Spruce quality in mixed stands

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SUMMARY

Due to changes in Swedish forestry there is an increasing interest in growing mixed stands. Earlier studies indicate that shelterwood systems combined with dense natural regeneration of spruce resulted in reduced branchiness and improved graded quality of spruce. The study aims at answering the question: what could be the benefit of growing mixed stands with spruce in regard of the wood quality? The thesis is divided into two parts: a literature review and research based on the field data. The second part is a field study examining quality traits of spruce trees growing in different types of mixed stands. The first type represents "nurse trees" (shelter) where spruce is mixed with a fast growing species. The second type is spruce planted with noble tree species, which is designated as a final crop (e.g. beech). The following properties were measured on sample trees: breast height diameter, height, height to the first living branch, the number of branches per 1 meter of stem, the diameter of the thickest branch, stem crookedness, quality, tree class, vitality, occurrence of spike knots and double top. The significance calculations were made as planned comparisons (contrasts) in ANOVA. Every row was regarded as an independent variable. Contrasts were made between "control" (spruce stands) and the two other categories, which represented two models of competition within the stands, namely: sheltered spruce (spruce- hybrid aspen, spruce- birch and spruce- larch) and dominating spruce (with beech). The general trend was that spruce in pure stands and in mixture with beech was on average higher and had bigger diameter than spruce under shelter wood conditions. The frequency of dominant trees was also bigger in this group. The quality properties (branch properties, stem defects, vitality) indicated that superior timber quality was obtained in monocultures.

Key words: spruce, wood quality, mixed stands, competition, sheltered stands

CONTENTS

1. INTRODUCTION

1.1 Swedish forest under change

"The forest is one of Sweden's most important natural resources" (Ekelund and Liedholm 2000) and the spruce is the most important component of Swedish forests.

According to the Swedish National Forest Inventory (period 1999-2003), the spruce dominates in proportion of the standing volume (42%). The spruce meets favourable conditions in Sweden and covers almost all the country area with its distribution range, except to the northernmost part (Ekelund and Liedholm 2000). Furthermore, there is a tradition of growing spruce.

A wide range of uses is the crucial factor contributing to an intensive exploitation of the spruce wood. Starting from commodities like: joinery products, furniture, composites and veneer, the spruce wood is used for construction purposes, paper products and bioenergy (National Atlas of Sweden 1996). Solid wood products, followed by pulp and paper, have by far the largest economic importance (Hannup et al. 2004).

Nowadays the Swedish forestry is changing, although the spruce remains the major element of it. In Sweden, the forest is a resource supposed "to provide a valuable yield" (Swedish Forestry Act 1994). The role of a forester is to improve economics of production. In order to achieve good economic results, the forestry should aim for an increase of the yield and the value of produced wood with a reduction of costs at the same time (Klang 2000).

The Swedish Forestry Act puts the need of biodiversity preservation in the same order of priorities. Also the Swedish forest policy puts the equal emphasis on the environmental and production goals (Swedish Forests Agency 2005). An implementation of those regulations implicates many trends in today's Swedish forestry: the forests structure is changing, more focus is put on the broadleaves (*Figure 1*). According to Forest Impact Analyses 1999 it is estimated that the proportion of deciduous species will increase to 17-18% in 2010 and 18-25% by 2100 (Yrjölä 2002). Simultaneously the extent of mixed coniferous- deciduous stands as a percentage of the forest area in Sweden is expected to increase (Lindén 2003).

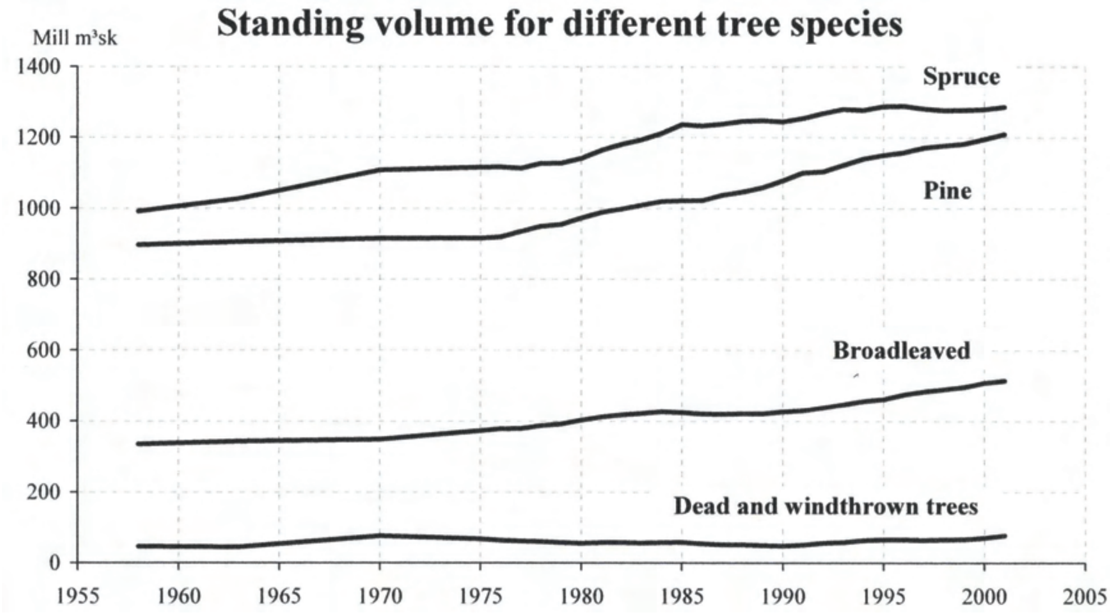

Figure 1. The increase of the share of broadleaves in the standing volume according to The National Forest Inventory 1956-2001. All land-use classes. Ten and five years average before 1973. Five years moving average afterwards.

Although the occurrence of mixtures is tending to increase, there is a lack of knowledge about benefits of growing mixed stands, especially in regard to the quality of spruce grown with other species. The effects of mixture on spruce quality are in the focus of the thesis. In addition, there is a need of general knowledge about the management of mixed stands.

1.2 Overview of mixed stands with spruce in Sweden

In Sweden the most common way of understanding "mixed forest" implies conifer stand composed of pine and spruce. Lindén (2003) quotes the concept of mixed stands as " anything but a pure stand". The Swedish definition describes the mixed conifer forest with broadleaves as "a type of stand in which the total percentage of broad-leaved species is 30-70 % of the growing stock" (Johansson 2003). In Sweden, the most common are mixtures of spruce, pine and birch.

According to data from the National Forest Inventory in period from 1999 to 2003, "mixed coniferous" stands occupied 15,2% of the forest area in Sweden, while "mixed coniferous-deciduous" had 7,6% of share (NFI 1999-2003). The share of mixed stands composed of coniferous and broadleaved trees is significant among young stands. In 40% of the young forests (dbh<10cm and height>1.3m) the proportion of broadleaves exceeds 30%. Usually they are removed in the pre-commercial thinning. Thus, the area of older forests with significant proportion of broadleaved species (>25%) is severely reduced to only 5% (Fahlvik et al. 2005).

Depending on an establishment method, two types of mixed stand can be distinguished. First, and more common, is a result of planting and a spontaneous natural regeneration. The soil scarification prior to the regeneration of conifers enhances the potential for natural regeneration of birch (Fahlvik et al. 2005). The second type represents stands, where two species are planted together, for instance: spruce and oak or beech and larch. For the most common mixture of naturally regenerated birch and planted spruce, the "Kronoberg method" is widely used in stands management.

The method is most commonly used in moist and wet sites, where an abundant regeneration of birch often appears spontaneously. The birch is used as a shelter for the spruce regeneration to avoid frost damages on spruce plants. The spruce is planted as an under-storey or it is naturally regenerated. When the birch is 3-5m high, it is thinned to the distance of 1,8m between trees. The second step is conducted, when the birch is 6-8m of height. At this stage the birch is thinned to the density of 1000 trees per ha. The wood can be utilized as firewood. The birch storey is removed at the age of 20-25, when it is 12-14 m high. At the same time spruce is thinned to the density of 1500 trees per ha. Simultaneously, the strip roads are cleared in the stand.

1.3 Benefits of growing mixtures

An increasing interest in growing mixtures has been observed during last few years (Johansson 2003). Nowadays great efforts are made in order to enhance biodiversity by appropriate forest management (Lindén 2003). Mixtures harbour a richer species diversity than monocultures, because they offer greater variety of niches (Ractliffe and Jardine 1992, Fahlvik et al. 2005). Some researchers opine that natural forests are composed of relatively unmixed stands. On the contrary, other theories claim that most of the natural forest consists of mixtures of tree species (Lindén 2003). Forests of southern Sweden contained an abundance of many of naturally occurred tree species. According to the Swedish Forestry Act, all spontaneously regenerated deciduous species can be included in newly established stands (Lindén 2003).

Mixtures are reported to be less susceptible to wind-throw and diseases, although it depends on species composition and the type of mixture (Lindén 2003). In addition, the nutrient balance may be better in mixtures than in monoculture (Fahlvik et al. 2005).

A conifer/broadleaved mixture produces returns earlier than pure broadleaved stands (Kerr et al.1992). Lindén and Ekö (2002) found the payback period shorter in the oak/spruce mixture compared to the oak monoculture. This statement applies also to the spruce mixed with the birch compared to the pure spruce stands (Klang 2000). The shorter payback period in first case is a result of income from spruce thinning; while in the second study faster growing birch gives an early income and an increase in volume yield. Agestam (1985) reports an increased cutting income with a slight admixture of birch in comparison to pure spruce stand. However, researches conducted for spruce with birch mixture found no higher yield than for monoculture of spruce (Agestam 1985). Bergqvists's (1999) studies also indicate a wood volume yield significantly lower in the spruce sheltered by the birch than in the unsheltered stand. Even though the spruce yield is lower, Tham (1998) found the total yield, including the birch, higher comparing to the pure spruce. If a production of the dry matter is considered, mixed stands produce up to 15% more than conifer stands (Frivold and Kolström 1999). A slight admixture of the birch resulted in an additional volume increment during the rotation period (Agestam 1985, Frivold and Kolström 1999).

In aspect of forming wood quality the nursing role of one component for the other species is emphasized (Kerr et al. 1992). In the shelterwood stand the moderating effect of shelter on frost damages works in two ways. The shelter increases minimum temperature and decreases a load of incoming radiation following the frost (Bergqvist 1999). If spruce quality in mixed stands is considered, using fast- growing admixture provides shelter effect and increases competition. Sheltered spruce has thinner branches and lower frequency of stem defects (Klang and Ekö 1999). Evans (1984) stated that by protecting from unseasonal frosts and providing side shelter, tree form of broadleaved species can be improved with conifer admixture.

1.4 An influence on spruce quality by establishing mixed stands

Spruce wood quality can be improved by growing mixed stands (Johansson 2003). Earlier studies investigating quality of spruce grown with a birch shelter, up to the first thinning shows promising results. Shelterwood systems combined with dense natural regeneration of spruce resulted in reduced branchiness and improved graded quality of spruce (Ekö and

Agestam 1994, Johansson and Persson 1996). Due to hampered growth the sheltered spruce had reduced branch thickness and thinner annual rings. Shelter protects the spruce from early summer frost and prevents from the damages inducted by it: spike knots and sharp bends (Klang and Ekö 1999, Bergqvist 1999).

1.5 Definition of spruce quality

The wood value is determined by the wood quality. The term "timber quality" is not easy to define, but it is assessed by the market demands. According to the Swedish "Regulations for measuring of roundwood" (The Timber Measurement Council 1999) the quality can be defined as "… suitability of a log for specific processing or use". Other definition states: "Quality is the resultant of physical and chemical characteristics possessed by tree or part of tree that enable it to meet property requirements for different end products" (MacDonald and Hubert 2002). The perception of what constitutes the quality depends on different sectors of wood-using industries.

The dimensions of wood are crucial for specific uses. For instance, long lengths of timber of known properties are required in some constructions. Nevertheless, finger jointing and glued timber technologies make use of shorter lengths of timber and may become more common in the future (MacDonald and Hubert 2002). If structural purposes of sawn timber are to be considered, quality of wood is defined in terms of form stability, strength and stiffness (Hannup et al. 2004, Johansson 1997). Pulp and paper production requires an appropriate tracheid structure and wood chemical composition (Hannup et al. 2004).

1.6 Aims of the study

The study aims at answering the question: what could be the benefit of growing mixed stands with spruce in regard to the wood quality? The thesis is divided into two parts: the literature review and research based on the field data. The literature survey describes main factors contributing to the process of forming wood quality. The second part is a field study focusing on quality traits of trees growing in different types of mixed stands.

The objective of the study is to investigate and compare spruce properties in young mixed and pure stands of the same age. Even – aged growing systems with, or without, a two-storeyed phase, has been the most common strategy of mixed stands management in Sweden. Lindén (2003) underlines that in the future silviculture of mixed stands will be based on the modifications of those systems. The study aims at comparing spruce quality in different types of mixtures depending on the planting pattern and growth dynamics of the species.

Spruce in pure stands is compared to spruce in mixtures with birch, hybrid aspen, larch, and beech. The study comprises comparison of:

- dimension
- branch properties
- quality properties

Based on earlier studies the following hypothesis can be postulated:

1. Due to hampered growth, the spruce grown in mixed stands will have reduced branch thickness and less abundant branches.
2. The sheltering effect of the admixture species will result in lower occurrence of stem defects inducted by early summer frost.

Therefore, the quality of spruce is better in mixed stands compared to in monoculture, at given similar site properties.

2.LITERATURE REVIEW

2.1 Wood properties as measures of timber quality

One of the most important properties is the tree diameter. It has a primary economic effect as the dimension determines the size of sawn timber (MacDonald and Hubert 2002). Larger logs result in higher volume recovery, which consequently reduces the processing costs (Klang 2000). Log dimensions influence also the result of quality grading as the boards of larger dimensions have larger acceptable knot size (Johansson 1997).

If the tree grows fast during the juvenile phase, it produces a wide juvenile core, which is undesirable. Juvenile wood is characterized by short cells, thin cell walls and high microfibril angles. Those features cause a low strength of wood, a low stiffness and a decreasing dimensional stability, what leads to the risk of a distortion during a drying process. If the pulp production is considered, short tracheid lengths make the wood less suitable for this purpose by reducing strength of paper (MacDonald and Hubert 2002). It was identified that the strength of sawn timber is affected more by the extent and quality of the juvenile core than absolute density of mature timber (Lee 1999). The growth rate of spruce determines the wood density. An increasing ring width indicates a lower wood density. It is a result of an increasing width of the early wood characterized by cells with large lumens and thin walls, while the late wood dimension stays invariable, irrespective of the tree growth rate, although the proportion of it increases with age (Klang 2000, Lee 1999). A low density means a weaker sawn timber, but for the pulp and the panel board production it is an advantage. Lower density panels are easier to process and transport. During the paper production cell walls of low density wood collapse more easily leading to a better joining between fibres (MacDonald and Hubert 2002).

Stem straightness is closely connected with deviations in the grain angle and the formation of the compression wood. The less straight a stem is, the higher values of those properties. An increased grain angle leads to the reduction in the strength of sawn timber, larger drying distortions and warp. Comparing with the normal wood, the compression wood has a shorter tracheid length, higher microfibrile angle and larger lignin content. A presence of this kind of wood can result in a failure under the bending and in the longitudal shrinkage. The compression wood conspicuously decreases a suitability of the pulp production since the high lignin content results in a lower yield of the chemical pulping. Bent stems cause a bad economic impact during all stages of processing. Firstly, they increase costs of the harvesting and the transporting, because a bigger space is occupied. Secondly, the debarking is more costly and difficult. Finally, saw logs have a lower volume recovery and a lower mechanical performance (MacDonald and Hubert 2002).

In respect of the sawn goods quality, branch properties are of great importance as they are associated with an occurrence and a size of knots on the sawn goods. The most significant trait is a branch diameter, which is positively correlated to dbh (Johansson 1992 , Vestøl et al. 1999). It was found that with an increasing branch diameter, the rate of natural pruning decreases (Agestam et al.1998). A large diameter of branch results in a bigger size of knots. In forest research practice the diameter of the thickest branch located below 2m is measured as an indicator of timber quality, as well as an indicator of the growth rate of the young tree. It has been found that the growth rate has a greater correlation to the thickest branch diameter than to the average branch size (Klang 2000). The fiber disturbance around knot reduces stiffness and strength of sawn timber (MacDonald and Hubert 2002). Therefore, the knot area ratio, expressed by knot area divided by cross section area, is proved to have a negative correlation to the strength of sawn goods (Kliger et al.1995). An increasing knot size and a number of knots result in higher harvesting and processing costs for all types of the end-use. It is more costly to remove bigger and numerous branches. A large amount of knots induces consequences also for a pulp production. As the knot wood is coloured and denser than normal wood, it increases costs of processing (MacDonald and Hubert 2002).

2.2 Main factors forming quality

2.2.1 Genetic factors

Wood properties of a tree are the result of a genetic potential to produce a certain kind of wood and an influence exerted by the environment (Zobel 1995).

Wood properties are genetically controlled in two ways. A genetic control works directly by controlling internal processes of the wood formation. At the same time genes act indirectly influencing a form and growth of a tree (Zobel 1995). Agestam et al. (1998 a) reports a low heritability referring to the branch thickness as it is influenced more by the growth rate, whereas branch angle can be controlled genetically (Ekö and Agestam 1994).

The phenological development is under a strong genetic control. Among spruce populations and individuals there is a well-defined classification into “early and late flushers” (Zobel 1995, Giertych 1998). A flushing term is connected with the risk of frost damages. The early flushing makes spruce more susceptible for spring-frost damages of an apical bud, what results in the formation of spike knots, sharp bends and double tops and, consequently, reduces timber quality. Therefore, late bud flushing is a desired feature of spruce (Persson and Persson 1997).

Studies of genetic parameters show that some of the wood traits have a significantly high heritability. It was found for the lignin content, growth traits and spiral grains. Cell wall thickness, microfibril angle, tracheid diameter and length show moderate heritabilities. Low heritability was proved for the fibre strength and the wood stiffness (Hannrup et al. 2004). Hannrup et al. (2004) found that wood density has a high heritability, but it is in contradiction with other authors, who link wood density with the growth rate. The same set of genes can perform differently at different photoperiodic and temperature conditions (Persson and Persson 1997).

2.2.2 Site factors

There is little quantitative information about effects of the site quality on wood properties (MacDonald and Hubert 2002). Properties related to the tree growth, such as a stem diameter and a tree height, have a low heritability and they are directly determined by the site quality (Giertych 1998). Depending on the climate zone and the region, the water or the nutrient availability can be the main limiting factor. A nutrient optimization experiment conducted in spruce stands proved that nutrient availability is a major constraint of the spruce yield in Sweden. The fertilization had a positive effect on the tree height and the diameter (Bergh et al. 1999). Szymanski (1998) states that the high quality of spruce is possible to obtain only within an optimum range of the climate and the soil conditions. Nevertheless, with an increasing rate of growth, the strength of wood can be reduced due to the lower density (MacDonald and Hubert 2002). Considering fiber properties, spruce shows a weaker reaction for different environment conditions in comparison with other species (Zobel 1995). Furthermore, local variation in site conditions results in quality differences between individual trees.

The high quality spruce stands should be grown in a suitable location, not exposed for strong wind (Szymanski 1998). The increasing wind exposure is linked to the leaning stems with elliptical cross sections, the increased compression wood and the poor stem straightness. The windiness influences quality also indirectly by limiting possible silvicultural options, for instance selective thinnings. Damages caused by the snow or the ice can affect stem straightness and branching (MacDonald and Hubert 2002).

2.2.3 Competition

The single tree's characteristics, such as the thickness of branches and the width of annual rings are influenced by the competition (Nilsson and Gemmel 1993). Trees in stands share limited resources: the light, the water and the nutrients. The resources availability determinates a survival and the growth; therefore, strong interactions exist between trees aiming for their persistence and the reproduction. The interspecific competition effects have not been investigated thoroughly enough (Burkhart and Tham 1992). A model of differential resource utilization explains the coexistence of competing plants considering both: dynamics of the resources and dynamic of the competing species. Ecological field theory (EFT), which describes competitive relationships between plants in community, has a methodology based on variable amounts of the spatial interaction as a function of a plant size, climatic and environmental conditions (Burkhart and Tham 1992).

An extent of a development of tree organs such as needles, apical shoots and roots influence the growth hormones production, which form a physiological response of a tree for external factors (Klang 2000). The competition between trees growing in a vicinity results in the hampered growth (Burkhart and Tham 1992) and, ultimately, self- thinning (Nilsson and Gemmel 1993). A decrease in competition results in the faster growth, wider annual rings, larger crowns, an increased branch diameter and a lower basic density (Johansson 1992).

Nilsson and Gemmel (1993) found that spruce of the same height has similar branch basal area and branch length irrespective of competition from neighbours. The plastics response of spruce is proved to be significantly smaller than for pine. Only a small number of current shoots was conspicuously affected by the competition (Nilsson and Gemmel 1993). A forestry manager influences the competition by regulation of a growing space for an individual tree, chiefly: choice of the planting density and the thinning. Nevertheless, in aspect of the high quality timber production, spacing in young stands appears less important in spruce than in pine stands (Nilsson and Gemmel 1993).

2.3 Silvicultural methods affecting timber quality

To some extent, the forester, through an appropriate silvicultural management, can influence wood properties (Klang 2000). Management factors, like: initial spacing, thinning intensity and form, affect the timber quality through an influence on living space and level of competition between trees (Johansson 1997). Beside methods regulating an individual growth rate, choice of plant material and prevention from defects and damages by using the shelter systems are of the great importance in forming quality.

2.3.1 Regeneration method

Comparing with the planted spruce, naturally regenerated stand has a lower number of trees with stem defects. The small proportion of spike knots and sharp bends occurs due to the shelter trees protection against summer frost. Also a diameter of the thickest branch is lower in stands originating from seed trees with high initial seedling density (Klang and Ekö 1999, Johansson and Persson 1996). Similar traits are obtained for the spruce planted in the shelterwood system. At the same time, Klang (2000) found no significant influence of the regeneration system for the number of branches per stem and the width of annual rings. Johansson and Persson's (1996) study indicate the number of branches in the stem section between 1 and 2 m lower in naturally regenerated stands. In naturally regenerated stands and stands planted under the shelter volume yield is lower due to a high initial competition from shelter trees and between seedlings, which hampers growth at young stage. Simultaneously, the yield of stand as a whole is higher. It is an effect of different growth patterns between species and a higher initial basal area on shelter plots (Klang and Ekö 1999). It has been proved that the graded quality of the butt logs is considerably better for trees from the naturally regenerated stand (Johansson and Persson 1996). The natural regeneration contributes to the increasing timber quality and, additionally, helps to reduce costs of stand establishment (Klang 2000).

2.3.2 Initial spacing

An improvement of timber properties can be obtained by the high initial density. Johansson (1992) found an evident positive respond of the branch and the stem diameter due to the initial density. Both properties increase with an increasing spacing. Consequently, the timber quality tested in two grading systems increases with the decrease in spacing

(Johansson 1992). The reduced spacing results in a lower dbh and annual ring width, higher wood density, thinner branches and smaller stem taper (Klang 2000).

2.3.3 Choice of seedling material

According to the seedlings origin, trees respond differently for environment conditions on given area. One of the most important features is flushing term as it is linked to a risk of early frost damages. Each spruce population has genetically determined needs for given amount of warmth, which is necessary to start flushing. The "earliest flushers" are spruces originating from north of the species distribution and eastern populations from Ural (Giertych 1998).

Since the good quality of a stem is associated with an intensive growth, dependent on environment conditions, there are only slight differences between provenances. However, a common opinion exists among researchers: the best growth characterizes spruce populations from northern-east Poland, Lithuania, Latvia, Estonia, northern Belarus and western Russia (Giertych 1998).

One of the trials in Southern Sweden, conducted with a purpose to test trees of a different origin, shows an evident variation in a performance. For instance, Carpathian provenances have the highest stem volume and density. Provenances from the Baltic States and Belarus combine high growth, high basic density and a low incidence of spike knots. Provenances from southern Scandinavia have rather thin branches and high wood density but relatively low stem volume (Persson and Persson 1992). According to Persson (1985) provenances from Belarus and northern Poland should be preferred in southern Sweden.

2.3.4 Thinning regime

By realization of the thinning, forester regulates a stand density and makes a selection in order to favour desirable trees. The reduced stand density results in the increasing growth rate of individual trees. The accelerated growth may lead to development of thicker branches in upper part of stem and may cause an increase in the spiral grain (Klang 2000). Effects of a thinning depend on the selection method, thinning intensity and within-stand variation. There is a considerable within-stand variation of growth related properties, which increases with increasing density (Johansson 1993, Pape 1999). Variation between stands is smaller. It should be noted, that at the time of first thinning main formulation of quality is terminated and influenced mostly by initial density (Pettersson 1992). The effects of thinning is significant for the top log and it concerns dominant and co-dominant trees (Pape 1999, Klang et al 2000).

Thinnings influence wood properties in two ways. It accelerates the growth rate of the trees left in the stand. By the thinning trees with desired characteristics are left to the final stand and the future growth is concentrated on them (Pape 1999). In regard of the wood traits, thinning leads to a decrease in basic density, although this effect depends on the thinning intensity and the annual ring width prior to the thinning. A decrease in basic density, with given increase of the ring width, is larger when the ring is narrow. The selection of crop trees determinates also the proportion of juvenile wood in final stand, but it is not a direct influence since thinnings are conducted after the transition to the mature wood. Pape's (1999) investigation indicates that increasing thinning intensity results in a higher amount of thin-walled and large- diameter earlywood tracheids.

A thinning form above, oriented on removing large trees, results in: the slight reduction of volume production, a higher wood density and a lower average annual ring width, comparing with thinning from below. Thinning from below causes an increasing stem taper and a lower "height/diameter" ratio. With an increasing thinning intensity, the height to first living branch decreases, while "crown/stem" ratio increases (Pape 1999). The thinning can be realized using selection methods, which are oriented on given stem properties. If main target in the research was high quality, investigated effect shows increase in proportion of straight trees without stem defects. That means the forester can have significant influence on quality of final crop by an appropriate selection (Klang et al. 2000). It should be kept in mind that possibilities of the selection are limited in stands with the previously conspicuous tree removal, like during establishment of strip roads and a removal trees with low vitality, or in stands with the high proportion of trees with serious stem defects (Klang 2000).

In Poland the best quality results are obtained, if spruce is treated according to "gradual Wiedemann's thinning" system. In a young phase, a schematic cutting intensively thins stand. Starting from the age of 15 ("youth phase") the thinning from below is recommended with 5 years intervals. Individuals with the best growth are left. The final, single-storey stand is composed of dominant and co-dominant trees (Szymanski 1998).

2.3.5 Other treatments

The forester can improve spruce quality also by choosing mixed stands as an alternative for monocultures. Though the mixture of spruce with birch was widely studied in Nordic countries, there is need of knowledge concerning spruce development in various mixtures.

3. MATERIALS AND METHODS

3.1 Description of the Snogeholm object

The study has been conducted in the Snogeholm plantation (*Figure 1*). Snogeholm is situated in Southern Sweden approximately 40 km west of Malmö (latitude: 55 °35'N, longitude: 013° 40'E).

Figure 1. Location of the Snogeholm plantation in Skåne region (Sweden).

The climate is characterized as maritime. The mean annual temperature is 7,5°C with the mean temperature of July equal 16°C and the mean temperature of January equal -1°C Precipitation totals 700 mm per year with the highest monthly value of 70 mm occurring in June. The growing season lasts 220 days (National Atlas of Sweden 1996).

According to the" National Atlas of Sweden" (1996) the terrain determinate by the surficial deposits is a prevailing landform of the region including an investigated area. The plantation is located on hilly terrain; thereby soil conditions vary between plots and within them.

The Snogeholm plantation was established on agricultural land situated in an extensively forested area. Forest was planted in 1994 within a framework of a project aiming for demonstration of the potential of the forested land with a special focus on recreation. The plantation is divided into plots representing various types of mixtures and monoculture stands of most of the Swedish tree-species.

Two types of mixtures were comprised within the study. The first type represents “nurse trees” (shelter) where a slow growing tree species is mixed with a fast growing species, which provides shelter against harsh weather conditions during first 10-20 years (e.g. the aspen mixed with the spruce). The second type also contains species with a different growth pattern. Spruce is planted with noble tree species, which is designated as a final crop (e.g. beech).

3.2 Description of study stands.

With the exception of the spruce clones stand, searched stands were composed of two tree species. In two stands, namely: “Spruce and beech” and “spruce with larch”, two components had the same proportion of occupied area. Spruce planted with birch and hybrid aspen took 67% of the stands area. In “spruce and oak” stand, spruce occupied 80% of the plot area. Initial spacing varied from 1,5m x 1,7m (spruce with noble tree species: beech and oak) to 1,5m x 2,8m (spruce and hybrid aspen). In “spruce and birch” stand, one row of birch was planted between every two rows of spruce seedlings. Spruce was planted on alternate rows in “spruce and larch” and “spruce and beech”. In mixture of “spruce and hybrid aspen” two seedlings of spruce were followed by one hybrid aspen in each row. Oak was established in groups in spruce stand. Stand made of spruce clones was homogenous. If spruce is a target species, the number of trees planned for final crop is 300. The characteristics of stands were examined during the inventory conducted by SLU in 2004 *(Table 1)*.

Table 1. Stands characteristics at the age of 11 [1]

Stand characteristics	**Types of mixtures**					
	Spruce / Birch	**Spruce / Beech**	**Spruce / Larch**	**Spruce / Hybryd aspen**	**Spruce / Oak ("Spruce monoculture")**	**Spruce**
% of spruce in stand area	67	50	50	67	80	100
% of admixture in stand area	33	50	50	33	20	0
Origin of spruce [2]	Maglehem	Maglehem	Maglehelm	Maglehelm	Maglehelm	Maglehelm
Origin of admixture [2]	Asarum	Ramsasa	Maglehelm		Klan	
Spacing (m)	1,5x2,2	1,5x1,7	1,5x2,4	1,5x2,8	1,5x1,7	1,5x2,2
No of seedlings per ha	3000	4000	2800	2400	4000	3000
No of target trees [3]	300	200	300	300	50	300
Species of target trees	spruce	beech	spruce	spruce	oak	spruce
Planting pattern of spruce	Two rows	One row	One row	Two trees followed by one tree of admixture (in one row)	Filling	Monoculture
Planting pattern of admixture	One row	One row	One row		Groups	_
Mean height of spruce (dm)	65	61	62	72	64	61
Mean height of admixture (dm)	95	44	98	134	44	_
Mean diameter of spruce(mm)	73	94	67	79	87	83
Mean diameter of admixture (mm)	100	40	135	133	39	_
Volume of spruce (m^3/ ha)	33	47	16	33	54	59
Volume of admixture (m^3/ ha)	44	6	55	70	2	_
Total production of spruce (m^3/ ha)	33	47	18	33	63	_
Total production of admixture (m^3/ ha)	44	6	91	70	2	59

[1] Data obtained during the SLU inventory conducted in 2004

[2] Provenances from Southern Sweden

[3] Target trees- trees left until the rotation age

Two stands were examined as a comparison with mixtures. One was a pure spruce stand established a clone of one individual. The other is the one composed of spruce and oak planted in groups *(Table 1)*. In order to investigate properties of a pure spruce stand, only trees not affected by oaks were measured, therefore every 4 trees, which were close to oak groups were not sampled. In further analysis, this stand is called "spruce monoculture", because measured trees had grown in conditions comparable to monoculture.

Some stands were thinned in 2002. On the plot with spruce and oak groups, the spruce was thinned with intensity of $9m^3$/ha. The spruce and the larch mixed in one stand were thinned with intensity $2m^3$/ha and $36m^3$/ha respectively. In mixture of the spruce and the hybrid aspen, the aspen was thinned in the 2004.

3.3 Data collection

Data for studies were collected during winter 2005. About 120 spruce trees were measured in each stand. The number of sample trees varied between stands due to not equal amount of trees in rows *(Table 2)*. Within mixtures, also sample trees of admixture- species were examined. In the "Results" part, those species are called "shelter trees", although not all of them are significantly higher than spruce. A simplification is used in order to visibly present the results.

Table 2. Number of sample trees in stands

	Types of mixtures					
	Spruce / Birch	Spruce / Beech	Spruce / Larch	Spruce / Hybryd aspen	Spruce / Oak ("spruce monoculture")	Spruce
Number of spruce sample trees	125	125	121	125	123	121
Number of shelter sample trees	50	50	41	35	0	0

In order to comprise different micro-site conditions within stands 5 rows were investigated in each stand. Rows were chosen with equal distance between them. All trees growing in assigned rows were measured as sample trees. Exceptionally, to reduce influence of "edge effect" 4 trees closest to an open area were skipped within rows.

The breast height diameter was measured on every spruce sample tree. Additionally, the following data were measured on sample trees: the height to the first living branch, the number of branches in three whorls closest to breast height and the distance between the uppermost and the lowermost whorls of those three, the diameter of the thickest branch located in a whorl closest to the breast height. As a "living branch", a branch with green needles was considered, irrespectively of their abundance. Spike knots on sample trees were counted and a part of the stem with occurrence of it was determined as a location within particular 2m-section. The presence and the estimated heights of double tops were also noted. The occurrence of other stem defects (stem lean, sharp bends, breaks and cracks) was recorded. The stem crookedness, quality, tree class and vitality were determined according to criteria presented in Table 3. The height was measured for 30 sample trees per plot, on every fifth tree within selected rows.

For each of the shelter sample trees the diameter was measured.

Table 3. Criteria of tree properties estimation

Tree property	Ranks	Description of criteria
Crookedness of stem	1	Straight, the stem without crookedness or slightly crooked in part above 4 m of height
	2	Slightly crooked stem with estimated small proportion of the compression wood
	3	Significantly crooked stem with estimated substantial proportion of the compression wood
Stem quality	1	Well shaped, regular and vital crown, a moderate number of branches, branches with small diameter, straight stem with small taper, stem without defects
	2	Properly shaped crown, a conspicuous amount of branches, branches with the average diameter, the stem with single defects like: a spike knot, a double top; an insignificant crookedness and a slight distortion of the stem base acceptable
	3	The crown conspicuously distorted, significant stem defects making it unsuitable for sawn wood,(i.e. sharp bends, double top located on low height), numerous spike knots, a high number of branches with big diameter, a conspicuous distortion of the stem base; the tree severely suppressed or declining
Tree class	1	A dominant tree with the top located significantly above the stand canopy or above the crowns level of the same species-trees growing in vicinity
	2	A co-dominant tree with the top located within the stand canopy or within the crowns level of majority of the same species- trees in the stand
	3	A dominated tree with the top located in a lower part or slightly below the crown level of the same species- trees in the stand, with hindered growth, but possible to alter after crown releasing in the thinning
	4	A suppressed tree with the top located conspicuously below the crown level of the same species- trees in the stand, with the significant indicates of out-competing: small dimensions, significantly slow growth, impossible to alter after crown releasing in the thinning.
	5	A wolf tree with significantly bigger dimensions and distinctly wider crown than the same species- trees in the stand, very long branches situated at right angle on stem; tress in vicinity indicate suppression
Vitality	1	Lively crown, abundant green needles without any indicators of damages and diseases
	2	Slightly thinned crown, low proportion of discoloured needles affected by damages or diseases
	3	Sparse crown with significant indicators of declining, high proportion of discoloured needles affected by damages or diseases

3.4 Data analyzing

Collected data were analyzed by a comparison of mean values of spruce properties in different mixtures. In a first step, features of spruce dimensions were analyzed (diameter, height). Simultaneously percentage of spruce trees in tree classes was calculated and frequency of the quality characteristics was analyzed within the classes. Then mean values of properties referred to spruce quality were analyzed: the diameter of the thickest branch, the sum of branches, the number of branches per stem meter and height of the first living branch. For all of the spruce properties a standard deviation within stands was calculated. In a next step percentage of subjectively estimated features, namely: quality, crookedness, tree class and vitality were analyzed together with the occurrence of stem defects (spike knots, double tops) assigned to stem sections.

The significance calculations were made as planned comparisons (contrast) in ANOVA. Every row was regarded as an independent variable. Contrasts were made between "control" and the two other categories, which represented two models of competition within the stands. Two spruce stands were considered as a "control". This group was compared with stands of sheltered spruce (spruce- hybrid aspen, spruce- birch and spruce- larch) and dominating spruce (with beech).

4. RESULTS

4.1 Results concerning spruce dimensions and vitality

4.1.1 Height

The general trend is that spruce in pure stands and in mixture with beech is on average higher than spruce under shelter wood conditions *(Figure 2).* The height calculated for spruce grown under a shelter (with hybrid aspen, birch and larch) is on average 0.7 m lower than the height of spruce under open conditions. The difference in height between sheltered stands and the reference group is however not significant (p=0.0727), as is not either the comparison between the spruce/beech mixture and the reference group (p=0.9787).

The on average highest spruce is found in the clone stand, while the lowest value is recorded in the mixture with birch.

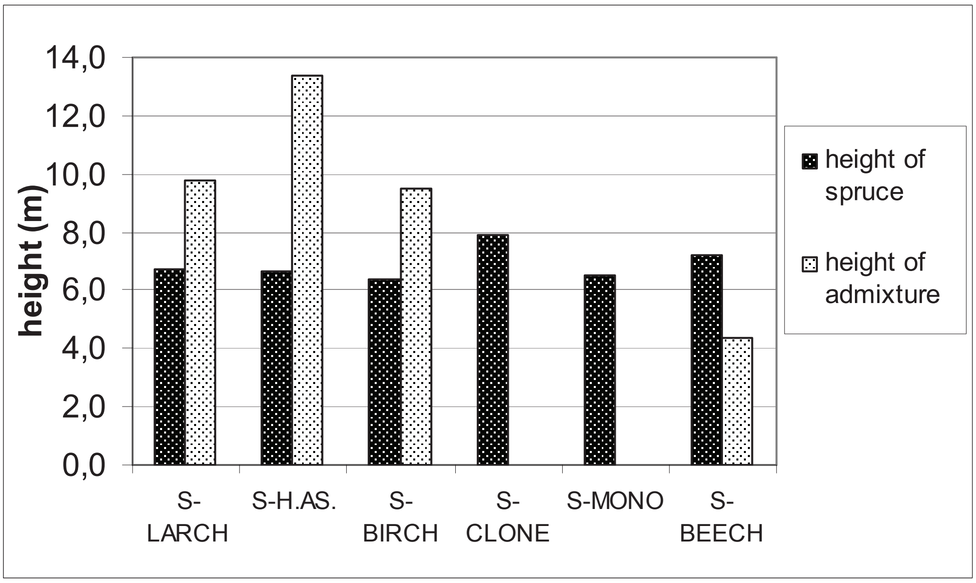

Figure 2. Mean height of spruce in pure stands and mixtures.

The highest proportion of trees above 8m of height is found in the spruce clones stand *(Figure 3)*. Spruce planted with beech has the lowest variation of heights within the stand, where 76% of trees have a height from 6 to 8 m. The least homogenous stand is spruce planted with larch. It has conspicuous share of trees with low heights, however 26% of trees has a height bigger than 8m.

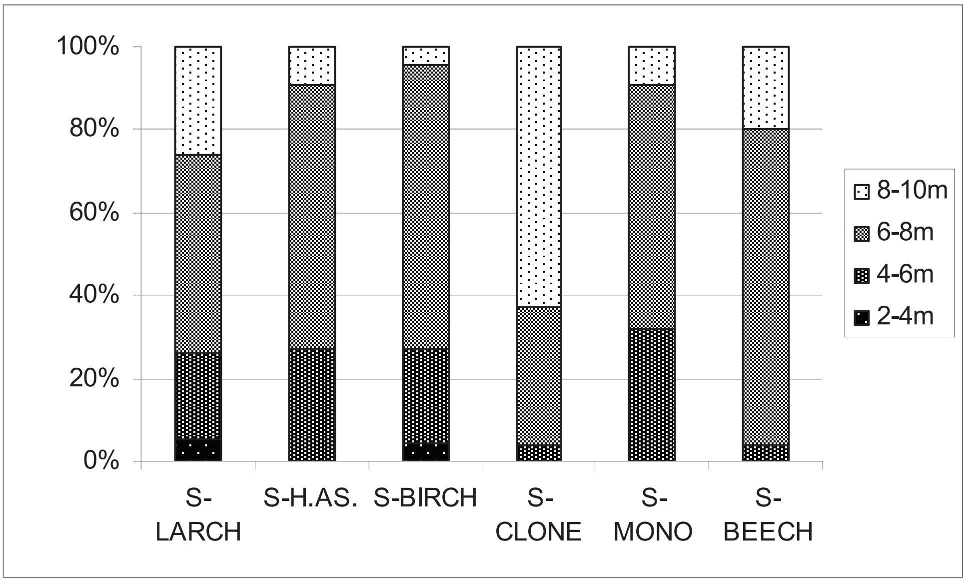

Figure 3. Frequency of spruce in different height classes

The top height is similar in all stands and varies from 8.3 to 8,6m *(Figure 4)*.

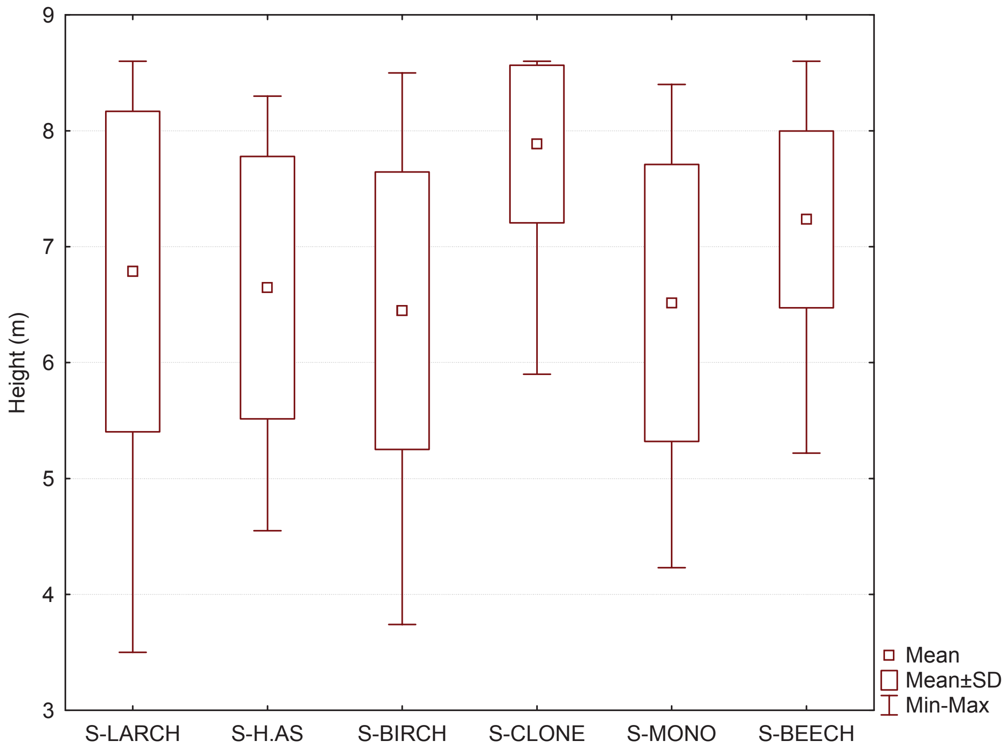

Figure 4. Height of spruce within the stands.

4.1.2 Diameter

Depending on the development of the species in mixture, there is a division of spruce trees into two groups. Spruce grown together with fast-growing species has developed smaller diameter than spruce grown with beech and spruce in pure stands *(Figure 5)*. The difference in diameter between the spruce/beech mixture and the reference group is significant (p=0.0015). However, the difference between the sheltered stands and the reference group is not (p=0.3099).

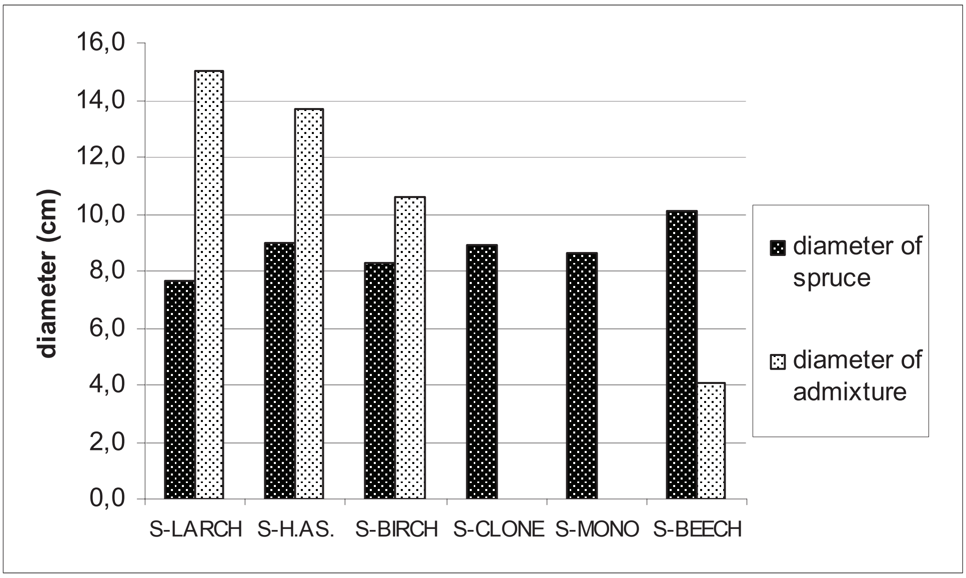

Figure 5. Mean diameter of spruce and admixture-species

The difference in average diameter between the pure spruce stands in the reference group is small.

The smallest average diameter for spruce is found in the mixture with larch (7.6 cm), while larch has the biggest diameter among the admixture-species (15.0 cm). The opposite situation is found in the spruce/ beech stand, where spruce reached the biggest average diameter (10,1 cm) and beech has the smallest diameter (4,1cm).

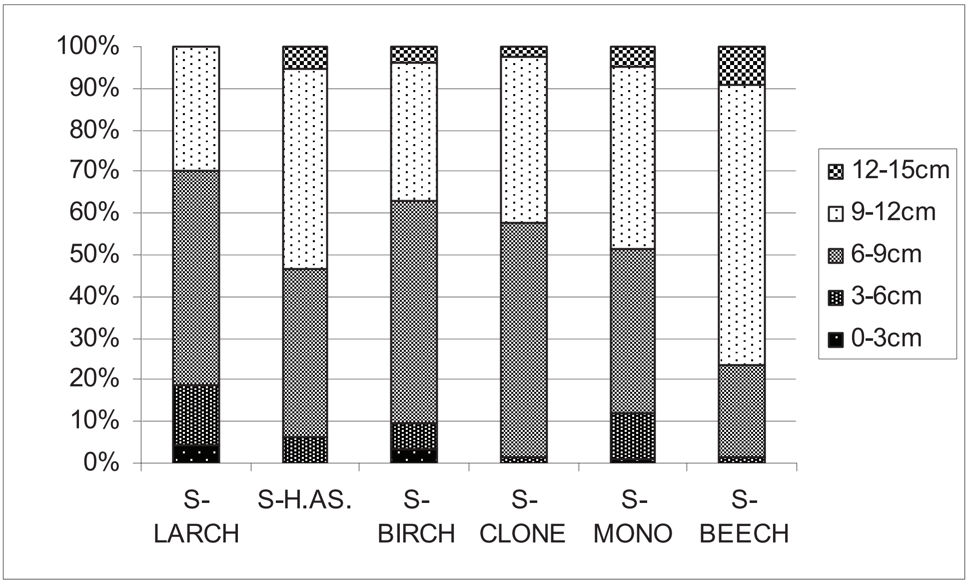

Figure 6. Frequency of spruces in diameter classes in the study stands

The highest proportion of trees in small diameter classes is observed in the spruce/larch mixture, while spruce grown with beech has the highest share of trees in larger diameter classes *(Figure 6)*. The widest distribution of diameters for spruce is found in the spruce/birch mixture, while the narrowest range of diameters is noted in the clone stand *(Figure 7)*.

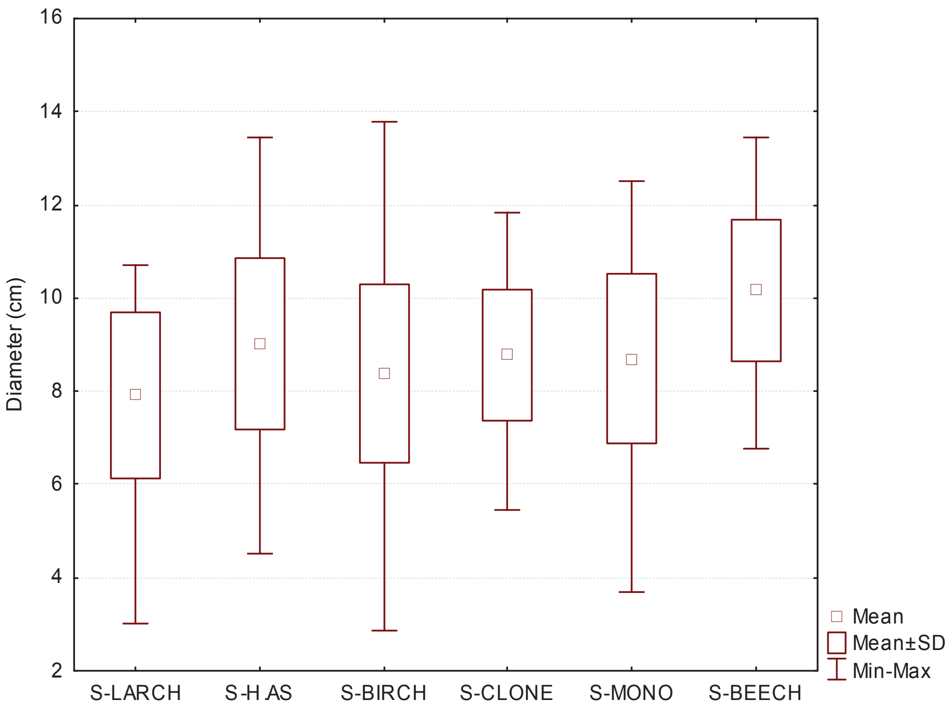

Figure 7. Diameter distribution of spruce within the stands

4.1.3 Tree classes

The no-shelter stands have on average 23% higher proportion of dominant trees (class 1) than the sheltered stands, but the share of co-dominant individuals is similar in the two groups of stands. There is a conspicuous difference in the frequency of dominated trees (class 3), which was on average 19% higher in the sheltered stands *(Figure 8*). The percentage of suppressed trees was also higher in this group. Furthermore there was a small difference in occurrence of "wolf trees" (class 5).

The highest frequency of dominant trees was found in the clone stand *(Figure 8*). Spruce planted with hybrid aspen had the lowest percentage of those trees, while the biggest percentage of suppressed trees (class 4) was noted in the spruce/larch mixture.

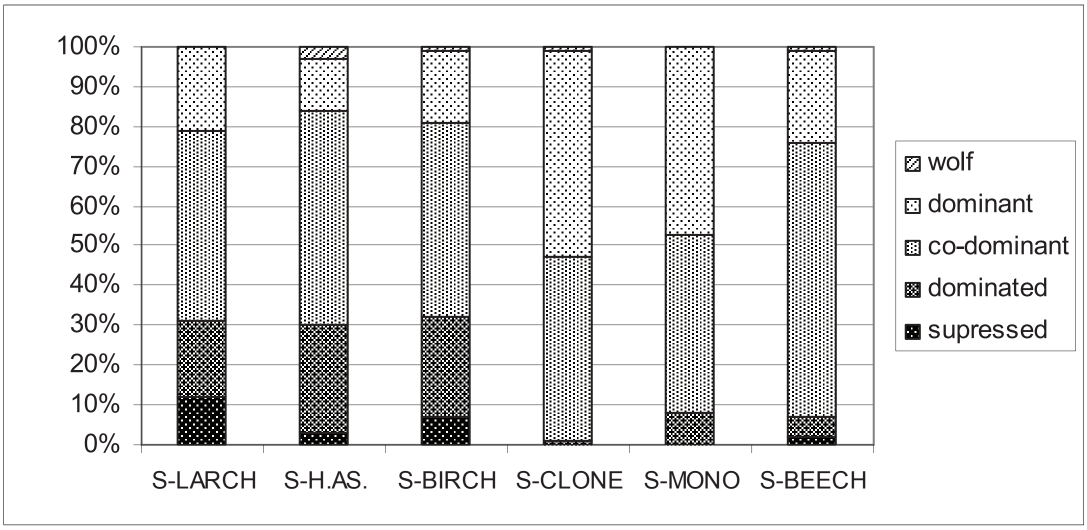

Figure 8. Frequency of spruce trees in tree classes.

4.1.4 Vitality of spruce

There is a significant difference in frequency of vital trees between sheltered stands and the reference group ($p<0.0001$).The sheltered stands have conspicuously less trees assigned to the most vital class than the no-shelter type. If the second vitality class is compared, the spruce grown under shelter conditions has 13% more trees in this category than the spruce in no-shelter stands. Within the no-shelter group two stands included declining trees (class 3), but with a very small proportion (*Figure 9)*.

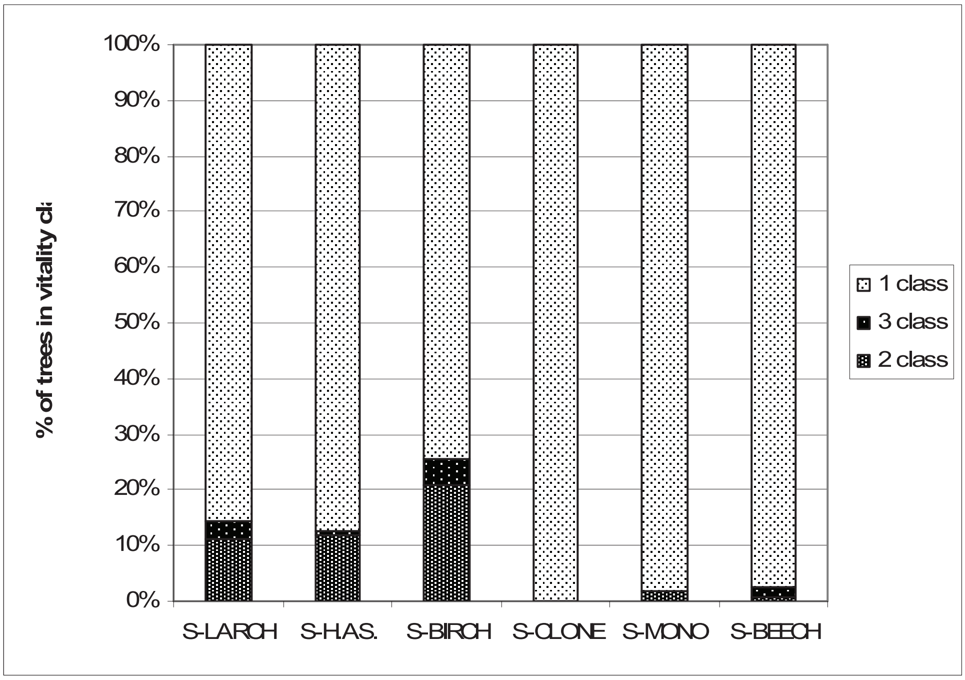

Figure 9. Frequency of spruce trees in vitality classes.

All the trees investigated in the spruce clones stand are assigned to the first vitality class. The lowest frequency of the most vital trees is found in the spruce/birch mixture.

4.2 Results concerning spruce quality

4.2.1 Diameter of the thickest branch

With an exception of spruce grown with larch, the average diameter of the thickest branch does not vary conspicuously between stands *(Figure 10)* and tree classes, although the average diameter of the thickest branch is smaller for trees grown under a shelter (11mm). The difference between the sheltered stands and the reference group is significant (p=0.0004).

Spruce grown with larch has the thinnest branches, significantly lower than in the other stands. The biggest diameter of the thickest branch is found among dominant trees grown with beech. However, the difference in mean branch diameter between the spruce/beech stand and the reference group is not significant (p=0.9709). The open grown spruces stands have a similar average branch diameter (approximately 13 mm), the variation among trees is however considerably smaller in the clone stand.

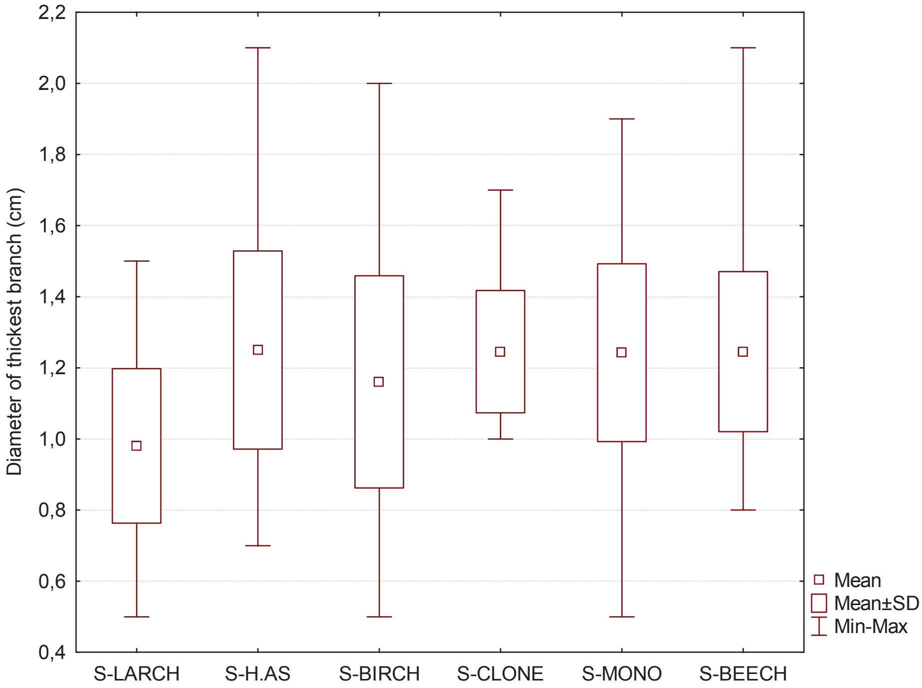

Figure 10. Diameter of the thickest branch in the studied stands

4.2.2 Number of branches per meter of stem

The highest average number of branches per meter of stem is found for spruce planted with beech. Spruce grown with birch and larch tends to develop similar amount of branches (*Figure 11*). The lowest number of branches is recorded in the clone stand.

The difference in number of branches between shelter and no-shelter conditions is significant (p=0.0004). However, the comparison of number of branches per meter of stem between spruce-beech and the reference group was not significant (p=0.9709).

The dominant, co-dominant and dominated trees have on average a similar number of branches. The variation in number of branches is considerably lower in the clone stand compared to the other stands.

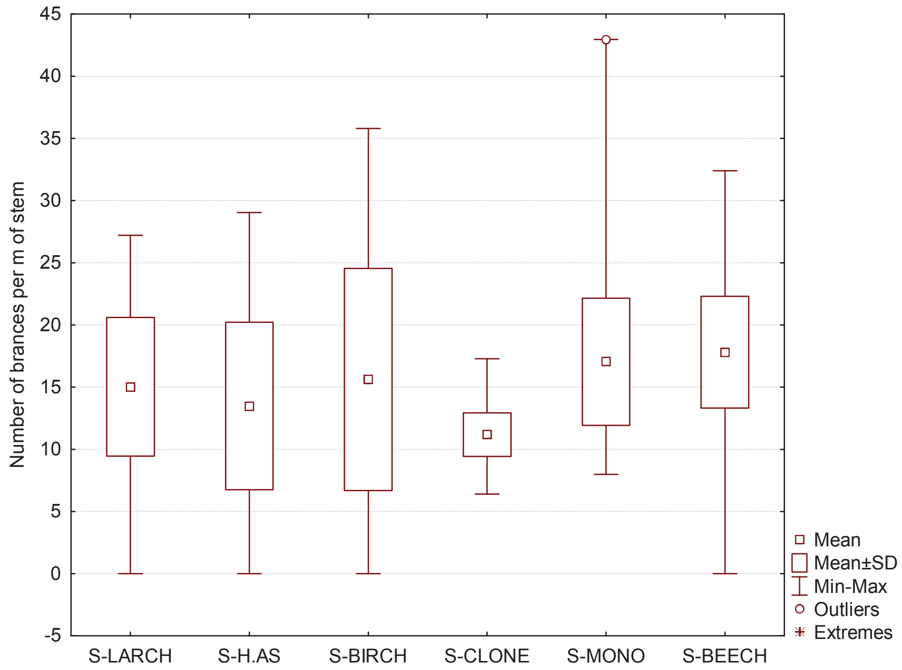

Figure 11. Number of branches per meter of stem

4.2.3 Height to the first living branch

A clear distinction between the two groups of stands is noted. It refers mostly to the maximum values, which were on average 95 cm higher for no-shelter stands (*Figure 12*). Also the mean height to the first living branch is significantly higher in stands grown in the open. The average height to the first living branch in the "shelter group" is 16.3 cm, while in the second group the average height is 34.8 cm. According to the statistical analysis the difference between the sheltered stands and the reference group is significant (p=0.0002) .

The highest mean value for the height to the first living branch is found in the spruce monoculture, where the first living branch is located 25.9 cm higher than in the spruce/ birch stand. The within stand variation is higher in the open grown stands, and highest in the clone stand.

Among the dominant trees the biggest height to the first living branch is noted in spruce grown in the pure stands (approximately 40cm).

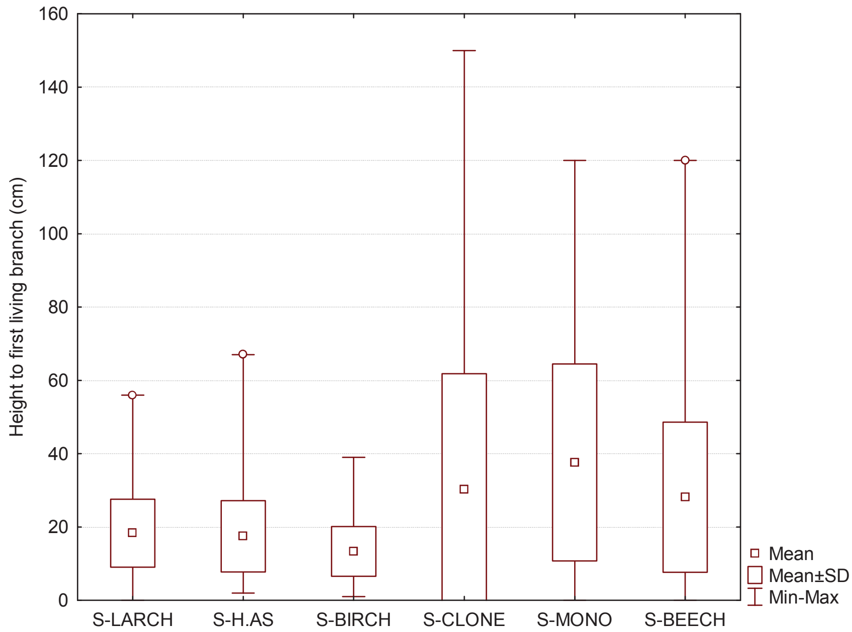

Figure 12. Height of first living branch

4.2.4 Crookedness

The biggest proportion of straight spruces, 75%, is found in spruce planted with birch (*Figure 13*). "Spruce/beech" and "spruce /hybrid aspen" have also a large share of straight spruces. Spruce mixed with larch has the smallest frequency of straight trees with only 26% of class-1 trees. This stand also has the biggest percentage of severely crooked trees (13%). The clone stand has the smallest frequency of severely crooked trees, but this stand has also the highest frequency of slightly crooked trees (62%). There is no significant difference in the average proportion of crooked trees between the two groups of stands, sheltered and no-sheltered (p=0.1302). However there exists a significant difference between the spruce and beech stand and the reference group (p=0.0006).

In all the stands, the dominated trees have the highest frequency of severely crooked trees.

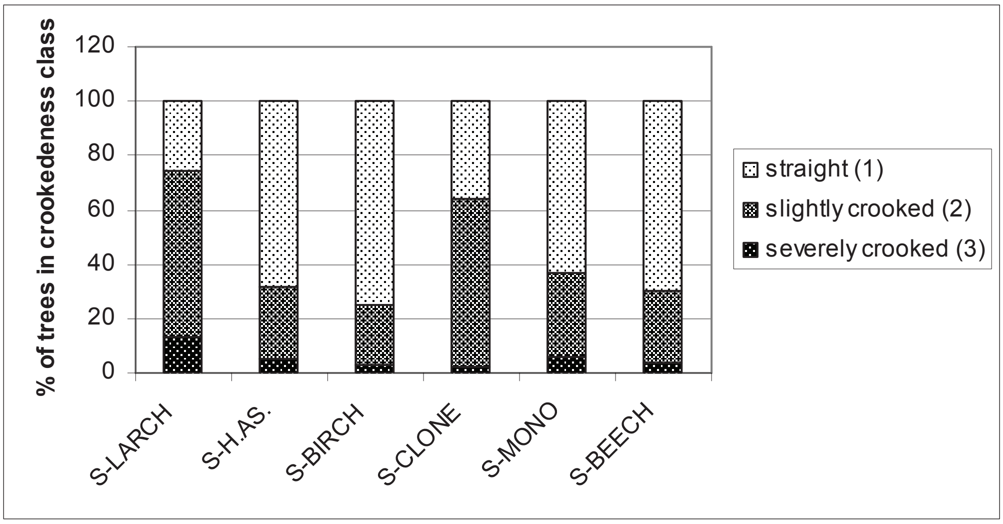

Figure 13. Frequency of trees in crookedness classes in mixtures.

4.2.5 Occurrence of stem defects

The frequency of trees without spike knots is significantly higher in the no-shelter stands (p=0.0003). Spruce in the clone stand has the lowest frequency of trees with this defect (*Figure 14*). The smallest proportion of spike knot-free trees is found in the spruce and larch stand. In addition, exceptionally for this stand, four spike knots are found on one stem.

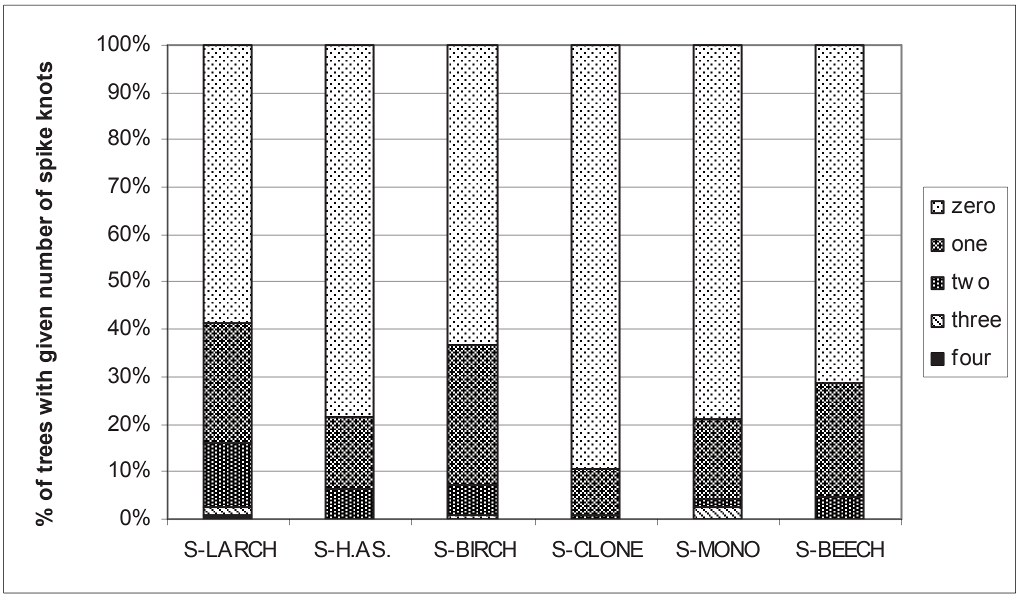

Figure 14. Frequency of trees with given number of spike knots.

Dominant trees have, on average, the highest number of spike knots in the spruce and larch stand, while the lowest occurrence of spike knots among these trees is found in spruce planted with hybrid aspen.

A majority of the spike knots is located in the section up to 2 m of height (*Figure 15*). Spruce grown with larch has the biggest number of spike knots in this section. Simultaneously, in this stand the biggest amount of spike knots is recorded from 2 to 4m. In the clone stand there are no defects located in the 0-2m section. The highest occurrence of spike knots in section 4-6m is noted in spruce planted with beech.

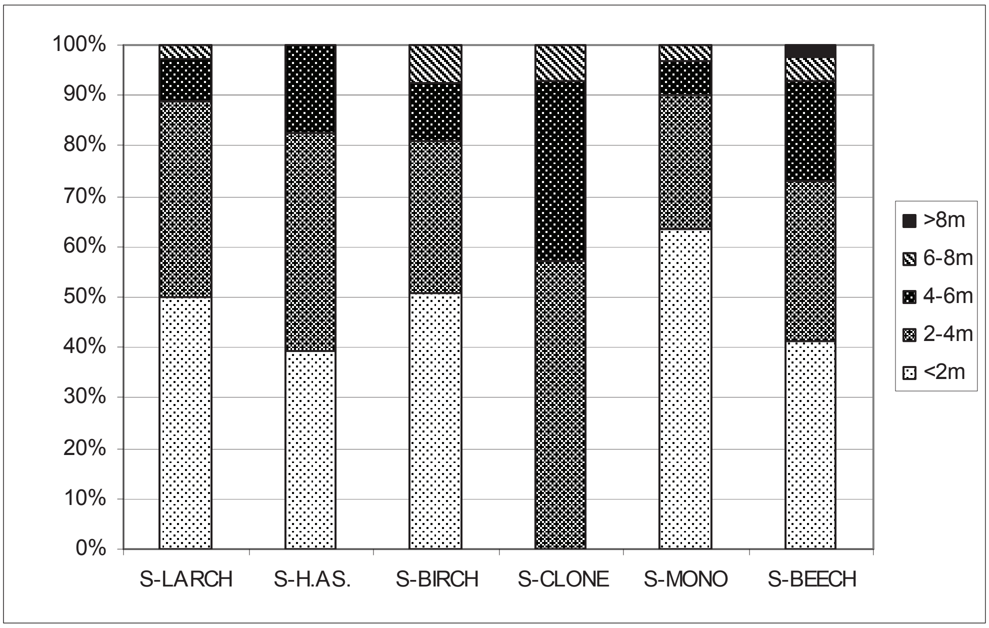

Figure 15. Frequency of spike knots located in different tree sections.

On average, spruce grown in the shelter stands has conspicuously more spike knots than the spruce grown in open conditions. The difference is obvious especially in the number of spike knots in the first 2m-section, where the average number for spruce grown in shelter conditions is on average 24 per stand while the corresponding amount in no-shelter stands is 12 per stand.

The frequency of double tops in the spruce/birch mixture is 30%, which is the biggest percentage among found in the investigated stands (*Figure 16*). A high proportion of trees with this defect occurs also in spruce planted with hybrid aspen. Contrary, almost all the trees in the clone stand (94%) have a single top. The spruce monoculture has also a high frequency of single top trees. The no-shelter stands have on average 11% more trees with only one top than spruces mixed with fast-growing species. The difference between the shelter group and the reference stands was significant (p=0.0001).

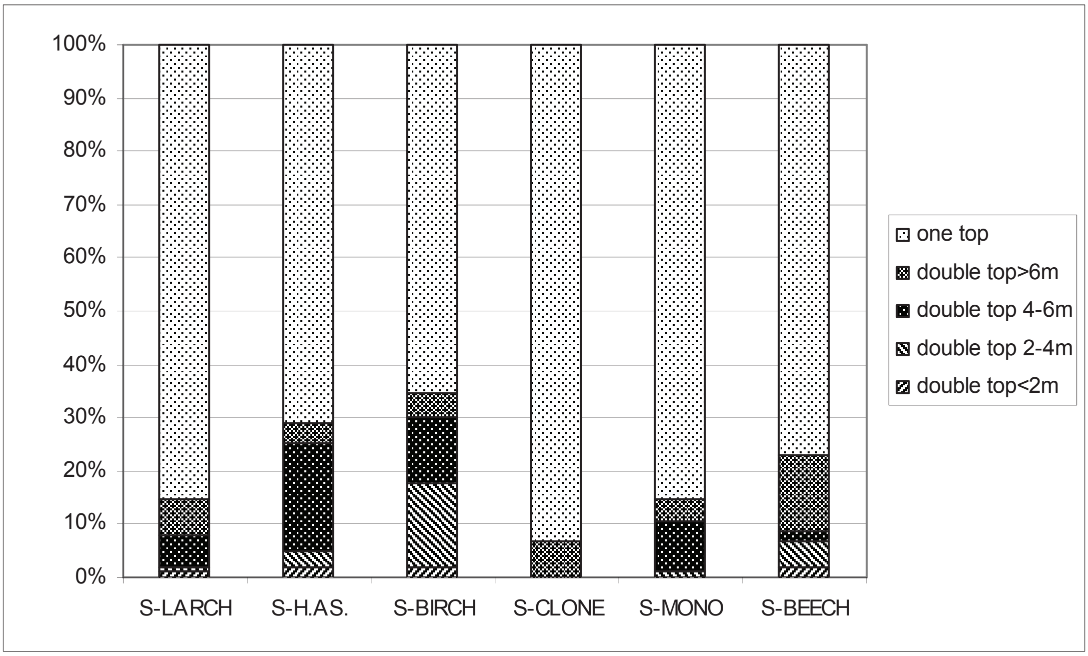

Figure 16. Frequency of trees with double top located in different stem sections

Spruce, which has grown under shelter conditions, has a stronger tendency to develop double tops within almost all stem sections compared to spruce in no-shelter stands. The most significant difference between two groups of stands is revealed for the section 4-6m, where spruce in shelter stands has three times more of double tops than in no-shelter stands.

Pure spruce stands have no double tops recorded in the first 2m-section. In the rest of the stands a very low number of double tops are noted in this section. The spruce with birch admixture has the biggest amount (17 per stand) of double tops located between 2 and 4m.

Dominant trees were most affected by double tops in the spruce monoculture, while co-dominant trees had the biggest occurrence of double tops in the spruce and birch mixture. A conspicuous number of double tops is noted also among co-dominant trees of spruce planted with beech.

4.2.6 Spruce quality assessment

The average percentage of trees belonging to the highest quality class is similar for both shelter and no-shelter stands. The proportion of trees in second quality class differs and is on average 8.7 % higher in no-shelter stands

Spruce grown with hybrid aspen has the highest percentage of trees in first quality class (40%). A very close percentage is found also in the spruce monoculture (39 %). The spruce-larch stand has the lowest frequency of first class trees and the biggest share of trees graded to the worst quality (*Figure 17*). The smallest share of the third class quality is noted in the clone stand.

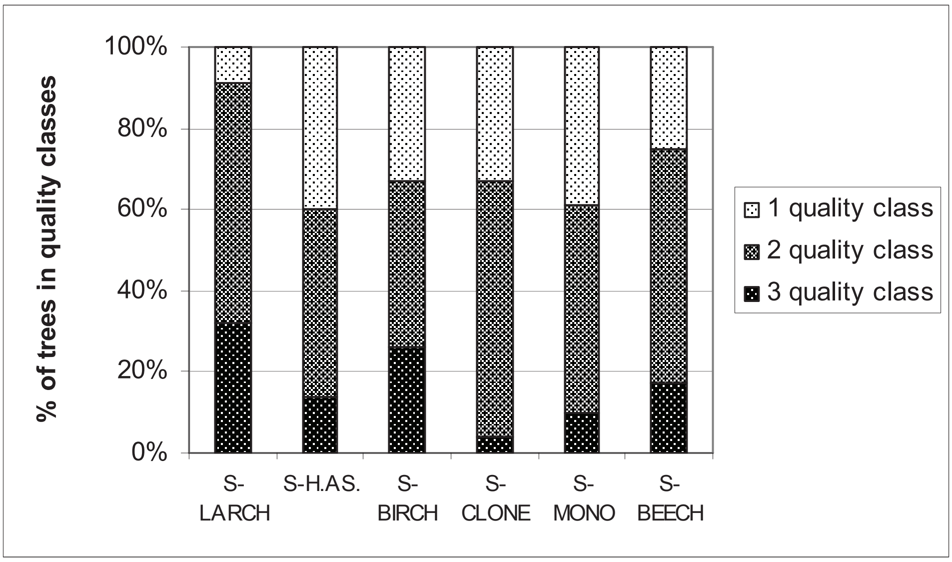

Figure 17. Frequency of trees in quality classes

Dominant trees have the worst quality in the spruce/larch mixture. Similar proportion of third quality spruces is recorded in the mixture with birch. In the pure spruce stands dominant trees have the biggest occurrence of first quality trees.

5.DISCUSSION

5.1 Stem properties

The most visible effect of competition in the studied stands is reduction of diameter and height. Nilsson and Gemmel (1993) found both that both diameter and height of spruce were suppressed by the presence of larger neighbours. Other studies show a more pronounced effect on diameter than on height (Bergqvist 1999).

5.1.1 Height

In contrast to the diameter, the height of spruce appears to be less affected by competition (Lindén 2003). Existing studies concerning development of height in spruce/birch admixture are not consistent. Bergqvist (1999) reported the mean annual height growth of spruce, up to 56 years of age, to be similar with and without a birch shelter. In contradiction, Klang and Ekö (1999) found the height growth in spruce up to 33 years of age to be reduced by a birch shelter. However, the settings for the studies were different concerning: length of shelter period, shelter wood density and initial difference between height of spruce and birch. The present study does not indicate significant differences between the height of spruce in the sheltered stands, the spruce/beech stand and the reference group of stands.

It has been reported that crown damage to spruce, which is overtopped by a dense over storey of aspen or birch, causes persistent growth reductions (Lindén 2003). Such effects are not found in this study. In the case of hybrid aspen sheltering it could be due to that after the rapid initial height growth of the species, it did not interfere with the spruce crowns. In addition, the stand was planted with a low density. Therefore spruce had enough space to develop its crowns.

5.1.2 Diameter

In the present study spruce grown with species characterized by fast initial growth had an average diameter smaller than spruce grown in pure stands and with beech. This result is in accordance with the shelter wood effect found by Klang and Ekö (1999). Also Bergqvist (1999) found the mean diameter of spruce to be smaller under a birch shelter. However in other studies of more single-storied stands the effect was found to be less evident (Lindén 2003). In this study the average diameter of spruce grown with birch was similar to the diameter of spruce in the monoculture. In German studies (Lindén 2003 after: Metzel 1979), the diameter increment of spruce was reported to be greater in mixtures with pine and larch than in pure stands. The present study does not confirm these results, as the diameter of spruce grown with larch was the smallest among the investigated stands. Lindén (2003) found the diameter growth in spruce to be smaller in mixtures than in monocultures. In the present investigation spruce has smaller average diameter in sheltered stands. However, the difference between the sheltered stands and the reference group is not significant.

According to Lindén (2003), the diameter increment of the dominating tree species in mixtures will be greater than in corresponding monocultures. This effect is visible in the spruce/ beech stand, where spruce has the biggest diameter. The difference in diameter between this mixture and the reference group is significant.

In addition, the frequency of spruces in the upper diameter classes was conspicuously higher in the spruce/beech stand than in the other mixtures. The bigger dimensions of trees will increase competition between them and consequently self-pruning. This can improve the timber quality.

5.1.3 Tree classes and vitality

Competition between trees has been shown to be of negligible importance for crown conditions in spruce (Solberg and Moshanug 1999), but in this study spruce in mixed stands has a lower vitality compared to spruces in monocultures. This effect is most pronounced in the spruce/birch stand, where crown damages were caused by whipping. Suppressed trees are less stable and more susceptible to snow and wind damages. It has also been found that crooks are more common among suppressed trees (Klang and Ekö 1999).The share of dominated and suppressed trees in this study is conspicuously higher among spruces in sheltered stands. In pure spruce stands there are no suppressed trees, while in mixture with larch 12% of trees are classified as suppressed.

Low competition leads to less differentiation of crown characters within stands (Pape 1999). In the present study spruces in pure stands and in mixture with beech are more uniform than spruce in sheltered stands. More than 90% of the spruces in these stands belong to the dominant and co-dominant class. The best quality of spruce can be obtained in single-storey monocultures, where crowns have homogeneous light conditions (Szymanski 1998).

5.1.4 Diameter of the thickest branch

Growing spruce under a shelter has been shown to significantly reduce the branch diameter (Johansson 1992, Klang and Ekö 1999). The results of the present study correspond with the previous investigations. Spruce grown in sheltered stands developed significantly thinner branches compared to the reference group.

5.1.5 Number of branches per meter of stem

Previous investigations focused on spruce under birch shelters revealed no significant effects of the shelter on the number of branches per length unit of the stem (Klang and Ekö1999). There are studies suggesting that the number of branches in the whorls is primarily determined by the genetic factors (Johansson 1992). The present study indicates that spruce in pure stands has significantly less branches per meter of stem than under sheltered conditions.

5.1.6 Height to the first living branch

The height to the first living branch is an indicator of the self-pruning rate. In studies conducted by Johansson and Persson (1996) the self-pruned part of the stem was found to be longer in naturally regenerated stands compared to in planted spruce, where spruce had grown faster in the initial phase. Bergqvist (1999) found no significant reduction in crown size caused by shelter trees. Klang and Ekö (1999) did not either found any significant differences in the height to the first living branch comparing sheltered and not sheltered stands. In the present study spruce mixed with fast-growing species has on average a significantly reduced height to the first living branch. The self-pruned part was conspicuously longer in the unsheltered stands. These stands had also a higher within stand variation, most pronounced in the clone stand. In some spots spruces tended to get side-closure earlier than in other locations. Growth of trees might be influenced by the microsite conditions, which the most conspicuously varied in the clone stand due to hilly terrain. Side- shading reduces the growth of needles and twigs (Johansson 1997) and thus influences self-prunning.

5.1.7 Stem crookedness

Earlier studies indicate that the proportion of straight trees does not vary between planted and naturally regenerated spruce stands (Klang 1999). Furthermore it has been indicated that the share of straight threes does not either differ between sheltered and not sheltered stands (Klang and Ekö 1999). The present study confirms the last mentioned result as there is no significant difference between shelter and no-shelter stands. However, a significant difference exists between the reference group and the spruce/beech stand, which has a greater share of straight trees. It should be noted that the majority of trees in the clone stand have a stem crook at 3.5-4 m, severely influenced the wood quality.

5.1.8 Stem defects

Using birch as shelter has proved to protect spruce seedlings from frost damages. In a previous study significantly lower frequency of stem defects induced by frost has been recorded in sheltered stands (Klang and Ekö 1999). The results in this study do not indicate similar effects of using mixed stands. The occurrence of spike knots is significantly higher in sheltered stands and it is more frequent in lower parts of the stem, while spruces in pure stands have no spike knots in the lowest stem section. The number of double tops is also significantly higher in the sheltered stands due to whipping. However the most frequent double tops was found among dominant trees in the monocultures.

5.2 Quality assessment

On average, the share of trees assigned to first quality class is similar in the two groups of stands. The highest share of trees in the first quality trees is found in the mixture with hybrid aspen, but the share in spruce monoculture was almost similar. In addition, mixed stands have a considerably higher share of trees in lower quality classes. The quality of dominant trees is also higher in unsheltered stands. This could be due to better conditions for crowns of these tress, which are not affected by inter-species competition. It should be noted that Snogeholm is located in relatively mild climate, so the protection of shelter against frost-induced damages is of negligible importance. Physical competition for space may cause damages on spruces by admixture species. This can be attributed to differences in respect of some features, like branch stiffness, crown structures.

5.3 Comments on the overall results

Table 4 presents overall results. Total evaluation indicates that the superior quality was found in pure stands and with beech admixture. Thus, present study does not support the hypothesis that spruce quality is better in mixtures comparing to monocultures. In most of wood properties the positive effect of admixture was lower than it was previously assumed. Basing on these results it can be concluded that it is not beneficent in regard to wood quality to mix spruce with other species in the initial phase. The examined stands were not distinctly stratified, intimate mixtures. Spruce was planted with other species at the same time. Probably, crown structures of two species interfered too much. It seems that damages on spruce crowns are caused by over competing by other species (e.g. whipping in spruce/birch stand). Simultaneously, the protecting function of faster growing admixture was of insignificant importance due to mild climate in Snogeholm. To reduce the unfavourable influence of the admixture species, it could be established in groups or planted in few years advance. To keep it in long-term mixtures other silvicultural methods should be considered during the regeneration stage (e.g. selective cutting systems in mature stands, different planting design).

Table 4. Contribution of spruce properties to wood quality in mixtures: +++ positive effect of mixture ++ no influence, + negative effect of mixture on wood quality.

Stand	Property										
	Diameter	Height	Diameter of the thickest branch	Number of branches per 1m of stem	Height of first living branch	Crookedness	Spike knots	Double tops	Quality class	Vitality	Total evaluation
Spruce hybrid aspen	+++	++	+	++	+	++	+++	+	+++	++	*21*
Spruce birch	++	+	++	++	+	+++	++	+	++	+	*17*
Spruce larch	+	++	+++	++	+	+	+	+++	+	++	*17*
Spruce beech	+++	+++	+	+	++	+++	++	++	++	+++	*22*
Spruce clones	+++	+++	+	+++	+++	+	+++	+++	++	+++	*25*
Spruce monoculture	++	+	+	+	+++	++	+++	+++	+++	+++	*22*

5.4 Is it worthwhile to plant mixed stands with spruce?

Planting mixed stands is, in some aspects, reasonable in economic forestry. Mixed stands are considered to be more resistant to damages caused by pathogenic organisms. It reduces risk of production since pests and diseases don't spread within mixtures as easily as in monocultures. It was proved that admixture of more resistant tree species decrease the occurrence of butt rot in spruce. According to the ecological niche theory mixtures better utilize site resources, thus yield is likely to be higher comparing to monocultures (Lindén 2003).

Although the present study does not indicate improved spruce quality in mixtures, there are important reasons for growing mixed stands beside wood production. Recently other considerations have focused in Swedish forestry. Mixed stands appears superior to monocultures, if improvement of: biodiversity, water quality, nutrient sustainability, carbon cycling and social values are taken into account (Lindén 2003, Bergqvist 1999). Growing mixed stands is recommended in the concept of a multifunctional forest. There are efforts made in order to increase or keep a minimum level of mixed forest. International agreements (e.g. Helsinki Conference 1994), Swedish society (Swedish Cabinet Office 2001) and forest certification organizations are promoting an increase of mixed forest. According to current concepts of forest policy an increasing share of mixed forest in future can be predicted. Lindén (2003) reports that the occurrence of mixed forests among young stands tends to increase, due to a change in silviculture practices, promoting broadleaves and a less intensive tending of young stands.

However, traditional forestry is still focused on monocultures, mainly of Norway spruce. Monocultures have been thoroughly researched and managed for centuries, while knowledge about mixed stands is relatively poor. For a forest owner growing mixed stands the future is more uncertain, as mixtures have a more heterogeneous stand structure and thus are more complicated to predict and manage (Lindén 2003).

5.5 Need of further studies

There is a need of studies concerning many aspects of growing mixtures to improve their understanding and management (Lindén 2003). Earlier research has focused on shelterwood system. If an increasing amount of deciduous trees in the forest is to be achieved it is necessary to establish single-storied and long-term mixtures (Linden 2003). The present study only partly covers this aspect, as the stands are still relatively young and their future development quite unpredictable.

The economical aspect is essential for a forest manager. Studies conducted by Lindén and Ekö (2002) compared economical performance of oak and spruce mixtures with monocultures. The conclusion was that the economic outcome is intermediate in the mixture, indicating that if the long term goal is an oak stand it could be advantageous to establish it as mixture. There is a general lack of analysis concerning not only spruce as a main species, but also accompanied species.

5.6 Shortcomings of the studies

The investigated plantation is located in a hilly terrain, with varying growth conditions in different parts. The growth potential of different species depend on soil conditions, which were not investigated. A major shortcoming is that there are no true replications on the site, making it impossible to make a more elaborated statistical analyze.

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