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Mixed stands in Nordic countries—a challenge for the future

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Abstract

Mixed stands are the most frequent type of stand in Nordic countries. A mixture of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) is the most common stand type in the region. But for most foresters and persons familiar with forestry, a mixed stand implies a conifer species and at least one broad-leaved species.

Management and silviculture of mixed stands of conifers and broad-leaves has increased rapidly during the last 15 years. Efficient management of mixed stands increases profits for the owner as well as wood quality in the stand.

Practical examples of how to manage mixed stands of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) and Norway spruce are now available. In Finland, Norway and Sweden this is a common alternative to management of pure stands of conifers. In Norway, as well as mixed stands of birch and spruce, there are examples of mixed stands of European aspen (*Populus tremula* L.) and Norway spruce.

Existing yield information for mixed stands is based on studies of stands which were managed improperly prior to the start of the study. The yield for birch at 35 years of age was 100 $m^3\,ha^{-1}$. The growth of Norway spruce was reduced by 10% compared with spruce growing in pure spruce stands. In a mixed stand of European aspen and Norway spruce growing on farm land, the 36-year-old aspen overstory produced 480 $m^3\,ha^{-1}$. The spruce understory had a reduced yield compared with pure spruce stands.

Depending on the biofuel price and the market for utilisation of biofuel the forest owner might use the broad-leaves as biofuel. Some studies indicate that the harvested biomass yield of birch in a mixed stand of birch and spruce could be 48 t d.w. ha^{-1}.

Keywords: *Betula* spp.; Management; Mixed forest; Nordic countries; *Picea abies*; yield

1. Introduction

Frivold [1], in reviewing the status of mixed forest in European forestry, concluded that the concept of "mixed forest" is not universally defined and differs between countries. In Norway and Finland a stand is called mixed forest if 20% of its basal area is made up of another species, mostly broad-leaves. In Sweden the proportion is 30%, and in Italy and Yugoslavia 10% of basal area. Few European countries provide statistics of the proportion of mixed stands in their forests. Frivold mentioned Norway, Sweden, Italy and Yugoslavia as examples of countries, which provide such statistics.

The Swedish definition of mixed forest including mixed broad-leaved and coniferous stand is "a type of stand in which the total percentage of broad-leaved species is 30–70% of the growing stock". Mixed

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Table 1
Forest area, 1000 ha, percentage by land area and growing stock, Mm^3, for Nordic countries, 2000 (Anon, 2001)

Country	Forest area		Growing stock		
	ha	% by land area	Conifer	Broad-leaves	Total
Denmark	490	11	31	23	54
Finland	22 900	72	1601	359	1960
Iceland	14	0.3	0.2	0.2	0.4
Norway	6609	20	534	138	672
Sweden	22 236	67	2187	378	2565

stands are the most frequent type of stand in Nordic countries. A mixture of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) is common in the region. But for most foresters and other persons familiar with forestry, a mixed stand implies a conifer species and at least one broad-leaved species.

To manage mixed forest stands the use of stratified mixtures composed of a shade-tolerant, late-succession species in the lower stratum and an early succession species in the upper stratum has been recommended [2,3]. The natural relation between birch and Norway spruce makes it possible to combine those tree species in a mixed stand with the likelihood of producing a good ecological combination.

The area of forest area as a percentage of the total land area varies among the five Nordic countries. In Finland and Sweden the percentage of forest area is 72% and 67%, respectively [5,6]. In Denmark only 11% of land area is covered by forest and in Norway 20%. In 1967, 37% of the Norwegian forest area was covered by mixed forest. Mixtures of coniferous and broad-leaves occupy 57% of the mixed forest area [4]. However, in Iceland land areas are afforested to increase the forest area for forest production as well as for wind shelters. As shown by Table 1, Finland and Sweden have large forest land areas covered by conifers. The main species for both countries are Scots pine and Norway spruce. Sweden has more Norway spruce growing stock than Scots pine (Table 2). On the other hand, in Finland the growing stock of Scots pine is greater than for Norway spruce (Tables 3 and 4). Birch makes up 14.9% of the total growing stock in Finland, which is more than in Sweden (10.7%). The same species are the most common and most important in Norway.

Denmark has a different topography and soil types and a warmer climate than the other Nordic countries, which explains its greater amount of agricultural area. In forest areas, Norway spruce, oak (*Quercus robur* L.) and beech (*Fagus sylvatica* L.) are the most common species.

Table 2
Growing stock by species, Mm^3, by regions in Sweden, 1995–99 (Statistical Yearbook of Forestry, 2001)

Species	Northern Sweden	Central Sweden	Southern Sweden	Total	%
Scots pine	549	306	245	1100	39.4
Norway spruce	510	313	428	1251	44.8
Pendula birch	14	24	36	74	2.7
Pubescent birch	144	40	39	223	8.0
Common alder	1	7	16	24	0.9
Grey alder	6	3	1	10	0.4
Aspen	13	14	13	40	1.4
Sallow	7	2	3	12	0.4
Rowan	1	1	3	5	0.2
Other hardwoods	1	1	2	4	0.1
Beech	—	—	17	17	0.6
Oak	—	2	24	26	0.9
Ash	—	—	3	3	0.1
Maple	—	—	1	1	0.03
Elm	—	—	1	1	0.03
Lime	—	—	1	1	0.03
Total	1246	713	833	2792	100

Table 3
Tree-species dominance, % by forest area, on forest land in Finland, 1987–99 (Finnish Statistical Yearbook, 2000)

Species	Northern Finland	Southern Finland	Mean
Scots pine	74.8	56.9	64.9
Norway spruce	15.6	31.6	24.4
Pendula birch	0.2	3.5	2.0
Pubescent birch	7.8	5.1	6.3
Alder spp.	0.0	0.6	0.3
European aspen	0.2	0.4	0.3
Other broad-leaves	0.0	0.1	0.0
Total area, 1000 ha	8962	11 065	20 027

Table 4
Growing stock by species, Mm^3, by regions in Finland, 1987–99 (Finnish Statistical Yearbook, 2000)

Species	Northern Finland	Southern Finland	Total	%
Scots pine	355.6	556.4	912.1	46.5
Norway spruce	129.2	559.4	688.6	35.1
Birch	98.0	194.8	292.8	14.9
Other broad-leaves	10.5	55.5	66.0	3.4

2. Types of mixed stands

Several types of mixed stands are recognised in forest management [7]. Two methods of establishment can be distinguished:

1. The mixed forest can be established through a combination of planting and natural regeneration. Generally, one of the species is planted and the other species is established by natural seeding or vegetative regeneration by sprouts or suckers.
2. Sometimes two species are planted together on farmland. This type of mixed forest is expensive and demands great effort and good knowledge of species, planting technique, risks from grazing, plant development, etc.

Many different species mixtures are used in mixed stand management. Some of the most common mixtures are:

- Norway spruce/Scots pine,
- Norway spruce/alder,
- Norway spruce/aspen,
- Norway spruce/birch,
- Scots pine/birch,
- Birch/alder,
- Birch/aspen,
- Norway spruce/beech,
- Norway spruce/oak,
- Mixtures of noble species.

In the present paper, mixtures of Norway spruce and alder, aspen or birch are discussed. Some mention is also made of mixtures of Norway spruce and oak and mixtures of broad-leaf species including an understory of one species under a noble tree species. The management and potential of mixed coniferous and broad-leaf stands is discussed. More specifically, the mixed stands described consist of young Norway spruce with a shelter of aspen, alder or birch. Generally, management of mixed stands including broad-leaf species demands intensive and careful silvicultural methods. Otherwise, decreasing growth of the understory species (mostly Norway spruce) and also the shelter species will be the result.

Birch grows throughout Sweden [8] and two species are used commercially, pendula birch (*Betula pendula* Roth) and pubescent birch (*Betula pubescens* Ehrh.). Pubescent birch is widespread throughout Sweden and pendula birch grows mainly in central and southern Sweden (Table 2). Birch is also found over most of Finland and Norway (Tables 3 and 4).

European aspen (*Populus tremula* L.) grows throughout Denmark, Finland, Norway and Sweden (Tables 1, 2 and 3).

Both alder species, grey alder (*Alnus incana* (L.) Moench.) and common alder (*Alnus glutinosa* (L.) Gaertn.) grow in Nordic countries. In Denmark, Finland, Norway and Sweden they grow in pure or mixed stands. Common alder grows in Denmark and southern parts of Finland, Norway and Sweden. Grey alder occurs in northern parts of Finland, Norway and Sweden, but also in small groups in Denmark. The alder generally mixes with Norway spruce through natural regeneration. Management of mixed alder and spruce stands is not common at present.

3. Present and future management of mixed stands

Until recently the management of mixed stands was based on stands which had not been cleaned in time. There is now an increasing interest in managing mixed stands per se. The spontaneous establishment of the broad-leaf stand may take up to 10–20 years. Another way to create a mixed stand is to clean the broad-leaf stand when the plants have been established and have reached 1.5–2 m in height. Then an understory of planted and/or naturally regenerated Norway spruces is established successively.

At least two methods for managing mixed stands have been introduced in Nordic countries:

3.1. The shelter method

This method is common in Finland, Norway and Sweden. It was introduced in Sweden by Tham [9]

and some modifications have been developed [7]. The same technique has been used for management of birch and Norway spruce in Finland and Norway. There are many initial positions in unmanaged stands of birch and Norway spruce but the principal aim is to create an initial mixed stand with an optimal density of birch. The shelter method involves two or three steps:

1. When the spruce are 1.5–2 m high the density of birch is reduced by cleaning to 600–800 stems ha^{-1}.
2. The "birchshelter" is clear felled when the birch are 30–35 years old and the breast height diameter is about 160 mm.
3. With the present increased interest in biodiversity on forest land and the possibility of increasing the proportion of high-quality timber, a "third step" is included in which 100–150 stems ha^{-1} are left at the second step.

The modified second step or "third step" is interesting for two reasons. First, the stand will not create as much shade as if only spruce are left. Second, the remaining birch stems will produce high quality timber.

3.2. The Kronoberg method

This method was introduced in southern Sweden primarily in order to avoid frost damage on Norway spruce plants and to minimise the number of sprouts establishing after a complete removal of the birch stand in one step. The method is divided in three steps as described below:

If the density of birch is very high and there is a risk of decreased growth of the spruce, birch trees growing close to the spruce plants must be cut before the first step.

1. The birch stand is cleaned when the birch are 3–4 m high. After cleaning the remaining birch stand consist of 3000–4000 stems ha^{-1}. The Norway spruce stand is not cleaned.
2. When the birches are 6–9 m high the stand is cleaned again. After cleaning, the density of birch should be 1000–1500 stems ha^{-1}. Diameter at breast height is about 50 mm.
3. The birch shelter is felled 5 years later. The birches are now 20–25 years old, 8–12 m high and have a diameter at breast height of 80 mm. The mean height of Norway spruce is 3–4 m. The spruce stand should be thinned (2000–2500 stems ha^{-1} left).
4. Alternatively, instead of clear felling the birch stand at this stage, 600–800 birch may be left for 10–15 years. When the birch are then clear felled, the mean diameter at breast height will be 165 mm.

When managing this type of stand it is important that the density of birch stems is not too high when the spruce are established. According to Braathe [10], the spruces experience too great a competition if the birch density is more than 1200 stems ha^{-1} and the birch are higher than 3 m. In that case he estimated a 30% decrease in spruce height increment.

4. Mixed stand management in Nordic countries

Most mixed stands are established spontaneously. Parts of a clear felled area with moist site conditions are easily colonised by broad-leaf species, such as birch and alder. As such sites are often subject to frost and are moist, frost and unfavourable growing condition damage planted Norway spruce or Scots pine. The growth of broad-leaf species is high but for the conifers the growth and survival are low. Later, when a dense stand of broad-leaves has become established the growing conditions for Norway spruce will be better. The site has become drier and the risk of frost has decreased. At that stage an understory of Norway spruce has been established naturally and the forester may decide to "save" the coniferous plants.

In 1988, a report was published dealing with the production of birch in a mixed stand of birch and Norway spruce [9]. The main result indicated an additional yield of 100 m^3 ha^{-1} birch. These figures were based on older experiments with mixed birch and Norway spruces where the birch was reduced to 1500–2000 stems ha^{-1}.

The above-mentioned results were published in a period when costs for cleaning and other silvicultural activities were increasing rapidly. Furthermore, chemical treatment, the cheapest method of reducing the number of broad-leaves, was forbidden in Sweden in 1983. A realistic and relatively cheap method to reduce the number of broad-leaves was required. Mixed stands of birch and Norway spruce

have been established since then on many sites in Sweden. But the management of the stands has focussed on the elimination of broad-leaved stems or at least a very significant reduction in the number of broad-leaved stems.

5. Yield studies in mixed stands

The most frequently utilised mixture is Norway spruce and birch, as birch is the most common broad-leaf species in Sweden (Tables 1 and 2). Managed mixed stands of Norway spruce and birch are sometimes seen on specific sites and locations at present. In some cases, low-density alder stands used for fuelwood will be colonised by Norway spruce. Managed mixed stands of alder and Norway spruce have not been common in Sweden.

During the last 15 years management and silviculture of mixed stands of conifers and broad-leaves has increased rapidly. The main interest at first was methods of reducing the cleaning costs in conifer plantings. But very soon it was obvious that efficient management of mixed stands could increase profits for the owner as well as wood quality in the stand.

5.1. Birch

There are now practical examples of how to manage mixed stands of birch and Norway spruce. In Finland, Norway and Sweden this is more or less a common alternative to managing pure stands of conifers [9–14]. Frivold and Groven [15] discuss the importance of managing mixed stands of birch and Norway spruce for future high timber quality.

In one Swedish study, mixed birch and Norway spruce stands were examined 13–15 years after establishment of a shelter. Volume production of birch growing for 13–15 years was 80 $m^3\,ha^{-1}$ [16]. The mean annual increment (MAI) of Norway spruce in mixed stands, 7.2 $m^3\,ha^{-1}\,year^{-1}$, was less than that of spruce grown in pure spruce stands, 7.9 $m^3\,ha^{-1}\,year^{-1}$ (Fig. 1). But the total MAI in mixed stands of birch and Norway spruce was 11.5 $m^3\,ha^{-1}\,year^{-1}$ compared with pure spruce stands (7.2 $m^3\,ha^{-1}\,year^{-1}$).

Biomass production was estimated for the mixed stand [16]. Biomass functions for birch were used,

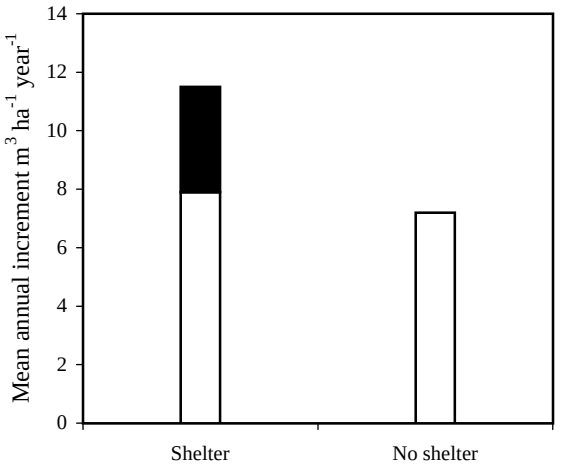

Fig. 1. Mean annual increment, $m^3\,ha^{-1}\,year^{-1}$, for mixed stands of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) (■) and Norway spruce (*Picea abies* (L.) Karst.) (□).

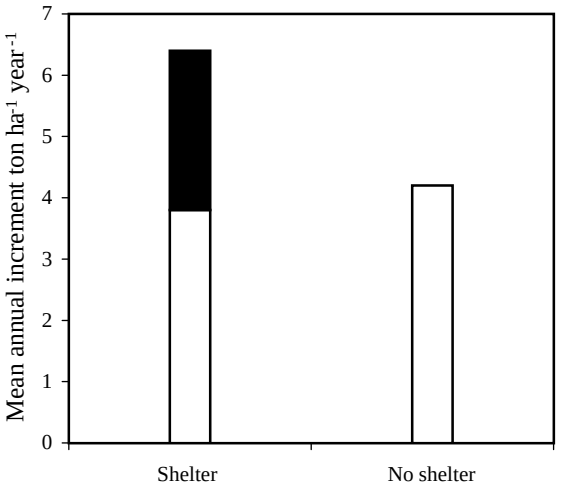

Fig. 2. Mean annual growth, $t\,ha^{-1}\,year^{-1}$, for mixed stands of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) (■) and Norway spruce (*Picea abies* (L.) Karst.) (□).

cf. Johansson [8]. Mean total production for the birch shelter was 48 (15–95) t d.w. ha^{-1} after 13–15 years. The mean annual biomass production for the birch shelter was 2.6 t d.w. $ha^{-1}\,year^{-1}$ (Fig. 2). Norway spruce stands growing under a birch shelter produced 3.8 t d.w. $ha^{-1}\,year^{-1}$ and pure spruce stands 4.2 t d.w. $ha^{-1}\,year^{-1}$. The MAI of mixed stands was

6.4 t ha^{-1} year^{-1} compared with 4.2 t ha^{-1} year^{-1} for pure stands.

During 1975–1978 experimental trials with different mixtures of conifers and birches were established in Norway [17]. The trials were examined 5 years later. The conclusion was that Norway spruce height increment decreased in mixed stands by 30% on seven of the 14 plots.

In 1990, an experiment on farmland with mixed or pure stands of Norway spruce, pendula and pubescent birch was established. The main objective was to study the most suitable planting time for the species on plots with mixture. The results have not yet been analysed but there are severe problems to manage a mixed stand by different planting time for the species.

5.2. Aspen

Practical examples and results from experiments with European aspen and Norway spruce in Nordic countries are sparse. In Norway, Hegre and Langhammer [4] reported on a study of mixed stands of European aspen and Norway spruce planted in spring 1947. On an area of 0.48 ha, 2000 aspens (2/0) and 2000 Norway spruces ha^{-1} (2/2) were planted in a mixture. The spacing was 1.5 × 1.5 m^2. They found a rapid growth of aspen but a very low current annual growth (1.8 m^3 ha^{-1} year^{-1}) for the spruce. The main conclusion from the experiment was that too many aspens (2000 stem ha^{-1}) were planted together with the spruces.

Langhammer [18] reported on subsequent examination of this trial, Fig. 4. The aspen were then 36 years old and the spruce 38 years old. The aspen were thinned at 25 years of age, removing 156 m^3 ha^{-1} or 750 stems ha^{-1}. The MAI of the 36 year-old aspen was 13.5 m^3 ha^{-1} year^{-1} (Fig. 3), but only 3.6 m^3 ha^{-1} year^{-1} for the spruce. The aspen stand was too dense for the spruce and competed strongly with the spruce. A practical conclusion from the study was that only 800–1000 aspen ha^{-1} should be planted mixed with 2000 spruce ha^{-1}.

5.3. Alder

In Nordic countries, there are few studies dealing with management for wood quality in mixed stands. Existing studies are based on stands, which were not managed correctly at first. There are no reports dealing with mixed stands of alder and Norway spruce growing in Nordic countries. In practical experience, both common and grey alder grow fast and might during short rotation period (30–50 years) produce volumes similar to aspen [19,20]. However, the mixture of alder and spruce must be carefully managed.

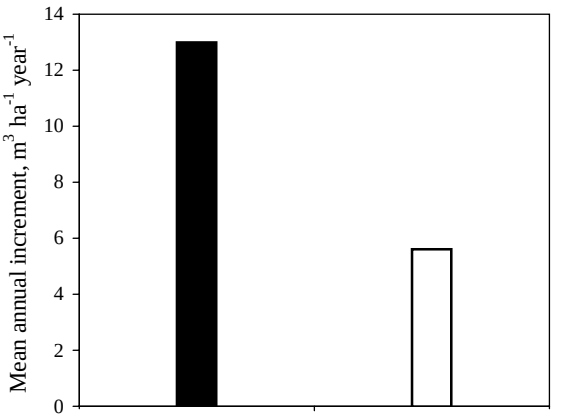

Fig. 3. Mean annual increment, m^3 ha^{-1} year^{-1}, for European aspen (*Populus tremula* L.) (■) and Norway spruce (*Picea abies* (L.) Karst.) (□) growing in mixed stands (after Langhammer, 1982).

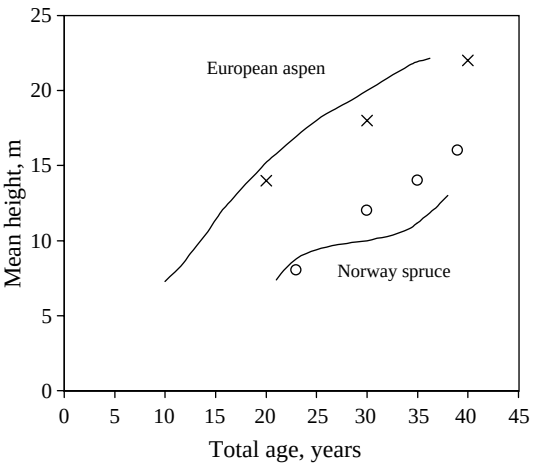

Fig. 4. Mean height, m, for European aspen (*Populus tremula* L.) and Norway spruce (*Picea abies* (L.) Karst.) growing in mixed stands. The symbols indicate heights from corresponding yield table values for pure stands of aspen (×) and spruce (○) (after Langhammer, 1982).

Only 1000 alder stems ha^{-1} and 2000–2500 spruce stems ha^{-1} should be managed. But as alder grows best on moist sites, there is a risk of frost damage to the spruce. Thus, the alder density must be initially greater to protect the spruce from frost damage.

6. Mixed forest including noble broad-leaved species

Within the Nordic countries, managing noble broad-leaved species is most common in Denmark among. Management of noble broad-leaved species such as pedunculate oak (*Quercus robur* L.), ash (*Fraxinus excelsior* L.) and European beech (*Fagus sylvatica* L) often involves a mixture of some other species. Most noble broad-leaved species are mixed for at least two reasons:

- Promoting high timber quality for oak.
- Increasing the profit especially by shortening the period until the first returns at 50 years of age compared with 80–100 years for a pure oak stand.

For beech it is important to keep the stand dense in order to avoid more than one leader developing. Otherwise the future timber quality will be low.

In southern Norway the use of mixed stands with oak is at the same level as in southern Sweden. In Finland both oak and beech are at the northern limit for acceptable growth in commercial forestry.

Among Nordic countries Denmark is practicing mixed forest of oak and Norway spruce, oak and Norway spruce, and oak and sycamore (*Acer pseudoplatanus* L.). In Sweden it is more or less normal practice to mix oak and Norway spruce.

7. Conclusion

In Nordic countries, managing mixed stands is a common method for producing conifers with high timber quality and for harvesting pulpwood or biofuel from the young broad-leaved stands and subsequently producing conifer pulpwood and timber through conventional management.

As the demand for pulpwood of broad-leaf species especially birch is still high most of the broad-leaf trees are cut for pulpwood. The highest quality trees are used for veneer or timber production.

Depending upon the biofuel price and the market for utilisation of biofuel the forest owner might used the broad-leaves as biofuel. Some studies indicate that the biomass yield of birch in a mixed stand of birch and spruce could be 48 (15–95) t d.w. ha^{-1} or a MAI of 2.6 t ha^{-1} $year^{-1}$. The growth of spruce under a birch shelter is reduced compared with spruce in pure stands.

Growth of Norway spruce in an aspen stand was strongly reduced. The density of aspen stems must be less than 1200 ha^{-1}.

Further studies on mixed stands of birch, aspen or alder and Norway spruce have been started. The main objective is to increase the total yield of broad-leaves per hectare. A mixture of conifer and broad-leaves produces a high wood quality for both species including thin branches on the stem and few and small knots on the log.

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