease in the bulk density of the soil from 1.36 g/cm^3 down to the optimum value gave a 1.2 to 2.5-fold increase in spruce transplant size and mass of times by the end of the fourth year. Fertiliser application gave a corresponding 1.1 to 1.9-fold increase. The best spruce and pine transplant vigour was obtained with the

optimum combination of all these factors, i.e. a low soil density, high organic matter content, sufficient supply of nutrients and large-sized seedlings selected from one lot according to groups size. The root systems of the transplants were well developed and the shoot/root ratio low, resulting in 90 to 100% survival in the plantations.

The experiments have shown that growth self-regulation between different parts of seedlings, takes place after transplanting. It is possible, within certain limits, to influence this process by changing the physical and chemical conditions of the soil and, by promoting more intensive development of either the shoot or roots, to change the root/shoot ratio and improve the quality of the planting stock. Another important feature is that the seedlings divided according to size groups retain their size differences, i.e. their ranking remains the same both in the transplant section of the nursery and during the first years of growth in the plantations.

Seedling production in plastic greenhouses

The use of greenhouses for the production of seedlings, especially in areas with frequent episodes of cold weather and frost, is the most promising development. The production time is decreased by 1 to 2 years, and the output per area unit increased 3 to 5-fold.

Research carried out over a number of years has provided a theoretical basis for developing suitable techniques for growing seedlings in greenhouses. The greenhouses reduce the variation in the daily temperature, and increase the effective temperature sum during the growing season. Specific regulations have been drawn up covering the choice and preparation of areas for greenhouses, their construction and use, the preparation and application of substrates, and the measures used in growing bare-rooted seedlings (Синников et al. 1982, Синников et al. 1983, Синников et al. 1986).

Permanent greenhouses with various types of supporting structure (arched, block-type, single-span, multi-span) made of wood (beams, logs, glued-wood elements) and/or metal, manufactured industrially or constructed on site, are used in the region (Photo 19). All of them have sufficient air volume per unit area, are covered with PVC film, are used during spring and summer, and have a natural, unheated microclimate.

The substrate primarily consists of well composed fen peat. Studies have shown that the hydrological properties of the substrate have remained within the optimal limits for seedling growth and development after 4 to 6 years use. A technique for repeated substrate utilisation (for more than 14 years) has been developed, and is now in use on a practical scale; it reduces the costs of substrate production (up to 40%) and the total costs of seedling growing (up to 15%). In addition to peat, composted lignin (after hydrolysis) has proved to be a rather satisfactory substrate, and has a beneficial effect on seedling growth and development (Мочалов et al. 1991).

The efficient growing of seedlings in greenhouses is based on the modification of physiological and biochemical processes in the plants induced by changing the microclimate. Our experiments have shown that the optimum temperature for the photosynthesis of seedlings is increased when they are grown in greenhouses. The growth and development of seedlings throughout the growing period are also closely connected with the microclimatic conditions. The duration of each development phase and the rate of elongation and biomass accumulation are determined, among other factors,

by the average daily temperature sum and by the occurrence of a daily period (hours) at a specific temperature. Thus, in one of the intermediate elongation stages in one-year-old pine seedlings, the above-ground part of the plant develops at a faster rate than the roots at an average daily temperature sum of 200 to 220°C, while at a sum of 240°C and more the root system develops faster. Introducing pre-determined microclimatic parameters into the automatic environment control program would be one means of influencing the growth and development of the seedlings.

Increasing the temperature and humidity of the air in the greenhouses enhances microbiological activity in the substrate, and the presence of the protective plastic film results in an increase in the CO_2 concentration in the air. Studies (Мочалов 1976) have shown that the carbon dioxide concentration in the morning and evening hours in greenhouses is more than 2 to 7-fold the CO_2 concentration outside the greenhouse. This increases the photosynthesis of the seedlings by 1.5 to 2.5-fold. However, the CO_2 concentration inside the greenhouse is not optimal. The rate of photosynthesis is 1.5 to 3 times higher and the seedlings 30–80% larger when carbon dioxide is added via the air and soil (Синников et al. 1986).

Production of containerised planting stock

The use of containerised planting stock is a promising trend in reforestation. The advantages offered by the method include a considerably extension of the time when the stock can be planted and high survival in plantations. However, the transportation of relatively bulky containerised planting stock to sites, as well as within sites, means an increase in material and technical investments.

Containerised planting stock is widely used in many countries. In Russia it is employed to a lesser extent (Маслаков et al. 1985), and it has not been used on the practical level in our region until recently. Small-scale studies on growing seedlings with roots enclosed in plastic rolls were carried out in the Arkhangelsk Region during the 1980's (Синников and Новосельцева 1986). The experiments gave good results as regards the quality of the planting stock and its survival in plantations, but the technique has not been widely applied owing to problems with the procurement and processing of the substrate, and the production and transportation of rolls to the site are labour-consuming operations.

Since 1997 the production of containerised seedlings using containers "Pant", based on Finnish technology, has been operating in the Arkhangelsk Region. Survival and growth in the first plantations established with these seedlings were rather good during the first year. Widespread use of the technology in the region will depend on its applicability to local conditions, the suitability of local peat and domestic fertilisers, the length of the growing period in the greenhouse and in the open etc. Furthermore, the quality of the planting stock should not be lower and the production costs not higher than those incurred in the production of bare-rooted seedlings in greenhouses according to existing technologies.

Investigations in some other regions of Russia have shown that containerised planting stock used in plantations established on poor soils suffers from the "hemotropism" phenomenon, i.e. the roots do not readily grow out of the planting container into the surrounding soil. As a result, the 4- to 10-year-old plantations established with containerised planting stock have a lower height increment compared to plan-

tations established with bare-rooted seedlings (Родин 1978, Майсеенок and Копытков 1993).

Conclusions

The techniques developed in the region for growing seedlings and transplants in the open and in greenhouses allow the production of different-sized, high-quality planting stock. They meet the requirements of plantation forestry, are appropriate for a wide range of sites, and will increase the yield of timber in the future. However, nursery production in the region still needs to be improved. The techniques still need to be developed in order to improve the quality of the planting stock and to lower the costs of production and plantation establishment. Greenhouse and nursery complexes with tree-breeding seed orchards are to be set up, and long-term planning is to be promoted in order to facilitate decision-making concerning the amounts required of containerised and bare-rooted seedlings and transplants of different species.

REFERENCES

Майсеенок, А.П. & Копытков, В.В. 1993. Рост культур сосны, созданных различным посадочным материалом. Лесное хозяйство 3: 32–33.

Маслаков, Е.Л., Огиевский, Д.В. & Гомельский, Ю.Н. 1985. Производство посадочного материала с закрытой корневой системой. In: Обзорная информация. Лесоразведение и лесомелиорация. ЦБНТИ Гослесхоза СССР. Moscow. 40 p.

Мочалов, Б.А. 1976. Содержание углекислого газа в полиэтиленовых теплицах и влияние его на рост сеянцев сосны и ели. In: Вопросы лесовосстановления на Европейском Севере. Arkhangelsk. p. 116–126.

Мочалов, Б.А. 1988. Совершенствование агротехники выращивания посадочного материала в лесных питомниках. In: Леса и лесное хозяйство Архангельской области. Arkhangelsk. p. 39–50.

Мочалов, Б.А. & Мочалова, Г.А. 1996. Окультуривание почв в лесных питомниках Севера. In: Почвенные исследования на Европейском Севере. Arkhangelsk. p. 149–154.

Мочалов, Б.А., Мочалова, Г.А. & Новосельцева, Т.И. 1991. Рекомендации по выращиванию посадочного материала хвойных пород в лесных питомниках средней и северной подзон тайги Европейского Севера. Arkhangelsk. 80 p.

Попов, В.Я., Мочалов, Б.А., Сунгуров, Р.В., Беляев, В.В. & Тучин, П.В. 1992. Проблемы искусственногКо лесовосстановления на Европейском Севере. In: Повышение продуктивности лесов Европейского Севера. Arkhangelsk. p. 79–91.

Родин, А.Р. 1978. Явление хемотропизма при создании культур хвойных пород саженцами с закрытой корневой системой. In: Лесоводство, лесные культуры и почвоведение. Межвузовский сборник научных трудов ЛТА. Leningrad. Вып. 7: 98–102.

Синников, А.С. & Новосельцева, Т.И. 1986. Выращивание саженцев сосны и ели в рулонах. In: Вопросы искусственного лесовосстановления на Европейском Севере. Arkhangelsk. p. 40–44.

Синников, А.С., Мочалов, Б.А., Драчков, В.Н. и др. 1982. Нормативы по выращиванию посадочного материала хвойных пород в условиях контролируемой среды в зональном разрезе. Arkhangelsk. 24 p.

Синников, А.С., Мочалов, Б.А. & Драчков, В.Н. 1986. Выращивание сеянцев хвойных пород в полиэтиленовых теплицах. Агропромиздат. Moscow. 126 p.

Синников, А.С., Мочалов, Б.А., Смирнов, Н.А. и др. 1983. Лесотехнические требования на полиэтиленовые теплицы для выращивания лесного посадочного материала. Moscow. 6 p.

6. ARTIFICIAL REGENERATION

SOIL PREPARATION FOR FOREST REGENERATION

H. Mannerkoski [1] and E. Mälkönen [2]

[1)] University of Joensuu, Faculty of Forestry, P.O. Box 111, FIN-80101 Joensuu, Finland

[2)] Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN-01301 Vantaa, Finland

Need and goals

Improvement of the seedling production capacity of the soil is often necessary for both natural and artificial regeneration in order to achieve successful regeneration within a moderate period of time.

Final cutting causes considerable changes in the properties of forest soil, and this has a wide ranging effect on natural seedling production. A change in the radiation conditions results in extreme temperature conditions at the soil surface, which in turn increases the amplitude of the variation in diurnal temperatures (Kubin and Kemppainen 1991). As a consequence of increased soil temperatures, reduced acidity and the logging residues left on the soil surface, nutrient mineralisation increases. Final cutting increases the amount of water reaching the soil and decreases evaporation. As a result of these changes, the water table rises and the pore volume available for storing extra water in the soil correspondingly decreases. The increasing amount of soil water decreases the air space and causes compaction of fine-textured soils (Соколовская et al. 1977, Иванов 1980). In areas where the rise in the water table after cutting creates capillary connections between the surface soil and the water table, both the soil temperature and soil aeration decrease. Runoff and the leaching of nutrients increase up until the time when a vegetation cover has become re-established in the regeneration area and starts to retain water and nutrients more effectively.

Depending on the quality of the site, the environmental changes following final cutting have both positive and negative effects on forest regeneration. Factors retarding regeneration can be substantially reduced by site-specific soil preparation. The goals of soil preparation are:

– to guarantee successful regeneration of the tree stand, and

– to improve soil productivity for as long a time as possible.

How to reach these goals is very much dependent on the prevailing site factors and the soil preparation methods used (Fig. 1). The key factors as regards germination and seedling production are the soil temperature and water conditions. Seedling development is also dependent on many other physical and chemical properties of the soil. Because the roots need oxygen for respiration and water for growth and nutrient transport, soil aeration and water conditions are important properties. The long-term effects of soil preparation are primarily dependent on the water conditions in the soil and the release of nutrients from the organic layer.

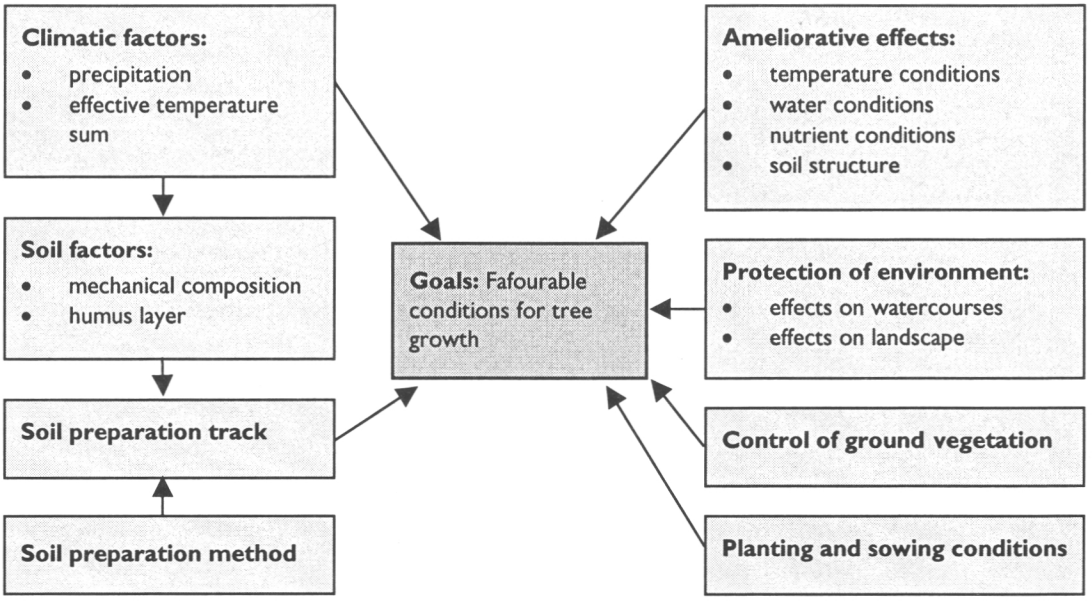


Figure 1. Factors linked to soil preparation.

Soil preparation methods

The soil preparation method should be chosen in accordance with the site properties. Patch scarification, in which the humus layer is removed from the surface of the mineral soil, is suitable on nutrient-poor, highly water-permeable soils for promoting natural regeneration or establishment of a sowing substrate.

Disc ploughing forms low irregular furrows about 0.5 m wide, exposing the mineral soil over about 20% of the area. In southern Finland, disc ploughing is the most common soil preparation method for both sowing and planting. It is not, however, suitable for sites where the water-permeability of the soil is poor or where there is strong competition from ground vegetation.

Mounding is intended primarily for planting on moist and wet soils (Маркова et al. 1978). Mounding is used to raise the planting point above the level of the surrounding ground and, if necessary, the area can be drained at the same time. The location of each mound can be chosen individually in order to locate the seedlings on optimal growing points in the terrain (Photo 20).

Ploughing has been the most common soil preparation method in northern Finland. The plough makes furrows about 30–50 cm deep and ca. 5 m apart, and the edges or turned ridges of the furrows are used as the sowing or planting points. Owing to aesthetic reasons and other disadvantages, the use of ploughing has almost completely stopped.

The effect of soil preparation on soil properties

Porosity

Soil aeration and the water conditions are strongly dependent on the porosity and the pore size distribution of the soil. The

porosity increases substantially by soil preparation only when the organic layer is mixed with the mineral soil or the structure of the surface layer of the mineral soil is otherwise disturbed (Ritari and Lähde 1978). Even the pore size distribution changes to some extent as a result of soil movement. Figure 2 shows the average water retention curves for ploughed experimental sites on upland and peat soils in North Karelia, eastern Finland (Mannerkoski 1998). On sites with fine sand there were only a few macropores (diameter >50 μm; -6.2 kPa, pF 1.8), and the soil subsequently remained wet for an extended period after rain. On the ridges there were clearly more macropores as a result of moving and turning the soil during soil preparation.

Typically the water retention curves of glacial till are evenly sloping. On till soils there were more large macropores in the ridge than in untreated soil. On peatland soil preparation also increased the proportion of large macropores in ridges and mounds compared to that in untreated soil. This was accompanied by a corresponding reduction in the volume of small macropores (50–10 μm), and sometimes also of medium pores (10–2 μm), because the total volume of the pores did not change. However, the amount of plant-available water did not decrease significantly.

Soil water conditions

Soil water conditions can be described by means of the soil water content or soil water potential, and by the water permeability of the soil. First of all, it is important to know

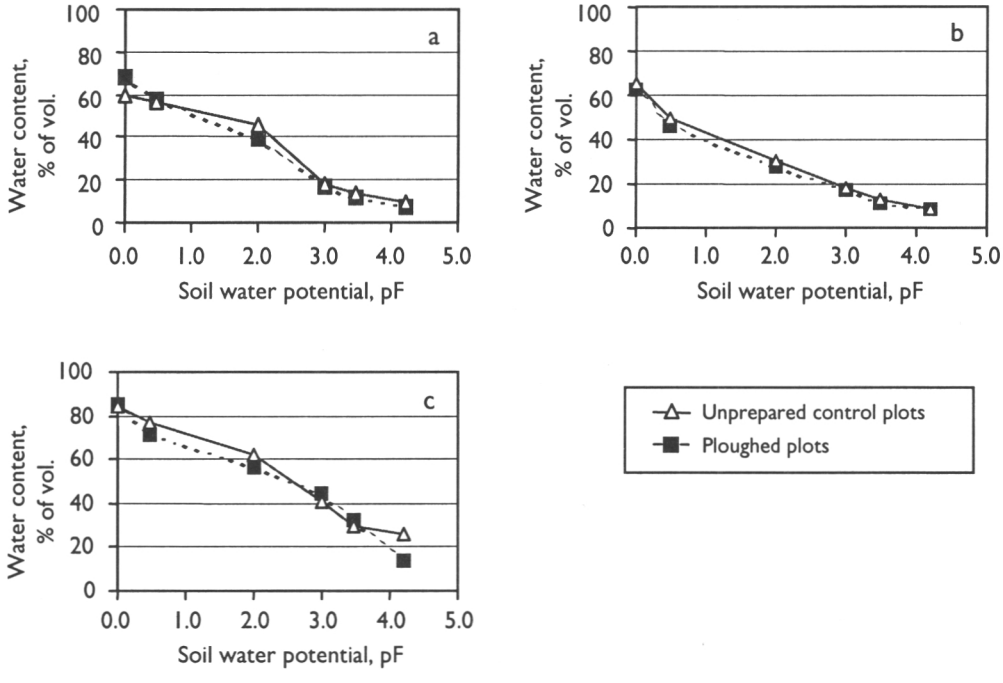


Figure 2. Examples of water retention curves in the ridges of ploughed plots and in the unprepared soil consisting of: a) fine sand, b) fine sandy till, and c) peat.

whether the prepared soil can become too dry, and in what kind of conditions this may occur. On the other hand, once the soil is nearly or totally saturated with water, or the soil water potential is close to zero or even positive, the oxygen supply to the roots is inhibited if these conditions continue for an extended period. Figures 3–5 show examples of the development of soil water potential in some ploughed, mounded and disc-ploughed areas in North Karelia. The soil water potential is clearly lowest in the ridges and mounds (Ritari and Lähde 1978, Mannerkoski and Möttönen 1990). At the experimental sites in North Karelia, the soil water potential never dropped below the detection limit of the tensiometers (ca. -80 kPa) during the three-year monitoring period (1987–1989). This means that the ridges or mounds (at the depth of 10 cm) were by no means too dry for the seedlings because the wilting point is ca. -1400 kPa. Potential drying of the soil surface, on the other hand, effectively retards the drying of deeper soil layers.

Rainwater readily infiltrates into ridges and mounds owing to their looser structure and larger pores, but clearly more slowly into patches (Ritari and Lähde 1978). On upland soils, the fast infiltration of rainwater is seen as a very rapid increase in the soil water potential of ridges and mounds to the same or even higher level as in the untreated soil lying between the treated areas (Mannerkoski and Möttönen 1990). However, after a rainfall episode the soil water potential decreases rapidly in the ridges and mounds. In paludified mineral soil and in peat soil the soil water potential in the ridges and mounds does not increase to the same level as in untreated soil because the high ground water level always keeps the untreated soil moister than in the ridges and mounds. The disc-ploughed soil was generally slightly moister than the untreated soil, where the organic layer retains part of the rainwater and transpiration by the ground vegetation has a drying effect on the soil.

Soil aeration

A key factor in determining the significance of aeration is the period of time which tree roots can withstand insufficient air space. Oxygen deficiency lasting for only a few days stops the growth of roots, although older roots can survive for a relatively long time. On the other hand, the timing of oxygen deficiency is also significant. If flooding occurs at a time of no active root growth, they will resist oxygen-poor conditions for periods lasting up to a few weeks even.

On mineral soil sites the air space at a depth of 10 cm generally dropped below 10% only temporarily during rainfall episodes. This value is considered to be the minimum air space required for the development of roots. However, in dense silt soil, for instance, an air space of 10% may occasionally be reached only in conditions drier than field capacity. In untreated silt soil the air space may thus be almost constantly below this limit value. In paludified mineral soils and peatlands, the untreated soil in most areas was, irrespective of furrows and mounds, constantly above field capacity. This indicates that, despite soil preparation, the water table remained so high that capillary rise of water replaced the loss through evaporation. In these conditions the depth of the water table and the pore size distribution of the soil determine the proportion of air space in the pore space. In the ridges and mounds the minimum air space is exceeded most of the time, even in paludified mineral soils and peatlands.

Soil temperature

In soil preparation the insulating organic layer is removed from the surface ot the

mineral soil, or ridges or mounds are formed which warm up better than the flat soil surface. For the growth of seedling roots and their water and nutrient supply, an increase in soil temperature is beneficial on all types of site. The annual temperature sum in mounds was 30–60% higher at a depth of 5 cm than in untreated soil (Table

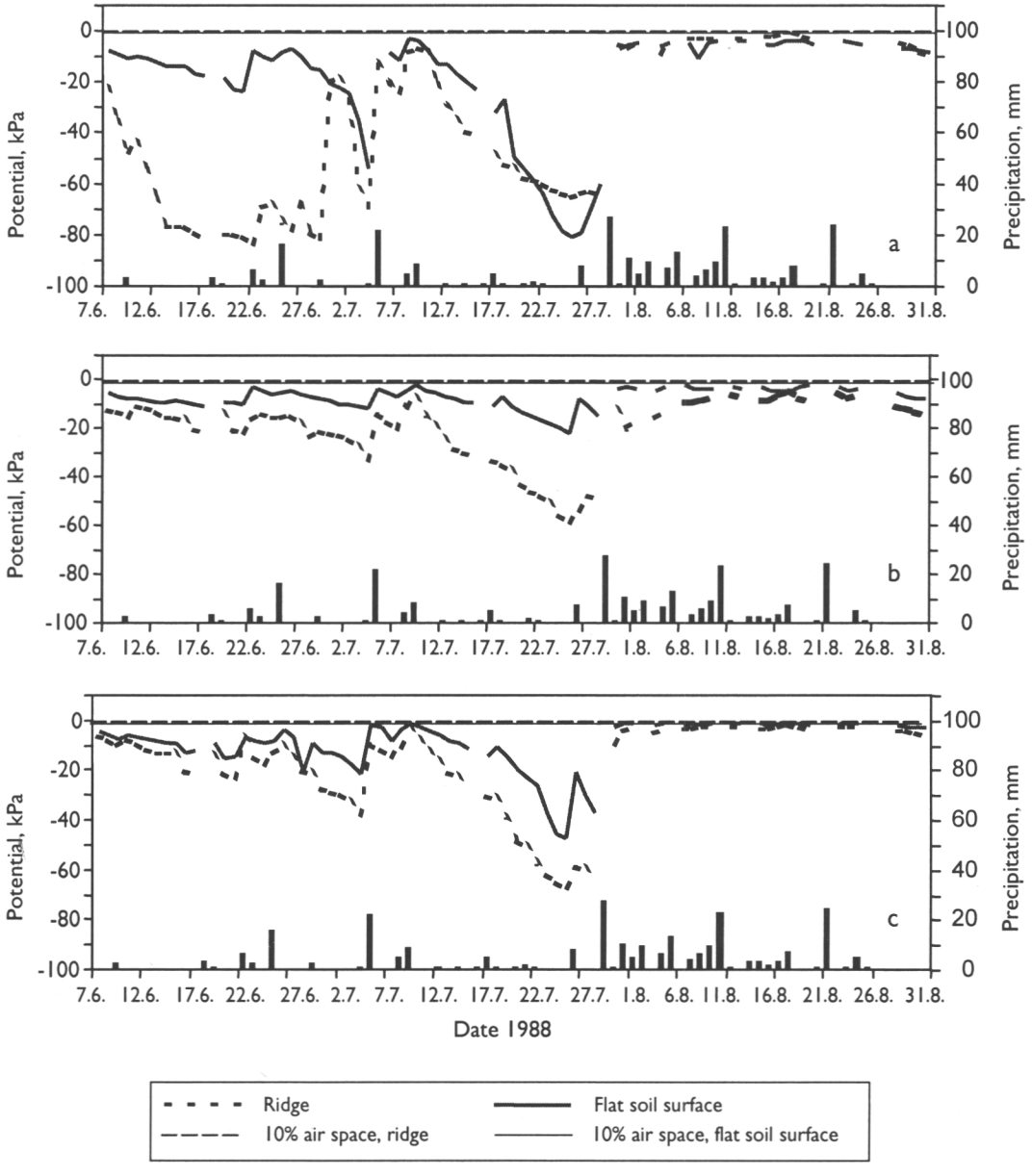


Figure 3. The dynamics of soil water potential in the ridges of ploughed plots and in the unprepared soil in Kontiolahti, eastern Finland. a) Coarse loamy soil, b) paludified soil, and c) peatland. Precipitation during the monitoring period, and the potentials representing 10% air space in the soil are also depicted.

1). The differences in temperatures are highest in the middle of summer and during drought periods. Even the minimum temperatures are slightly higher in mounds than in untreated soil. The significance of the increased temperature resulting from soil

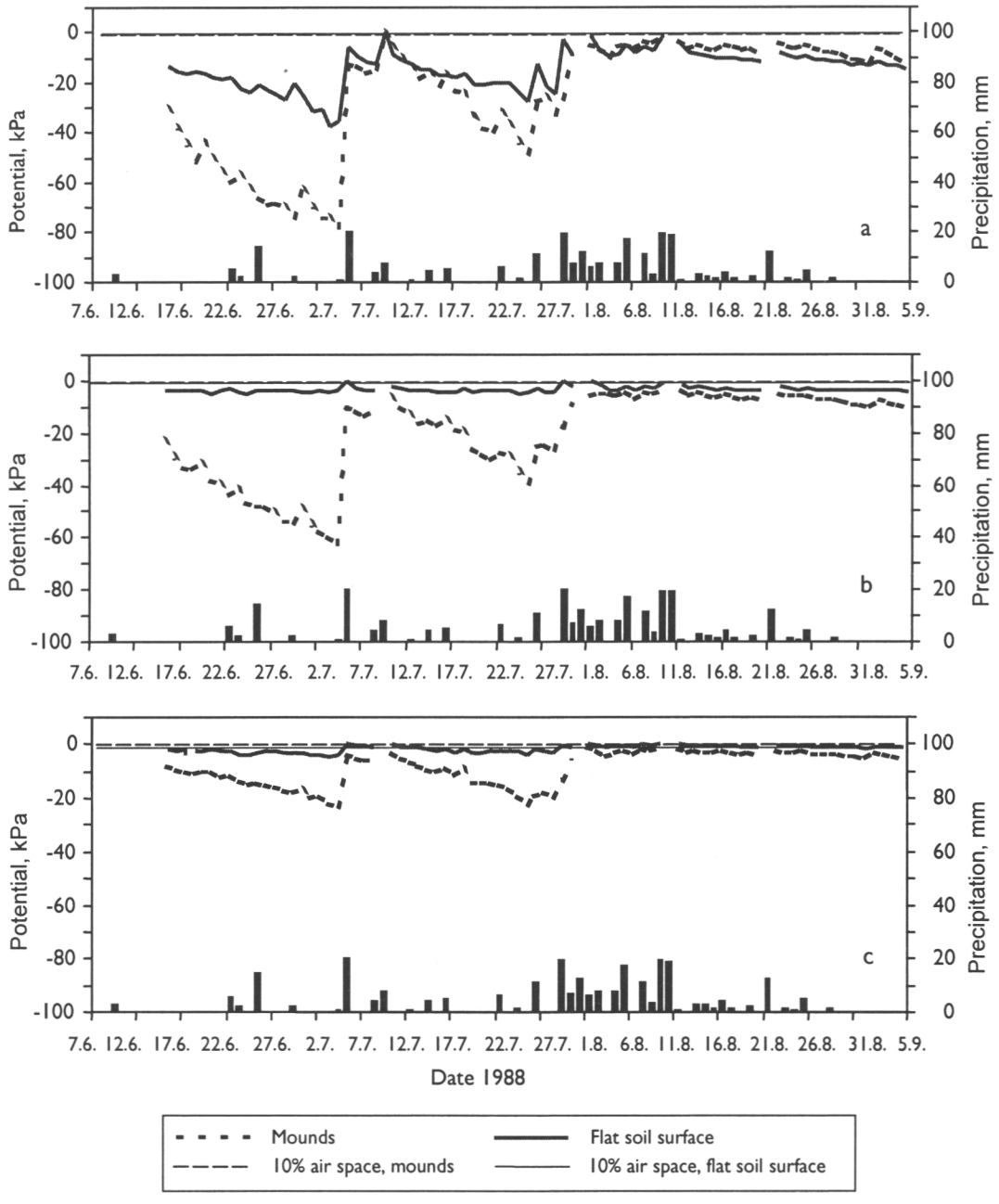


Figure 4. The dynamics of soil water potential in the mounds and in the unprepared soil in Kiihtelysvaara, eastern Finland. a) Coarse loamy soil, b) paludified soil, and c) peatland. Precipitation during the monitoring period, and the potentials representing 10% air space in the soil are also depicted.

preparation is greatest in northern, cool conditions. As the seedlings grow, however, the roots gradually have to adjust to the low temperatures prevailing in the surrounding and underlying untreated soil.

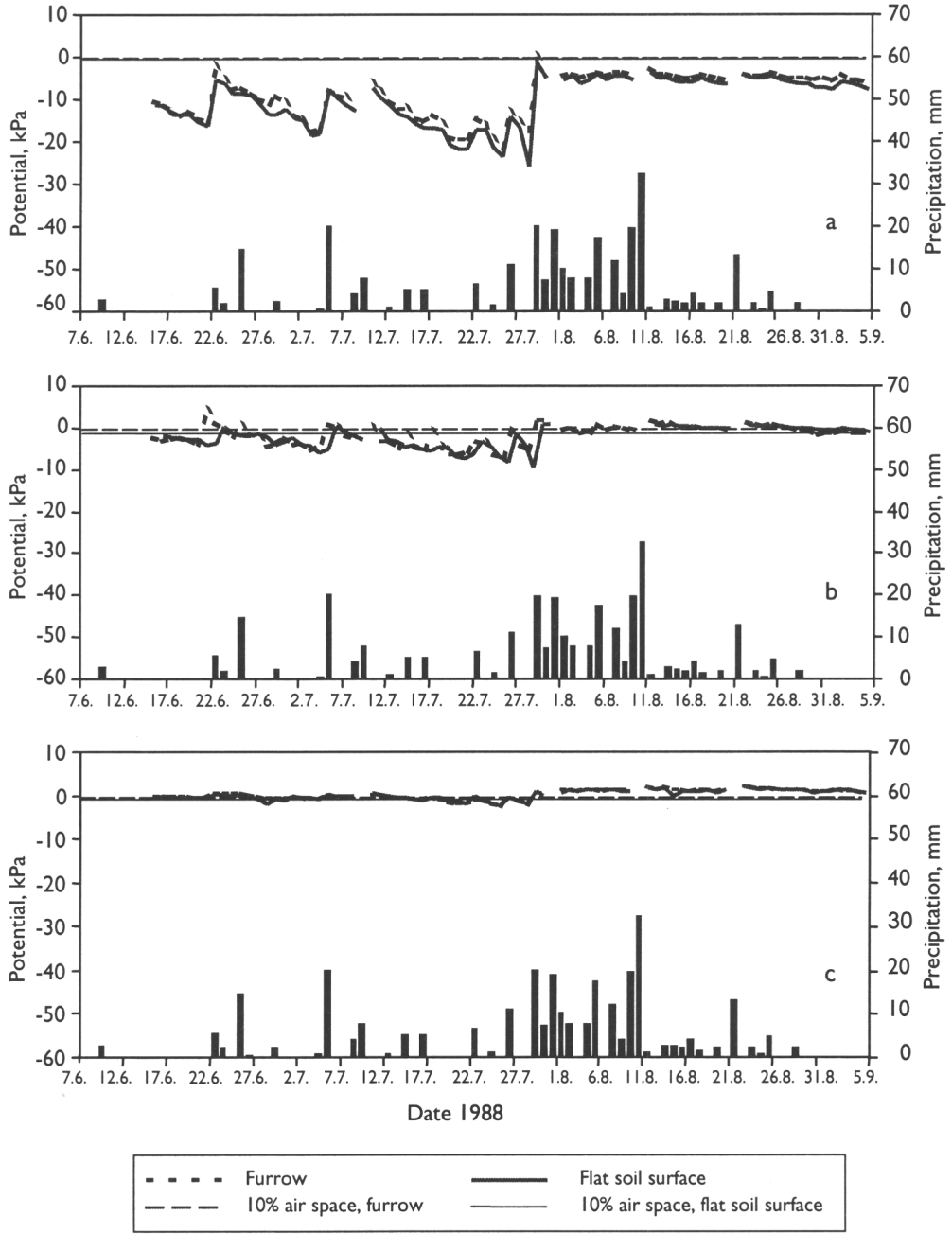


Figure 5. The dynamics of soil water potential in the furrows of disc-ploughed plots and in the unprepared soil in Kiihtelysvaara, eastern Finland. a) Coarse loamy soil, b) paludified soil, and c) peatland. Precipitation during the monitoring period, and the potentials representing 10% air space in the soil are also depicted.

Table 1. The effect of different soil preparation methods on temperature conditions of forest soil at the depth of 5 cm (Leikola 1974, Mälkönen 1976). Kuru, western Finland, Rovaniemi and Sodankylä, northern Finland.

Soil preparation method	Kuru		Rovaniemi		Sodankylä	
	°C·d	Relat.	°C·d	Relat.	°C·d	Relat.
Unprepared control	1022	100	888	100	602	100
Ploughing with two-winged plough, ridge	1374	134	1245	140	1040	173
Disc ploughing	1157	113	1013	114	-	-
Preparation with a chain rototiller	1080	106	970	109	932	155

In fine-textured soils small seedlings can be destroyed by frost heaving in autumn. In addition, the mounds may freeze strongly during winter because the snow cover on the mounds is thinner than that on flat soil (Pohtila 1977).

The minimum temperature of the air layer near to the ground can be 2–3°C higher on mineral soil mounds than on unprepared soil. Soil preparation thus slightly decreases the risk of frost damage.

Soil fertility

On regeneration areas the acidity of the surface soil layer decreases as a result of clear cutting. The increase in temperature, better aeration and mixing of the humus layer and mineral soil resulting from soil preparation promote microbial activity, which accelerates nutrient mineralisation. On dry upland sites it is not beneficial to accelerate the decomposition of organic matter because, in addition to nutrient losses, it may reduce the water-holding capacity of the soil.

Most attention concerning the release of nutrients has been paid to nitrogen because it is essential for tree growth, and in nitrate form it is readily transported by the soil water. For instance, at a regeneration site of the *Oxalis-Myrtillus* site type in southwestern Finland, the total nitrogen concentration of soil solution under mounds was about double that in untreated soil (Smolander et al. 1999, Fig. 6). Elevated nitrate concentrations were associated with low pH values in the soil solution because nitrification acidifies the soil. It is, however, clear that the same level of decomposition activity is enough to double the amount of mineral nitrogen in mounds with a double humus layer compared to untreated soil. In addition, the uptake of nitrogen by the ground vegetation is apparently considerably greater in untreated soil than in mounds that remained almost bare for a couple of years.

The more intensively the soil is prepared, the higher is the risk of nutrient losses through leaching (Kubin 1998). However, this loss can be reduced by preparing only a small area of the regeneration site, as is the case with mounding. A short-term increase in leaching, however, is inevitable and acceptable if, at the same time, this promotes the establishment of a new stand.

Initial stand development

A high degree of certainty is required in forest regeneration because failure increases the costs, produces stands of poor quality

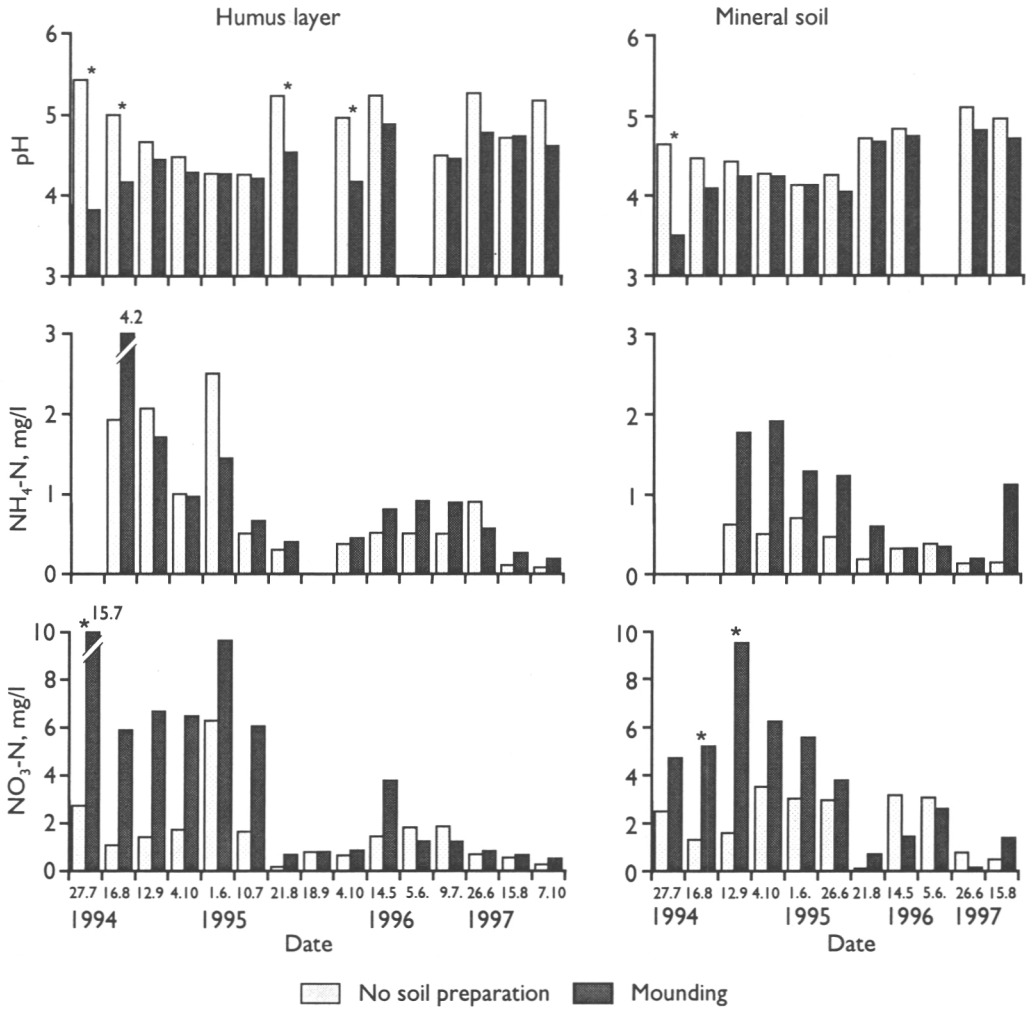


Figure 6. pH, NH_4-N and NO_3-N concentrations of soil solution collected under the undisturbed humus layer, at the depth of 10 cm in the mineral soil, under the double humus layer of mound and at the depth of 10 cm in mineral soil under the mound in the regeneration area of *Oxalis-Myrtillus* site type (Smolander et al. 2000). Mounding was carried out in October 1993. The site is located in Punkaharju, south-eastern Finland.

and eventually reduces the income from cuttings. The density of a stand is one of the most important indicators of successful regeneration. Natural regeneration or sowing generally produces a sufficient density on nutrient-poor sites. When seedlings are planted, however, sufficient density must be achieved through natural replenishment. Prepared soil usually remains suitable for restocking for 3 to 4 years in southern Finland, and longer in northern Finland. A natural admixture of birch, which tends to develop on prepared soil, should be aimed at in both pine and spruce stands. This improves the soil properties, increases the diversity and enhances the sustainability of the stand.

A suitable preparation method is essential for the initial development of plantations (Fig. 7). The quality of pine in fast-growing plantations may, however, remain poorer than that in natural or sown stands.

Conclusions

The key ecological factors in reforestation under northern conditions are low temperature and unfavourable moisture/oxygen conditions in the soil, and a low mineralisation rate of humus. Improving soil conditions for seed germination and seedling growth is thus often an essential measure for reforestation.

The need for soil preparation and the intensity of such measure have to be evaluated on the basis of prevailing site conditions and the ameliorative effect that can be achieved. It is also important that the aspects of environment protection are taken into account. On moist sites, soil preparation should be directed at forming mounds to improve the soil temperature, water, and

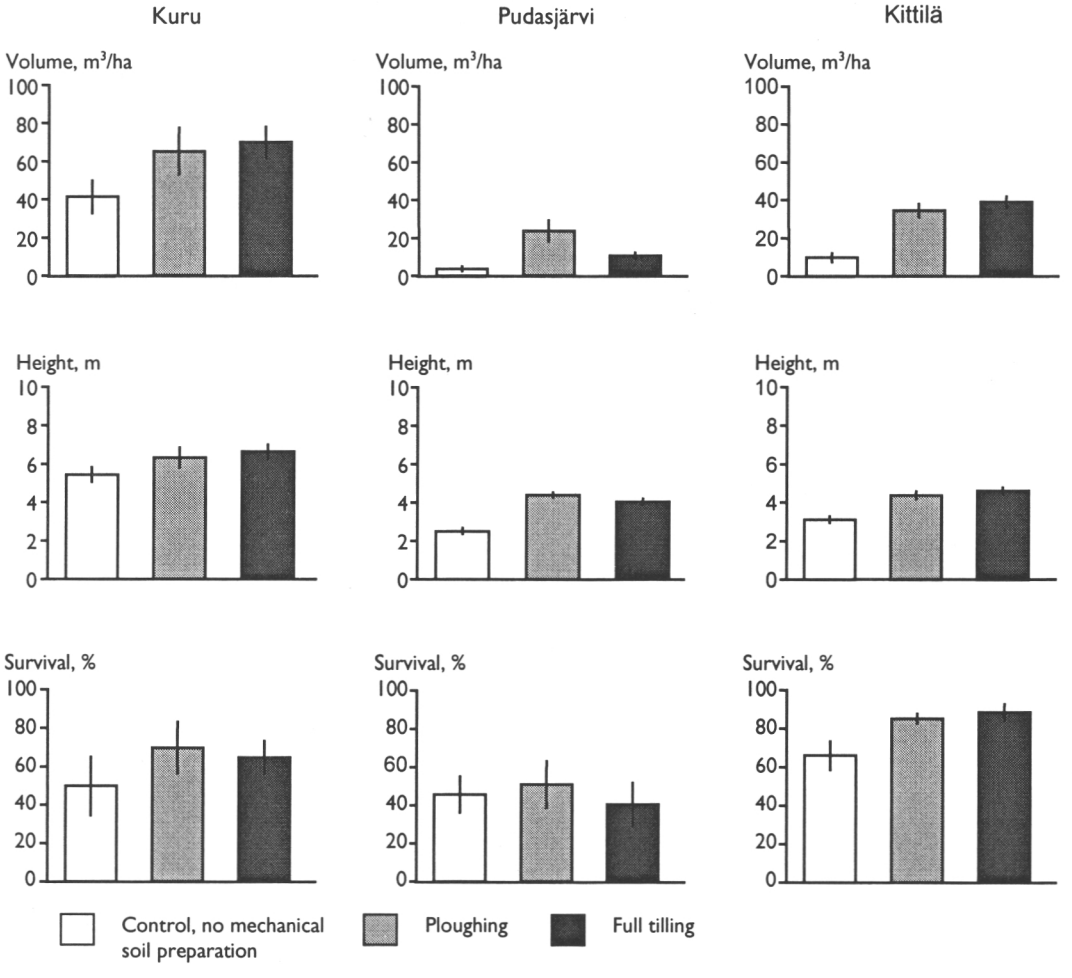


Figure 7. Stem volume, height and survival of Scots pines 18 years after planting (mean ± sd): a) in Kuru, western Finland, b) in Pudasjärvi, central Finland, and c) in Kittilä, northern Finland.

nutrient conditions. On dry and poor sites, the benefit of soil preparation is often restricted to making the stand establishment easier.

Soil preparation can produce considerable changes in soil properties and markedly speed up the initial development of young stands.

REFERENCES

Kubin, E. 1998. Leaching of nitrate nitrogen into the groundwater after felling and site preparation. Boreal Environ. Res. 3: 3–8.

Kubin, E. & Kemppainen, L. 1991. Effects of clearcutting of boreal spruce forest on air and soil temperature conditions. Acta For. Fenn. 225. 42 p.

Leikola, M. 1974. Muokkauksen vaikutus metsämaan lämpösuhteisiin Pohjois-Suomessa. Summary: Effect of soil preparation on soil temperature condition of forest regeneration areas in Northern Finland. Commun. Inst. For. Fenn. 84.2. 64 p.

Mälkönen, E. 1976. Markberedningens ekologi och inverkan på planteringsresultatet. Forskningsstiftelsen Skogsarbeten. Redogörelse 6: 11–15.

Mannerkoski, H. 1998. The effect of site preparation on soil water and air conditions. Ninth North American Forest Soil Conference, August 9–14, 1998, Tahoe City, California. Abstracts.

Mannerkoski, H. & Möttönen, V. 1990. Maan vesitalous ja ilmatila metsäaurausalueilla. Summary: Soil water conditions and air-filled porosity on ploughed reforestation areas. Silva Fenn. 24(3): 279–301.

Pohtila, E. 1977. Reforestation of ploughed sites in Finnish Lapland. Commun. Inst. For. Fenn. 91.4. 98 p.

Ritari, A. & Lähde, E. 1978. Effect of site preparation on physical properties of soil in a thickhumus spruce stand. Commun. Inst. For. Fenn. 92.7. 37 p.

Smolander, A., Paavolainen, L. & Mälkönen, E. 2000. C and N transformations in forest soil after mounding for regeneration. For. Ecol. Manage. 134: 17–28.

Иванов, Б.Н. 1980. Влияние влажности почвы на вырубках на ее плотности. Лесоведение 5: 29–36.

Маркова, И.А., Матюхина, З.Ф., Шалыгина, Т.А. & Верт, А.Е. 1978. Значение микроповышений при создании лесных культур. Лесоведение 6: 25–32.

Соколовская, Н.А., Ревут, И.Б., Маркова, И.А. & Шевляков, И.Р. 1977. Роль плотности почвы при лесовосстановлении. Лесоведение 2: 44–51.

ARTIFICIAL FOREST REGENERATION TECHNIQUES IN FINLAND

M. Hyppönen
Lapland Forest Centre, P.O. Box 8053, FIN–96101 Rovaniemi, Finland

Forest regeneration in Finland

The forest regeneration methods used most widely in Finland are 1) natural regeneration using seed-tree or shelterwood methods, 2) sowing with collected seed, and 3) planting with seedlings grown in a nursery. Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pendula* Roth.) are mainly regenerated naturally using the seed-tree method, and Norway spruce (*Picea abie*s L. Karsten) by the shelterwood method. Clear cutting usually precedes artificial regeneration.

Combinations of these methods are also used, natural regeneration combined with the seed-tree method, and artificial regeneration combined with sowing (Luonnonläheinen... 1994). A tree stand is often regenerated naturally by utilising the understorey developing under the parent stand without any regeneration measures (Moilanen and Saksa 1998). Two thirds of the forests regenerated in Finland during the 1990's were regenerated by artificial means. Of these, 75% were planted (Finnish statistical... 1997).

Cutting and the following regeneration measures form a so-called regeneration chain (Kaila 1984). The regeneration method used depends on the soil conditions (Nygren et al. 1997) (Table 1). After cutting, clearing is usually carried out using a clearing saw followed by mechanical site preparation. The site preparation methods include patch scarification, disc ploughing, ploughing, mounding or mounding connected with drainage. Site preparation is not always necessary in connection with natural regeneration, e.g. on dry upland sites with a thin humus layer. The natural regeneration areas are usually prepared lightly in order to promote regeneration. In order to ensure the success of regeneration, all the measures in the individual phases of a regeneration chain should be carried out carefully.

Sowing

Use of sowing

During the past few years in Finland, the annual sowing area of Scots pine has been about 30 000 ha (Finnish statistical... 1997). The sowing area of Norway spruce and birch is each about 1 000 ha. Sowing is a favourable method for Scots pine especially. In contrast, it is not recommended to sow Norway spruce, because the germinating capacity of spruce seed is usually poor. In addition, the sites suitable for spruce become fast overgrown with herb/grass vegetation (Kellomäki 1992, Saarenmaa 1997). These factors inhibit both seed germination and initial development of the seedlings. Silver birch can be sown on moist upland sites and sites with herb/grass vegetation if the mineral soil is exposed for regeneration purposes. If this is not done, grass and sprouts inhibit the initial development of the seedlings (Luonnonläheinen... 1994). Planting is the most successful means of regenerating silver birch, too (Kellomäki 1992).

Table 1. Recommended regeneration methods on different site types in southern Finland (Nygren et al. 1997).

Site	Principal/ complementary tree species	Natural regeneration potential		Need for site preparation	Need for sowing or planting
		Principal tree species	Complementary tree species		
Dry upland site	Pine	Usually sufficient	Naturally pure pine stands	Generally not needed	Generally not needed
Dryish upland site	Pine/birch, spruce	Sufficient when seed crop is abundant	Sufficient after site preparation	Needed	Sowing/planting of pine
Moist upland site	Spruce/birch, pine	Seldom sufficient	Sufficient after site preparation	Needed	Planting of spruce
Herb-rich site	Spruce, silver birch/other species	Seldom sufficient	Sufficient after site preparation	Needed	Planting of spruce/silver birch

Sowing is used especially when natural regeneration is not possible, but also as an alternative to natural regeneration. Pine is sown on dry or sub-dry upland sites with a thin humus layer and coarse-textured or medium-textured soil. There must be no soil frost or ground vegetation problems on the regeneration area (Pohtila and Pohjola 1985, Kinnunen 1992). The best time for sowing is May or June, immediately after the ground has thawed (Heikinheimo 1940, Kangas 1940, Pohtila and Pohjola 1985, Kinnunen 1992). Autumn is an uncertain time for sowing (Heikinheimo 1940, Kangas 1940, Kinnunen 1992). Sowing too early in the spring is also uncertain, at least in the case of broadcast sowing. Broadcast sowing on the snow cover has proved to be more uncertain than sowing on thawed soil (Pohtila and Pohjola 1985).

Sowing is usually preceded by clearing with a clearing saw, and nearly always by mechanical site preparation. The best soil preparation methods for sowing are prescribed burning combined with patch scarification or disc ploughing or light site preparation alone (e.g. Pohtila and Pohjola 1985).

Sowing methods and equipment

Sowing methods can be divided into three according to how the seeds are distributed: 1) Broadcast sowing. The seeds are distributed as evenly as possible over the entire regeneration area by hand or using special devices, or even from an aircraft. 2) Directed broadcast sowing. The seeds are sown evenly over the surface of the exposed mineral soil. 3) Spot sowing. A number of seed are placed at certain points on prepared soil surface at specific intervals.

Broadcast sowing is nowadays not very common in forest regeneration. This is partly due to the excessive consumption of seed, since some of the seeds fall on unprepared soil, and partly to the variable results obtained with this method (Pohtila and Pohjola 1985). One reason for the variable results with broadcast sowing is that the seeds are not covered. Covering the seeds has two effects on the success of sowing. Covering shelters the seeds from seed-eating animals, and also stabilises the temperature and moisture conditions in the vicinity of the seeds and seedlings (Heikkilä 1977, Kinnunen 1992). According to ex-

periments carried out in Finnish Lapland, seed consumption in broadcast sowing is 0.5–1.0 kg/ha on pine-dominated sites and 2–6 kg/ha on spruce-dominated sites (Pohtila and Pohjola 1985). The consumption of seed obviously also depends on the germination capacity of the seed.

Directed broadcast sowing is nowadays the most common sowing method. It has almost totally replaced the traditional broadcast sowing. In manual sowing the seeds are sprinkled over the prepared soil by hand from a seed bag, or by shaking them from a bottle fitted with a lid with suitable sized holes. Usually the seeds are not covered, but they can be pressed into the soil by foot, which slightly improves the result of sowing (Yli-Vakkuri and Räsänen 1971, Kinnunen 1982).

Directed broadcast sowing is increasingly being carried out mechanically. In the middle of the 1990's the proportion of mechanical sowing was already one half the total sowing area (Saarenmaa 1997). In 1996 the majority of the sowing work performed by forest companies and the Finnish Forest and Park Service was done mechanically in connection with soil preparation (Hämäläinen 1997). Many devices have been developed for mechanical sowing (Photo 21). Such devices include TTS/Palonen, TTS/Sigma, TTS/SeedGun, Top-100 of Marttinen Ky, Tume MKL 2 of Turengin Metalli and Swedish Bräcke of Robur Maskin Ab (Tervo 1998).

The sowing devices have usually been installed on the machines performing light soil preparation, e.g. patch scarification or disc ploughing, as well as on the bucket of an excavator. The sowing devices are either driven mechanically by a rotating soil preparation disc or pneumatically. The seeds pass from a seed tank via adjustable tips, holes and pipes onto the exposed soil (Hyppönen 1998). In directed broadcast sowing the target density of the future seedling stand is 4 000–5 000 seedlings/ha. In southern Finland good results have been obtained with a relatively low seed consumption in manual-directed broadcast sowing (0.3–0.4 kg/ha) (Kinnunen 1992). In mechanical sowing the seed consumption is 0.15–0.30 kg/ha depending on the germination percentage of the seeds (Tervo 1998).

According to Pohtila and Pohjola (1985), sowing success is the poorest, the longer is the time between soil preparation and sowing. In mechanical-directed broadcast, sowing soil preparation and sowing are performed simultaneously. The soil is soft and moist and the seeds are therefore located in favourable temperature and moisture conditions, and become at least partly covered and sheltered from seed-eating animals. There are some additional advantages to mechanical sowing: even spreading of the seeds, the avoidance of high-density seedling groups with increased risk of damage, a reduction in the problems caused by the ground vegetation, low sowing costs etc.

Experiences of mechanical sowing are mainly positive (Korhonen and Kumpare 1994, Kinnunen 1997, Hyppönen 1998). However, some disadvantages should be mentioned. The use of mechanical sowing is restricted by the short working season especially in northern Finland. Soil preparation cannot start until the frozen ground has thawed and the soil is dry enough to carry the preparation machines. Before this, part of the optimal sowing season has already passed, and the remaining sowing season remains short (Hyppönen 1998).

Manual methods are still being used in addition to mechanical broadcast sowing. In these methods the seeds are spread on prepared soil spots at specific intervals using tools and devices developed for this purpose

(e.g. Kinnunen 1992) (Fig. 1). The most well-known method of spot sowing is streak sowing. In this method, 20 to 30 cm-long streaks are made with e.g. a wooden stick. The seeds are then sprinkled into the streaks by hand from a seed bag or bottle, and are lightly covered with a thin layer of soil. Streak sowing corresponds to the earlier used furrow sowing, in which a small furrow was made with a drill punch or some other device. The seeds were sown into the furrow from a seed bag or seed can (e.g. Kaila 1984). The seeds can also be spread on the sowing spots without making a furrow. Thereafter the seeds are pressed lightly with the feet against the soil. In spot sowing the target is 4 000–5 000 sowing spots per hectare. Seed consumption is 0.3–0.4 kg/ha depending on the germination capacity of the seeds.

In shelter sowing the seeds are sown on the spots by hand or using a shelter-sowing device. The seeds are then covered with small sowing shelters made of transparent plastic that disintegrates after a years in sunlight. The method was used widely in the cold conditions of northern Lapland during the 1970's and 1980's (e.g. Lähde and Tuohisaari 1976). Today the method has been abandoned, as is the case with many other manual methods based on special devices and tools. In shelter sowing the consumption of seeds can be reduced by as much as 50 % compared to that of normal spot sowing

Sowing devices have been developed that distribute the seeds individually onto prepared soil. For instance, the Jalco device has a rotating disc in the lower part of the handle. When the device is pushed over the prepared soil surface, the disc rotates and forms a continuous small furrow into which the seed fall at specific intervals from a tank inside the handle or from a separate tank (Kaila 1984). This kind of sowing is an intermediate form between directed broadcast sowing and spot sowing. The use of these devices has never become common.

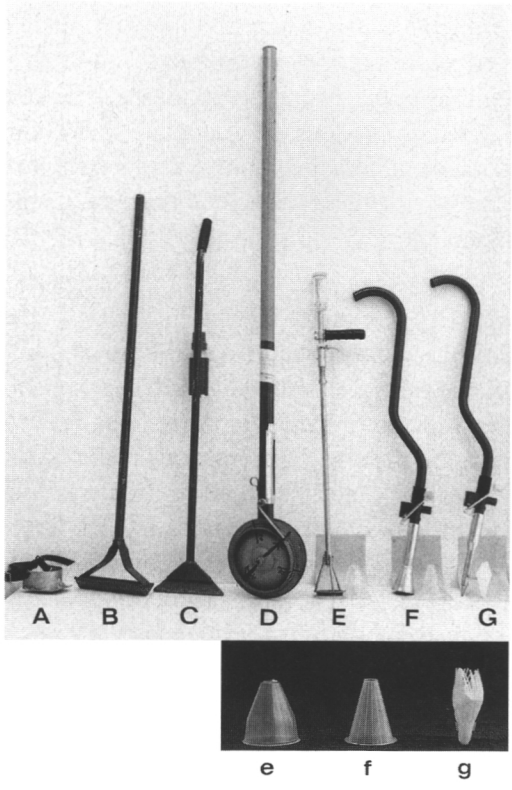


Figure 1. Manual sowing devices (Kinnunen 1992). Photo H. Latvajärvi.

A Heel iron
B Drill punch
C Männistö device
D Jalco device
E Shelter sowing device (Finnish model) and shelter (e)
F Shelter sowing device (Swedish model) and shelter (f)
G Funnel-shelter sowing device (Swedish model) and shelter (g)

Selection of the sowing point

Selection of the sowing point is not possible in broadcast sowing because the seeds fall randomly over the regeneration area. Thus, part of the seeds fall on the prepared soil

and part on unprepared soil. In manual directed broadcast sowing the sowing point can be chosen rather precisely. In mechanical sowing on uneven and stony ground, the soil-preparing machine swings and leans from side to side with the result that part of the seeds fall onto soil outside the prepared soil area. The accuracy of sowing depends on how well the sowing device is installed.

In manual spot sowing the sowing spot is chosen on the prepared mineral soil. On a regeneration area prepared with a disc plough, the sowing spots are usually chosen along the edge of the preparation track, not on the bottom (Fig. 2a). The seeds should be sown on the highest point of the exposed mineral soil. On a regeneration area prepared with patch scarification, care should be taken to ensure that the seeds do not fall into pits or other lower water-logged points where there is a shortage of oxygen and a risk of soil frost (e.g. Kaila 1984). If there is no risk of excessive moisture, soil frost or a lack of oxygen, seed germination in small pits and holes will be more certain (Winsa and Bergsten 1994). It is also important to ensure that the seeds are not placed in conditions where germination begins immediately (Kinnunen 1992). The shorter the time between sowing and germination, the more seedlings will be produced from the seeds (Yli-Vakkuri 1961, Pohtila and Pohjola 1985).

Sowing costs

Sowing costs include the costs of sowing work and seed. Good quality pine seed with a germination of 95% collected from a known stand costs 2 500 FIM/kg, and seed with the same germination capacity collected from a seed-orchard costs 2 900 FIM/kg. According to Kinnunen (1997), seed costs are 70% of the total costs of sowing. In 1996 the average total costs of sowing were 863 FIM/ha (Finnish statistical... 1997). In mechanical sowing the seed costs may be 80–90% of the total costs of sowing. In the first half of the 1990's the unit costs of sowing work were less than one half of the costs at the end of the 1980's. The decrease was due to the mechanisation of sowing. During the same period the seed costs doubled (Kinnunen 1997). The working costs of mechanical sowing can nowadays be 30–40% of the costs of manual sowing.

In the middle of the 1990's the average total costs of an artificial regeneration chain based on sowing were 1 900 FIM/ha. Of this, the proportion of clearing the regeneration area was 18%, site preparation 35%, and sowing 46% (Finnish statistical... 1997). In mechanical sowing the total costs were slightly lower, and in manual sowing higher than the average costs.

Planting

Use of planting

During the last few years the annual planting area has been about 80 000–90 000 ha, less than half of which was Norway spruce, about one third Scots pine, and about one fifth birch (Finnish statistical... 1997). All the domestic tree species are suitable for planting as long as their site requirements are taken into consideration. The regeneration areas to be planted are usually fertile, fine-textured and paludified sites with a thick humus layer and sites that easily become overgrown with herbs and grass. Natural regeneration or sowing on these areas is not possible without considerably increased costs. Abandoned agricultural land is mostly afforested by planting (Luonnonläheinen... 1994). The sites suitable for pine are moist and poorer upland sites. Spruce and birch are planted on moist and more fertile upland sites.

Planting is usually carried out in the spring, but containerised seedlings especially are also planted in the autumn. Bare-rooted spruce seedlings are mostly planted in the spring, and commonly also at the end of the summer or in autumn (Kaila 1984).

The planting density of Scots pine is usually 2 000–2 500 seedlings/ha. The corresponding densities of Norway spruce, silver birch and downy birch are 1 400–2 000, 1 200–1 600 and 1 600–2 000 seedlings/ha, respectively. Clearing of a regeneration area with a clearing saw and mechanical site preparation usually precede planting. Site preparation of a planting area is generally more intensive than that of a sowing area. The most usual preparation methods are patch scarification, disc ploughing, mounding, mounding connected with drainage, and in northern Finland also ploughing. Studies have shown that ploughing is more suitable for planting than for sowing (Pohtila and Pohjola 1985).

Nowadays the majority of the transplants are one- or two-year-old containerised seedlings, and they will continue to gain ground over bare-rooted seedlings (Finnish statistical... 1979). Nevertheless, bare-rooted seedlings still have a range of uses. For example, two-, three- or four-year-old bare-rooted Norway spruce seedlings are still used in the afforestation of abandoned fields, and on the most fertile forest sites. In the future containerised seedlings will most likely completely replace bare-rooted ones when containerised seedling techniques have been further improved. In general, the more fertile is the site, the larger the seedlings that should be planted. Careful management of seedlings from the nursery to the regeneration area is the basis of successful regeneration.

Planting methods and devices

In Finland the majority of seedlings are still planted by hand. Containerised pine and spruce seedlings are usually planted with a planting tube, the diameter of which varies according to the size of the seedling (Kaila 1984). A hoe for planting containerised seedlings is also used especially when planting large containerised seedlings. For example, large containerised birch seedlings are always planted with a hoe. Bare-rooted seedlings are usually planted with a grooved hoe. On the regeneration area, the seedlings to be planted with a tube are carried in a planting basket attached to the side of the planter, or in an other carrying device. In contrast, bare-rooted seedlings and large containerised birch seedlings to be planted with a hoe are carried in a basket or bucket by hand. Carrying devices intended for transporting the seedlings from a seedling store to the regeneration area have also been developed (e.g. Kaila 1984).

Although planting is mostly done by hand, planting machines have also been developed (Photo 22). There are three types of planting machine: 1) small, partly mechanised machines, 2) machines that move, stop and plant the area within reach, and 3) continuous working machines (Hallonborg et al. 1997). The Nordic machines Hevotrack and Silviplant belong to the first group, Bräcke-Planter, Eco-Planter and Ilves planter to the second, and Silva Nova to the third (Tervo 1998). The use of planters is not widespread, because manual planting is still cheaper than mechanical planters (Rummukainen 1993, Hämäläinen 1997, Kautto 1997, Tervo 1998). As forests will be artificially regenerated in the future, the development of planting machines will continue and the capacity to use various planting alternatives maintained (Tervo 1998). The use of planting machines will

most likely increase in the future, because it may be difficult to get labour for manual planting.

Selection of planting point

The seedlings are generally planted on prepared soil. On a regeneration area prepared with a disc plough the seedlings are planted on exposed mineral soil at the edge of the ploughed strip, as high above the bottom of the furrow as possible (Fig. 2b). This means that the seedlings are not water-logged even during wet periods, and there is no risk of soil frost (Kaila 1984). In ploughing and mounding the seedlings are planted on the raised, warm points such as the mounds and the tilths made by a plough (Kaila 1984) (Figs. 2c and 2d). When planted on a mound or the tilth, the soil around the planting point should be compacted in order to ensure that the seedling does not become too dry in loose soil, or lean or fall on a mound eroded by the rain or wind.

Planting costs

In 1996 the average total costs of planting in Finland were 3 225 FIM/ha (Finnish statistical... 1997). The total costs mainly comprise the labour costs and seedling costs, because the costs of mechanical planting were very small. Working costs include all secondary costs without supervision. The unit cost depends on a number of work-difficulty factors, of which working conditions and seedling species are the most important. In planting the costs of the work and the seedlings are almost equal. During the past few years the unit costs of planting have decreased slightly, whereas the seedling costs have remained unchanged (Kinnunen 1997).

In the middle of the 1990's the total costs of the regeneration chain based on planting in Finland were about 4 400 FIM/ha. The proportion of cleaning, site preparation, and planting including seedlings were about 8%, 18% and 74%, respectively (Finnish statistical... 1997). When using light preparation and small containerised seedlings the costs of the chain were about 3 500 FIM/ha. In contrast, when using mounding and older bare-rooted seedlings the costs were 5 500 FIM/ha.

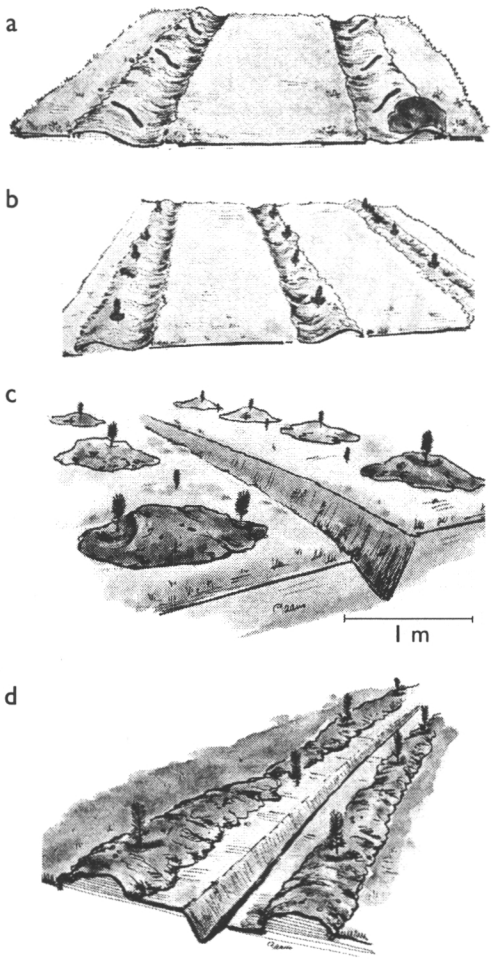


Figure 2. Sowing and planting points in different site preparation methods. Figures Paavo Simola.

a) sowing on a disc ploughing area,
b) planting on a disc ploughing area,
c) planting on a mounding area. Seedling distance must be at least 1 m,
d) planting on a ploughing area.

Summary and conclusions

In Finland about 120 000 ha of forest were artificially regenerated each year during the 1990's. The proportion of sowing was 25%, and that of planting 75%. The share of sowing has since increased, especially in southern Finland. Most of the sowing has been done mechanically in connection with site preparation. Mechanical sowing has proved to be a cheap and reliable artificial reproduction method, and it has a number of advantages compared to manual sowing. One of the disadvantages is the short working season. Manual sowing methods are still carried out, too. The methods and devices used in manual sowing have become simplified.

Planting is still mainly carried out manually. It has not been possible to develop machines that can complete with the costs of manual methods. The development of planting machines must be continued, because in the future it may be difficult to obtain sufficient labour for regeneration work. Nowadays most of the transplants are containerised, and their share is still increasing.

In artificial regeneration the selection of the proper regeneration chain is the basis of successful regeneration. Regeneration method, tree species, preparation method, date of regeneration and selection of the planting and sowing point, together with the precision of the work, all have a decisive influence on the regeneration result.

REFERENCES

Hallonborg, U., von Hofsten, H., Mattsson, S. & Thorsen, Å. 1997. Planteringsmaskiner i skogsbruket – en beskrivning av metoder och maskiner. Summary: Forestry planting machines – a description of the methods and the machines. SkogForsk. Redogörelse 7. 24 p.

Heikinheimo, O. 1940. Metsäpuiden taimien kasvatus taimitarhassa. Referat: Versuch ins Baumschulen. Commun. Inst. For. Fenn. 29.1. 97 p.

Heikkilä, R. 1977. Eläimet kylvetyn männyn ja kuusen siemenen tuhoojina Pohjois-Suomessa. Summary: Destruction caused by animals to sown pine and spruce seed in north Finland. Commun. Inst. For. Fenn. 89.5. 35 p.

Hyppönen, M. 1998. Koneellisen männynkylvön onnistuminen Länsi-Lapissa. Metsätieteen aikakauskirja – Folia For. 1: 65–74.

Kaila, S. 1984. Metsänviljelyn suunnittelu ja toteutus. Metsätehon opas. Painovalmiste Ky, Helsinki. ISBN 951–673–049–3. 36 p.

Kangas, E. 1940. Tuloksia Pohjankankaan ja Hämeenkankaan metsänviljelyksistä. Referat: Ergebnisse der Waldkulturen auf den Heiden Pohjankangas und Hämeenkangas. Acta For. Fenn. 49.4. 64 p.

Kautto, K. 1997. Koneellisen istutuksen tuottavuus, työnjälki ja kustannukset. Työtehoseuran metsätiedote 5. 4 p.

Kellomäki, S. 1991. Metsänhoito. Silva Carelica 8. 501 p.

Kinnunen, K. 1982. Männyn kylvö karuhkoilla kangasmailla Länsi-Suomessa. Summary: Scots pine sowing on barren mineral soils in western Finland. Folia For. 531. 24 p.

Kinnunen, K. 1992. Kylvöalustan, ajankohdan ja menetelmän vaikutus männyn kylvön onnistumiseen. Summary: Effect of substratum, date and method on the post-sowing survival of Scots pine. Folia For. 785. 45 p.

Kinnunen, K. 1997. Uudistamisen tekniikka ja talous. In: Mielikäinen, K. & Riikilä, M. (eds). Kannattava puuntuotanto. Metsäntutkimuslaitos ja Tapio. Metsälehti Kustannus. Gummerus Kirjapaino Oy, Jyväskylä. ISBN 952–5118–06–1. p. 34–44.

Korhonen, P. & Kumpare, T. 1994. Koneellisesti kylvettyjen uudistusalojen taimettumistulokset hyviä. Metsähallitus, kehittämisyksikkö. Tiedote 2. 5 p.

Luonnonläheinen metsänhoito 1994. Metsänhoitosuositukset. Metsäkeskus Tapion julkaisu 6. ISBN 951–96739–9–7. 72 p.

Lähde, E. & Tuohisaari, O. 1976. An ecological study on effects of shelters on germination

and germling development of Scots pine, Norway spruce and Siberian larch. Commun. Inst. For. Fenn. 88.1. 37 p.

Finnish statistical yearbook of forestry 1997. Finnish Forest Research Institute. Gummerus Kirjapaino Oy, Jyväskylä. ISBN 951–40–1585–1. 348 p.

Moilanen, M. & Saksa, T. 1998. (eds). Alikasvokset metsänuudistamisessa – varjosta valoon. Metsälehti Kustannus ja Metsäntutkimuslaitos. ISBN 952–5118–19–3. 123 p.

Nygren, M., Ahonen, M., Koskinen, R., Kubin, E. & Mälkönen, E. 1997. Monimuotoinen metsänuudistaminen. Uudistamismenetelmien perustan tarkastelua. Metsäntutkimusl. tied. 636. 40 p.

Pohtila, E. & Pohjola, T. 1985. Maan kunnostus männyn viljelyssä Lapissa. Summary: Soil preparation in reforestation of Scots pine in Lapland. Silva Fenn. 19.3: 245–270.

Rummukainen, A. 1993. Ilves-metsänistutuslaite maataloustraktorissa. Summary: Loudermounted Ilves planting device. Työtehoseuran metsätiedote 7. 4 p.

Saarenmaa, L. 1997. Metsän uudistaminen. Julkaisussa: Häyrynen, M. (eds). Tapion taskukirja. Metsälehti Kustannus. Gummerus Kirjapaino Oy, Jyväskylä. ISBN 5118–08–8. p. 188–203.

Tervo, L. 1998. Taimituotannon ja metsän uudistamisen tekniikka. Finnish Forest Research Institute. 13 p.

Winsa, H. & Bergsten, U. 1994. Direct seeding of Pinus silvestris using microsite preparation and invigorated seed lots of different quality: 2-year results. Can. J. For. Res. 1: 77–86.

Yli-Vakkuri, P. 1961. Kokeellisia tutkimuksia taimien syntymisestä ja ensikehityksestä kuusikoissa ja männiköissä. Summary: Experimental studies on the emergence and initial development of tree seedlings in spruce and pine stands. Acta For. Fenn. 75.1. 122 p.

Yli-Vakkuri, P. & Räsänen, P.K. 1971. Siementen peittämisen ja kylvökohdan polkaisun vaikutus männyn ruutukylvön tulokseen. Summary: The influence of covering and of tramping the seeds into the soil on the success of spot sowing of pine. Silva Fenn. 5(1): 1–10.

ARTIFICIAL REGENERATION AND FOREST PROTECTION IN THE REPUBLIC OF KARELIA

V.I. Krutov and A.I. Sokolov

Forest Research Institute, Karelian Science Centre of the Russian Academy of Sciences, Pushkinskaya 11, Petrozavodsk, 185610, Russia

Forest plantations in the Republic of Karelia

One of the major challenges facing forest management in the Republic of Karelia is how to speed up regeneration, and to improve the quality of forest resources that are currently being depleted through clear cuttings. This challenge is being met by combining, in a flexible manner, the natural and artificial regeneration of clear-cut areas with coniferous species. This is in good agreement with the Russian State Regeneration Programme, adopted in 1993, which places priority on forest plantations.

The earliest forest plantations were established on clear-cut sites in Karelia in 1904 and, by 1938, their total area had reached 1 115 ha as a result of substantial regeneration by sowing with Scots pine (*Pinus sylvestris* L.) (Шубин and Казаков 1985). The soil was, as a rule, first prepared by horse-drawn implements – ploughs and harrows, and occasionally by hand. Complete eradication of the forest vegetation by burning normally preceded soil preparation. In accordance with the practices applied in Russia's southern areas, seed was applied at high sowing rates, from 1.2 to 4.8 kg/ha. As a result, the pine plantations established during this period, particularly those on clear-cut areas originally covered by pine stands of Pinetum vacciniosum and cladinosum types, had an extremely high density.

Mechanised logging came into wide use in 1948, and a few years earlier the cleaning of clear-cut areas by fire had been made compulsory. The resulting rapid expansion of clear-cut areas and the destruction of understorey and seed trees by fire, meant that artificial regeneration had to be significantly increased. Up until 1959 the soil was prepared manually, or using horse-drawn ploughs on sandy soils. Forest plantations were established by hand sowing, planting, and tending the young trees. Pine predominated on light sandy soils.

The period between 1960 and 1966 saw the wide-scale use of tractor-drawn implements – a range of scarifiers and scarifier-seeders of the PST-2A model for soil preparation. The proportion of mechanised soil preparation soon reached 80%. This technique resulted in the use of clear-cut fertile sites, subsequently increasing the area of forest plantations from 17 000 to 45 500 ha during the period. Regenerated areas increased by between 46 000 to 53 000 ha a year during the period 1967–1977. This resulted in a change in the balance between the main forest-forming species: the proportion of newly planted Norway spruce (*Picea abies* (L.) Karsten) plantations varied from 30% to 60% in some years. The reason for the large variation lies in the availability of seed, and the situation has continued up until today. Since 1960, new forests have been planted on an ever-increasing scale; their share out of the total

area of plantations was 42% in 1983, and had risen to 58% by 1990.

Regeneration studies have expanded considerably in Karelia since the 1960's following the establishment of the Forest Research Institute of the Karelian Branch of the USSR Academy of Sciences (today the Karelian Science Centre of the Russian Academy of Sciences). The new clear-cut area classification developed at the Institute is closely connected to the forest-type classification. Clear-cut areas with similar site conditions and vegetation type, which require identical management practices, have been combined into five groups of clear-cut area types that are not subjected to clearing by fire, and into three groups of clear-cut area types that are cleared completely by burning (Воронова 1964, Ронконен 1975). The Forest Research Institute has, in cooperation with the Petrozavodsk Experimental Forest Station of the Leningrad Forestry Research Institute, developed soil preparation methods and equipments for establishing the different types of forest plantations on the basis of zonal-typological site conditions. Various sowing and planting methods were proposed for the regeneration of clear-cut areas and technical plans were compiled for the practical implementation of forest plantations (Синькевич and Шубин 1969, Шубин 1975, Шубин et al. 1986).

In the period after the start of the first joint projects, these organisations have continued to carry out research on the silvicultural and ecological consequences of different forest management activities on forest ecosystems (chemical control of weeds and undesirable vegetation, application of mineral fertilisers, thinning of plantations etc.). The researchers have published a number of monographs, collections of academic papers, and practical recommendations.

At the present time, regeneration in the Republic of Karelia is performed naturally and artificially, and using their combination, as described in the Guidelines for the State Forest Regeneration in the Republic of Karelia (Руководство... 1995). The guidelines list criteria for selecting the optimal regeneration method. It recommends establishing forest plantations wherever commercially valuable species cannot be regenerated naturally within ten years after logging. The combined method is preferably used in areas where the understorey is unevenly distributed. The emphasis is on natural regeneration, which includes retention of the understorey and seed trees, combined with soil preparation. According to the Forest Research Institute's data, forests can be regenerated in the Republic by retaining the coniferous understorey on 27% of the annually harvested area, and by promoting natural regeneration on 47% of the harvested area. Forest plantations will have to be established by sowing or planting on the remaining 26% (Методические... 1983).

The national economic crisis that has resulted in a decline in annual logging operations and a decrease in harvested volumes (to 60% on an average) in recent years, has meant a narrowing of the scale of regeneration efforts. In 1993–1994 regeneration was carried out on an area of 50 000 to 55 000 ha annually, it dropped to only 36 100 ha in 1994, including 13 600 ha of new plantations, and then further down to 28 900 ha and 10 400 ha, respectively, in 1997. In 1998, the total area of forest plantations established in Karelia was 1 186 000 ha, or 12.8% of the total forest-covered area (Государственый... 1998) (Table 1).

Clear-cut areas in Karelia are located on very uneven terrain on the predominant dry sandy and sand-loamy soils with stones and boulders. Stony soils of this kind accounts

Table 1. Reforestation in the Republic of Karelia (data provided by the State Forest Committee of the Republic of Karelia).

	Survey year					
	1973	1978	1983	1988	1993	1996
	1000 ha					
Forest-covered area including:	8 175.3	8 331.6	8816.3	8 965.6	8 983.2	9 156.2
1. Forest plantations with closed canopies	167.7	322.9	518.4	723.0	829.1	953.5
(% of forest-covered area)	(2.1)	(3.9)	(5.9)	(8.0)	(9.0)	(10.4)
2. Forest plantations with unclosed canopies	305.0	326.1	363.1	315.2	294.7	226.4
3. Non-forested area	1 160.9	951.0	432.0	343.9	378.6	290.6

for 54% of the area of the Republic. This requires special techniques in the establishment of forest plantations, above all soil preparation. The technique widely in use is partial soil preparation in strips, with patch scarification of the organic layer (Photos 23 and 24). This technique has been accepted because it helps to achieve two key goals – improving seed germination, and mitigating the adverse effect of grass vegetation. To attain these objectives, wide use is made of combination disc scarifiers designed at the Forest Research Institute, in particular, models PDN-1 and PDN-2 and model PLS-2, the latter combining the functions of a scarifier and seeder. The first two devices permit the mechanisation of sowing together with soil preparation, and the PLS-2 makes patches in the ground in which seedlings can be planted.

These soil preparation devices are highly energy-intensive. In addition, they disturb the natural soil structure and promote the regeneration of deciduous species. In recent years, scientists at Petrozavodsk University and the Forest Research Institute have developed a technique for establishing plantations on drained clear-cut areas by means of large planting stock. Seedlings are planted in patches prepared by L-2 or L-22 scarifiers. This planting technique helps to mitigate the impact of heavy machines on the soil and to double the work performance of the planting crews (Photo 25). Promising results have been obtained in establishing spruce plantations with large planting stock into mounds 10 to 15 cm high. This planting techniques facilitates better distribution of the root system in the soil, the trees are spread more evenly on stony sites, and the temperature conditions in the upper soil layer are improved. These factors contribute to faster growth of the transplants and, as a result, an increase in their competitiveness with grass vegetation and deciduous species (Table 2, Photo 26).

Pine is the main forest-forming species in the northern part of the Republic, and pine and spruce are dominant in the south. Small amounts of larch, cedar pine, and Karelian birch plantations are also grown in the south as well. Pine plantations are established by sowing and planting. Sowing is primarily used on light and stony soils that have little grass vegetation, the consumption of seeds being 0.5 kg/ha. Planting is advised on all other site types, although spruce plantations are established by

Table 2. Characteristics of the trees in 5-year-old Norway spruce plantations established in soil prepared by different methods.

Characteristics	Soil preparation method		
	Removal of organic layer	Patches	Mounds
Height, cm	77.1 ± 2.5	82.9 ± 2.7	108.6 ± 2.7
Diameter, mm	17.4 ± 0.3	16.1 ± 0.5	21.1 ± 0.5
Crown width, cm	50.3 ± 1.3	49.3 ± 1.5	65.9 ± 1.4
Crown length, cm	67.4 ± 2.2	71.8 ± 2.5	97.9 ± 2.7

seeding in some cases. Pine and spruce plantations have a density varying from 3 000 to 4 500 trees/ha. This density favours fast canopy closure in the plantations and improves forest productivity, provided thinning is carried out. When large planting stock or container seedlings are used for stand establishment, the initial density can be reduced by 25%.

Two-year-old pine and three-year-old spruce seedlings grown in the open, or one-year-old bare-root seedlings grown in the greenhouse, are used in establishing plantations. The Republic has nine open-air forest nurseries and five greenhouses in operation. Four of the greenhouses purchased from Finland produce planting stock by the containerised system. Bare-root seedlings that are planted on clear-cut sites covered with grass require manual or mechanised treatment at least three times. In these conditions the chemical control of undesirable vegetation is justified. The chemicals can be applied by spraying or by the contact method, which is much safer (Рекомендации... 1997). Our experience shows that it is feasible to use large planting stock on fertile clear-cut sites, the tending of seedling stands being kept to a minimum.

Problems in artificial reforestation

Two of the most acute problems in artificial regeneration in the Republic is improving the survival and quality of newly established plantations, and increasing planting stock production by the forest nurseries.

We know from many years of experience with forest nursery operations that the planting stock production per hectare in some of the nurseries varied by between 50 and 70% of the targeted production. This shortfall is explained, on the one hand, by the low technical standards at the nurseries and, on the other, by the unsatisfactory sanitary conditions at the nurseries and high mortality of a considerable proportion (up to 90%) of the pine seedlings from fungal diseases, primarily pine-leaf cast (*Phacidium infestans*) (Photo 27). From time to time, when the seeds were brought from other regions, there were sporadic outbreaks of pine-leaf cast (*Lophodermium pinastri*). A fairly high proportion (up to 12%) of the seedlings was damaged by grey mould (*Botytis cinerea*) in polyethylene greenhouses where the hydro-thermal conditions did not strictly follow the recommended values and the seedlings were grown too densely.

Studies conducted in clear-cut sites in different years show that a significant proportion of the tree stands grown there from seed (to a smaller extent this also refers to plantations) have too low density to result in the formation of young coniferous stands and are suppressed by weeds and deciduous

species. The seed-transfer recommendations were seriously neglected in the 1970's. Owing to a lack of seed of local origin, the overwhelming majority of pine plantations in Karelia's northern districts were grown from seed brought from other Russian regions with climates differing considerably from that in Karelia. As a result, the plantations were infected and severely damaged by fungal diseases such as pine-leaf cast (*P. infestans* and *Lophodermium pinastri*), and scleroderris pine canker (*Gremmeniella abietina*).

Large clear-cutting areas, combined with inadequate slash removal from the sites, create conditions favouring increased damage by pine-leaf cast to sown and planted forests during the first ten years, and by the large pine weevil (*Hylobius abietis*) when the plantations are established on recently-cut sites.

By the time they reach the age of 11–15 years, almost half of the trees grown from seed (one third of sown sites) are, on the average, severely damaged by fungal diseases. The figure for plantations is up to 10%.

We have developed a Guidelines for Protective Measures for Forest Nurseries and Plantations in the Murmansk Region and the Karelian Autonomous Republic (1988) on the basis of our studies and experiments. For nurseries the guidelines foresee a combination of sanitary measures (isolation from forest-covered land, sanitary thinning, weed control etc.) and chemical treatment backed up by modern technique. When establishing plantations, these recommendations include a combination of silvicultural and forestry activities, with improved forest protection, fertilisation to intensify forest production, the use of large transplants, the use of local seed, tending of seedling stands to improve the tree-species composition and acceleration the growth of plantations etc. This system of protective measures has been in use for several years at nurseries and in establishing plantations on clear-cut areas in the Karelian-Kola region.

Conclusions

Artificial regeneration studies conducted in recent years at the Forest Research Institute aim at developing sound techniques that are based on the application of ecological plant protection methods, the avoidance of energy-intensive operations, a reduction in the use of chemicals, and the use of appropriate local industrial waste as fertilisers. As we have found, these techniques include soil preparation that minimises damage to the ground vegetation and is less energy-demanding, the use of large transplants to improve the survival and growth of plantations, pest control by non-chemical methods, selective suppression of undesirable vegetation by contact treatment with systemic herbicides, the improvement of soil fertility, and the acceleration of plant growth with the aid of nitrogen-fixing plants.

The principal objectives of regeneration are, as always, timely regeneration of the forests and improvement of their productivity and resistance. Long-term objectives are not confined to wood reproduction alone. Regeneration must provide multiple forest use, including continuous industrial functions, a reduction of anthropogenic impacts on forest ecosystems, environmental protection, and the maintenance of biodiversity. The list of regeneration sites in the Republic will tend to grow. Special approaches will be required for the regeneration of industrial areas severely damaged by mining operations, for certain forest plantations and recreational zones, hunting areas and other forest land that is many ways associated with the use of forest resources.

REFERENCES

Воронова, В.С. 1964. К вопросу о классификации растительности вырубок Карелии. In: Возобновление леса на вырубках и выращивание сеянцев в питомниках. Petrozavodsk. p. 22–32.

Государственный доклад о состоянии окружающей среды Республики Карелия в 1997. 1998. Petrozavodsk. 220 p.

Методические указания по планированию лесовозобновительных работ в Карельской АССР. 1983. Составители: Зябченко, С.С., Иванчиков, А.А. & Медведева, В.М. Petrozavodsk. 14 p.

Рекомендации по контактной обработке нежелательной растительности гербицидами в лесных питомниках и культурах. 1997. Составители: Соколов, А.И. & Крышень, А.М. Petrozavodsk. 16 p.

Ронконен, Н.И. 1975. Вырубки и естественное возобновление на них. In: Лесовосстановление в Карельской АССР и Мурманской области. Petrozavodsk. p. 36–65.

Руководство по лесовосстановлению в гослесфонде Республики Карелия. 1995. Petrozavodsk. 85 p.

Синькевич, М.С. & Шувин, В.И. 1969. Искусственное восстановление леса на вырубках Европейского Севера. Petrozavodsk. 180 p.

Шувин, В.И. 1975. Лесные культуры In: Лесовосстановление в Карельской АССР и Мурманской области. Petrozavodsk. p. 66–121.

Шувин, В.И. & Казаков, Л.А. 1985. Культуры сосны обыкновенной на северо-западе таежной зоны Европейского Севера. In: Система лесохозяйственных мероприятий в сосновых лесах Карелии. Petrozavodsk. p. 48–58.

Шувин, В.И., Кузьмин, И.А., Соколов, А.И. & Чистякова, Т.И. 1986. Создание культур сосны на вырубках Северо-Запада европейской части СССР. Petrozavodsk. 25 p.

THE MAIN FACTORS CONTRIBUTING TO SUCCESSFUL GROWTH OF FOREST PLANTATIONS IN NORTHWESTERN RUSSIA

I.A. Markova
St. Petersburg State Forest Technical Academy, Institutsky per. 5, St. Petersburg, 194018, Russia

Introduction

Clear felling, which is extensively used in the taiga zone, disturbs the ecological balance of the environment: the forest landscape undergoes fundamental changes and the original forest ecosystems are destroyed. Natural or artificial reforestation in such areas results in only partial restoration of the original ecosystems. The new ecosystems are considerably impoverished due to changes in species abundance and composition, lower soil fertility and partial elimination of zoocenosis.

The relatively crude techniques used in the establishment and growing plantations by leskhozes in the taiga zone usually do not result in any tangible benefits compared with the young growth of natural stands, and do not even prevent the natural succession stage of aspen and birch. The growth of these plantations is 50–65% lower than that of commercial stands managed using intensive silvicultural methods.

Main factors contributing to successful growth

The main factors contributing to a high survival and accelerated growth of artificially regenerated stands are:

1. Establishment of stands on areas with sufficiently fertile soils in conditions meeting the biological requirements of the species grown. It would be a waste of economic resources to plant trees on felled areas on poor soils because, in the presence of a natural seed source, natural forest regeneration takes place rather successfully (Чертовский et al. 1974, Мартынов et al. 1994).

2. Individual approach to soil preparation methods in different regions and site conditions. On the predominantly excessively wet soils (60–70% of the forest) in the taiga zone, trials have demonstrated that it is impossible to attain the desired regeneration result without optimal water, aeration and temperature conditions in the soil of the planting areas. Despite their comparatively high potential fertility, the soils in the region generally have a low biological activity and subsequently insufficient supply of available nitrogen and phosphorus for the plantations.

The maximum drainage effect is achieved by forming elevated ridges (30–35 cm high, 60–100 cm wide), comprising a mixture of the accumulation and illuvial soil horizons, in combination with drainage ditches (25–40 cm deep) at a distance of 70–100 cm from the planting sites. In automorphic soils the height and stem diameter in the stand increases by 30–80%, and in excessively wet conditions, where mounds or ridges are created in combination with drainage, by 100–200% (Tables 1 and 2). In order to avoid negative environmental effects, the water from the main drainage ditches should be discharged via settlers. If there is no need to discharge the

Table 1. Development of the growth parameters of Norway spruce plantations according to stand age on the clear-cut area of spruce forest (Piceetum oxalidoso-myrtillosum type) in the southern taiga sub-zone (Leningrad Region).

Soil preparation method	Stand age, a							
	2 (1977)	5 (1980)		10 (1985)			15 (1990)	
	Established, %	D_0, mm	H, cm	Survival, %	D_0, mm	H, cm	$D_{1.3}$, mm	H, cm
	Seedlings, H = 24±03 cm, D_0 = 4.3±0.1 mm							
1. Control without soil preparation	69	10±0.3	54±1.4	26	24±1.2	113±4	23±2.2	273±14
2. Ridge, 25 cm-high, formed of A_0A_1	81	17±0.6	75±5.3	51	34±1.4	172±8	45±2.8	394±20
3. Ridge (PSh-1 plough) on a 3 m strip, cleared by stump extraction	94	18±0.2	89±1.4	87	38±0.9	195±6	55±1.6	506±12
4. Ridge (PL-2–50 plough) after milling of the stumps	95	15±0.3	81±0.4	76	37±1.1	192±7	43±1.8	412±14
5. Continuous ploughing, 23–25 cm deep, after stump extraction; even surface	83	15±0.3	78±1.6	72	24±1.2	115±5	22±1.5	244±10
ridge	90	18±0.2	98±1.5	87	37±0.9	180±4	38±1.2	378±8
	Transplants, H = 38±0.5 cm, D_0 = 8.4±0.1 mm							
1. Control without soil preparation	39	15±0.3	63±1.4	36	29±1.4	113±7	26±1.9	259±15
2. Ridge, 25 cm-high, formed of A_0A_1	96	22±0.9	109±5.4	88	41±1.6	205±8	53±2.1	441±15
3. Ridge (PSh-1 plough) on a 3-m strip, cleared by stump extraction	81	28±0.5	113±2.5	75	51±1.3	252±8	63±2.0	539±14
4. Ridge (PL-2–50 plough) after milling of the stumps	68	19±0.4	85±1.9	74	44±2.0	203±10	50±2.1	440±17
5. Continuous ploughing, 23–25 cm deep, after stump extraction; even surface	84	21±0.3	88±1.5	81	28±5.9	131±3	26±1.4	264±10

Note: The stands were thinned in 1989.

excess water (fresh conditions of Piceetum oxalidosum and P. myrtillosum types, small moist areas of P. myrtillosum types), the best measure would be to prepare mounds with a diameter of 0.7–1.5 m, with one to three seedlings planted on each mound. The

Table 2. Mean parameters of an average (model) spruce tree in 17-year-old plantation (clear-cut area of grassy spruce forest, stand density – 2 000 trees/ha), Leningrad Region.

Soil preparation method	$D_{1.3}$, cm	H, m	Total mass, kg	Including				Ratio of root mass to above-ground part
				Stem and branches	Needles	Total above-ground part	Roots	
Control without soil preparation	4.5	3.0	8.7	4.3	2.7	7.0	1.7	1:4.1
Ridge of humus	5.5	3.7	10.8	5.2	3.5	8.7	2.1	1:4.1
Mounds	5.4	3.9	11.9	5.5	3.8	9.3	2.6	1:3.6
Ridge (PL-2-50 plough)	7.3	4.9	12.4	6.3	3.2	9.5	2.9	1:3.3
Ridge (PSh-1 plough)	8.0	6.7	19.5	11.0	3.7	14.7	4.8	1:3.1
Ridge (PLO-400 plough)	8.9	6.5	17.0	9.7	3.2	12.9	4.1	1:3.1
Ridge (LKN-600 ditch plough)	7.7	5.9	17.7	8.8	4.5	13.3	4.4	1:3.0

role of mounds is especially important during the first two months of the growing season, when spruce and pine grow vigorously if the soil warms up sufficiently.

Mounding does not increase the leaching of nutrients from the stand, and there is less machine time required and fuel consumption compared with ploughing, but the growth parameters of the trees on the mounds are 30–50% less than those on the ridges established along the drainage trenches (Tables 3 and 4). This is due to less marked warming of the soil, drying out of the upper layer of small mounds during dry periods, flooding to a depth of 15 cm during wet periods (Fig. 1), and to the intensive growth of grassy vegetation.

The depth of root penetration and root density in the soil layers in the northeastern part of the taiga zone also depend on the degree of soil drainage and soil warming. In plantations of the first age class the roots are concentrated within the planting site improved by soil preparation. Ploughing and mounding increase the area of the root zone and the depth of root penetration by 50–100% (Fig. 2). Most of the physiologically active spruce and pine roots are distributed in the 0–20 cm layer. The roots of the plantation die out on the edge of furrows (Figs. 3 and 4). The increased depth of the furrows and the drainage system of the clear-cut area increase the quantity of windthrows. The roots penetrate into the neighbouring ridge along the shallow drainage trench (Fig. 5), and this reduces their asymmetrical arrangement.

3. Use of genetically improved, large planting material with a compact root system produced in optimal soil conditions.

The coefficient of variation in the height of 3 to 6-year-old transplants equals 20–35%, while that for the diameter of the stem at ground level is 15–25% and for the mass 50–70%. Large transplants of the same origin may be twice as high as smaller transplants, and three times heavier. The overall variability, estimated on the basis of their appearance (phenotype), depends on two basic components: the effect of the environmental conditions on a biological group

Table 3. Growth parameters of Norway spruce plantation on sites prepared with different methods on a clear-cut area of spruce forest (Piceetum oxalidoso-myrtillosum type).

Soil preparation method	Stand age, a						
	5 (1984)		15 (1994)				
	D_0, mm	H, cm	Survival, %	$D_{1.3}$, mm	H, cm	$D^2_{1.3}H$, dm^3	%
	Soil preparation and silvicultural tending						
Control without soil preparation	11±0.6	56±3.6	42	38±2.7	386	5.6	100
Mounds (ORM-1.5)	13±0.4	62±2.0	84	42±2.8	432	7.6	136
Ridge (PSh-1 plough)	16±0.4	63±1.8	95	55±0.9	548	16.6	296
	Without tending						
Control without soil preparation	No data		49	13±1.9	186	0.3	1
Mounds (ORM-1.5)	11±0.3	57±0.3	94	31±1.0	338	3.3	60
Ridge (PSh-1 plough)	17±0.4	72±0.4	96	49±1.7	470	11.3	200

Table 4. Growth parameters of Norway spruce plantation on a moist site prepared with different methods on a recently clear-cut area of dried spruce forest (Piceetum myrtillosum, moist).

Soil preparation method	Stand age, a						
	5 (1985)		15 (1995)				
	D_0, mm	H, cm	Survival, %	$D_{1.3}$, mm	H, cm	$D^2_{1.3}H$, dm^3	%
	Seedlings, H = 25 cm, D_0 = 4.7 mm						
Control without soil preparation	12±0.3	65±2.0	83	25±1.7	293	1.8	100
Mounds (KLM-1)	13±0.3	74±2.1	83	38±1.2	380	5.5	305
Ridge (PKLN-500 plough)	19±0.5	91±2.4	97	58±1.1	546	18.4	1022
	"Briquet" containerised seedlings, H = 32 cm, D_0 = 4.8 mm						
Control without soil preparation	16±0.4	86±1.9	81	34±1.3	352	4.1	100
Mounds (KLM-1)	16±0.3	92±2.2	90	46±0.9	424	9.0	220
Ridge (PKLN-500 plough)	19±0.5	98±2.8	98	64±1.5	638	26.1	637

or individual transplant, and their genetic inheritance. In our experiments excellent results were obtained by selecting rapidly growing transplants from batches of planting material of the local climate types, grown on a large scale in the nurseries. The selection method based on the total mass of the plants in spruce plantations of the first

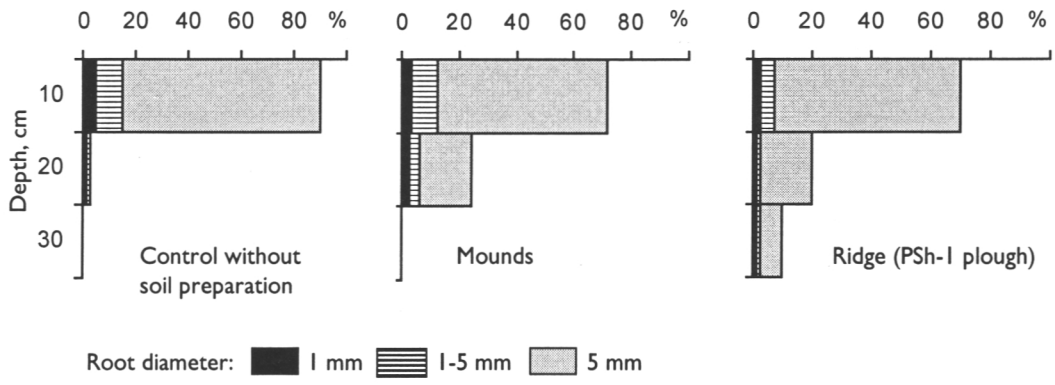


Figure 1. Distribution of root mass of an average model tree in a 17-year-old Norway spruce plantation according to the method of soil preparation in a grassy forest site.

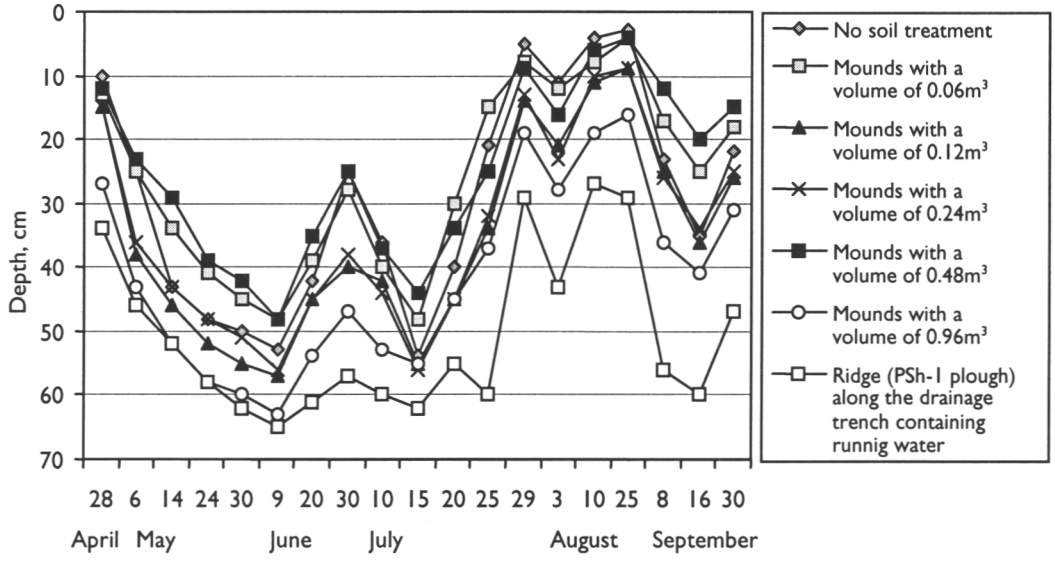


Figure 2. Depth of the ground water during the 1993 growing period on the clear-cut area of Norway spruce stand (Piceetum oxalidoso-myrtillosum type) in the southern taiga sub-zone (soil flooding, detrimental for spruce growth, took place in late July-August).

age class amounts to 130–200%, and was strongly influenced by the intensity of selection (Table 5).

Gradual (25% of the best seedlings to be planted in the nurseries, 50% of the best transplants for establishing stands) selection of the largest seedlings according to the mass of individual seedlings or distinctive fast-growing characteristics makes it possible to increase the proportion of trees in the stand with genetically determined high growth potentials, and reduce the checking period after planting.

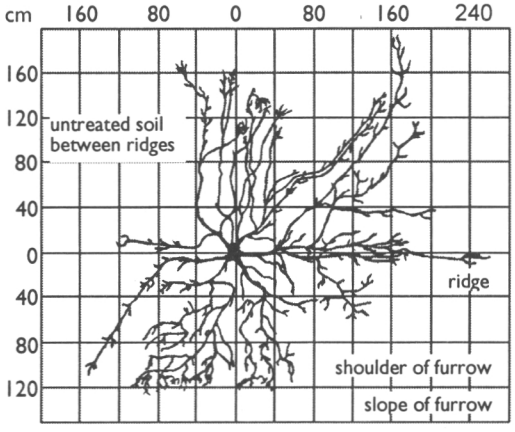


Figure 3. Horizontal projection of a Norway spruce root system in a 17-year-old plantation. Soil prepared with a PSh-1 plough.

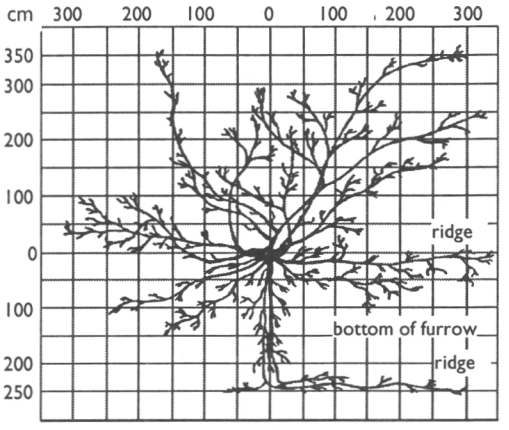


Figure 5. Horizontal projection of the root system of 17-year-old Scots pine on a drained transitional bog. In the absence of standing water the roots establish themselves at the bottom of the 30-40 cm deep furrows, in the furrow slope and spread out into the adjoining soil.

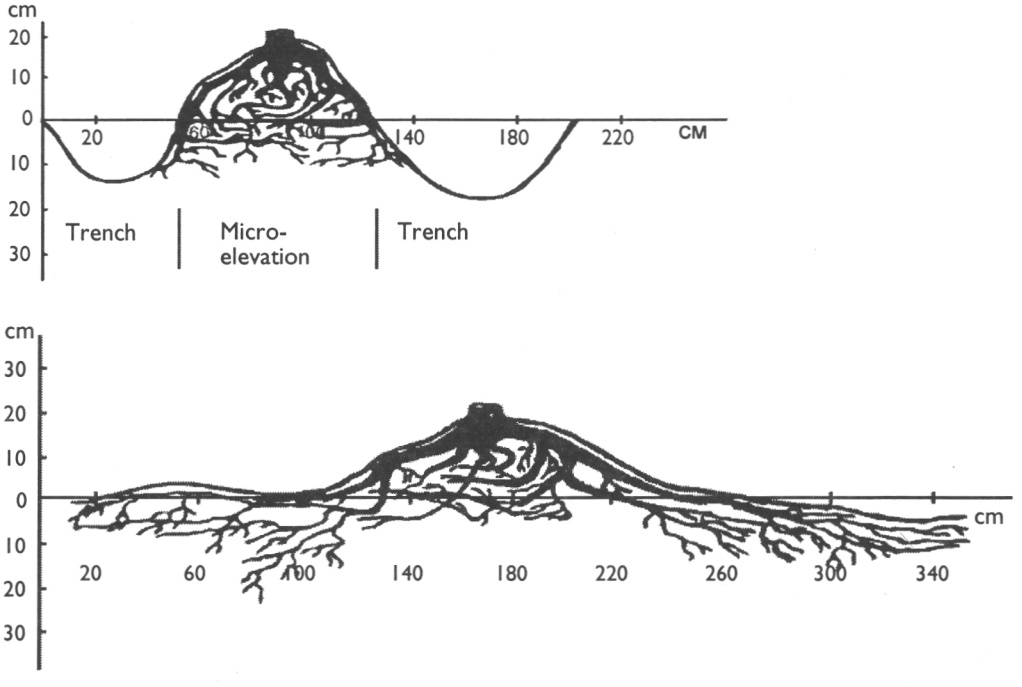


Figure 4. Distribution of the root system of a 17-year-old Norway spruce in the micro-elevation profile on the grassy clear-cut area of Norway spruce stand (during the first few years the spruce roots try to spread inside the micro-elevation).

The data obtained in a number of studies makes it possible to formulate a set of characteristics for diagnosing rapidly growing young trees in the early stages of their development:

Spruce – doubles or more than doubles its height, the growth starts and finishes late, intensive formation of second- and third-order branches, comb-like type of branching, branch whorls clearly found.

Pine – early bud opening and late bud formation, the buds are large enough, more than five in number, over 1.5 cm long, three-needled, over 6-cm-long needles.

The errors (20–30%) made during selection of the planting material can be easily corrected afterwards in first thinning.

Table 5 shows that the larger the mass of transplants is (with optimal ratio of small root mass to aboveground mass) the more rapidly the plantation grows. This rule is valid for all kinds of seedlings and transplants, including those grown in greenhouses and those with a containerized root system.

4. Prevention from competitive vegetation, insects and diseases. Improvement of the moisture and temperature conditions on the planting sites is accompanied by intensive growth of grassy vegetation. The largest mass of grassy vegetation (200–400 g air-dry material/m^2) was observed during the 3rd to 5th year after soil preparation, i.e. 1.3–2.5 more than the level when inhibited tree growth is observed. The use of Roundup (spruce) and Velpar (pine) provides reliable protection for transplants from competing vegetation, and the application of insecticides of the pyrethroid group during preparation of the planting material helps to control pine bark beetles *(Ipidae)*.

5. Realisation of optimal density regimes. This ensures that most of the wood mass is produced by trees with increased growth vigour. A study on the dynamics of the spatial and social structure of artificially regenerated stands has shown (Маслаков 1984) that the most rapidly growing trees account for one third of the original population. Their mass increases by 50–80%

Table 5. Effect of the mass of the Norway spruce transplants on the growth parameters of a 13-year-old plantation.

Trial variant based on transplant mass (g) and selection intensity (%)	Age, a	H, cm	$D_{1.3}$, cm	$D^2_{1.3}H$, dm^3
Trial with a fixed mass				
5	2+2	427	4.9+0.17	10.2
10	2+2	475	5.7+0.20	15.4
30	2+2	537	6.5+0.24	22.7
including August increment	2+2	575	7.0+0.29	28.2
60	2+2+2	600	7.1+0.20	30.2
including August increment	2+2+2	659	7.8+0.24	40.1
Trial with varying mass selection intensity				
100	2+2	481	5.6+0.19	15.1
50	2+2	537	6.0+0.18	19.3
25	2+2	572	6.7+0.20	25.7
10	2+2	611	7.1+0.16	30.8
1	2+2	620	7.4+0.19	34.0

more than the average trees, and during the growing period they produce 65–75% of the stand's total biomass and wood mass.

Consequently, if the target is to have 800–1 000 stems/ha by the end of the rotation period, the original planting density should be 2 500–3 000 trees/ha.

The quality of the trees is determined when they are 8 to 10-year-old, and it subsequently remains stable with a high (0.8–0.9) probability. Intense intraspecific competition at excessively high densities nullifies the effect of other silvicultural measures, and the negative effect is the more intensive, the more rapid is stand growth.

It takes more than one generation of foresters to grow a forest stand due to long rotation period. In this connection it is highly important to carry out stage-by-stage appraisal of the status of the planted trees. The indicators, developed by a group of scientists from the LenNIILKh (OCT... 1986), make it possible to effectively control and correct the execution of technical working regulations during the stages critical for stand growth.

Observations made during a period of 25 years on large areas have shown a high survival rate and stability of the intensively growing stands. Ten-year-old spruce trees are 1.8–2.2 m high in the middle taiga, 2.5–3.5 m high in the southern taiga and 3.5–5 m high in the mixed forest zone. The rotation period for pulpwood is 50–60 years (260–350 m^3/ha), and for sawtimber 70–80 years (400–500 m^3/ha).

Conclusions

Intensive forestry completely satisfies the requirements of environment protection, since the multi-storied system of forest phytocenosis is characterised by highly intensive assimilation of atmospheric carbon. If we take into account that 0.3 tonne of CO_2 is required to produce 1 m^3 of wood, the global ecological importance of increased forest productivity is clearly obvious.

REFERENCES

Мартынов, А.Н., Сеннов, С.Н. & Грязькин, А.В. 1994. Естественное возобновление леса. Текст лекций. ЛТА. St. Petersburg. 44 p.

Маслаков, Е.Л. 1984. Формирование сосновых молодняков. Лесн. пром-ть. Moscow. 165 p.

ОСТ 56–90–86. Культуры плантационные лесные и площади для их закладки. 1986. Оценка качества. Введ. С 01.01.87. ЦБНТИлесхоз. Moscow. 22 p.

Чертовский, В.Г., Мелехов, И.С. и др. 1974. Таежное лесоводство. Лесн. пром-ть. Moscow. 232 p.

EXPERIENCES IN GROWING SPRUCE UNDER A SHELTERWOOD WITH AN EVEN ALTERNATION OF TREE SPECIES GENERATIONS

A.F. Chmyr
St. Petersburg Forestry Research Institute, Institutsky pr. 21, St. Petersburg, 194021, Russia

Introduction

The idea of establishing and growing plantations under a shelterwood is based on the desire to carry out reforestation in a way that resembles the natural cycles of stand regeneration and development. Professor N.I. Rubtsov (Leningrad Forest Technical Academy) carried out the first investigations in this field in Russia. The first plantations were established in 1963 to 1965 on his initiative and with his personal participation. One of the plantations was converted into a permanent experiment, and the development of the plantation has been followed for over 30 years already (Рубцов 1964, 1968, Рубцов et al. 1985, Чмыр and Скиба 1984, Чмыр and Ониськив 1987).

The field experiment (3 ha) was established in the Lisino training and experimental forest management unit (leskhoz), and subsequently enlarged to 10 ha. The composition of the shelterwood at the beginning of the experiments on establishing plantations was 10 birches, one pine, one spruce and one aspen; age class IV, average height 19 m, average diameter 18 cm, stocking 0.5 to 0.6, site index class II. Rows of spruces were planted under the shelterwood on the cutover area in 1964 and in an adjacent clearing at the experiment site. 2- and 3-year-old Norway spruce seedlings from local nurseries and 4- to 5-year-old transplants from Estonia were used in the experiment. The planting stock was planted on the ridges and furrows made by a PLN-53/63 plough. The soil between the ridges and under the shelterwood was prepared in 1x1 m patches. Five 2-year-old seedlings were planted on each patch in an "envelope"-like form.

The growth of the spruce transplants, established in lines and groups with planting stock of different age using different soil preparation methods, was studied in the experiment. The treatments were:

1. Open areas
   – on the 1964 cutover
   – in a clearing (grassland).

2. Under a shelterwood in pine and birch stands
   – under the birch canopy until the age of 13, followed by the complete removal of the birch canopy (plantations under the canopy in 1977), and
   – under the birch canopy until the age of 13, followed by thinning (partial removal in 1977).

The experiment was rather complex and included a large number of factors. Only the growth parameters measured 32 years after establishing the plantations are presented here.

Results and discussion

The average diameter of the trees according to the type of planting stock and soil preparation method are given in Table 1 for the 32-year-old Norway spruce plantations.

Table 1. Mean diameters for the 32-year-old Norway spruce plantations under a pine shelterwood, on the 1964 cutover and in the clearing.

Plantation type	Diameter, cm		
	Pine shelterwood	1964 cutover	Clearing
2-year-old seedlings on a ridge:			
a) replication 1	7.8±0.5		15.0±0.4
b) replication 2	7.2±0.7		18.7±0.9
3-year-old seedlings on the double ridge	8.3±0.8		11.1±0.5
Isolated 4-year-old transplants on a double ridge	7.0±0.6	12.6±0.6	11.6±0.7
5-year-old transplants on a ridge	8.4±0.7	17.0±1.2	17.8±1.0
Planting in 1x1 m patches	5.6±0.5	10.5±0.5	
Mean diameter of the largest trees in the patches	8.6±0.9	15.6±0.4	

The plantation established with large (i.e. older) planting stock gave better results before the age of 13 and even up to the age of 18 years but, the growth dynamics changed to some extent during the period of intensive growth (up to the age of 32 years). However, the large transplants tended to retain their good growth rate. These trends are most probably due to the different density and structure of the plantations at the different points on the experiment site. The growth of the plantations established using 4-year-old transplants on double ridges, isolated from the roots of trees in the shelterwood, was clearly retarded due to the presence of excess water on these microsites in spring and autumn.

The average growth values in the group plantations in the patches of 1x1 m are also markedly lower. But due to a high variation in the tree diameters within the patches (variation coefficient varies from 60 to 70%), the average values appear to be much underestimated; that is why the average diameters of the largest trees in the groups are used in Table 1. As may be seen, statistically they differ only slightly from the average diameters of the trees in the row plantations both under the shelter and in the open areas.

The growth of the spruce plantations established on the 1964 open cutover, 1977 partial cutover (under the canopy of a sparse birch stand) and the 1977 clear cutover (preliminary plantations), as well as under the birch and pine shelterwood, are presented in Figures 1 and 2.

The growth of the plantations under the shelterwood remained consistently behind that of the plantations on the open cutovers, and the distance between the curves increased rapidly. In contrast, the growth of the plantations on the 1977 cutover approached that of the 1964 cutover.

The diameter growth of the preliminary plantations with an overstory, that was to be removed 13 years after establishment of the plantations, was close to that of the plantations established in open areas by the age of 23 to 28. The diameter distributions of the trees under the pine and birch shelterwood and on the 1964 cutover are compared to the reference sites (1964 cutover) in Figure 3. Figure 3 also illustrates the different distributions of the trees on the open cutover and under the shelterwood and how, in

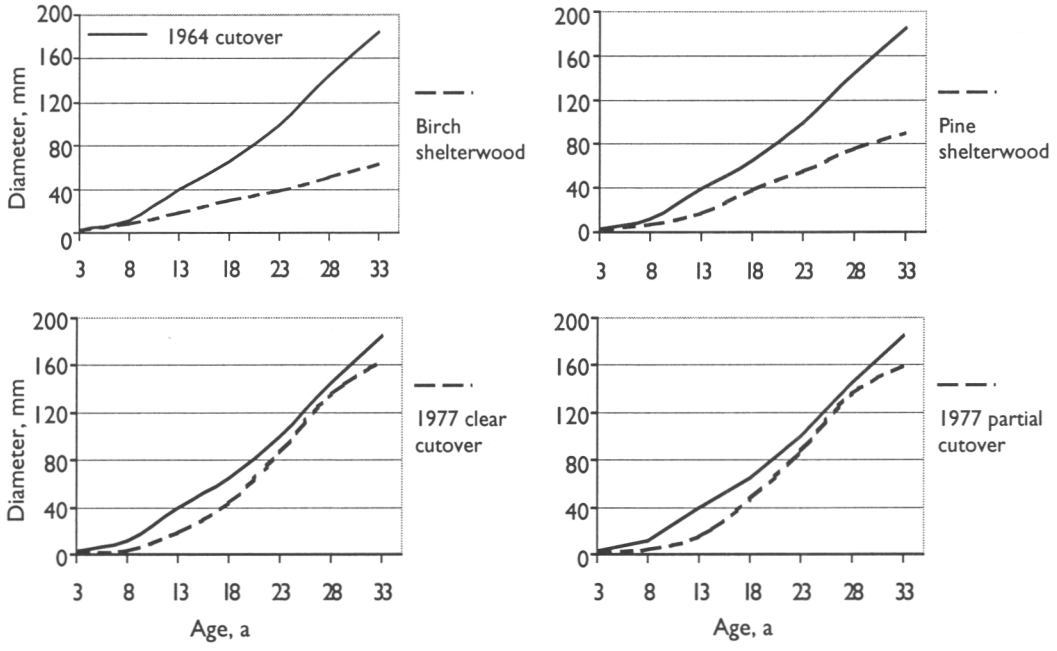


Figure 1. Diameter growth of trees in the different types of Norway spruce plantation.

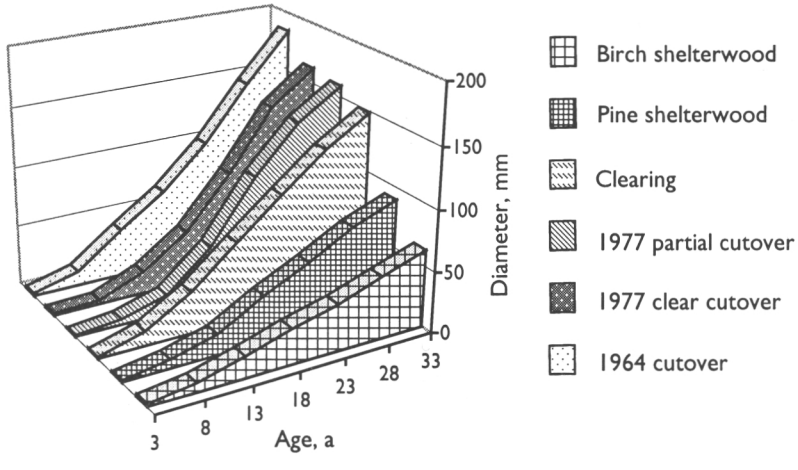


Figure 2. Development of tree diameter in the different types of Norway spruce plantation.

contrast, they are similar to the reference plot on the 1977 cutover.

The diameter increment in the same plantations is shown in Figure 4. First of all, it should be noted that there were rather distinct seasonal variations in the increment in all the treatments. These were not synchronous with similar fluctuations in the open areas, thus indicating that the environmental and microclimatic conditions in the treatments were different. Figure 4 also shows that the increment under the pine

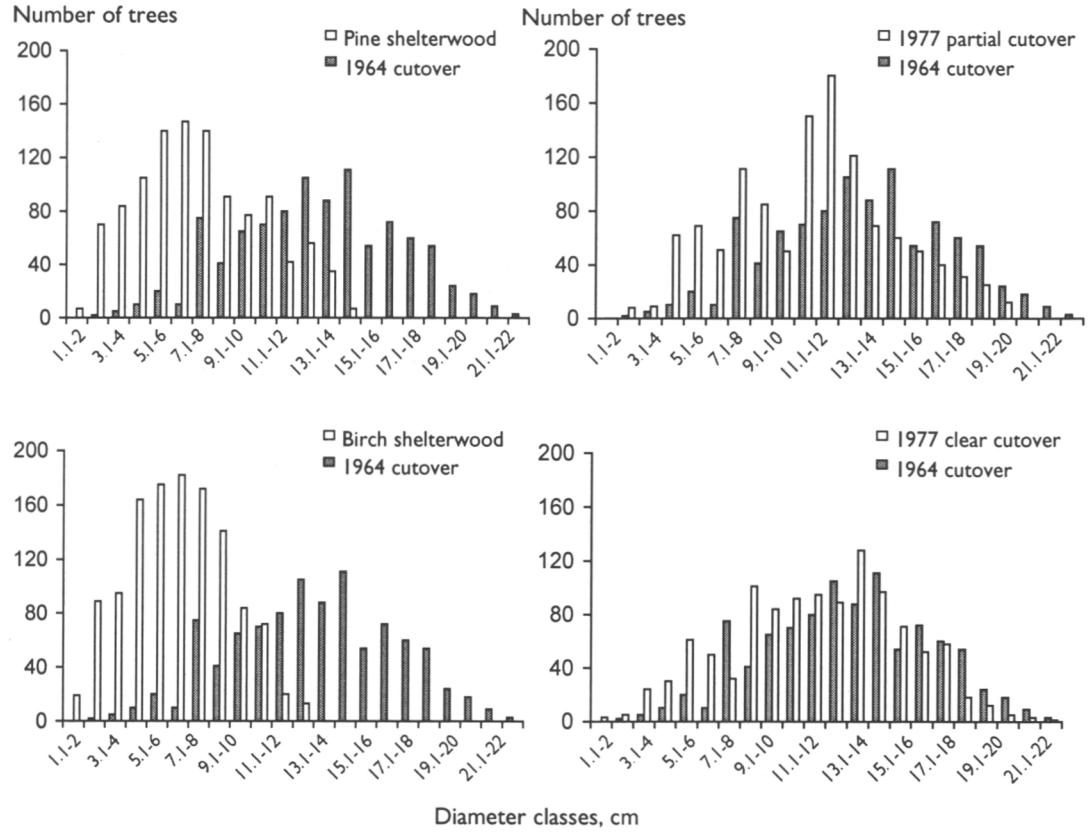


Figure 3. Distribution of trees to diameter classes in the different types of Norway spruce plantation (control = 1964 cutover).

shelterwood increased at a faster rate and was constantly higher than that under the birch shelterwood, i.e. the competition pressure on the pines was significantly lower than that of the birches. The figure also shows that, after the overstorey was removed, the plantations under the shelterwood rapidly caught up with the similar plantations in the open area. This characteristic of spruce (especially during its initial growth phase) to strongly increase its increment when released from competition, is also typical of the plantations under the shelterwood, and in this particular case even compensating for the increment losses before the age of 13 years.

Figure 5 show the height growth of the spruce plantations in all the treatments.

As was the case for the diameter, the height growth and increment of the plantations established on the 1977 cutovers were similar to those of the plantations in the open areas.

The stand volume of the preliminary plantations, after being released from the upper story 13 years later, was similar to that of the plantations in the open (Fig. 6). The curves of the volume growth in the plantations on the 1964 cutover, in the clearing and on the 1977 cutover were very similar to each other, but the volume on the partial 1977 cutover accumulated at a slower rate (it was lower initially). The

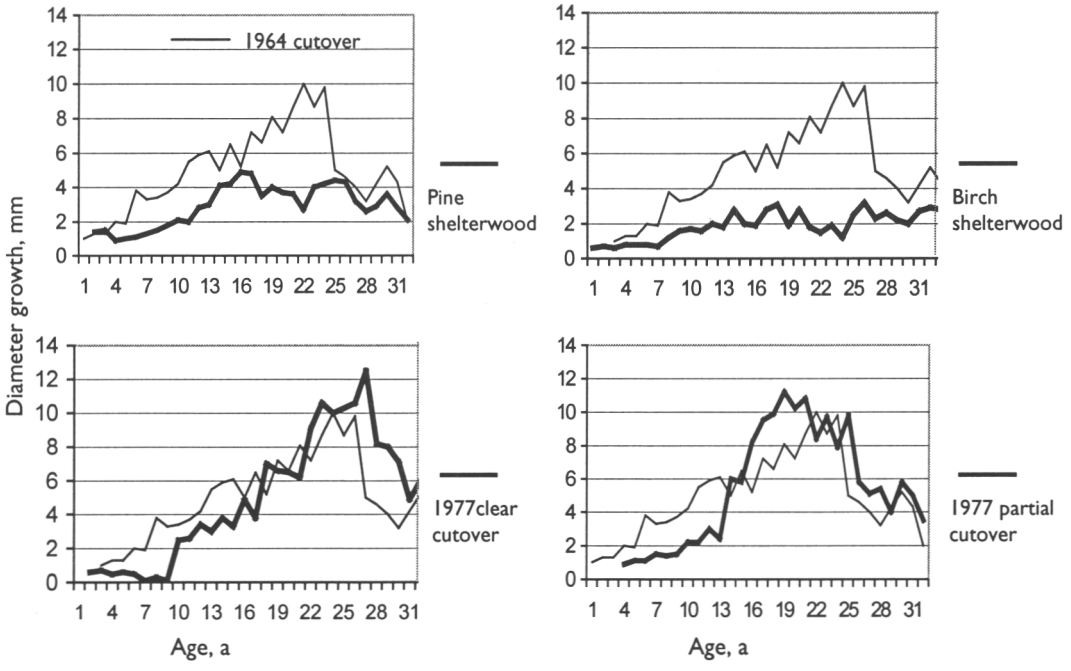


Figure 4. Diameter growth of trees in the different types of Norway spruce plantation.

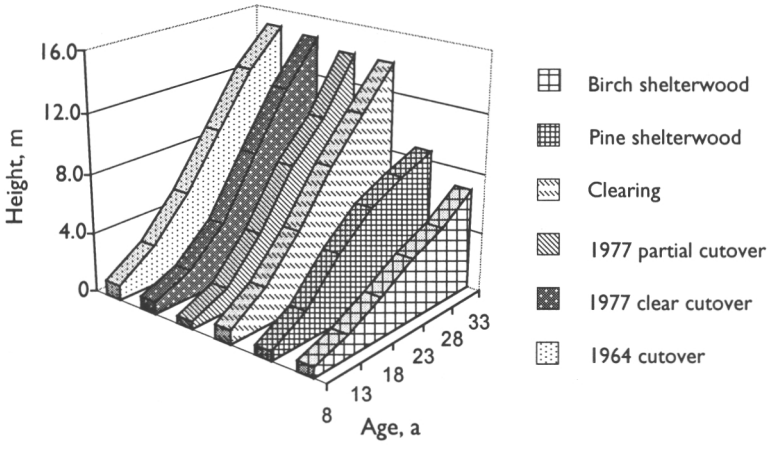


Figure 5. Development of tree height in the different types of Norway spruce plantation.

volume in the plantations under the birch and pine shelterwood was only 11 and 14% of that in the control plantation (1964 cutover). It is thus apparent that the increment in both the open areas and the preliminary plantations has increased considerably since the age of 13-18 years.

The period of fast growth starts at this point in all the treatments. On the other hand, the results obtained in this experiment indicate that the initial growth phase

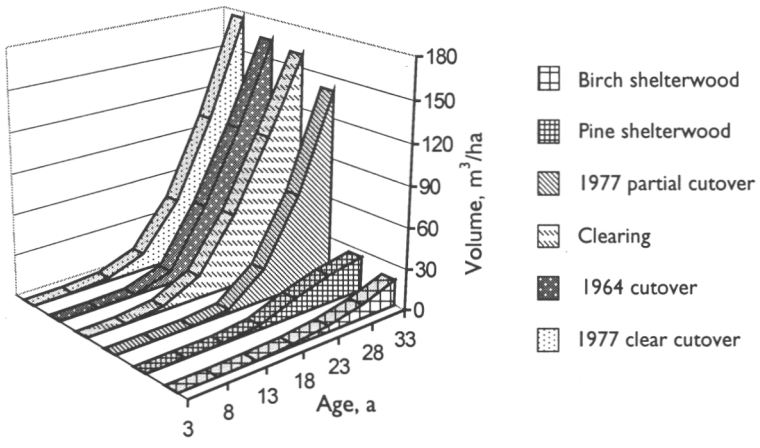


Figure 6. Development of stand volume in the different types of Norway spruce plantation.

in the preliminary and sheltered plantations in a closed cenosis may last for 12 to15 years without any decrease in the rate of growth and stand increment. However, plantations are established in the more favourable microclimate of a closed cenosis (Егорова 1984, Рубцов 1964, Чмыр and Скиба 1984).

Conclusions

While clear cutting in a stand results in catastrophic or drastic changes in many components of forest ecosystems (changes in the living above-ground cover, increase in litter mineralisation, profound changes in the upper soil horizons and in the composition and activity of soil animals and microorganisms; species changes and many other radical changes in the vegetation), preliminary reforestation (under the shelterwood) and the formation of new stands by different plantation methods brings about the replacement of the previous tree generation, maintaining almost all the vital ecological functions of a forest cenosis and its continuous transformation through age dynamics.

REFERENCES

Егорова, В.А. 1984. Регулирование взаимовлияний древесных пород в культурах ели под пологом леса. Автореферат дисс. канд. с.-х. наук. Фонды ЛТА. Leningrad.

Рубцов, Н.И. 1964. Предварительные культуры хозяйственно-ценных пород. Лесное хозяйство 12: 41–45.

Рубцов, Н.И. 1968. Выращивание лесных культур под пологом древостоя в таежной зоне. ЛТА. Leningrad. 16 p.

Рубцов, Н.И., Чмыр, А.Ф. & Мелешин, П.И. 1985. Предварительные культуры ели в таежной зоне. ЦБНТИ лесного хозяйства. Moscow. 179 p.

Сироткин, Ю.Б. & Турлюк, В.Д. 1982. Фитоклиматические особенности произрастания культур ели под пологом березовых насаждений. Ботаника. Минск. Наука и техника, Вып. 24: 73–79.

Чмыр, А.Ф. & Ониськив, Н.И. 1987. Лесные культуры под пологом леса. ЛТА. Leningrad. 54 p.

Чмыр, А.Ф. & Скиба, А.А. 1984. Водорегулирующая роль материнского полога на участках подпологовых культур. ЛТА. Leningrad. 64 p.

NORWAY SPRUCE GROUP PLANTATIONS UNDER A FOREST COVER AND IN OPEN AREAS

A.F. Chmyr and E.L. Maslakov (†)
St. Petersburg Forestry Research Institute, Institutsky pr. 21, St. Petersburg, 194021, Russia

Introduction

Group plantations, due to the characteristics of their crown layer, appear to be a suitable method for establishing preliminary plantations under canopy layer. The use of group plantations in reforestation work can drastically reduce the size of the soil preparation area. For example, when 1 000 patches (each with an area of 1x1 m) are established per hectare, the soil preparation area is equivalent to 1 000 m^2/ha, which is only 10% of the total area of the plantation. When other modern methods of soil preparation are used, such as ploughing, the treated area is much larger (up to 40%). From the environmental point of view, the establishment of group plantations and careful use of soil preparation minimises the impact on the forest site, and preserves the natural soil structure and processes of soil formation.

In a number of silvicultural papers it has been reported that group plantations are better able to compete with a dense cover of grasses and deciduous species on clear-cut areas, and that their productivity is higher (Антонов 1990, Колпиков 1968, Маслаков 1971, Прудников 1987). Because of the dense planting within a small area, the trees in group plantations have specific competition relationships and characteristic dynamics of social structure and growth development (ontogenesis).

The productivity, social structure and correlation between different factors and structural elements are analysed in 32-year-old Norway spruce plantations in this paper. Different aspects of their growth and development (ontogenesis) are also discussed under different growing conditions: in open areas, under the forest canopy, and after release from under the forest canopy (Карпов 1969, Еремин 1974, Сироткин and Тулюк 1982, Чмыр and Ониськив 1987).

Material and methods

The plantations were established in 1964 on a clear-cut site and between rows of preliminary plantations in an experimental area of the Lisino training and experimental forest management unit (leskhoz). The work has been carried out under the leadership of N.I. Rubtsov (Рубцов 1964, Рубцов et al. 1985).

The overall experience gained from this experiment was rather complex. The spatial structure of the plantations comprised row and group plantations under the shelter of mature pine and birch trees, as well as plantations on clear-cut areas and in clearings (grassland).

The group plantations were established after soil preparation by planting 2-year-old spruce seedlings between the rows of trees or by sowing. The main aim of this experiment was to create planting sites where the root systems of the trees in the older stand would not compete with the newly planted seedlings. Different soil preparation methods were tested at the same time. Another aim was to study the development of the

plantations under different growing conditions, i.e. under the forest canopy and in open areas.

The spruce plantations were established on 1x1 m patches using the following soil preparation methods in a random plot design:

– No soil preparation. This is the control or "natural" treatment.

– Mounding without root isolation. The mounding of these plots was done by adding organic layer from an adjacent plot.

– Root isolation without mounding. These plots were surrounded by 25-cm-deep ditches, which cut the roots of the shelter trees. The soil on the plots was mixed manually by spade.

– Mounding and root isolation. This was a combination of the two previous methods. The organic layer was doubled and the plot ditched to prevent root penetration from competing trees and to drain the plot. However, rainwater or melted snow accumulated in the ditches, water-logging the planted seedlings and disturbing the water conditions on the plots.

– Five 2-year-old spruce seedlings were planted on each prepared point in a so-called "envelope" design.

During 1995–1996 the trees in the 32-year-old plantation were counted and the surviving trees mapped. The height and diameter at the ground surface and breast height were measured. The overall vitality of each tree was estimated.

Results and discussion

The number of preserved plots and surviving trees in the plantations on the areas clear-cut in 1964 are given in Table 1. The plots were well preserved and tree survival was 92.6%.

There were no plots where all five trees had survived, but 37 of the 68 plots had 4 surviving trees (54.4%), 13 plots with 3 surviving trees (19.1%), 8 plots with 2 trees (11.8%) and 5 plots with 1 tree (7.8%). This means that 4 or 3 trees survived on 75% of all the plots, indicating good group. On the clear-cut area 202 trees (61.2%) out of 340 survived, which is a good result for a 32-year-old plantation.

Table 1. The number of preserved plots and surviving trees in the different treatments.

Number of trees per plot	Treatment							
	Control (no soil preparation)		Mounding		Root isolation		Mounding and root isolation	
	Number of plots	Number of trees	Number of plots	Number of trees	Number of plots	Number of trees	Number of plots	Number of trees
4	6	24	11	44	11	44	9	36
3	3	9	2	6	3	9	5	15
2	2	4	2	4	1	2	3	6
1	3	3	1	1	1	1	-	-
0	3	-	1	-	1	-	-	-
Total	17	40	17	55	17	56	17	57
Survival, %	82.4	47.1	94.1	64.7	94.1	65.9	100.0	67.1

The average diameter of the spruce trees in the different treatments is given in Table 2. The table also includes the average diameter of the largest, second largest etc. trees in the group.

The standard deviation and coefficient of variation of the treatments were high. According to the Student's t test, the treatments did not differ statistically significantly from the control at the 95% confidence level.

Analysis of variance (ANOVA), in which the variation in diameter between the ranked first, second, third and fourth trees in the groups were compared by treatment, was therefore performed on the data (Table 3).

According to ANOVA, only the first ranking trees in the groups showed variation in diameter between the treatments. The average diameter of the first ranking trees was considerably lower in the "root isolation" treatment (Table 2).

Table 2. Tree diameter in the Norway spruce group plantations according to treatment.

Size ranking of the trees in a group	Mean diameter, cm				
	Control (no soil preparation)	Mounding	Root isolation	Mounding and root isolation	Mean
1	16.3	17.4	13.6	15.3	15.6
2	8.6	12.1	9.2	10.4	10.1
3	6.2	9.2	5.6	8.3	7.4
4	5.7	6.8	4.4	5.3	5.6
Average	10.3±1.1	12.0±0.9	9.3±0.9	10.5±0.8	10.5±0.5
Standard deviation	6.6	6.4	6.7	5.8	6.4
Coefficient of variation, %	64.1	53.3	72.2	55.2	61.9
t value compared with control plot		1.2	0.7	0.2	
t value at the 95% confidence level		2.01	2.01	2.01	

Table 3. ANOVA indices of the variation between the treatments.

Statistical analysis	Variance estimate for the trees			
	1st ranked	2nd ranked	3rd ranked	4th ranked
Variance estimate inside treatment, S^2_r	43.8	24.6	19.8	10.3
Variance estimate between treatment, S^2_m	419.7	1.7	38.3	0
Variance rate, $F = \frac{S^2_m}{S^2_r}$	9.6	0.07	1.93	0
F factor at 95% confidence level	2.75	2.78	2.81	–

The diameter distribution of the first ranking trees in the 32-year-old spruce group plantation on the area clear-cut in 1964 is shown in Fig. 1. The diameter curve corresponds to normal criteria and could be rightfully used in statistical calculations and conclusions.

The correctness of selecting the diameter of the first ranking tree as the best estimate of productivity of all the trees in the group was verified by the correlation analysis for this and other factors describing group productivity. The correlation (ΣD_1^2)r between the first ranking tree diameter (D_1) and the basal area of all the trees in the group was 0.884 (Fig. 2). Figure 3 shows the relationship between D_1 and the basal area of the first two trees in the group (r = 0.944).

The differences between the treatments in the stem volume of the trees in the groups were more distinct (Table 4).

The most productive plantations (including all the trees in the group) were those grown in the mounding treatment. The stem volume was the highest in this treatment – 167.9% compared to the control plot, followed by the "mounding and root isolation" with 140.0%. This is obviously due to the "mounding" effect. Although the ditches drain the site, rainwater accumulates and the area becomes water-logged.

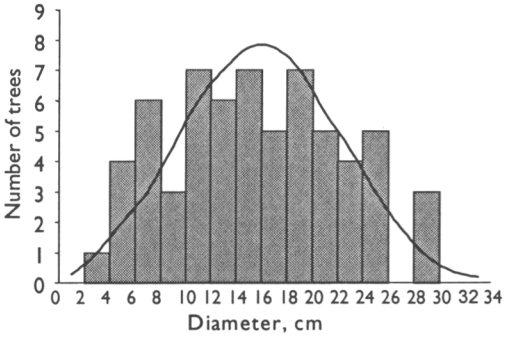


Figure 1. Diameter distribution of the first ranking trees in the groups planted on the area clear-cut in 1964.

The root isolation treatment was the least productive. The isolation ditches had a negative effect owing to water-logging of the sites after snow melt in the spring and heavy rain in the autumn (Рубцов et al. 1985, Чмыр and Ониськив 1987). One interesting feature is that the first ranked trees accounted for 2/3 and more of the stem volume in the groups. On the average they

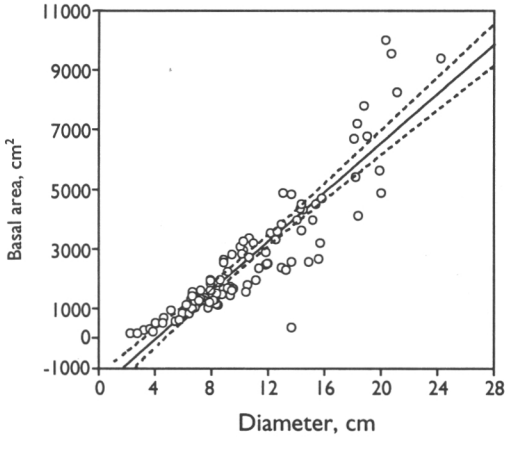


Figure 2. The reationship between the diameter of the first ranking tree and the basal area of all the trees in the group.

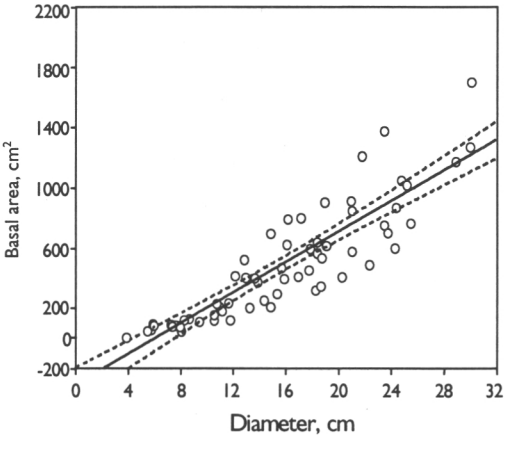


Figure 3. The relationship between the diameter of the first ranking tree and the basal area of the first two trees in the group.

Table 4. Stem volume in the groups of Norway spruce plantations with different treatments on the area clear-cut in 1964.

Tree size ranking in the groups	Stem volume							
	Control		Mounding		Root isolation		Mounding and root isolation	
	Dm^3	%	Dm^3	%	Dm^3	%	Dm^3	%
1	3924	72.0	5096	59.6	2936	61.6	4294	60.2
2	796	15.6	2006	23.5	1385	24.1	1759	24.7
3	264	5.2	1078	12.6	328	6.9	921	12.9
4	108	2.2	371	4.3	120	2.3	276	2.2
Total	5092	100.0	8551	100.0	4769	100.0	7126	100.0
% of the control	100.0		167.9		93.7		140.0	

grew 2-3 times faster than the second ranked trees, and many times faster than the third and fourth ranked trees (Fig. 4).

The diameter growth of the trees in spruce plantations with different planting and growing conditions is given in Table 5.

Plantations under a forest canopy normally grow slower than those growing in open areas. In this experiment in which a plantation was established on a cutting area and the upper story (birch) was removed in 1977, when the planted trees had reached the age of 13 years, the growth of plantation by the age of 32 years was equal to those trees grown in open areas (clear-cut in 1964).

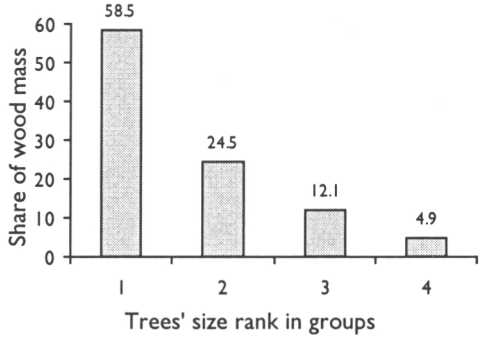


Figure 4. Ratio of the wood mass of trees of the different ranking groups.

The planting methods used in establishing group plantations and plantations where the trees are planted in rows are different. First of all this concerns soil preparation. For group plantations the soil is prepared in patches, contrary to the situation for row plantations. The mounding under a forest canopy makes it possible to change the distribution of the trees from rows to patches, and to take into consideration the distribution of the trees in a "mother" stand. When establishing plantations under a shelter stand, soil preparation and planting in patches is clearly better for carrying out selective cuttings in the future and managing the forest.

Much attention has been paid to methods for soil preparation in patches. In northwestern Russia, where reforestation is mainly carried out on water-logged sites, trees growing on mounds with a double organic layer have the best survival.

There is another factor, which is very important in these conditions: growing preliminary plantations under crown layer. Paludification usually occurs on clear-cut areas in our region if the reforestation rate

Table 5. Diameter growth of the spruce trees in the group plantations with different planting and growing conditions.

Planting and growing regime	Mean diameter, cm				
	Control plot	Mounding	Root isolation	Mounding and root isolation	Mean for all treatments
Under a birch stand canopy	5.9	8.3	7.1	6.8	7.0
Including 1st ranked trees in the group	6.7	12.0	9.2	9.6	9.4
Under a pine stand canopy	5.6	6.5	4.8	7.7	5.6
Including 1st ranked trees in the group	7.2	8.9	6.9	10.9	8.6
On the area clear-cut in 1964	10.3	12.0	9.3	10.5	10.5
Including 1st ranked trees in the group	16.3	17.4	13.6	15.3	15.6
On the area clear-cut in 1977	10.7	11.3	8.4	10.1	10.0
Including 1st ranked trees in the group	13.2	17.6	9.8	15.0	13.9

is low (Маслаков 1971, Прудников 1987). This process is often irreversible in natural conditions. Drainage, which is very expensive, needs to be carried out before artificial reforestation on clear-cut sites. Establishing a preliminary plantation under the canopy helps to prevent this phenomenon and reduces the drainage investments in clear-cut areas.

The average diameter growths in 32-year-old group and row spruce plantations, established the same year, are presented in Table 6.

According to the growth and diameter, group plantations are inferior to row plantations. However, the first ranking tree in the groups grow significantly better than the average trees in group plantations, and

Table 6. Growth parameters for Norway spruce plantations established by using different techniques.

Site	Mean diameter, cm		
	Row plantations	Group plantations	
		Average	1st ranking tree in the group
On a clear-cut area in 1964	13.1	10.5	15.6
In a clearing	13.7	–	–
On a clear-cut area after selective cutting in 1977	12.5	10.2	15.2
On a clear-cut area in 1977	11.2	10.3	14.0
Under a birch canopy	6.6	7.0	9.4
Under a pine canopy	9.2	5.6	7.3

the growth rate is close to that in row plantations.

Conclusions

Spruce group plantations were established on clear-cut areas and under a birch and pine canopy by planting in 1x1 m patches. At the age of 32 years they had a survival rate of more than 90%.

Most productive method of establishing plantations was planting on mounds, the soil being prepared in patches with a double organic layer.

Plantations established under a canopy and preliminary plantations arranged on small plots have high tree differentiation. The coefficient of variation of tree diameter was 60–70%. The first ranked trees in the groups grow 2–3 times faster than the second ranked trees, and several times faster than the third and fourth trees, and the first trees comprise 60 to 70% of tree production.

Attention should be paid to the following specific features of group plantations: accumulation of the volume in the first ranked tree in the group and big differentiation in tree dimensions on most of the plots. The first ranked tree accounted for 60–70% of the stem volume in the group. The wood mass of the second ranked tree was half that of the first tree, and rarely competed with it. The proportion of the mass of the remaining trees in the group was very small.

A minimum of three trees should be planted on each patch or mounds. The number of patches or mounds can be reduced to 700–1000 per hectare.

When the upper story has been removed at the age of 13, the preliminary group plantations according to their growth parameters (height, diameter and stem volume) at the age of 32 years reached the size of the group plantations established on the open areas at the very beginning. The preliminary group plantations were by growth and productivity factors close to row plantations established in the clearings.

REFERENCES

Антонов, Е.И. 1990. Лесоводственная оценка формирования и технологии создания групповых культур ели на свежих вырубках в центральной части зоны хвойно-широколиственных лесов. Автореферат дис. канд. с.-х. наук. Leningrad. 19 p.

Еремин, Н.В. 1974. Новая технология создания предварительных культур ели. Лесохозяйственная информация 7: 14–16.

Карпов, В.Г. 1969. Экспериментальная фитоценология темнохвойной тайги. Наука. Leningrad. 333 p.

Колпиков, С.И. 1968. Особенности дифференциации роста деревьев в сосновых молодняках произрастающих биогруппами. Лесной журнал 3: 16–18.

Маслаков, Е.Л. 1971. Оценка роли некоторых факторов дифференциации деревьев в групповых культурах сосны. In.: Исследования по лесному хозяйству. Псков. p. 175–182.

Прудников, Е.А. 1987. Ценотические особенности формирования ельников при лесовосстановлении на свежих вырубках. Автореферат дис. канд. с.-х. наук. Leningrad. 19 p.

Рубцов, Н.И. 1964. Предварительные культуры хозяйственно-ценных пород. Лесное хозяйство 12: 41–45.

Рубцов, Н.И., Чмыр, А.Ф. & Мелешин, П.И. 1985. Предварительные культуры ели в таежной зоне. ЦБНТИ лесного хозяйства. Moscow. 179 p.

Сироткин, Ю.Б. & Турлюк, В.Д. 1982. Фитоклиматические особенности произрастания культур ели под пологом березовых насаждений. Ботаника. Минск. Наука и техника, Вып. 24: 73–79.

Чмыр, А.Ф. & Ониськив, Н.И. 1987. Лесные культуры под пологом леса. ЛТА. Leningrad. 54 p.

FOLLOW-UP OF FOREST REGENERATION AND QUALITY STANDARDS FOR PLANTATIONS AND SAPLING STANDS

P. Puttonen

University of Helsinki, Department of Forest Ecology, P.O. Box 24, FIN-00014 University of Helsinki, Finland

Introduction

Forest regeneration consists of all the activities that are needed to establish a new stand and secure its growth and development. Forest regeneration is a chain of actions that is comprised of planning, carrying out and follow-up of activities and followed by necessary silvicultural treatments (Räsänen et al. 1985). Follow-up of forest regeneration plays an important role because follow-up surveys yield information to carry out silvicultural and other measures needed to safeguard future growth and yield of the stand by ensuring that tree species are suitable for the site, regulating stand density and spatial arrangement of trees, and overseeing seedling and sapling stand's health.

Until early 1990's in Finland, forest regeneration and silvicultural practices were based on recommendations that defined the minimum requirements for regeneration (Laki... 1987, Luonnonläheinen... 1995). The new Forest Act, that came into force on January 1st, 1997 (Metsälaki 1996), replaced the recommendations but maintained the principle of minimum requirement of silvicultural practices in a stand (Maa- ja metsätalousministeriön... 1997). The Forest Act requires that after felling a seedling stand, which has economic growth potential and whose growth and development is not directly threatened by other vegetation, shall be established within a reasonable time period. Economic growth potential is defined by suitable species for the site, seedling health and adequate growing density.

The reasonable time period for stand establishment depends mainly on the climatic region and regeneration method. The establishment of a seedling stand must be completed within five years of the start of the regeneration felling, or within three years of the completion of the regeneration felling in southern Finland. Establishment of a new stand must also be done in such a manner that the overall requirements for the preservation of habitats for maintaining biological diversity are ensured (Metsälaki 1996).

In addition, visual amenity must be considered. The silvicultural activities needed for establishment of a stand depend on the regeneration method (natural, planting or seeding), climatic region and forest site type. These may include fill-in planting, replanting the site, brush control (Luonnonläheinen... 1985).

Success of forest regeneration is monitored by different types of field surveys. Surveys yield information about the current status of the stand and need of follow-up measures; is the seedling stand free growing, is fill-in planting or sowing needed, or is a replanting or sowing needed to re-establish the stand? Prior to the field survey, it need to be specified what are the specific goals of the inventory since those goals influence on the extent, sampling

method, variables to be measured, costs and validity of results of the survey. Equally important for the surveys is that they are done at right time with proper methods.

Follow-up of forest regeneration

Information needs in forest regeneration

Information from forest regeneration and its success are currently needed at least for four purposes that consider different functional levels of forestry: 1) to verify functionality of current forest policy regarding regeneration, 2) to collect information from regeneration areas to check if regulations have been met (compliance aspect), 3) to develop silvicultural guidelines, training and extension in forest regeneration, and 4) to develop quality assurance or quality management systems within an organisation. Therefore, data collected from a particular seedling stand can be used for inferences concerning just the stand, a region, or the whole country. Typical data collected include tree species, density, spacing and health.

1. Functionality of current forest policy

Forest policy on regeneration and its follow-up requires information about the volume and success of forest regeneration activities in different regions of the whole country on annual basis. In Finland, this type of information is needed by the Ministry of Agriculture and Forestry, the extension services such as the Forestry Development Centre Tapio and the regional Forest Centres that act as the authority monitoring the compliance of forest regulations. Regeneration surveys are done at several levels of Finland's forestry administration; they are country-wide as in the National Forest Inventory, regional as carried out by the Forest Centres, covering a few municipalities in the occasional surveys by the Forest Owner's Associations, or focussing just on a woodland of a forest owner.

2. Legislated monitoring of regeneration success in seedling stands

The Forest Act (Metsälaki 1996) requires that a new stand is established after cutting, ie. there is an obligation for the forest owner to renew the site. The compliance of the obligations is followed with surveys carried out by the authority, the regional Forest Centres. The centres typically sample about 2–5% of the regeneration area that was renewed 5 years ago. The information helps decide if the minimum level of forest regeneration set by the Act has been achieved.

3. Guidelines, training and extension

Progressive forestry needs to follow up its forestation activities, collect feedback from results and evaluate how effective, and especially how cost-effective the regeneration activities are. This information together with the professional knowledge can then be used to develop guidelines for seedling stand management, and in training of foresters and forest owners.

4. Development of quality assurance systems in organisations

The concept of total quality management (TQM) (Wilkinson et al. 1997) has lately been adopted by most forest organisations as a basis to evaluate and help in directing their overall functions. In case of forest regeneration, the goal is to assess how effectively resources (personnel, funds, information systems etc.) have been used in achieving the goals of regeneration, typically the preset volume and quality of the activities. In the near future, even more emphasis will be put in monitoring the achieved quality of forest renewal. A pilot study has examined if the quality monitoring could be carried out by the same or-

ganisation that implements the regeneration work (planning, site preparation, planting, sowing, stand tending).

Comparability of regeneration surveys

Regeneration surveys are done at several levels of Finland's forestry administration; countrywide, by the Forest Centres, Forest Owner's Associations, forest companies, and forest owners. Surveys methods, however, differ among the organisations and the results of surveys may be poorly comparable. The survey results serve the owner, but the option of using results for a general and joint purpose may be missing. A larger survey of forest regeneration in southern Finland was accomplished in early 1980's (Räsänen et al. 1985) where the survey and sampling framework was well designed based on the National Forest Inventory. This sampling scheme made the results valid for larger areas. Similar surveys have not been implemented since.

Surveys are ongoing activity in many forest organisations, but due to poor comparability, the data cannot be used for example in modelling of development of young stands for use e.g. in MELA-system (Hynynen and Ojansuu 1996). The forest regeneration practices have changed in the recent years and will typically produce stands that are mixed-species stands. In mixed-species stands, the single-species growth models cannot be used because of lack of common variables (Hynynen and Ojansuu 1996).

Goals of seedling stand surveys

Seedling and sapling stand surveys are required to yield information on success of the regeneration, need of early stand management measures and give an estimate of the future development of the stand. In Finland, recommendations have been given, as the interpretation of the Forest Act, for planting density, density that requires fill-in planting, targeted free growing density, density when replacement planting is needed, height when stand tending is recommended and density after tending of seedlings stands (Table 1). As these recommendations are the minimum requirements, some forest enterprises have in their guidelines adopted higher standards. Information needed to assess if the minimum requirements are met is typically seedling density, spacing and health, all of which are easily surveyed.

Estimation of the further development of the seedling or sapling stand, however, will require a more thorough survey. Surveys of acceptable regeneration stands show typically a wide range of stands, that vary in density, spacing, in number and proportions of species, or in aspects of biodiversity. These stands all have several potential growth and development trajectories, depending on how the sapling stand will be managed. An assessment of future development will need estimates of seedling densities by species, their height growth, spacing, seedling condition and damages, competing vegetation. Also, several aspects of biodiversity need to be included in surveys, such as number of reserve or leave trees, patches of advanced regeneration, and especially the features defined by the Forest Act (Metsälaki 1996). These considerations have been summarised in guidelines that define growing density by region, site type, species, seedling height and spacing (e.g. Table 1).

Surveys of forest regeneration should yield quantitative information that is unbiased for establishing a "ground truth". Also, it would be desirable that the measured variables could be used to predict future development of the stands.

Table 1. Recommendations for planting density, density that requires fill-in planting, targeted free growing density, density when replacement planting is needed, and height when stand tending is recommended and density after tending of seedlings stands (Luonnonläheinen... 1995).

	Scots pine seedlings/ha	Norway spruce seedlings/ha	Silver birch seedlings/ha	Downy birch seedlings/ha	Siberian larch seedlings/ha
Planting density	>2000	1400–1800	1200–1600	1600–2000	1300
Fill-in planting needed if density under	1500	1300	1200	1300	1000
Free growing density	1400	1200	1000	1000	900
Replanting if density under					
–southern Finland	600	600	600	600	600
–northern Finland	500	500	500	500	500
Tending of stands					
–at height, m	4–7	4–5	4–7	4–7	4–7
–growing density	1800–2000	1600–1800	1600	2000	1300

Timing of seedling stand surveys

Proper time to carry out surveys of regeneration is crucial. When to carry out the surveys, depends mainly on the regeneration method but also on region and site type.

1. Natural regeneration

A strong recommendation for using shelterwood system for regenerating Norway spruce (*Picea abies* (L.) Karsten), based on research and experience, is that an abundant natural regeneration already should exist in the stand before a shelterwood cut is carried out (e.g. Räsänen et al. 1985, Fig. 1). Thus, the first estimate of the potential for natural regeneration can be made in a visual survey before a shelterwood cut. Another, even if not a full survey need to be done after the cut to find out possible damages and seedling losses (e.g. Leinonen et al. 1989).

Regeneration survey to determine the restocking of a site and describe the number of trees on a site that have reached acceptable standards is carried out about 5 years after the shelterwood cut.

In the seed tree method for Scots pine (*Pinus sylvestris* L.) most of the seedlings are born after the cut (e.g. Räsänen et al. 1985, Fig. 1). Regeneration survey is done 3–5 years after the seed tree cut, allowing more years to pass in northern Finland. Attention need to be paid not only on the density of the regeneration but also on spatial

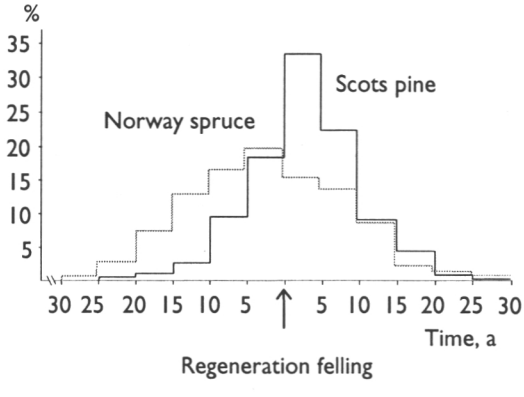


Figure 1. Date of emergence of seedlings capable of growth relative to regeneration felling in naturally regenerated Scots pine or Norway spruce stands (seed tree for Scots pine or shelterwood for Norway spruce) (Räsänen et al. 1985).

distribution. If the site has been prepared, site preparation typically causes some clustering of seedlings because more seedlings are born on the prepared track than on unprepared. Also the seed trees left on the site may cause unevenness in the distribution. There are less seedlings, that also can be shorter, close to seed trees (Niemistö et al. 1993).

2. Planting and sowing

Biologically successful and cost-effective regeneration requires that the quality of work is monitored during all the regeneration activities, including site preparation, planting and sowing. If sowing is done using a combination equipment that both prepares the site and sows it simultaneously, it is important to check the proper functioning of the sowing unit often during the course of the work. Sown areas should be initially surveyed one to two years after the sowing. The whole area should be surveyed and visual survey is usually adequate.

In case of planting, the first survey of the whole regeneration area is one to two years after the planting. Surveys are easier to carry out either in the spring or fall when ground vegetation is not covering the seedlings. A visual survey is usually adequate at this stage.

Both naturally regenerated and cultivated seedling stands are surveyed in more detail when they have reached the height of about 1 m.

Methods for assessing regeneration success

Principles of assessment methods

Essential features of a young stand surveys are proper timing and appropriate sampling and measurement methods. Some of the requirements for survey methods are that they are simple, accurate, precise, low-cost, and that the method yields estimates of variability for young stand characteristics.

In statistical sense, single surveys are not suitable for establishing cause-and-effect relationships for success or failure of regeneration site. Cause-and-effect relationship will require established trials where factors of interest are controlled and varied and are tested for significance. However, for practical forestry purposes, reasons for unsuccessful development or failures of regeneration can often be detected surveying damages caused by pests, diseases or other damage agents. Some survey plots could be established as permanent and followed as an operational trial. If plots are replicated over time across several sites, valuable information of operational practices can be collected and utilised in the forest organisation.

Young stand characteristics can be estimated either in the field using surveys or using remote sensing methods (air photos or satellite imagery). The field survey methods are based on: 1) various types of count methods where plants counted on a specific area (Räsänen et al. 1985, Saksa 1992), 2) counting of empty plots (Räsänen et al. 1985, Saksa 1992) and 3) the distance method where a distance from a random point to a seedling are measured and analysed (Cox 1971, Pohtila 1977, 1980).

Field survey

Sampling

Field surveys are based either on cursory surveys or representative sampling. Cursory or subjective survey is simple and low-cost but it typically includes bias that limits the strength of inference. For example with regard to spacing, clustering of seedlings may cause bias in estimation of the quality of a seedling stand. In general, cursory surveys suffer from the deficiencies of subjective

methods and rely much on the experience of the person conducting the survey.

Representative sampling is used to describe a population and make inferences about the population without having to measure characteristics of the whole population. Random sampling is used in numerous types of surveys to provide the basis for statistical inference and representativeness of the surveys. Regeneration surveys can be descriptive or analytic (Schwartz 1998).

Descriptive surveys describe characteristics of a particular population. A random sample from the population provides basis for inference and allows calculation of measures of variation of characteristics in the form of standards errors or confidence intervals. Information from the descriptive survey is pertinent to the particular regeneration site or stand and no inferences can be made about other sites or stands.

Analytical surveys use randomly selected sites from a population of regeneration sites to test if there is a difference among populations, for example if there is a difference in height growth among sites with different preparation method. A random or systematic sampling is then carried out in each selected regeneration site. These surveys provide estimates of means of measured characteristics and measures of variability within and among regeneration sites or stands.

Sampling population

In Finland, some of the more extensive regeneration surveys have used large databases as the base sampling population. For example, Räsänen et al. (1985) used as the sampling population the plots of the 7th National Forest Inventory from which they randomly selected different types of regeneration areas, Saksa (1992) used information on regeneration carried out on private woodlots and Saarenmaa (1992) used the regeneration database of the Finnish Forest and Park Service. These databases are, however, not always fully encompassing. This has lately become a concern when there have been delays in regeneration activities, typically on private woodlots (Saksa 1998).

For an efficient sampling to meet better the survey's goals, stratification is commonly used. A stratum is the population of similar regeneration areas under interest. For comparison of regeneration methods, typical strata are naturally regenerated and planted stands of the same species in the same geographic region and site type. Also, different years can form a stratum if variation in annual conditions or actions are assumed to cause variability in regeneration results, as it may be the case with natural regeneration relying on seed crops. As inferences about regeneration surveys typically refer to larger areas, surveys must also have adequate regional coverage. Different strata are represented in the samples by their proportion of the total area under interest.

Sampling

Sampling can be either random or systematic. Random sampling is the principal method. Random sampling provides each element of the base population an equal chance to be included in the sample, and this allows proper and relatively easy calculation of error terms (Schwarts 1998). However, random sampling is not very cost-effective method because location of the plots is time consuming. Modern Global Positioning Systems (GPS) now allow an easier location of random plots within a unit or polygon. Randomly selected plots from a site receive co-ordinates and are then located in the field. Compared to random sampling, systematic samples are equally effective or even better in estima-

tion of the population mean. Therefore, regeneration surveys are commonly conducted using systematic sampling because the locations of sample units (plots) is easier and cheaper than in random sampling.

The most common systematic survey methods are systematic line and cluster sampling. Figure 2 depicts the structure of a cluster in systematic sampling. Cluster sampling provides locally accurate information from a stand since the variation within a small area can be estimated well. Cluster sampling is recommendable for cost efficiency reasons if distances between sample locations are long. In regular inventories of regeneration stands, cluster sampling is typically not cost effective.

Counting and measuring seedlings on a plot always includes subjective assessment and therefore, training is needed to establish common goals for the surveys and calibrated measurement and classification methods. Training decreases both systematic and random errors. Attempts to eliminate systematic errors is highly desirable (Pohtila 1977). Training thus also increases the reliability of the results and allows better comparison with other similar surveys.

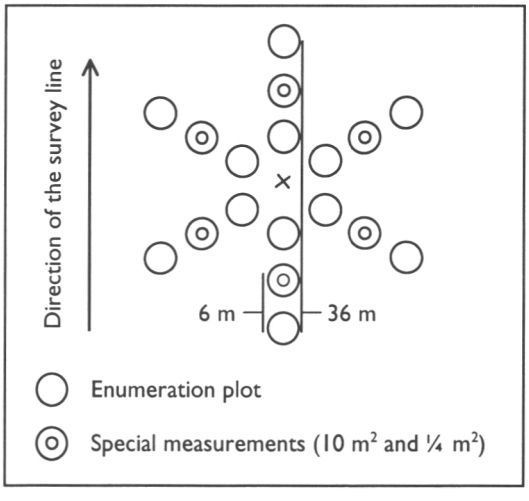


Figure 2. An example of the lay-out of a cluster sample plot (Räsänen et al. 1985).

Clustering in seedling stands

Natural patterns of seedling locations often show clumping or clustering caused by environmental heterogeneity (Stoyan and Penttinen 2000). Clustering in young stands may be caused by variation in soil properties, site preparation (existence or not, evenness of site preparation), regeneration method (natural or cultivated with seeds or seedlings, planting or sowing density), pests and diseases, number of natural seedlings, number of leave (or reserve) trees, distance to the adjoining old stand, or the history of the forest land use (e.g. grazing, abandoned agricultural field, peat harvesting area etc.).

In Finland, new stands established since early 1990's are generally more heterogeneous with regard to many stand characteristics than those from before 1990's. An increase in within stand diversity was a goal of the silvicultural regulations established in early 1990's. Most of the variability is brought out by site preparation, leave trees and small patches of advanced regeneration. In terms of forest management and silviculture, new regulations and practice have introduced some uncertainty and possible bias in stand development models since they assume uniform spacing and uniformity in the site conditions. This increased heterogeneity presents both basic and practical questions such as what are influences of heterogeneity on seedling and sapling stand development and how best to characterise heterogeneity.

Trees naturally show clumping or clustering in the very early stage of stand establishment. Causes are many; environmental heterogeneity, type of plant dispersion (seeds, sprouts), type of competition. With ageing, regularity is typically developed in stands (e.g. Pohtila 1980) and mortality shows up. In a given forest area, both

forms of variability, ie. clustering and heterogeneity, may coexist at various scales. Regularity may exist due to competition and regular planting, clustering may appear at a large scale due to site differences.

Spatial arrangement of plants and other elements can be described with the methods of: 1) number of empty space, 2) nearest neighbour and 3) Voronoi or Dirichlet tessellation that defines the area available for a plant (Stoyan and Penttinen 2000). These methods have been used and tested typically in homogenous conditions, or assuming homogenous conditions. Spatial pattern of plants may occur at different scales, of which the nearest neighbour method reveals only the smallest. However, this is the scale at which competition between individuals is typically manifested. Even if an interaction occurs between nearest neighbours, the effect of such dependence can create large-scale patterns, e.g. creation of mosaics. As the neighbours are correlated, we cannot assume independence of individuals and cannot use classical statistical methods and inference (e.g. Tomppo 1986).

In the empty plot method, the percentage of empty plots is calculated based on the survey. The empty percentage depends largely on the size of the survey plot. A small plot (e.g. 10 m^2, r = 1.78 m) has a higher probability to be empty of a seedling than a much larger plot (e.g. 50 m^2, r = 3.99 m). Hence, empty plot percentages from different surveys can be compared only if the plot size has been the same.

In the distance method, the distance from a random point, that is typically the plot centre, is measured to the nearest seedling of interest, e.g. a free growing seedling. The nearest seedling can also be outside the fixed area plot that may be used at the same time for estimation of other seedling stand characteristics. The distance from a random point (= plot centre) to the closest seedling can be regarded as radius for a plot that has no seedlings. These distances, and consequently, the plot sizes vary in the stand according to the spatial distribution of the seedlings (Pohtila 1980). Based on the survey data, an empirical distribution of the seedling spatial pattern can be calculated and compared to the Poission distribution (e.g. Pohtila 1980). In addition, numeric indices can be estimated, such as Cox's empty space statistics (Cox 1971), aggregation index (Clark and Evans 1954), or other indices (Payandeh and Ek 1986).

Table 2 shows an assessment of the count method, empty space method and nearest neighbour method for estimating seedling stand density and spatial distribution. Figure 3 shows an example of presenting the results of seedling stand surveys. The figure includes information on: seedling density (trees/ha), proportion of empty plots, proportion of empty plot in different densities as expected by the Poisson (random) distribution and the proportion of the stands where over 2000 seedlings/ha are relatively evenly distributed (Saksa 1998).

Aerial photographs and satellite imagery

Modern aerial photographs in the scale of 1:5 000 or 1:10 000 help to recognise main types of cuttings, thinnings and various types of regeneration cuttings. With moderate ease can one interpret from aerial photographs if a harvested area has been site prepared, how many leave trees have been left, or how much area has been maintained for biodiversity purposes. Unprepared sites are difficult to interpret and may be classified as open areas. Photograpgs are thus useful to find out if a silvicultural activity has been carried out, but less well useful in assessing the results of the activity, e.g. planting density or seedling height. Only

Table 2. An assessment of the count method, empty space method and nearest neighbour method for estimating seedling stand density and spatial distribution.

Method of estimation	Estimated parameters	
	Density	Spatial distribution
Count method	- somewhat biased - functional	- dependent on the scale - not functional
Empty space method	- sensitive to deviation from the Poisson distribution - not functional	- good but narrow scale - functional
Nearest neighbour method	- sensitive to deviation from the Poisson distribution - not functional	- good but narrow scale - functional

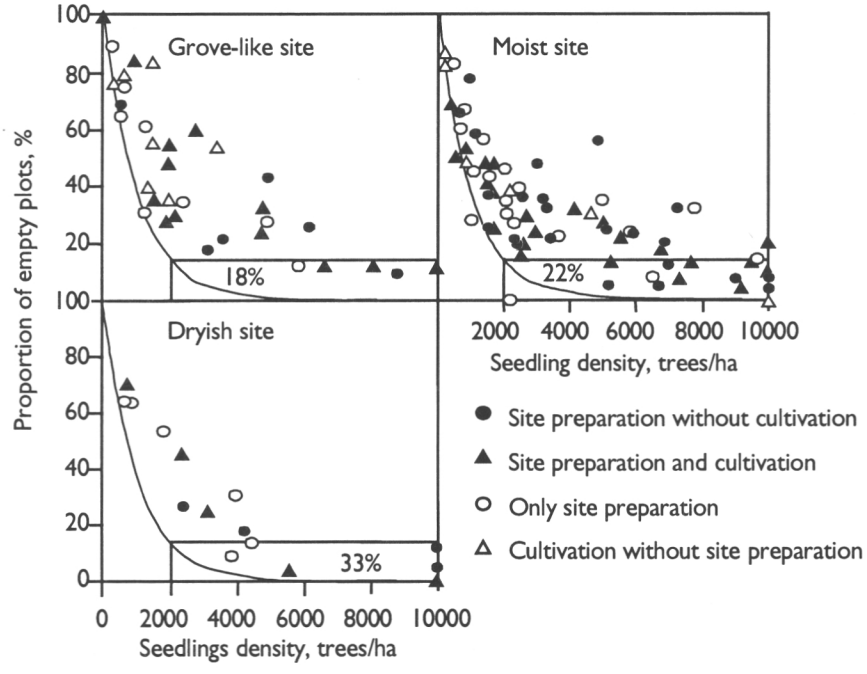


Figure 3. An example of presenting the results of seedling stand surveys. The figure includes information on: seedling density (trees/ha), proportion of empty plots, proportion of empty plot in different densities as expected by the Poisson (random) distribution and the proportion of the stands where over 2000 seedlings/ha are relatively evenly distributed (Saksa 1998). The plot size is 10 m^2.

after the seedlings are over 1.5 m, they can be better detected because before that brushes and broadleaves impede interpretation.

Satellite images can nowadays used to monitor many changes in natural resources either in the short-term or long-term (Häme 1991, Häme 1998, Varjo 1996, 1997). Short-term changes of interest can be

vegetation, seasonal variation, harvesting, or damages. A long-term monitoring is typically used for detecting trends, and needing also a large number of observations. Some regeneration activities, such as clear-cuttings can fairly reliably be detected from sequential satellite images (Varjo 1996).

As with aerial photographs, satellite images are not yet useful in assessing the results or success of the regeneration activity. Both aerial photographs and satellite images provide a good basis for establishing the sampling population and focussing the field surveys to areas of special interest. Both methods can help in detecting areas where harvesting activity has occurred, but where no subsequent regeneration measures have been started.

Accuracy and cost of surveys

The major factors influencing what survey method is used are cost and required accuracy. Table 3 shows an example how the number of samples depends on sampling area and required accuracy. In this example, the mean seedling density is estimated in cases where the mean density of seedlings is with 95% confidence within 10, 15 or 20% maximum error from the true density (Hämäläinen and Räsänen 1993).

Accuracy in estimation of stand characteristics can be increased by using different plot sizes for different sized trees. For larger saplings and small trees, a plot of 50 m^2 (r = 3.99) is recommended. In dense stands, smaller plots of 20 m^2 (r = 2.52) can be used to make sure that all trees are found, counted and measured. Small seedlings under 10 cm tall and germinants should be counted on a small plot of 1 m^2 in size or even less.

Survey costs and accuracy depend on number and size of the plots. Increase in number of plots increases the required time of the survey in two ways; first, by increasing the total time to measure the plots and second, increasing the time to move from a plot to another plot (Hämäläinen and Räsänen 1993).

Table 3. The number of samples depends on the area to be sampled and required accuracy. This example shows the number of samples in different sizes of the survey area when 10, 15 or 20% maximum error is allowed (Hämäläinen and Räsänen 1993).

Plot Radius, m Area, m^2	Size of the area, ha	Error 10%	15%	20%
		Number of samples/area		
	1	47	24	14
3.99	5	58	27	15
50	10	60	27	15
	20	61	27	15
	1	60	28	16
2.52	5	66	30	17
20	10	67	30	17
	20	67	30	17
	1	121	58	33
1.78	5	135	61	34
10	10	136	61	34
	20	137	61	34

The total measurement time is quite similar in using either 20 or 50 m^2 plots. Small plots of 10 m^2 are fast to measure but the total expenditure of time is larger than with 20 or 50 m^2 plots in same sampling intensity (same percentage of area covered by the plots in the survey).

Free growing seedlings

Free growing is a key concept used in seedling stand surveys. A free-growing stand is a stand of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees. Free-growing assessment determinates whether young

trees have attained free-growing status. Some of the criteria for each free growing are: 1) a preferred or acceptable species for the site, 2) well-spaced, 3) free from damaging forest health agent incidences, 4) free from unacceptable damage, 5) the required minimum height, 6) free from unacceptable brush and broadleaf tree competition. Acceptable levels of competition vary depending on the type of vegetation (broadleaf tree or non-broadleaf tree) that is found within the effective growing space of the crop tree. Seedlings that are under 10 cm are not usually counted as they a part of a changing population of small seedlings among which mortality is very high.

Definitions for free growing seedlings, as above, have been tried to define well because the concept of free growing can be very subjective and thus prone to interpretations in the field surveys. However, no exact definitions can be given for free growing seedling, mainly because the underlying biological phenomenon, competition in young stands is still poorly known.

Mortality of plan"ted seedlings is typically largest during the first few years but mortality continues at least up to 10 years. Climatic conditions influence seedling mortality so that in the northern areas mortality continues even longer and at higher rate than in the southern areas (Fig. 4). The planting height of seedlings affects mortality with smaller seedlings having greater risk of mortality (e.g. Thompson 1985), and in the north mortality risk seems to be even higher (Fig. 4).

Reasons for mortality vary and some damages are more easily recognised in the field such as those caused by insects, pests, moose, or frost. However, mortality rates can be reliably detected only in regeneration trials, but with the caveat that in maintained experiments mortality can be underestimated.

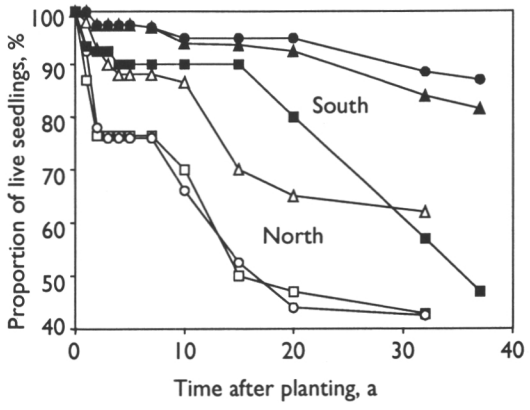


Figure 4. The proportion of live Scots pine seedlings 35–40 years after the planting. Planting sites were in southern and northern Sweden, and included three seedling types (one-, two-, and three-year old Scots pine seedlings (Jäghagen and Albrektson 1996).

How a free growing seedling is defined, is contractual covenant or a legislated decision that combines research information, practical knowledge and goals of current forest policy. In Finland, the effective growing space of a crop tree is defined as a 0.5 m radius cylinder centred around the conifer crop tree and 1 m for a birch crop tree. The distance depends on the height of the closest tree so that the closer the tree the smaller height difference is allowed.

If the seedling stand is clustered, the clusters can be of different height but within a cluster the trees should be fairly even in height.

Conclusions

Forest regeneration is a chain of actions and measures that is comprised of planning, carrying out and follow-up of the activities, and followed by necessary silvicultural treatments (Räsänen et al. 1985). In this regard, the operational concept of forest regeneration is parallel to the concept of total quality management (TQM). Information

about the success of forest regeneration with different methods in different conditions should be part of the quality assurance system of the practitioner, the forest owner, extension services or forest authorities.

Regeneration surveys yield information to follow functionality and relevance of forest policy on regeneration, check if regulations and compliance have been met, help in developing silvicultural quidelines, provide information for training and extension in forest regeneration, and are a part of quality assurance systems within an organisation.

Nowadays, separate or single surveys are seldom relevant or cost-efficient. Regeneration surveys should be carried out as much as possible as multipurpose surveys that yield information not only about the current status of the but also information to help to forecast future development.

Forest regeneration surveys can today effectively utilise both remote sensing data from aerial photographs or satellite images and field data sampled in a statistically representative manner.

If the organisations carrying out surveys would have more common methods, comparability of regeneration surveys at different regions and time periods could be established and maintained. Surveys of regeneration are an important tool in monitoring sustainable use of forest resources in regionally, nationally and internationally.

REFERENCES

Clark, P.J. & Evans, F.C. 1954. Distance to the nearest neighbor as a measure of spatial relationships in populations. Ecology 35: 445–453.

Cox, F. 1971. Dichebestimmung und Sytrukturanalyse von Pflanzenpopulationen mit Hilfe von Abstandmessungen. Mitt. Bundeforsch. Anst. Forst- und Holzwirtsch. Reibek b. Hamburg 87:184 p.

Häme, T. 1991. Spectral interpretation of changes in forest using satellite scanner images. Acta For. Fenn. 222. 107 p.

Häme, T. 1998. An unsupervised change detection and recognition system for forestry. Int. J. Remote Sensing 19(6): 1079–1099.

Hämäläinen, J. & Räsänen, T. 1993. Menetelmä metsänuudistamisen varhaistuloksen mittaukseen. Metsätehon katsaus 6.

Hynynen, J. & Ojansuu, R. (eds) 1996. Puuston kehityksen ennustaminen (MELA ja vaihtoehtoja). Metsäntutkimusl. tied. 612. 116 p.

Jäghagen, K. & Albrektson, A. 1996. Induced competition among Scots pine seedlings and its effect on future timber quality. New Forests 12:163–174.

Laki yksityismetsälain muuttamisesta. 1987. Suomen asetuskokoelma 817/87.

Leinonen, K., Leikola, M., Peltonen, A. & Räsänen, P.K. 1989. Kuusen luontainen uudistaminen Pirkka-Hämeen metsälautakunnassa. Summary: Natural regeneration of Norway spruce in Pirkka-Häme forestry board district, Southern Finland. Acta For. Fenn. 209. 53 p.

Luonnonläheinen metsänhoito. 1995. Metsänhoitosuositukset. Metsäkeskus Tapion julkaisu 6/1994. 72 p.

Maa- ja metsätalousministeriön päätös metsälain soveltamisesta 224/1997.

Metsälaki. 1996. Suomen asetuskokoelma 1093/1996.

Niemistö, P., Lappalainen, E. & Isomäki, A. 1993. Mäntysiemenpuuston kasvu ja taimikon kehitys pitkitetyn luontaisen uudistamisen aikana. Summary: Growth of Scots pine seed bearer and the development of seedlings during a protracted regeneration period. Folia For. 826. 26 p.

Payandeh, B. & Ek, A.R. 1986. Distance methods and density estimators. Can. J. For. Res. 16:918–924.

Pohtila, E. 1977. Taimiston inventoinnin tarkkuus. Abstarct: Accuracy of regeneration surveys. Commun. Inst. For. Fenn. 92.2. 43 p.

Pohtila, E. 1980. Havaintoja taimikoiden ja nuorten metsien tilajärjestyksen kehityksestä Lapissa. Abstract: Spatial distribution devel-

opment in young tree stands in Lapland. Commun. Inst. For. Fenn. 98.1. 35 p.

Räsänen, P.K., Pohtila, E., Laitinen, E., Peltonen, A. & Rautiainen, O. 1985. Metsien uudistaminen kuuden eteläisimmän piirimetsälautakunnan alueella. Vuosien 1978–1979 inventointitulokset. Summary: Forest regeneration in the six southernmost forestry board districts of Finland. Results from the inventories 1978-1979. Folia For. 637. 30 p.

Saaremaa, L. 1992. Induktiivinen oppiminen metsänviljelyn tietokannan tulkinnassa. Metsähallituksen metsänhoitotöiden kirjanpitoaineistoon perustuva tutkimus. Helsingin yliopiston Metsäekologian lait. julk. 3. 173 p.

Saksa, T. 1992. Männyn istutustaimikoiden kehitys muokatuilla uudistusaloilla. Abstract: Development of Scots pine plantations in prepared reforestation areas. Metsäntutkimusl. tied. 418. 48 p.

Saksa, T. 1998. Metsänuudistamistulos viivästyneillä avohakkuualoilla Etelä-Savossa. Metsäntutkimusl. tied. 695. 31 p.

Schwartz, C.J. 1998. Studies of uncontrolled events. In: Sit, V. & Taylor, B. (eds) Statistical methods for adaptive management studies. British Columbia Ministry of Forests. Land Management Handbook 42: 19–39.

Stoyan, D. & Penttinen, A. 2000. Recent applications of point process methods in forestry statistics. Statistical Science 15(1): 61–78.

Thompson, B.E. 1985. Seedling morphological evaluation – what you can tell by looking. In: Duryea, M.L. (ed.) Evaluating Seedling Quality: principles, procedures, and predictive abilities of major tests. Workshop held October 16–18, 1984. For. Res. Lab., Oregon State Univ., Corvallis, Oregon. p. 59–72.

Valkonen, S. 1998. Miten syntyy uudistamistulos? Folia For. 2: 231–234.

Varjo, J. 1996. Controlling continously updated forest data by satellite remote sensing. Int. J. Remote Sensing 17(1): 43–67.

Varjo, J. 1997. Change detection and controlling forest information using multi-temporal Landsat TM Imagery. Acta For. Fenn. 258. 64 p.

Wilkinson, A., Redman, D., Snape, E. & Marchington, N. 1997. Managing with total quality management. Theory and practice. Macmillan Press.

7. ENVIRONMENTAL IMPACTS

ENVIRONMENTAL IMPACTS OF FOREST REGENERATION

E. Kubin

Finnish Forest Research Institute, Muhos Research Station, Kirkkosaarentie 7, FIN-91500 Muhos, Finland

Introduction

Special attention is paid in Finnish forestry to retaining the biodiversity and ecological sustainability of forest ecosystems. The leading principle is to minimise the environmental impacts of forestry in all aspects of forest treatment.

The environmental impacts of the tending and use of the forests have been included in several international conventions. The United Nations Conference on the Environment and Development, held in Rio de Janeiro is the most significant of these (UNCED 1992). Among the forestry principles approved by the Conference were those of sustainable forest use, conservation and preservation of biodiversity to be applied globally. The process of taking of the principles of the sustainable forestry to the national level was continued in 1993 at the Ministerial Conference on the Protection of Forests of Europe and in its follow-up meetings. Criteria have been developed for the set objectives and these criteria can be used to evaluate forest use (Criteria... 1997). Furthermore, indicators demonstrating what changes have taken place have also been developed. These indicators are used, for example, to see how measures to reduce the environmental impacts of forest regeneration are applied in practice.

As a means of promoting the principles of ecologically sustainable forestry, the various forestry organisations in Finland have renewed their silvicultural directives (Luonnonläheinen... 1994, Hänninen et al. 1996, Environmental... 1998). Furthermore, instructions for charting and tending of valuable habitats (Meriluoto 1995, Meriluoto and Soininen 1998) have been drawn up and research focusing on biodiversity has been stepped up (Kouki 1993, Annila 1998). The guidelines for this development work have been provided in the form of the Environmental Programme for Forestry approved by both the Ministry of Agriculture and Forestry and the Ministry of the Environment.

The environmental impacts of forest regeneration target on natural biodiversity and ecological habitat factors, as well as being manifested in effects outside the regeneration site. In the present context, the examination of the subject matter is delimited to site factors, the impacts of regeneration on water systems and their prevention.

The impacts of regeneration on site factors

The effect of the regeneration on site factors depends on the regeneration method used. Clear-felling causes the greatest changes in site conditions; the resultant increasing in-

solation and outgoing radiation lead to extremes in diurnal temperature variation, particularly during the growing period (e.g. Odin 1978). Daytime temperatures rise especially on the ground level and in the adjacent layer of air (Kubin and Kemppainen 1991). Site preparation promotes the warning up of the soil (Mälkönen 1972, Leikola 1974, Kauppila and Lähde 1975, Kubin and Kemppainen 1994) and temperature rises especially in the tilt and mounds. Higher temperatures promote microbial activity and this in turn accelerates the decomposition of organic matter and the release of nutrients (Photo 28). Disruptions in the nutrient cycle between the forest growing stock and the soil and the nutrients released from the felling residue also contribute to increasing of the soil's stock of nutrients (Fig. 1) (Kubin 1977).

Changes in the micro-climate affect the structure and species composition of the ground vegetation. Species needing shade decline or disappear leading to an increase in the amount of dead organic matter and more nutrients are released into the biological cycle. Changes in the light climate and the abundance of nutrients bring about a powerful succession of pioneer species of flora (Photo 29), which together with the plants to be grown uses the available nutrients. However, regeneration felling is followed by a stage in which nutrient fixing is of minor significance and some nutrients are leached away into surface waters and groundwater (Tamm et al. 1974, Wiklander 1974,1983, Vitousek and Melillo 1979, Kubin 1995, 1998). The results of experimental research have shown that a balance between the fixing and leaching of nutrients is attained in a few years once the vegetation cover has re-established itself. The point in time when this happens, as well as the extent of leaching, depend on the site properties and the rate of development of the ground vegetation and of the new tree crop.

Forest regeneration also affects the physical properties of the soil. Temporary cessation of transpiration by the growing stock can lead to a rise in the groundwater level in certain terrain conditions and it can also promote paludification. Furthermore, site preparation and drainage connected to regeneration cause solid matter to be carried away by flowing water.

Site preparation also causes changes in topography. The impacts of disc ploughing and patch scarification are very minor and momentary. However, those of mounding and ploughing (the latter still being practised in places) are more powerful and long term. In locations requiring draining, ditch excavation of mounding affects both the topography of the site and the environment. Site preparation methods have in recent years developed to such an extent that changes in topography are minimised.

Water system impacts of forest regeneration

The oldest research carried out within the coniferous forest zone on the effects of clear-felling on the leaching of nutrients was conducted in Sweden in the early 1970's (Tamm et al. 1974, Wiklander 1974). In Finland, the effect of clear-felling and site preparation on the quality of surface runoff has been monitored since 1974 (Kubin 1995) and on the leaching of nutrients from entire catchment area since 1983 (Ahtiainen 1988, Huttunen et al.1990). The leaching of nutrients into groundwater has been monitored since 1986 (Kubin 1998). Research looking into the impacts of forestry on water systems was intensified in the early 1990's in the form of an extensive joint research project (Kenttämies and Saukkonen 1996), which addressed the

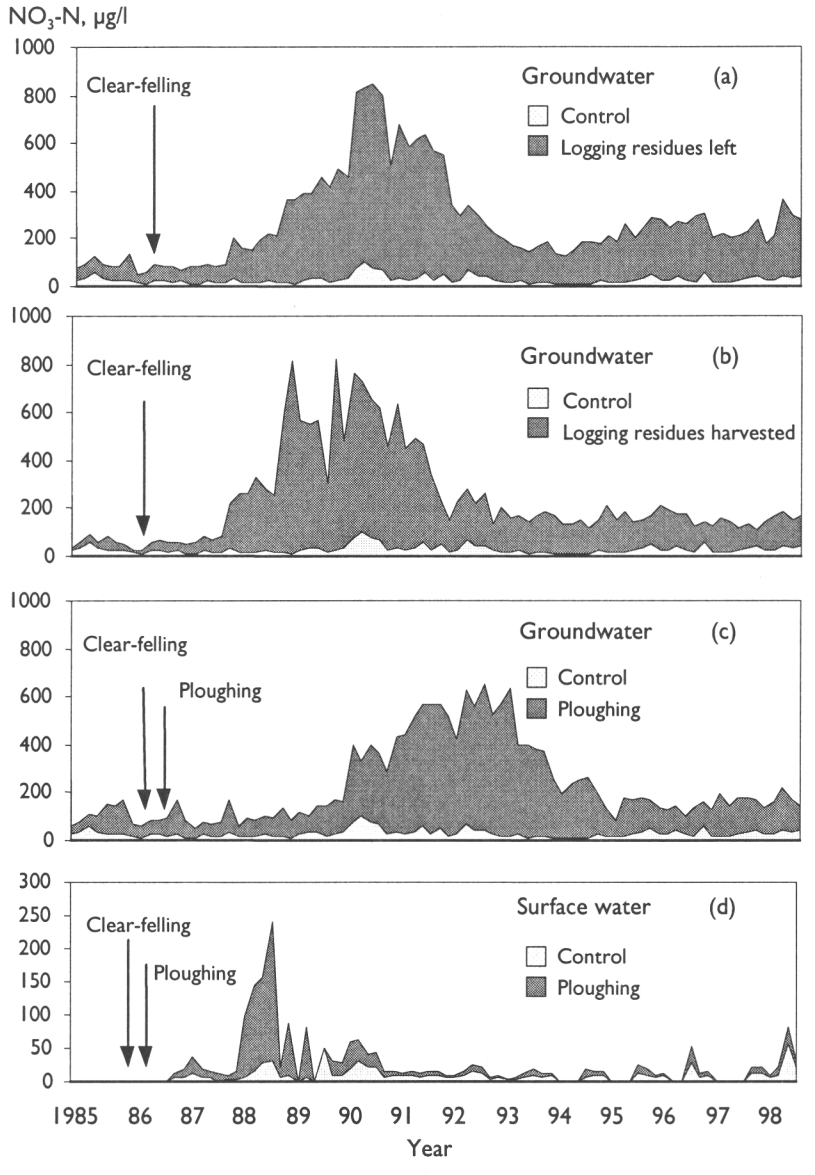


Figure 1. The effect of clear-felling (a), harvesting of logging residues (b) and ploughing (c and d) on the nitrate nitrogen concentrations of groundwater and surface water at the Hautala experimental field in Paltamo. Level 0 on the ploughed site (d) indicates the point in time when there was no surface water flow.

subject from the standpoints of various forestry measures. The results of the project confirmed earlier knowledge concerning matters such as increased runoff as a consequence of timber felling, the duration of the nutrient load focusing on groundwater and surface waters, and the effect of buffer zones on the biology of water systems. The scientific base provided by this research project was subsequently used in drawing up the Environmental Programme for Forestry (New... 1994), which laid down the

guidelines for promotion sustainable forestry in Finland starting from the middle of 1990's.

Nutrient leaching into surface waters has in several studies been found to be a few years in duration, after which the concentrations have dropped to the level preceding the regeneration measures. As the result of long-term monitoring new research knowledge has been obtained of the quality of groundwater (Kubin 1998). It has been observed that after the regeneration felling nitrate nitrogen is leached most of all, compared to which the leaching of other nutrients into groundwater is minor. Also, the timing of maximum leaching of nutrients into the groundwater following felling takes place a few years later, but the concentrations of nutrients are above normal even after more than 12 years later (Fig. 1). On ploughed plots, nitrate nitrogen leached at first into the surface waters and then into the groundwater.

Preventing impacts on water systems

The impacts of forest regeneration on water system can be prevented in two basically different ways: by using sufficiently wide uncut, or slightly thinned buffer zones or by stopping leached nutrients and solid matter on overland-flow fields before they actually enter water systems.

A buffer zone retained between the regeneration site and a brook efficiently prevents quality changes in water (Huttunen et al. 1990, Holopainen and Huttunen 1998). That is why attention must be paid to water quality control by leaving uncut buffer zone along any watercourse. The immediate surroundings of the sources of brooks and small lakes have also nowadays been classified as especially important habitats (Metsäluonnon... 1998) where forest treatment is to be done by retaining the ecological characteristics of the habitat. The complete setting aside of these habitats or their cautious treatment help to maintain natural biodiversity and at the same time prevent impacts on water systems. Many moist and luxuriant habitats are also worth retaining in their natural state for the conservation of threatened species.

The purpose of an overland-flow field is to lead the waters discharging from a regeneration site through a filtering zone before they enter water systems (Photo 30). The first experiences obtained of the use of overland-flow fields in purifying these discharge waters have been positive (Kubin et al. 1997). Especially significant reductions have been obtained in the case of solid matter, but overland-flow areas have been efficient in stopping nutrients, too (Fig. 2). However, further research needs to be conducted on the more long-term functioning of these fields.

The impacts of forest regeneration on water systems can be prevented quite effectively concerning surface waters, but preventing impacts on groundwater is far more demanding. An essential aspect would appear to be that the biological cycling of nutrients on the regeneration site should function so that leaching of nutrients is minimised.

Research needs

The new silvicultural recommendations provide a good basis for water protection and biodiversity conservation as regards the forestry practice. Once we know the main aspects of the impacts of forest regeneration on water systems, research can be focused on the factors giving rise to nutrient leaching and to their minimisation on different types of regeneration sites and forest site types. Similarly, more in-depth knowledge is needed on the long-term functioning of

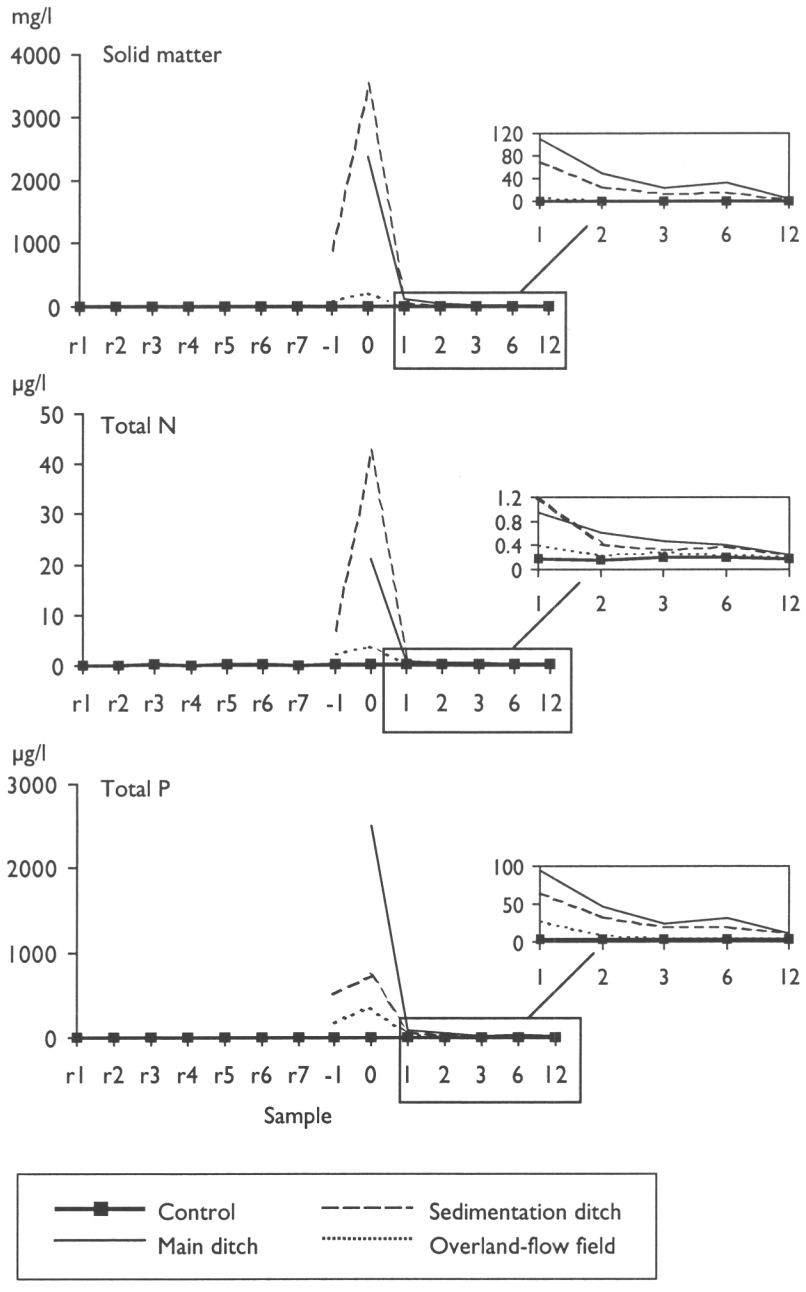


Figure 2. The effect of an overland-flow field on the leaching of solid matter, total nitrogen and total phosphorus from a drainage-mounding area. Control samples r1–r4 were taken in 1996, and samples r5–r7 in 1997. Time 0 = immediately on completion of mounding on 26.6.1997, and -1 = during excavation. Numbers 1, 2, 3, 6 and 12 indicate the sampling time in days since ditching was completed (Kubin et al. 1997).

buffer zones and overland-flow fields. Further research is also needed on the size of buffer zones from the point of view of water protection, biodiversity conservation and the practising of forestry.

REFERENCES

Ahtiainen, M. 1988. Effects of clear cutting and forestry drainage on water quality in the Nurmes-study. Proceedings of The International Symposium on the Hydrology of Wetlands in Temperate and Cold Regions. Joensuu, Finland 6–8 June, 1988. Vol. 1. Publications of Academy of Finland 1988(4): 206–219.

Annila, E. (ed.) 1998. Monimuotoinen metsä. Metsäntutkimusl. tied. 705. 335 p.

Borman, F.H. & Likens, G.E. 1979. Pattern and process in a forested ecosystem. Springer–Verlag. New York – Heidelberg – Berlin. 253 p.

Criteria and indicators for sustainable forest management in Finland. 1997. Ministry of Agriculture and Forestry. 70 p.

Environmental guidelines to practical forest management. 1998. Finnish Forest and Park Service. Vantaa. 124 p.

Holopainen, A.-L. & Huttunen, V. 1998. Impct of forestry practices on ecology of algal communities in small brooks in the Nurmes experimental forest area, Finland. Boreal Environ. Res. 3: 63–73.

Huttunen, P., Holopainen, A.-L. & Ahtiainen, M. 1990. Avohakkuun ja maanmuokkauksen vaikutukset purojen veden laatuun ja vesibiologiaan. Joensuun yliopisto. Karjalan tutkimuslait. julk. 91. 32 p.

Hänninen, E., Kärhä, S. & Salpakivi-Salomaa, P. 1996. Forestry and the protection of watercourses. Metsäteho. Helsinki. 23 p.

Kauppila, A. & Lähde, E. 1975. Koetuloksia maan käsittelyn vaikutuksesta metsämaan ominaisuuksiin Pohjois-Suomessa. Summary: On the effects of soil treatments on forest soil properties in North-Finland. Folia For. 230. 29 p.

Kenttämies, K. & Saukkonen, S. (eds) 1996. Metsätalous ja vesistöt. "METVE". Conclusions in English and Swedish. Maa- ja metsätalousministeriön julk. 4/1996.

Kouki, J. 1993. Luonnon monimuotoisuus valtion metsissä – katsaus ekologisiin tutkimustarpeisiin ja suojelun mahdollisuuksiin. Metsähallitus. Sarja A(11). 88 p.

Kubin, E. 1977. The effect of clear cutting upon the nutrient status of a spruce forest in northern Finland. Acta For. Fenn. 155. 40 p.

Kubin, E. 1995. Site preparation and leaching of nutrients. Proceedings of the Symposium Northern Silviculture and Management, August 16–22, 1987 in Lapland, Finland. Finnish Forest Research Institute. Research Papers 567: 55–62.

Kubin, E. 1998. Leaching of nitrate nitrogen into the groundwater after clear felling and site preparation. Boreal Environ. Res. 3: 3–8.

Kubin, E. & Kemppainen, L. 1991. Effect of clear cutting of boreal spruce forest on air and soil temperature conditions. Acta For. Fenn. 225. 42 p.

Kubin, E. & Kemppainen, L. 1994. Effect of soil preparation of boreal spruce forest on air and soil conditions in forest regeneration areas. Acta For. Fenn. 244. 56 p.

Kubin, E., Ylitolonen, A., Välitalo, J. & Eskelinen, J. 1997. Prevention of nutrient leaching from a forest regeneration area by applaying overland flow. Paper presented in NATO Advanced Reserch Workshop on Environmental Reconstruction in Headwater Areas. Liberec, Czech Republic, November 24–28, 1997.

Leikola, M. 1974. Muokkauksen vaikutus metsämaan lämpösuhteisiin Pohjois-Suomessa. Summary: Effect of soil preparation on soil temperature conditions of forest regeneration areas in northern Finland. Commun. Inst. For. Fenn. 84.2. 64 p.

Luonnonläheinen metsänhoito. 1994. Metsänhoitosuositukset. Metsäkeskus Tapion julkaisu 6/1994. 67 p.

Mälkönen, E. 1972. Näkökohtia metsämaan muokkauksesta. Summary: Some aspekts concerning cultivation of forest soil. Folia For. 137. 11 p.

Meriluoto, M. 1995. Metsäluonnon arvokkaat elinympäristöt. Tunnistaminen ja hoitosuosituksia. Metsäkeskus Tapion julkaisu 12/1995. 32 p.

Meriluoto, M. & Soininen, T. 1998. Metsäluonnon arvokkaat elinympäristöt. Metsälehti Kustannus. Helsinki. 192 p.

Metsäluonnon monimuotoisuuden turvaaminen. 1998. Maa- ja metsätalousministeriö. 160 p.

New environmental programme for forestry in Finland. 1994. Ministry of Agriculture and Forestry and Ministry of the Environment. 63 p.

Odin, H. 1978. Meteorology in forest operations. WMO Symposium on Forest Meteorology in Ottawa 21–25 August 1978. Reprint from WHO – No. 527: 167–177.

Tamm, C.O., Holmen, H., Popovic, B. & Wiklander, G. 1974. Leaching of plant nutrients from soils as a consequence of forestry operations. Ambio III(6): 211–221.

UNCED 1992. YK:n ympäristö- ja kehityskonferenssi. Rio de Janeiro 3.–14.6.1992. Ympäristöministeriö ja ulkoasiainministeriö. 239 p.

Wiklander, G. 1974. Hyggesupptagningens inverkan på växtnäringsinnehåll i yt- och grundvatten. Summary: Effect of clear felling on the content of nutrients in surface and ground water. Sveriges Skogsvårdsförb. Tidskr. 1: 86–90.

Wiklander, G. 1983. Kväveutlakning från bördig skogsmark i södra Sverige. Summary: Loss of nitrogen by leaching from fertile forest soils in southern Sweden. Skogs- och Lantbr.akad. Tidskr. 122: 311–317.

Vitousek, P.M. & Melillo, J. 1979. Nitrate losses from disturbed forests: Patterns and mechanisms. Forest Science 25(4): 605–619.

ISBN 951-40-1757-9
ISSN 0358-4283