The development of beech in monoculture and mixtures

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Abstract

The importance of producing good quality beech timber seems to increase even if there are periods with low demands for it. Due to relatively substantial amount of fertile abandoned agriculture soils in Southern Sweden possibilities to increase the area occupied by beech seems to be high. Former studies indicate the positive influence of shelter on a survival of seedlings and quality formation e.g. crookedness, forking. The aim of the study was to answer the question: if the shelterwood benefit to better quality of beech and which admixture species creates the most favourable conditions for beech regeneration? Furthermore, the goal was to study a possible hampering of the beech growth, due to the shelter. The thesis comprises two parts. In the first literature was reviewed, in the second field results were analyzed. Different beech traits were compared in mixed and open grown stands. The following beech traits were measured and judged on sample trees: diameter in breast height, diameter of the thickest branch, tree class, stem crookedness, quality of the stem, shape of the tree and occurrence of the spike knots. The statistical analyze was made by means of ANOVA planned comparisons. Every measured row was regarded as an independent observation. Contrast was made between three groups; NS (no shelter) - pure beech and mixture with alder (control plot), LS (low shelter) – mixtures with hornbeam, aspen and spruce, HS (high shelter) – mixtures with larch, birch, and hybrid aspen. The results showed that mixing beech with fast growing species has a positive influence on beech quality formation, especially shape of the tree and commercial quality. There was no significant decrease of diameter and volume growth of beech, due to the shelter. Finally the admixtures with fast growing species were regarded as the most favourable for artificial regeneration of beech.

Key words: beech, beech quality, shelterwood, mixed stands, competition

Contents

Abstract 2
Contents 3
1. Introduction 4
  1.1. Beech general characteristic. 4
  1.2. Beech forests in Sweden. 4
  1.3. The value of beech wood. 6
  1.4. Quality of beech timber. 6
  1.5. Conditions of establishing beech stands 7
  1.6. Objectives of the study 7
2. Literature review 8
  2.1. Silviculture of the beech stands with focus on quality formation. 8
  2.2. Biotic and abiotic threats influencing growth and quality formation 8
  2.3. Regeneration of beech 9
    2.3.1. Beech natural regeneration 9
    2.3.2. Planting and Sowing 10
    2.3.3. Planting mixed stands 11
3. Material and Methods 12
  3.1. Experiment design. 12
  3.2. Data acquisition 15
  3.3. Analyzes 16
4. Results 19
  4.1. Growth analyse 19
    4.1.1. Height growth 19
    4.1.2. Diameter growth 21
    4.1.3. Total volume production 23
    4.1.4 Taper 24
    4.1.5. Tree classes 25
  4.2. Quality analyse. 26
    4.2.1 The diameter of the thickest branch 26
    4.2.2 Shape and stem defects 27
    4.2.3 Crookedness 31
    4.2.4 Commercial quality 32
    4.2.5 Tree quality classes. 33
5. Discussion 34
  5.1 Growth properties 34
    5.1.1. Height 34
    5.1.2. Diameter and volume production 34
  5.2. Quality properties 35
    5.2.1. Diameter of the thickest branch 35
    5.2.2. Stem shape and stem defects 36
    5.2.3. Crookedness 36
    5.2.4. Commercial quality 36
  5.3. The overall value of mixtures 37
  5.4. Is it worthwhile to plant beech in a mixture under the shelterwood? 40
  5.5. Considerations for practical applications 41
  5.6. Shortcomings of studies 41
  5.7. Field of future studies 41
6. Literature 42
7. Appendix 48

1. Introduction

1.1. Beech general characteristic.

Beech (*Fagus sylvatica* L.) is a European species with a natural range extending from southern Norway to northern Spain and from the south of England to the Black Sea. In much of these areas it is the most common broadleaved species (Ministry of Agriculture&Food of Ireland, 2005).

Beech is regarded as an Atlantic climate species (Jahn, 1991; Chojnacka-Ożga, 2002). It requires relatively warm conditions during the whole year and is not adapted to harsh climate and is susceptible to frost damages. Severe winters may cause a deterioration of timber quality – frost cracks - or may lead to tree death (Jaworski, 1995; Nicolescu, 2006). The species requires a high level of precipitation and humid climate but doesn't grow on soils with very high ground water table. Suitable soils for beech should be rich of mineral content and of humus components (Murat, 1999). Beech is favoured if the soil contains even small percent of calcium (Chodzicki, 1934). It is a shade tolerant species and can endure in a shadow up to 30 years (Jahn 1991; Evans 1994; Jaworski 1995). Beech leafs contain a substantial amount of calcium salts, therefore they have beneficial influence for soil conditions (Tomanek, 1997).

1.2. Beech forests in Sweden.

Two thousand years ago beech was a dominant component in the deciduous forests which covered also the southern part of Sweden (Kinka, 1948; Björse, 1997; Knoke, 2003;). During last twenty centuries mainly due to population development, the forest cover of southern Sweden was decreasing. Inefficient agriculture needed every year new areas for cultivation and it caused huge deforestation in southern Sweden, which has the most favourable conditions for agriculture practices. Additionally broadleaves forests were treated as a source of fire wood and browsing ground for domestic animals (Fanta, 2006). In the southern Sweden the most significant reduction of beech stands took place during the 18^{th} and 19^{th} century. Beech stands were felled and degradated into heathlands (Hahn, 2001). The increment of agriculture efficiency about 100 years ago by an implementation of ploughing and fertilizers caused that a lot of abandon agriculture areas were converted into fast growing coniferous forests. In connection with this, in the second half of 20^{th} century forest owners started to convert economically inefficient noble broadleaves stands into monocultures of fast growing coniferous species – mainly spruce. This shift of the management caused decrease of the broadleaves share in the landscape.

Currently the growing stock of beech in Sweden is estimated 21,5 million m^3 which is 0,7% of the total growing stock (NFI, 2005).

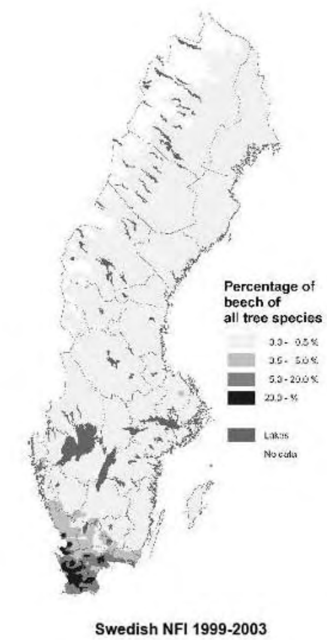

Figure 1. Distribution of beech stands in Sweden (NFI, 2005)

Beech in Sweden is limited to the south due to low winter temperatures, severe late spring frosts and a short vegetation season (Jahn, 1991). This is the reason why almost 85% of the beech stands are restricted to the most southern part of Sweden – mainly Skåne County which at present is the most important county as far as beech management is concerned. Apart form Skåne beech stands are found in nearby counties – Blekinge, Småland, Halland and Bohuslän. The observations show that natural border line is supposed to migrate northwards (Diekmann, 2001). In southernmost part of Sweden (Skåne region) beech accounts 40% of total standing volume of broadleaves stands (*Figure 1)* (Hahn, 2001; Holgen and Bostedt, 2004; NFI[1], 2005).

The increase of environmental awareness has lead in 1980's to implementation of a law which try to retain remaining beech stands which are known to have a big value for biodiversity maintaining and for social values. The Beech Forest Act from 1984 regulates a species composition of beech stands after final felling. The Beech Act was implemented into The Forestry Act (1994) where beech and 6 other species (oak, lime, ash, hornbeam, maple, wild cherry) became to be regarded as a "selected valuable broadleaved tree" (noble species). Each stand which is composed from broadleaves species after final felling has to be regenerated by new valuable broadleaves species by means of natural regeneration or planting

(SVO, 1994). Such tool seems to be good to stop a decrease of amount of beech stands. The Forestry Act (1994) gives a possibility to receive state subsidies to assure the regeneration of valuable broadleaved forests.

The market for beech timber is also factor which influences an interest in beech stands. Fluctuations of demands and prices on global market have caused low interest in beech stand establishing among forest owners. At present the situation in Sweden and in other European countries (e.g. Poland, Germany) is so bad that quite high quality timber ends up in the pulp industry or as a fuelwood.

1.3. The value of beech wood.

The main industrial importance of beech timber in Europe falls on 18^{th} and the first half of 19^{th} century. Before that time beech timber was used mainly as a source of firewood and significant amount of wood was utilized in a charcoal industry (Wijdeven, 2003). Beech stands were very intensively exploited to supply for industrial production especially an iron smelting industry (Zerbe, 2002; Löf et al., 2004). There was a lack of technology for processing beech timber until the 1850's when the technology of producing bend elements for furniture production was invented and implemented by Thonet (Surminski, 1990). Development of modern industry and technologies after World War II made it possible to utilize beech for furniture production (commonly use to bentwood furniture production), flooring industry, plywood and veneer production, boat production and in chemical and paper processing industry (Surminski, 1990; Hansen at el., 2003).

1.4. Quality of beech timber.

The beech timber is considered to have very good technical properties and is easy to process by industry. The timber is relatively heavy and hard. It shows good strength and elastic parameters and usually has a bright colour. Due to these properties the timber of beech is one of the most valuable wood species in Europe (Zell, 2004).

Log dimensions and the timber quality are decisive for final use in industry. As the material is utilized mainly by furniture and veneer factories the biggest pressure in the silviculture of beech is put to produce a good quality timber with a relatively big dimension (Račko 1985, Ekö 1995). The big dimension and good quality of beech logs influence the economical result of beech forestry (Knoke, 2003; Zingg at el., 2004).

Observations from the last century show that quality demands for beech timber have been stable. The most important quality features which are considered during grading of beech timber are: crookedness of logs, occurrence of knots on the log, occurrence of twisted and cross grain wood and occurrence of coloured (red) heartwood (Evans, 1984; Ekö, 1995). The features which can also significantly deteriorate quality of timber are residuals of epicormic branches which number in some cases can be significant.

For the furniture and veneer industry the main feature which disqualified use of timber and influence profitability of beech forestry is occurrence of red heartwood. The possibility of a red heartwood occurrence increases with stand age. Timber with the occurrence of red heartwood can however be used in paper or chemical industry (Zell, 2004; Knoke, 2003).

1.5. Conditions of establishing beech stands

The importance of showing good and reliable method of beech regeneration which can give possibility to increase area of broadleaves in southern Sweden seems to be very high.

The establishment of artificially regenerated beech monoculture requires 7-8 thousand beech seedlings per hectare. Usually new stands need an expensive fencing to reduce the possibilities of browsing damages. Substantial cost has to be spent on a weeding control.

Artificially planted mixed beech stands seem to be good alternative of beech regeneration. Reduction of hazardous factors (especially possibilities of frost damages) creates favourable conditions to a fast growth and quality forming. The costs of planting beech with fast growing species are lower than beech monoculture because lower prices for fast growing species seedlings. Mixing beech with other species (especially with fast growing) to produce a fast crop can make beech business more profitable. In connection with smaller regeneration costs it seems to have a great impact for economical profitability of beech stands.

1.6. Objectives of the study

Nevertheless many questions arise which are still unsolved. The main and the broadest objective of this study was to examine the influence of different tree species on beech growth and quality in young mixed stands. Pure beech is compared to beech mixed with:

- hornbeam,
- spruce,
- aspen,
- alder,
- birch,

– larch
– hybrid aspen.

The study comprises comparison of dimension and quality properties.

Based on earlier studies the following specific questions have been put:

- How does different admixture species affect height and diameter growth of beech?
- Which admixture species create the most favourable shelter conditions for beech regeneration when beech is artificially regenerated?
- Does the shelter influence the development of timber quality?

The study is performed in an eleven years old plantation in Snogeholm where beech where planted in a monoculture and in mixtures.

2. Literature review

2.1. Silviculture of the beech stands with focus on quality formation.

The quality of the beech timber is dependant on silviculture. Beech stands as every other can be influenced very early in the life span by silvicultural operations (Johansson, 1997; Zingg, 2004). The most important quality influencing factors are climate conditions, genetics factors, site conditions, methods of regeneration, performance of pre-commercial thinnings and early thinnings – choice of proper trees for future production (Ekö, 1995; Johansson, 1997; Klang, 2000; Hansen; 2003; Zingg, 2004). The most natural and common method of beech regeneration is natural regeneration (Skovsgaard at el, 2006).

Currently all over the Europe considerable increase of interest in beech from the socio-economic point is observed (Zerbe, 2002; Dittmar at el., 2003; Holgen and Bostedt, 2004;). The recognition of beech importance by the environmentalists, the timber industry and an implementation of Sustainable Forest Management ideas has caused an increment of a planted beech forests in Europe (Zerbe, 2002; Dittmar at el., 2003; Zell, 2004).

2.2. Biotic and abiotic threats influencing growth and quality formation

The most important abiotic factor is a frost and the most dangerous is a late spring frost. Very cold winters may cause occurrence of a frost cracks on the main steam. Top buds of beech seedlings are often damaged during winter and as a result the leading shoot is deformated or had dies (fork tops appear). Young stages of beech stands can be affected severely by huge snow falls especially when trees still haven't shed their leaves. Wind damages have importance in older stand stages and it is connected with heart root system which beech forms (Jaworski, 1995).

The most important biotic factor is game browsing even though beech is less browsed in comparison with e.g. oak which often occurs with beech in the stands. It is important to mention that beech seedlings are very vulnerable for mechanic damages. Small bark wounds, which can appear as a result of contact with neighbouring trees, can cause formation of death wood which deteriorates quality of future timber (Jaworski, 1995).

2.3. Regeneration of beech

2.3.1. Beech natural regeneration

The most natural and economically efficient method to regenerate beech is natural regeneration under shelterwood, as beech is not regarded as favourable species for open lands (Evans 1984, Skovsgaard at el., 2006). The establishment through natural regeneration is the most common method of beech regeneration and it is used extensively in many European countries (Agestam, 1993; Karlsson, 2000; Skovsgaard at el., 2006). In this method the feature of shed tolerance is used and young generation of beech is regenerated under the shelterwood created by mature trees which are also a seed source. Currently in many European countries near-natural silviculture regimes have been introduced which is characterised by use of natural regeneration as a dominant method also for beech (Tarp at el., 2000). Two main methods are suggested to regenerate beech naturally: either implemented in even-aged forest management or in uneven-aged forest management. The first method is the most common in European forestry, especially in the lowland areas (Tarp at el., 2000).

The shelterwood system seems to provide favourable growth conditions which is consider as crucial for the regeneration success (Madsen and Larsen, 1997). Using natural regeneration protects young beech generation against frost, drought and cold winds which are the most harmful factors affecting young seedlings. Seedlings under shelters are less susceptible for damages caused by these factors. Additionally the shelter of mature trees hampers competing field vegetation.

This of regeneration method provide in often very abundant occurrence of seedlings which create very severe competition between them. Olivier and Larson (1996) consider space between seedlings as a main component of the environment which affect growth. Availability of space which influence competition can significantly affect quality formation in the newly regenerated beech stands especially: straightness of the tree and occurrence of stem deteriorations e.g. tree crookedness, spike knots, number of branches (Johansson, 1997; Zingg, 2004; Olivier and Larson, 1996). According to Krahl-Urban (1955), the frequency of straight and well naturally pruned trees with one leading shot is higher in dense stands.

2.3.2. Planting and Sowing

Planting has been commonly used as a method of beech regeneration after clear-cuts. In many countries where conversion of monocultures of coniferous into natural broad-leaved stands takes place, planting of beech under the shelterwood of coniferous is a common practice. Planting is also used in case of restoration of forest areas after severe natural disturbances and in afforestation of farmlands which has became important source of increment of beech stands area e.g. Denmark (Zerbe, 2002; Löf at el., 2004).

In southern Sweden conditions the most common stock density of planted beeches is about 6-7 seedlings per hectare in beech monoculture. The combinations with other species can reduce this number to 2500-5000 seedlings per hectare (Löf at el., 2004). In countries which are influence by the German forestry school the number of seedlings which is planted on hectare may be significantly higher: in Poland from 6000 to 8000 seedlings per hectare is recommended (ZHL, 2003). Wijdeven (2003) described 4000-10000 seedlings per hectare as an optimal and common for beech stands in Europe. Quite high stocking of seedlings is necessary to create conditions to form good quality trees and minimized the risk of a high frequency of wolf trees. Beech has tendency to develop into wolf-trees, which very negatively also affect vicinity (Evanss 1984; Giertych 1990; Jaworski 1995; Murat 1999). The second crucial decision is to select an appropriate provenance which is adapted to the current site conditions, as beech inherits some important features e.g. the very well known tendency to develop forks (Leclercq 1979; Bolvansky 1980; Zingg at el. 2004).

Regeneration by planting is considered an extremely expensive method of regeneration (Löf at el., 2004; Holgen and Bostedt, 2004; Hahn 2001; Karlsson 2006). The cost of beech seedling is much higher then coniferous seedlings and it is difficult to find appropriate quality seedlings in large quantity (Holgen, 2004). Because of browsing it is necessary to fence the regeneration area.

An alternative to very expensive planting can be sowing of beechnuts. The costs of regeneration are in this case 30-50% (Madsen at el., 2006). Löf at el. (2004) considered sowing as method which has big potential to be effective alternative for planting when weed competition is limited and seeds are protected from rodents and other predators. Nevertheless future research is needed to implement this method on the broadest scale.

In artificially regenerated beech stands especially on big clear cuts or on the former agriculture land young seedlings are very vulnerable to frost damages which cause death of seedlings or significant deterioration of the shape. This thing of course has a huge impact on growth and quality of future merchantable timber. Now the question arises, what to do in such conditions where it is not possible to use a natural shelter for young beech trees? How to supply and support favourable growing conditions for newly regenerated beech on the open land?

2.3.3. Planting mixed stands

The main reason behind planting other tree species with beech is protection against frost damages because frost is regarded as the most severe factor which affects young beech stands especially on large open areas. Planting with other, so called nurse species support a favourable growth conditions for beech in young stages. Secondly fast growing nurse trees, give additional production which can give an early profit for the forest owners. Furthermore, planting fast growing seedlings which are cheaper then beech ones can reduce costs of stand establishment. Finally, planting mixed stands contribute to a better utilization of site potential (Evans, 1984; Burkhart & Tham, 1992, Kerr at el., 1992).

The advantage which is difficult to measure and results form several of surveys show differences is higher yield in mixed stands then in monoculture. Investigations carried out by Assmann (1970) which concerned yield of different species mixtures have shown that mixture of beech and spruce, beech and larch and beech and Scots pine and beech with high grade broadleaves have higher productivity then monoculture stands of this species. Klang and Ekö (1999) found that a spruce growing under the shelter of birch has lower volume then a spruce monoculture. From the other hand the whole stand has a total volume 25% higher then monocultures of those species.

On the other hand, problems with harvesting operation in mixed-stands and possibilities of negative influence between species are regarded as the most important problem (Matthews, 1989; Evans, 1984; Burkhart & Tham, 1992).

In literature an implementation of beech under earlier planted fast growing species as larch, birch and Scots pine is recommended (Evans 1984; Jaworski 1995; Prevosto and Curt, 2004). The first method has three steps, in the first fast growing, shade intolerant specie is planted which has a purpose to protect the later established beech. In the second step, after few years, seedlings of beech are planted under the shelter. The third step is performed when beech has reached a height when it will not be severely affected by spring frost, competition from weeds vegetation and browsing. In this step beech is released from the first, protection specie which is cut down (Jaworski 1995, Murat 1999). The main disadvantage of this method is a waste of at least 3-4 years when first specie is growing to create canopy layer which will be protect beech. This method is often used to regenerate forests damaged by different hazardous factors, especially in mountain areas.

A second way of planting beech on open areas is a simultaneous planting of beech with other nursing species. The nursing trees in this method are as in the first method fast growing species. Species which creates shelterwood in most cases is implemented rows-wise e.g. one row of beech and one row of birch or few rows of beech between rows of admixture specie. Karlsson at el. (2006) regards row-wise mixture of beech and spruce as an interesting option of establishing a broadleaf stand against pure coniferous.

3. Material and Methods

3.1. Experiment design.

The study area is located in Snogeholm, in southern Sweden *(Figure 2)*, 50 km west of Malmö (latitude: $55^0$35'N, longitude $13^0$40'E). The climate of this region is strongly affected by Baltic Sea. The mean annual temperature is $7{,}5^0$C. The hottest month is July, with mean temperature of 16^0C . The mean temperature of the coldest month - January is -1^0C. Annual precipitation is app. 700 mm per year. The area is located the nemoral vegetation zone where the growing season lasts 220 days on average (National Atlas of Sweden 1996; SFA 2008).

In spring 1994, an experiment concerning growth of all Swedish native tree species was established on former agriculture land. The area was divided into 69 experimental plots which were afforested by all indigenous Swedish tree species and also some exotic tree species, hybrid larch and hybrid aspen. The plantations were made as both monocultures and mixtures. The site conditions are judged to be quite favourable for all of the planted species. However the conditions vary in the area mainly due to the topography.

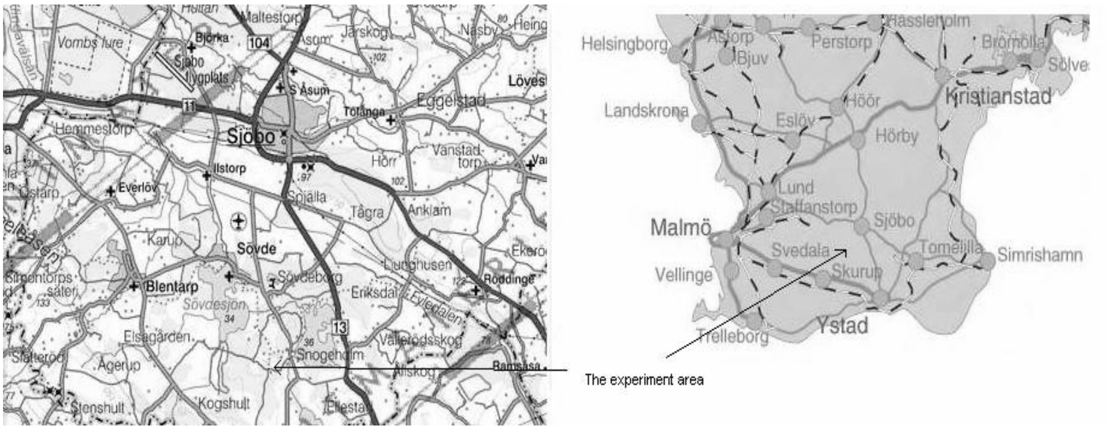

Figure 2. Location of the experiment: Snogeholm in the Skåne province (Sweden).

Beech stands were planted on 12 plots (0,25 hectare each), in one plot as a monoculture and in 11 as mixtures with different tree species. Eight plots were investigated. *Table 1* contains description of the stands included in the survey. The plant material for all plots with beech originates from a southern Swedish provenance – Ramsåsa (in The Skåne region). The spacing of planting varied between plots (*Table 1*) but the pattern of planting was the same with one exception "beech with hornbeam". In the majority of plots seedlings were planted in rows, one row of beech one row of the other species (*Figure 3*). In the deviating plot hornbeam was planted in the same rows as beech. The spatial pattern was: five beech seedling and two hornbeams (*Figure 3*). A pure and robust beech stand is the final aim in each plot.

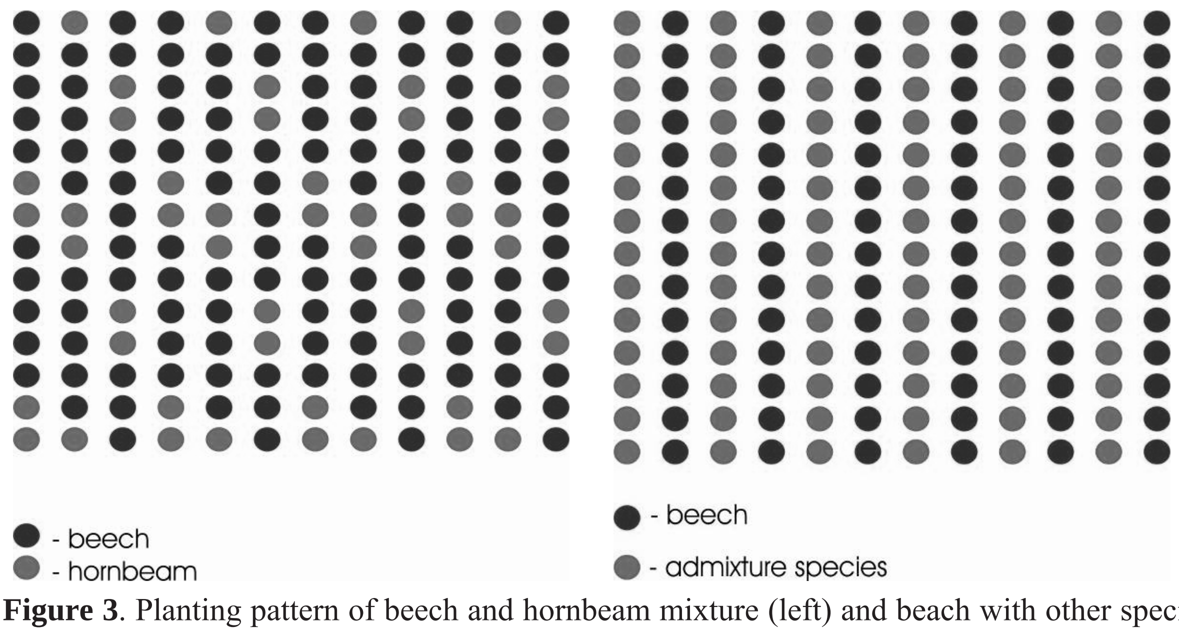

Figure 3. Planting pattern of beech and hornbeam mixture (left) and beach with other species (right).

Table 1. Stand characteristics at the age of 10 years, measured by the Southern Swedish Forest Research Centre (SLU, 2004).

Stand characteristic	Beech mixed with:							
	Silver Birch	**Black Alder**	**Larch**	**Hornbeam**	**Aspen**	**Hybrid Aspen**	**Spruce**	**Pure beech**
% of beech in the stand	67	80	71	71	80	80	50	100
% of admixture in the stand	33	20	29	29	20	20	50	0
Origin of beech	Ramsåsa	Ramsåsa	Ramsåsa	Ramsåsa	Ramsåsa	Ramsåsa	Ramsåsa	Ramsåsa
Origin of admixtrure	Asarum	Ingnaberga	Maglehem	L län	G län	Götaland	Maglehem	-
Spacing [m]	1,5x1,0 resp. 1,5x2,0	1,5x0,8 resp. 1,5x3,3	1,5x1,0 resp. 1,5x2,5	1,5x1,2	1,5x1,7	1,5x1,7	1,5x1,7	1,5x1,1
Number of seedlings 1000/ha	5	5	4,6	5,6	4	4	4	6
Number of seedlings beech/admixture	830/420	1050/250	830/330	1400	490/490	490/490	490/490	1500
Expected number of trees in the final stand	200	200	200	200	200	200	200	200
Beech – planting pattern	One row	One row	One row	See Figrue 2	One row	One row	One row	-
Admixture – planting pattern	One row	One row	One row	See Figure 2	One row	One row	One row	-
Mean height of beech [dm]	41	37	45	46	54	52	44	39
Mean height of admixture [dm]	84	39	86	60	88	124	61	-
Mean diameter of beech [mm]	36	37	37	40	45	38	40	41
Mean diameter of admixture [mm]	87	-	130	94	95	128	94	-
Volume of beech [m^3/ha]	3	5	5	13	23	6	6	14
Volume of admixture [m^3/ha]	21	6	34	20	15	50	47	-
Total production of beech [m^3/ha]	3	5	5	13	23	6	6	14
Total production of admixture [m^3/ha]	35	13	57	20	15	67	47	-
Total volume production [m^3/ha]	38	18	62	33	38	73	53	14

3.2. Data acquisition

Data were collected in winter 2005. On each plot from 3 to 5 temporary linear transects were systematically established to cover as much as possible of the variation in site conditions (*Figure 4*). In each row, the first four trees were excluded to reduce possible impact of an "edge effect". All trees belonging to a certain transect were measured and their features were judged. The number of measured trees is not equal in each plot due to differences in numbers of individuals in rows. On average around 120 trees were measured and judged in each experimental plot.

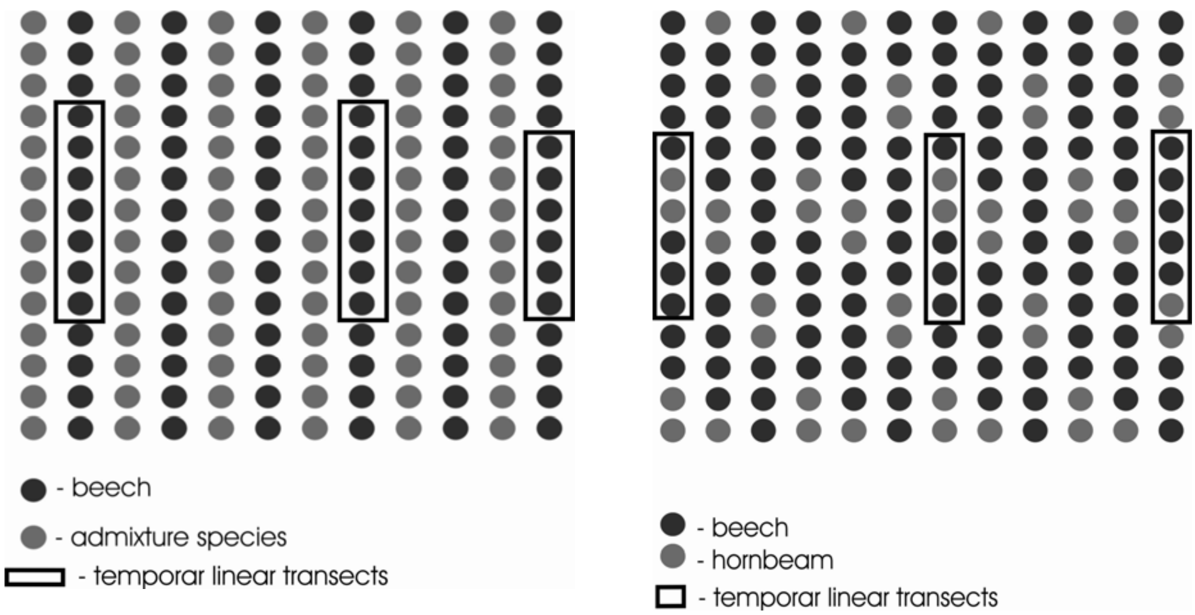

Figure 4. Establishment of linear transects among the stands where beech trees were measured.

The diameter at the breast height and the diameter of the thickest branch were measured on each beech tree. Height was measured on a randomly selected sub sample trees. On each plot a height of a minimum of 20 sample trees were measured (*Table 2*).

A relationship between height and diameter was established based on the sample tree data, in order to allot heights to trees that were only callipered.

Apart from measurements, some features of the trees were also judged: steam straightness, tree class, stem quality and tree shape. Classifications were based on criteria which were created as a result from a literature review (*Table 4*) (Veseleý, 1980). The deterioration of stem quality due to spike knots, damages etc. were noted and the heights of the deteriorating factor on the stem were judged.

Additionally, diameter on breast height and height were measured on sampled admixture species trees (*Table 2*).

Table 2. Number of sampled trees in the plots.

Stand characteristic	Beech mixed with:							
	Birch	**Alder**	**Larch**	**Hornbeam**	**Aspen**	**Hybrid Aspen**	**Spruce**	**Pure beech**
Number of measured beeches	154	138	116	112	108	114	117	132
Number of beeches sampled for height	21	25	23	24	22	23	24	26
Number of measured admixture trees	44	30	34	41	30	45	36	-
Number of admixture trees sampled for height	10	10	10	10	10	10	10	-

Since the establishment of the experiment in 1994, inventories on each plot have been made every fifth year. Data both about the stand and cutting operations has been gathered. These data will be used to calculate the total production on the different plots.

3.3. Analyzes

The analyses of data will have two objectives. The first is to compare mean values of growth of beech in different mixtures (volume, diameter, height). Furthermore the frequency of beech trees occurrence in different diameter and height classes will be studied. The evaluation of mean taper value for beech trees in each stand will also be calculated.

The second focus is on future timber quality. Mean values of the thickest branch will be analyzed. Furthermore the percentage of subjectively judged beech features will be analyzed. i.e. stem quality, crookedness of stem, tree class and shape of the tree as well as with stem defects (mainly spike knots).

The different quality traits were also studied simultaneously. The classification of trees was based on the features from *Table 4* and it was implemented to evaluate the silvicultural quality of the beech. The trees were graded due to the shape of the tree, tree classes, crookedness of the stem, quality of stem and stem defects. *Table 5* contains the description of each class in the invented classification system.

Based on the differences in the mean height of beech and mixed species, stands were divided into 3 groups to make statistical calculations (Table 3).

Table 3. Groups of stands taken into statistical analyze.

Group NS – no sheltered	Group LS – low sheltered	Group HS - high sheltered
Pure beech	Beech/aspen	Beech/larch
Beech/alder	Beech/spruce	Beech/birch
	Beech/hornbeam	Beech/Hybrid aspen

The calculations were made by means of ANOVA to check the significance differences between examined groups. Each row in the group was regarded as an independent observation. The first group was regarded as “control plot” and comparisons with other groups were made.

Table 4. Criteria of tree properties estimation.

Tree property	Classes	Description of criteria
Position in the stand (according to Kraft's classification)	1	Dominant trees. The top is located above the stand canopy or above the crowns level of the same tree species in the vicinity.
	2	Co-dominant trees. The top is located in the stand canopy level as majority tree tops in the stand.
	3	Dominated trees – tree tops located in the lower part of the crowns or slightly below them. Trees with limited growth but with chances to reach the co-dominant level after a thinning operation.
	4	Suppressed trees – the top is located below the stand crown level. Small dimensions and slow growth. After thinning the tree has no possibility to reach the upper part of the stand.
	5	A "Wolf-tree" – bigger dimension and distinctively bigger crown. Thick and long branches situated at right angle on the stem. Should be removed in a thinning operation due to inferior quality.
Crookedness and forkedness	1	Straight steam or slightly crooked above 4m height.
	2	Slightly crooked in the bottom part up to 4 m height. Small forks were allowed in upper part of the stem, above 4 meters.
	3	Significantly crooked stem. Forked trees and multi stem trees.
Stem quality	A	Well shaped straight stem, small number of branches, small diameter of branches, stems without defects.
	B	Proper shape, small crooks are acceptable. Conspicuous amount of branches with average diameter. Stem with single defects: double tops in upper part of the stem>4m, incidental spike knots.
	C	Crooked, double top located in lower part of the stem or multi stem, with significant number of branches or with serious defects. Numerous spike knots. Suppressed or declining tree.
Shape of the stem	1	Trees with one distinctive stem
	2a	Forked trees, with fork in the bottom part of stem (from 0 to 2 m height)
	2b	Forked trees, with fork in the upper part of stem (more than 2 m height)
	3	Trees with multi stems or with multi tops

Table 5. Classification of trees into three quality classes.

Class	Description of the tree
A	Shape: only one stem (1)
	Position in the stand: dominant or co-dominant (1 or 2)
	Crookedness: straight (1)
	Quality of stem: with A quality (see above)
	Stem defects: without spike knots and other defects
B	Shape: only one stem (1) or upper fork (2a)
	Position in the stand: dominant or co-dominant (1 or 2)
	Crookedness: straight (1)
	Quality of the stem: with A an B quality
	Stem defects: one spike knot allowed above 4 m height
C	Shape: only one stem (1) or upper fork (2a)
	Position in the stand: dominant ,co-dominant, or dominated (1,2 or 3)
	Crookedness: straight (1) or little crook (2)
	Quality of the stem: with A an B quality
	Stem defects: spike knots allowed above 4 m height and one allowed to 4 m height

4. Results

4.1. Growth analyse

4.1.1. Height growth

The mean height of beech seems to be quite unaffected by an over story of shelter trees. The differences between the three groups seem to be quite small. The highest mean height was found in the HS group. On the average the highest beeches are found in the beech/aspen stand (5,4 m), while the lowest are in the beech/hornbeam (3,9 m). Statistical analyze does not show statistically significant differences between groups (p=0.5338).

In all stands the height of the admixture species is higher then height of beech. The most significant differences in height between beech and admixture species are in stands where beech is planted with fast growing species (group HS). The highest admixture trees were measured in the beech/Hybrid aspen mixture (13,7 m) while the lowest admixture trees are observed in the beech/alder (5,2 m)(*Figure 5*).

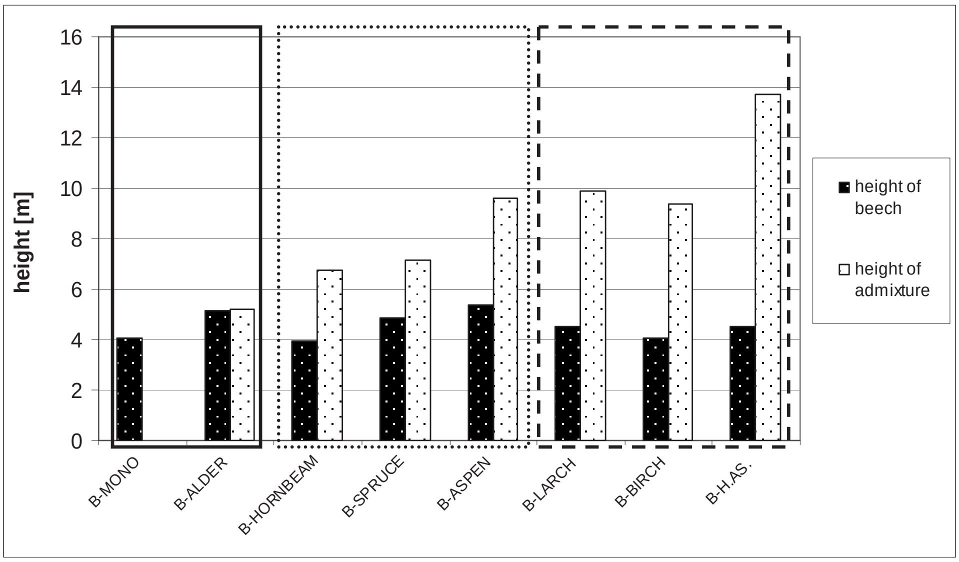

Figure 5. Mean height of beech and of admixture species (- NS group, ····· LS group, --- HS group – it concerns all figures).

Trees which belong to the height class from 4 - 6 m are most frequent in all of the analysed stands *(Figure 6).* In the stands where beech mean height is similar to the height of the admixture species (beech/alder and beech/aspen) the proportion of trees above 6 m is higher in comparison to the other mixtures.

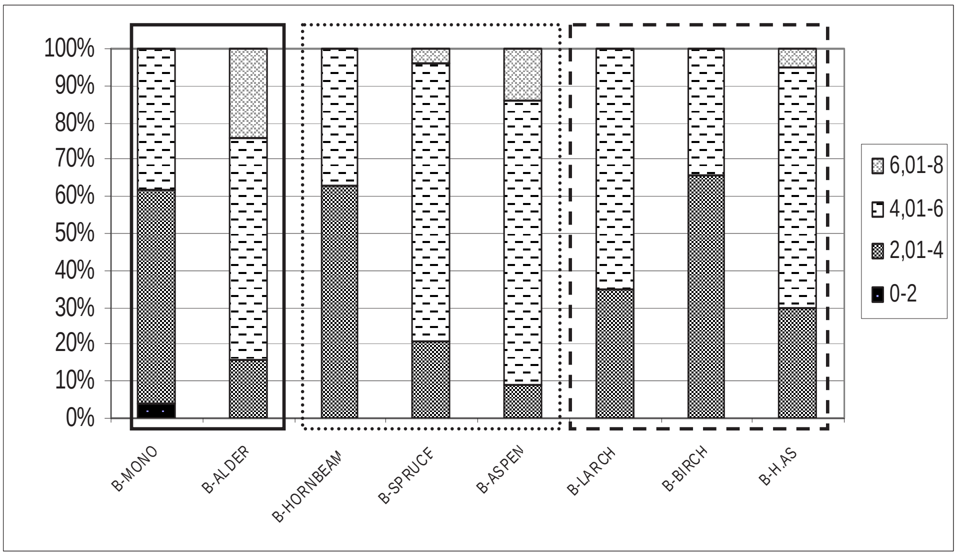

Figure 6. Distribution of trees in height classes in the examined stands.

The top height of beech varies between the stands from 5,2 to 7,5 m *(Figure 7).* The highest individual tree was observed in mixture with spruce (7,5 m). Mixtures of beech/spruce and beech/alder have the widest distribution of height while in the mixture of beech and hornbeam the distribution is the narrowest.

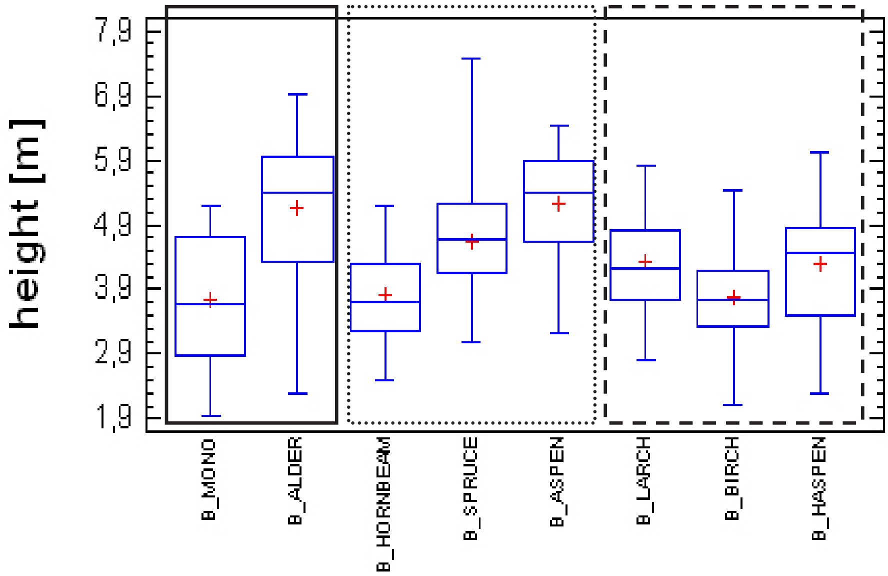

Figure 7. The height of beech in the stands (+ mean, □ - mean ± SD, I – min-max).

4.1.2. Diameter growth

Figure 8 shows mean diameters of beech and admixture species. As in case of the mean height there is a quite small difference in the mean diameter between the stands and the analyzed groups too. The over story seems to have so far small effect on the diameter development and the difference in average diameter between groups are not significant (p=0.0555).

The smallest average diameter for beech was observed in the beech/larch mixture (36 mm). The highest average diameter was found in the mixture of beech and alder (55 mm) while larch has the biggest diameter among the admixture-species (147 mm). The smallest diameter among all admixture species was observed in the beech/hornbeam mixture (42 mm).

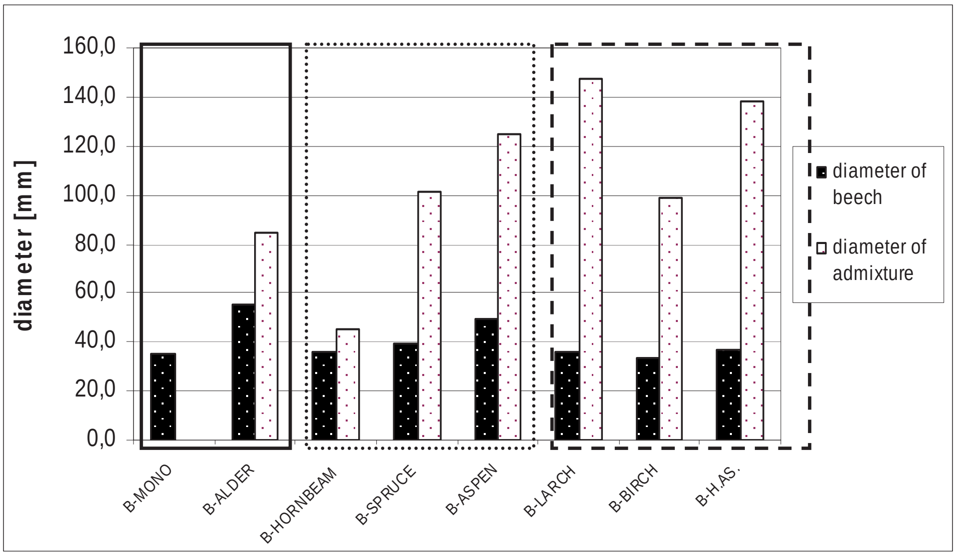

Figure 8. Mean diameter of beech and admixture species in mixtures.

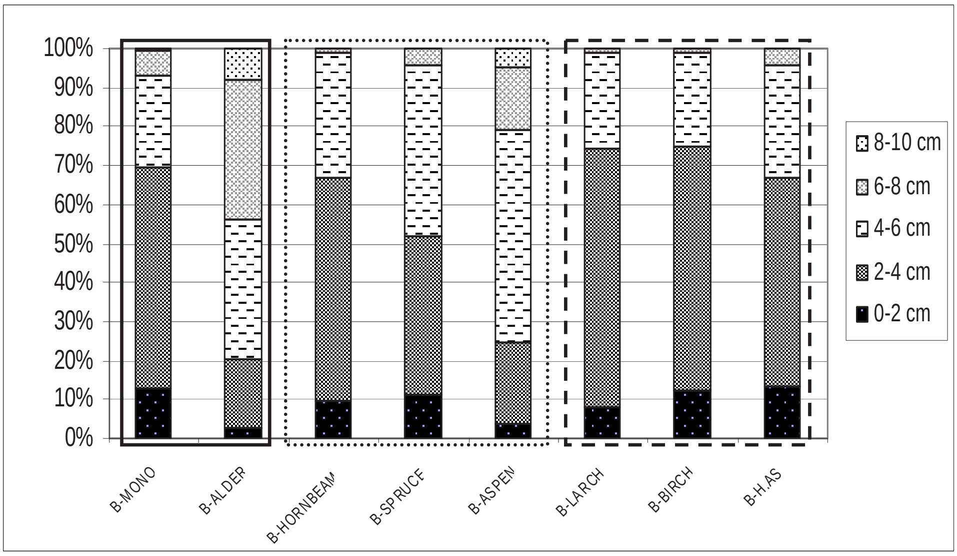

Figure 9. Frequency of beech in different diameter classes.

The distribution of diameter classes corresponds to the mean diameter results. In the mixture where beech has the smallest mean diameter (*Figure 8*) there is bigger proportion of small diameter classes (*Figure 9*). The beech/alder mixture has the highest share of trees in large diameter classes (6-8 cm). The widest distribution of diameters for beech is observed in the beech/aspen mixture and in the beech monoculture while the narrowest range is found in the beech/larch stand (*Figure 10*).

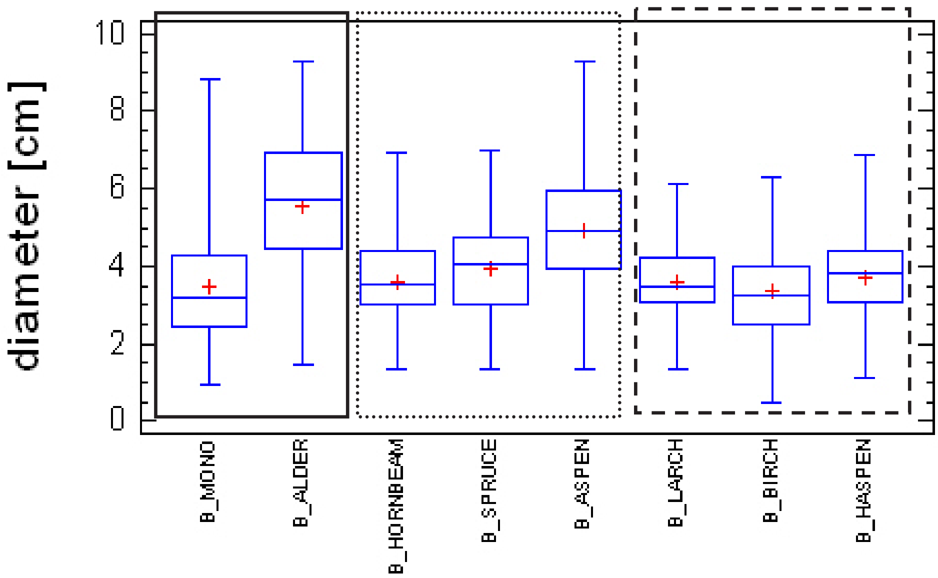

Figure 10. The diameter of beech in the stands (+ mean, □ - mean ± SD, I – min-max).

4.1.3. Total volume production

The NS group has the lowest volume production. In the HS group the volume was significantly higher *(Figure 11)*. The statistical analyze shows statistical differences between analyzed groups (p=0, 0466).

The highest total production was obtained in beech mixtures with Hybrid aspen (73 m^3/ha, MAI=6,63 m^3/year), larch (62 m^3/ha, MAI=5,63 m^3/year) and spruce (53 m^3/ha, MAI=4,81 m^3/year) *(Figure 11)*. But in this stands volume of beech was lower in comparison to the stands where total production was lower e.g. beech/aspen. The lowest total yield was obtained in the pure beech stand (14 m^3/ha, MAI=1,27 m^3/year) and in a mixture with alder (18 m^3/ha, MAI=1,64 m^3/ha). The difference in beech volume is to some extent a result of the different spacing and pattern of planting (Table 1.) However, the size of each individual seems to be similar with an exception of alder and aspen mixtures *(Figure 12).*

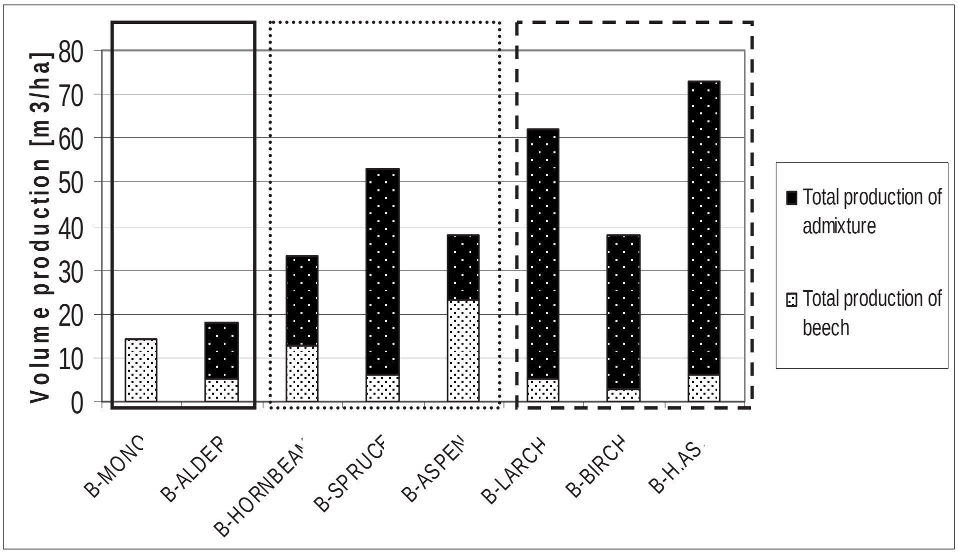

Figure 11. The total volume production in examined stands.

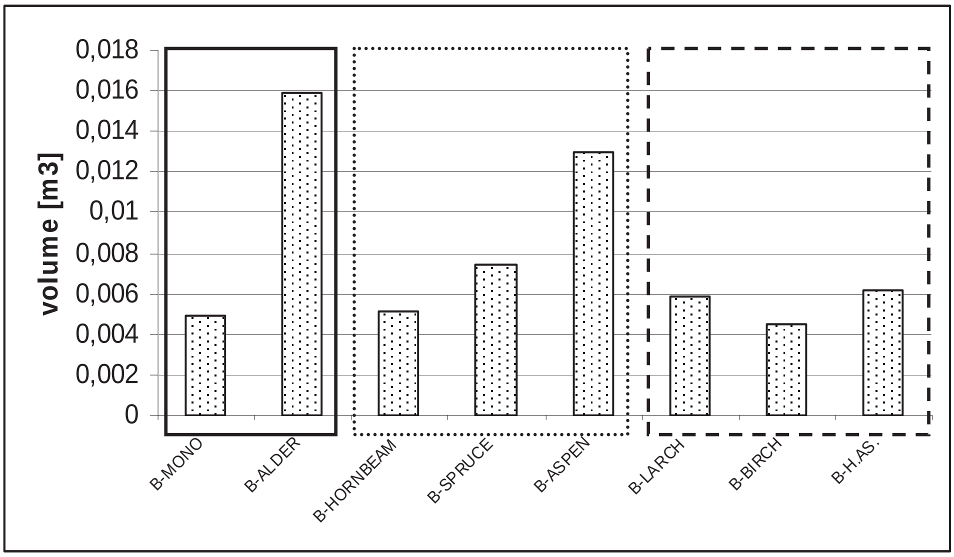

Figure 12. Average beech tree volume in examined stands.

4.1.4 Taper

The statistical analyze between the groups does not show significant differences ($p=0.0609$). In all mixtures apart from the beech/alder stand, the analysed ratio between height and diameter exceeds 1 *(Figure 13)*. In the deviating stand the ratio is 0,92. In stands with fast-growing species the ratio is higher than in other and the highest value has the beech/larch mixture (1,24).

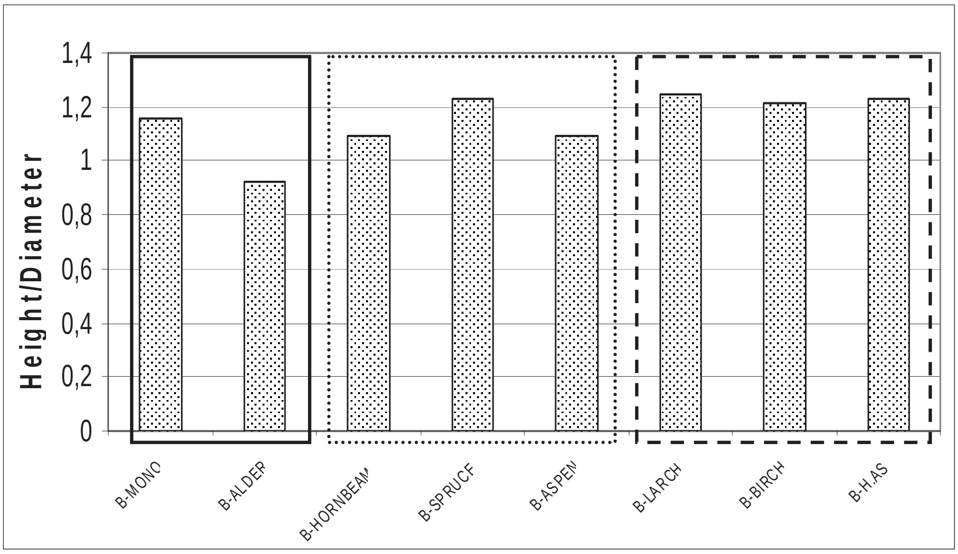

Figure 13. Taper height/diameter ratio

4.1.5. Tree classes

In all examined stand the percentage of dominant trees is similar. The highest frequency of dominant individuals is found in the beech/H. aspen mixture. In the stands without protection of the shelter (pure beech, alder and hornbeam) there are more trees classified as dominated and suppressed (class 3 and 4) but in comparison with fast-growing mixtures the differences are not so big. The occurrence of "wolf trees" (class 5) is quite small, on average 2,6% and does not differ so much between stands *(Figure 14)*.

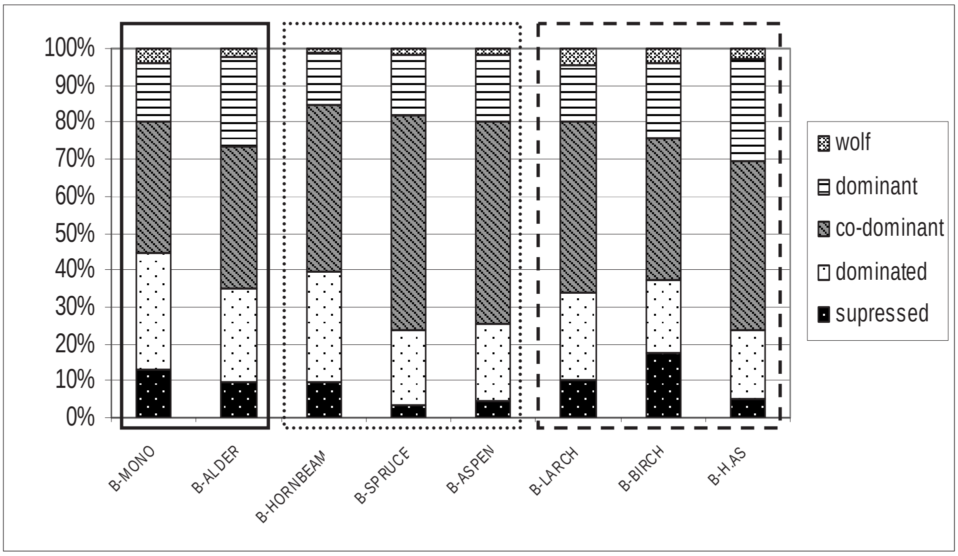

Figure 14. Frequency of beeches in tree classes.

In the beech/spruce, beech/aspen and beech/H. aspen mixtures the frequency of co-dominant and dominant trees (class 1-2) are 10-12 percent higher then in other stands.

Table 6. Mean diameter in the tree classes (mm).

stand/position	wolf	dominant	co-dominant	dominated	supressed
B-MONO	60	45	41	27	16
B-HORNBEAM	70	48	39	33	16
B-ALDER	89	62	62	45	35
B-SPRUCE	57	51	42	26	16
B-ASPEN	78	60	52	50	19
B-LARCH	50	46	38	29	23
B-BIRCH	53	45	35	29	19
B-H.AS.	54	48	37	37	23

4.2. Quality analyse.

4.2.1 The diameter of the thickest branch

The three compared groups do not differ significantly (p=0.1984). In mixtures of beech/hornbeam and beech/spruce the mean value of the thickest branch is the lowest among all stands (15 mm). It is little bit higher in a pure stand and in mixtures with birch and hybrid aspen *(Figure15)*.

The biggest mean diameter of the thickest branch was found in the mixture with alder - 18 mm *(Figure 15*).

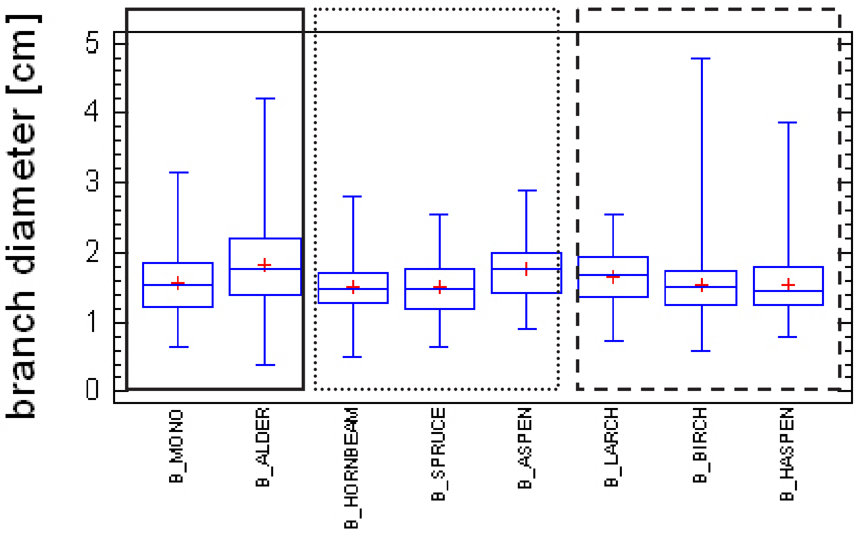

Figure 15. Diameter of the beech thickest branch in examined stands.

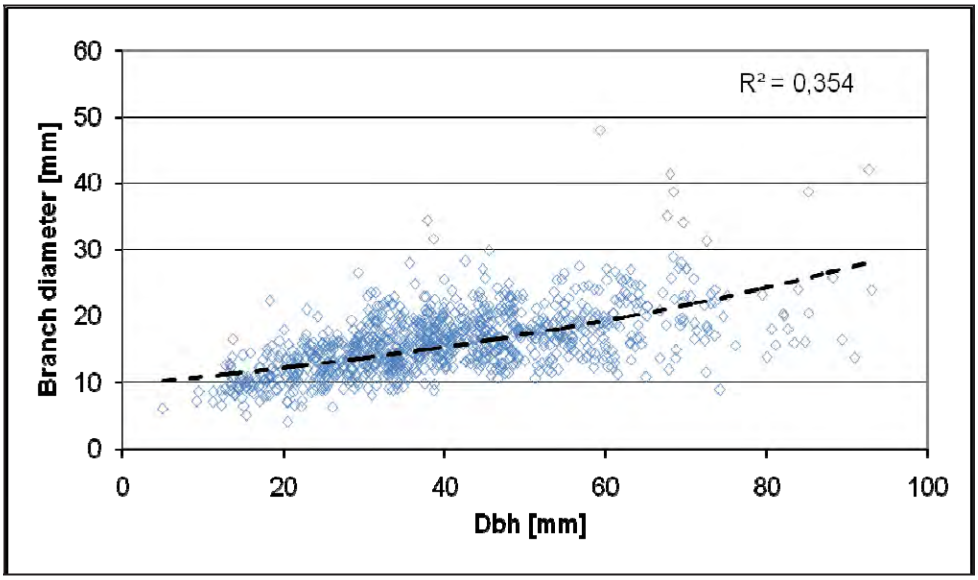

Figure 16. Correlation between diameter at breast height and diameter of the thickest branch (all beeches included in the analyze).

Generally, the differences between the average branch diameters among all mixtures are very small. As it is presented in table 2, there are no big differences between unsheltered and sheltered stands. Apart for one case (beech/alder), mean diameter of the thickest branch decreases with decreasing of tree classes.

Table 7. The diameter (mm) of the beech thickest branch differentiated for the tree classes.

stand/position	Wolf	dominant	co-dominant	dominated	supressed
B-MONO	22	18	17	14	11
B-HORNBEAM	28	16	16	15	11
B-ALDER	26	17	20	18	14
B-SPRUCE	24	18	15	11	12
B-ASPEN	24	19	19	15	12
B-LARCH	19	18	17	16	14
B-BIRCH	20	18	16	15	11
B-H.AS.	29	16	16	13	12

4.2.2 Shape and stem defects

In mixtures of the HS group the frequency of trees with one steam (without forks) is higher than in others groups *(Figure 17)*. Almost 60% of the beeches in the HS group are without forks and the frequency of double tops is at least 11% lower than in the NS and in the LS groups. Generally all stands where beech has grown under a shelter the proportion of one stem individuals is higher than in the pure beech stand. But in stands where the growing ratio of admixture species is slower, not providing a high shelter, the differences are not substantial (beech/hornbeam, beech/spruce).

The biggest percentage of fork trees was found in mixtures with hornbeam where the initial spatial pattern of seedlings differed from the other mixtures. A high proportion of trees with a double top occurred also in the pure beech and beech/spruce mixture *(Figure 17)*. Additionally pure beech and beech/birch stands contained more then 10% of trees which were judged as the out of shape trees (multi stem).

Beech in all stands has shown a tendency to form double top in the upper part of the stem. In all mixtures, forks in the upper part of the stem are more frequent *(Figure 17)*. The difference between frequency of double top in the bottom and upper part of the stem, in all stands is substantial. The highest frequency of forks in the bottom part of the tree was observed in the pure beech stand (19,7%).

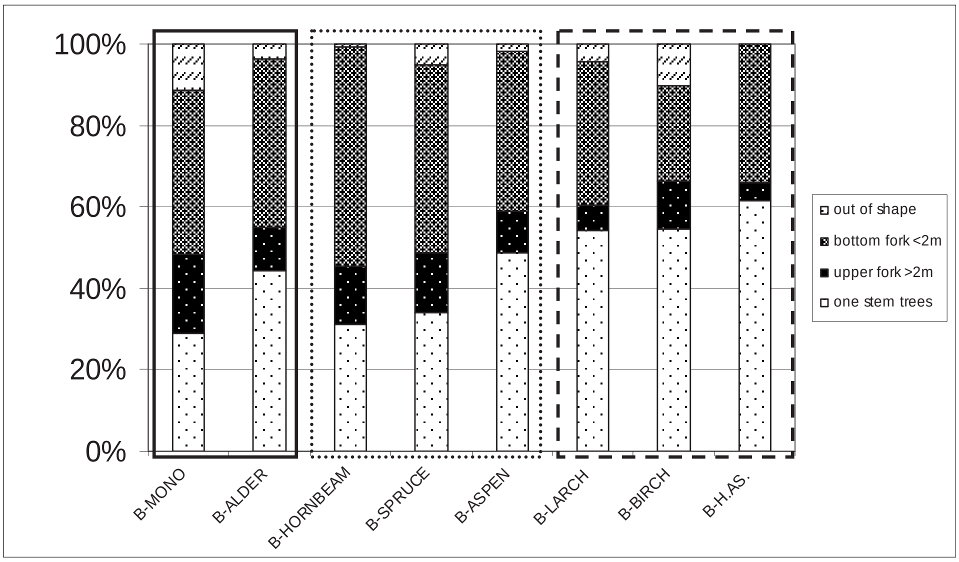

Figure 17. Occurrence of forks in different parts of the trees

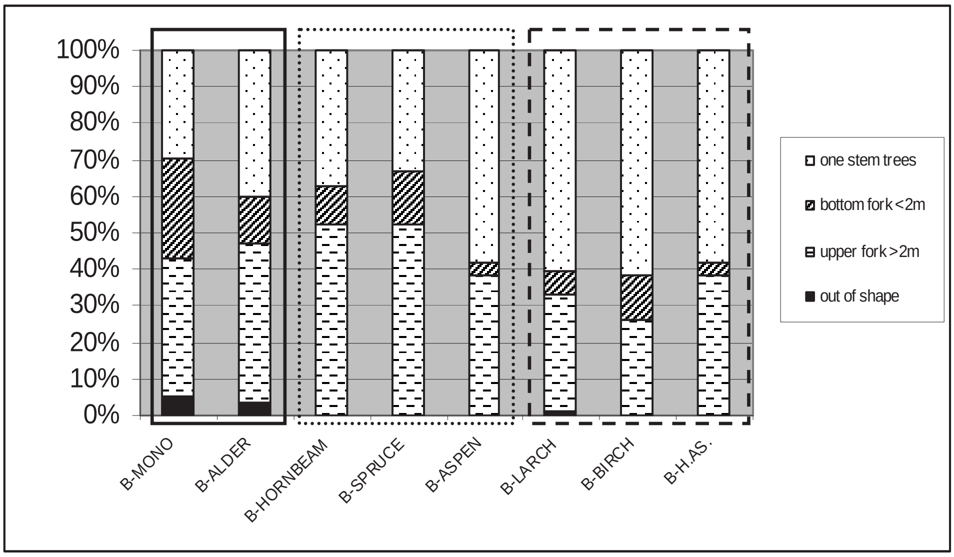

Figure 18. Occurrence of forks among dominant and co-dominant trees

In NS and LS mixtures, beech dominant and co-dominant trees were strongly affected by double tops, 60% of dominant trees had a double top *(Figure 18).* Mixture of beech and spruce is characterized by the highest amount of double top trees (71%).

There are no differences in the occurrence of spike knots between the NS stands and other groups. The highest amount of trees without spike knots is found in the beech/birch stand. The frequency of spike knots seems to be almost equal in all examined stands (on average 28 %) with exception of the beech/aspen stand. In this stand 50% of trees had spike knots (*Figure 19*).

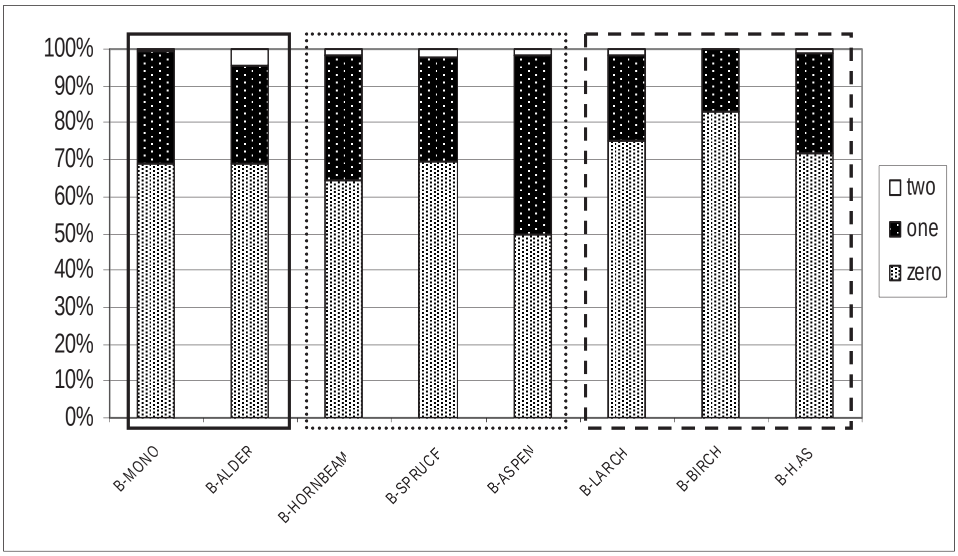

Figure 19. Frequency of trees with spike knots.

The majority of trees have only one spike knot on the stem *(Figure 20)* which are usually located in the bottom part *(Figure 20)*. The highest proportion of spike knots located in the bottom part was observed in the beech/larch mixture (90%). The highest frequency of spike knots in upper part of the stem was spotted in the beech/birch stand.

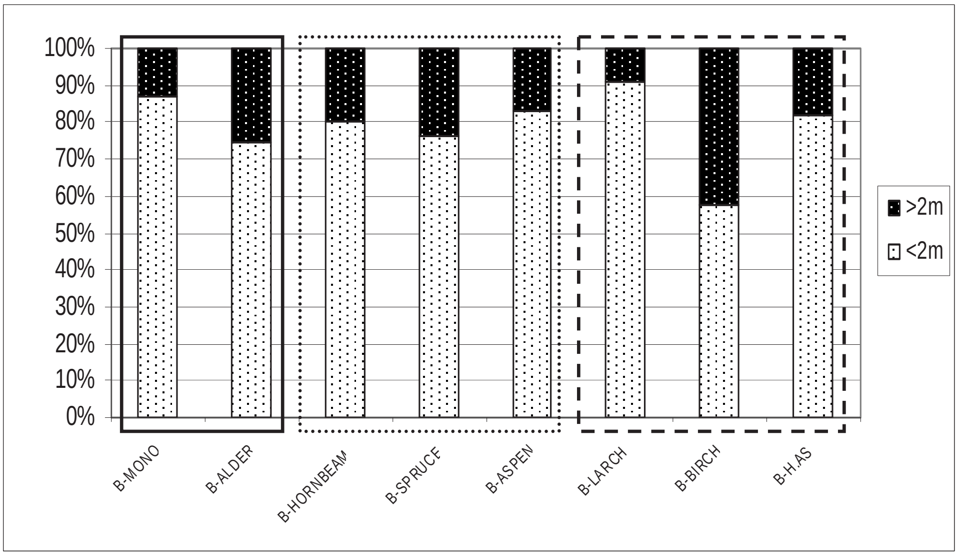

Figure 20. Frequency of spike knots on different part of the stem.

In the dominant and co-dominant tree classes the occurrence of spike knots is on similar level with an exception of aspen and birch mixtures. In mixture with birch a percentage of dominant and co-dominant trees with spike knots is the lowest (~ 14%). The beech and aspen mixture is strongly affected by spike knots occurrence. More than 60% of dominant and co-dominant trees have spike knots (*Figure 21)*.

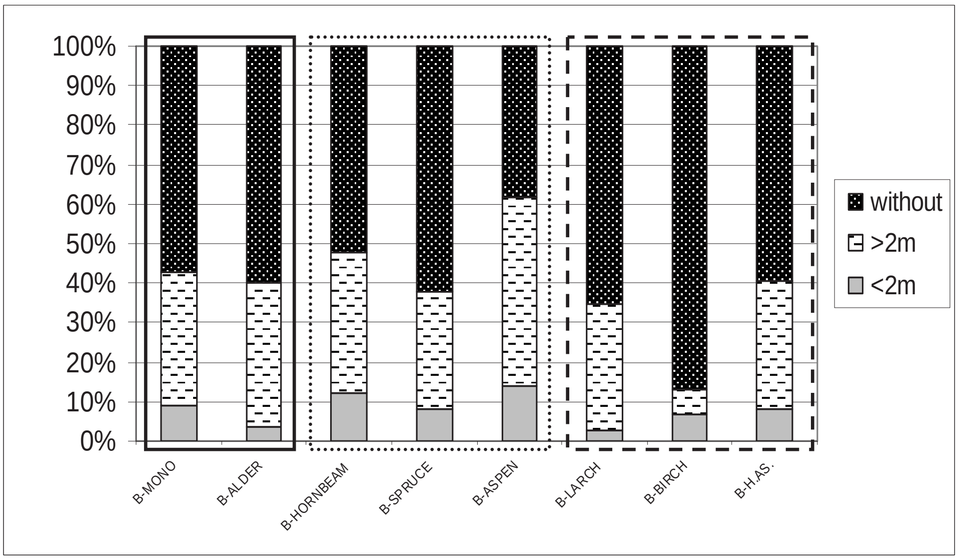

Figure 21. Frequency of spike knots among the dominant and co-dominant trees.

4.2.3 Crookedness

The highest frequency of the straight trees is found in the HS group. The differences between the NS and LS groups are rather small. In mixture with larch, beeches are the straightest. There are about 60% of trees which has been classified as a straight. A substantial share of straight trees was found in the beech/birch and birch/hybrid aspen stands. The smallest amount of straight trees was noted in the pure beech stand (35%). In four stands (beech/alder, beech/larch, beech/birch, beech/hybrid aspen) the amount of straight and slightly crooked trees is almost equal *(Figure 22)*.

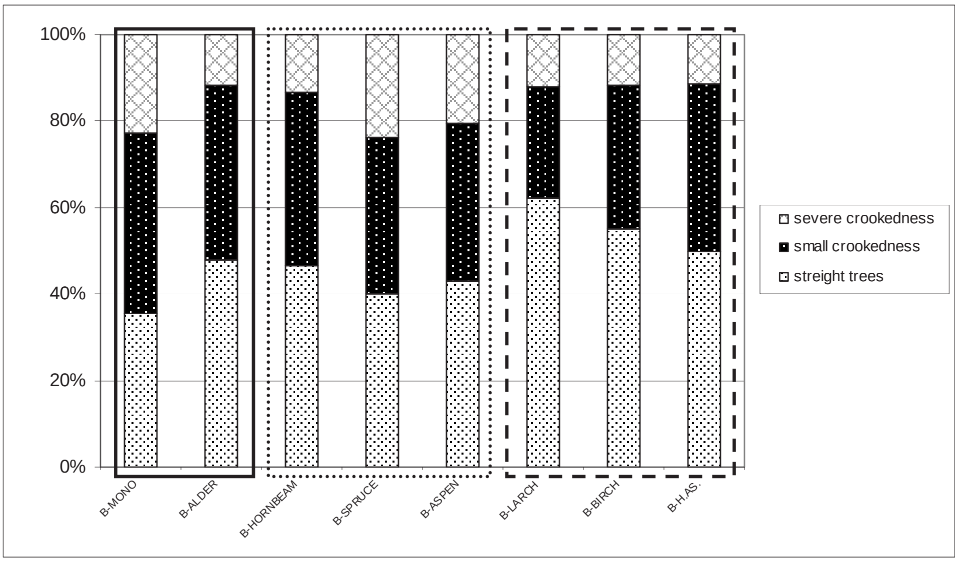

Figure 22. Frequency of trees in different crookedness classes.

The NS and LS stands differ compared to HS stands as far as crookedness is concerned. The biggest share of severely crooked trees is in the beech/spruce mixture. A substantial frequency of severe crooked stems is observed also in the pure beech stand.

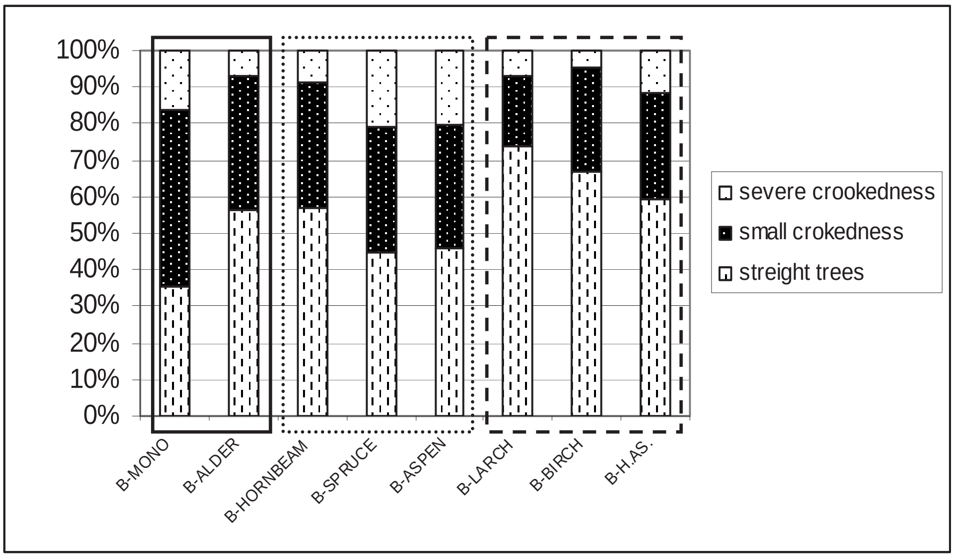

Figure 23. Frequency of trees in different classes among dominant and co-dominant trees.

In stands belonging to the HS group, dominant and co-dominant trees are characterized by substantial share of straight trees (>60%) In NS and LS the frequency of straight trees is also quite substantial (~ 50 %) with an exception of the beech monoculture (~ 35%) (*Figure 23*).

4.2.4 Commercial quality

In the mixtures of high shelter (HS), the share of trees belonging to the A quality class is higher than in the other groups. The biggest percentage of A quality trees is found in the mixture with Hybrid aspen (almost 40%). The lowest amount of A class trees is found in mixture with spruce but this stand has the biggest proportion of B quality trees. In stands classified to the HS group the frequency of first two quality classes is on similar level *(Figure 24)*.

Beech grown as a pure stand has the highest proportion of the worst quality class - 48% (C quality). The smallest percentage of the worst quality class is found in beech/larch and beech/hybrid aspen.

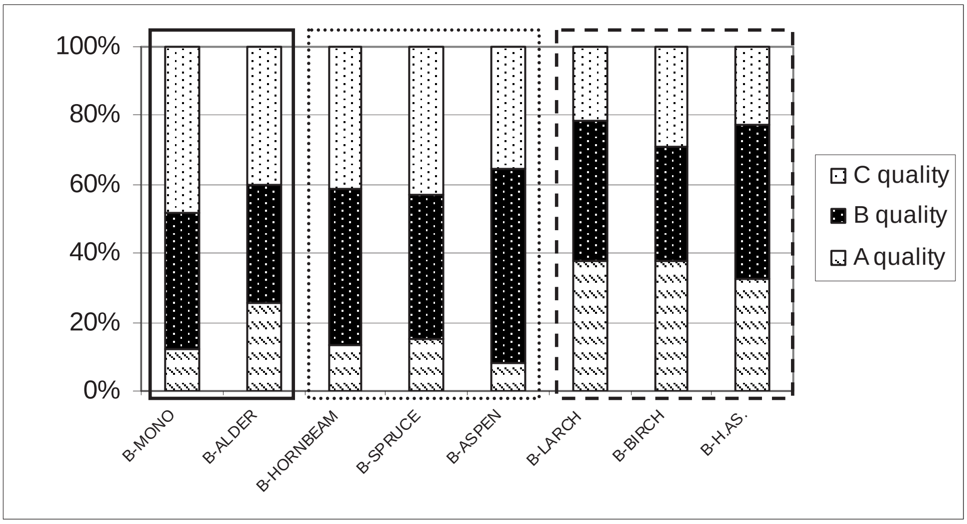

Figure 24. Frequency of trees in different commercial quality classes.

Dominant and co-dominant trees have the best quality in all stands belonging to the HS group (mixtures with fast growing). In other mixtures the proportion of A quality class ranges from 10-30%. Beech monoculture and beech/aspen mixture have the smallest proportion of the best quality classes (*Figure 25*).

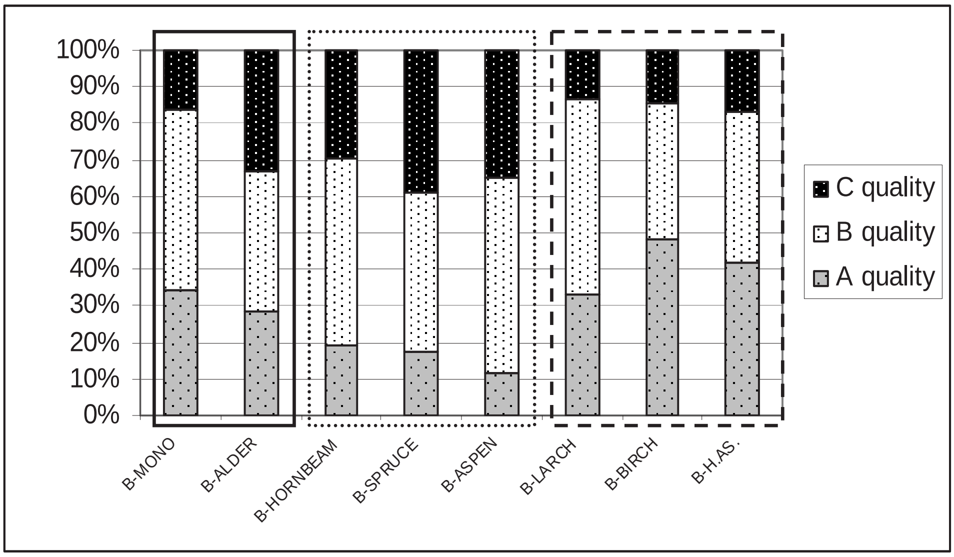

Figure 25. Frequency of trees in different commercial quality classes among dominant and co-dominant trees.

4.2.5 Tree quality classes.

As in case of the commercial classification of timber (chapter 3.2.4), beech in mixture with fast growing species (HS group) has the biggest share of trees belonging to the best quality class (class 1)*(Figure 26)*. These trees are supposed to have the best future value production and are candidates to become final crop trees. The lowest proportion of the class 1 trees is found in the pure beech stand (less than 5%).

Beech grown with birch has the highest proportion of potential acceptable final crop trees– more than 50% (classes from 1 to 3). The lowest proportions of these trees are found in monoculture and in mixture with spruce *(Figure 26)*. The mixture of beech and alder is characterized by substantial percentage of 1-3 class trees but in this case the percentage of top quality class is similar to in the beech monoculture.

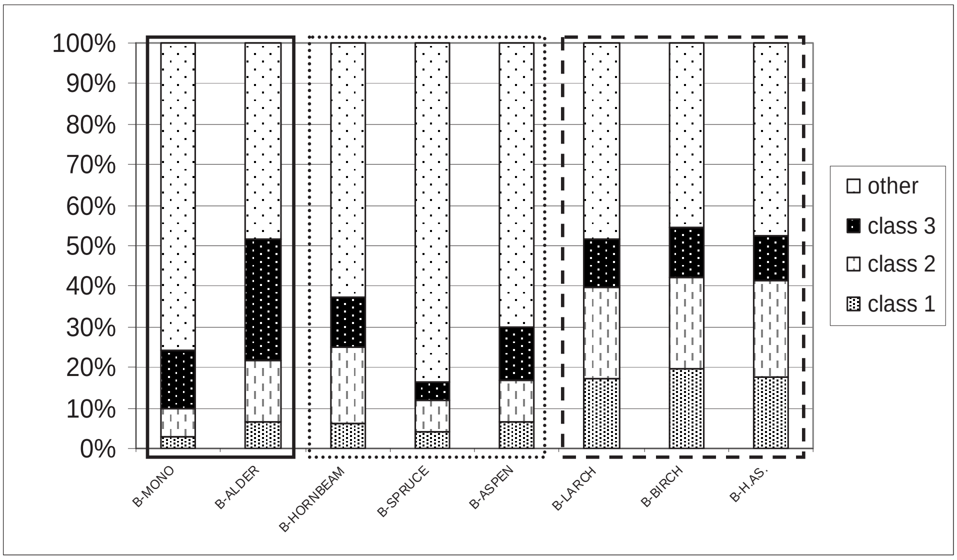

Figure 26. Frequency of tree quality classes in examined stands.

5. Discussion

5.1 Growth properties

Height, diameter and total volume are not affected significantly by the presence of shelterwood but the presence of shelterwood increases the productivity of the stand.

5.1.1. Height

Existing studies concerning height development of beech in mixed stands do not correspond with the results of the present study. Studies presented by Kerr at el. (1992) show a quite big difference between mean height of beech growing as pure stands and as mixtures with Japanese larch. However the stand structure differs between the studies. According to studies carried on by Kerr et al (1992) an over story can improve the growth rate of a wide range of broadleaves tree species. The present study does not show significant differences in case of height development between different mixtures. Beeches growing under the shelter are not higher than trees growing in the open.

5.1.2. Diameter and volume production

The diameter of admixture trees influences the total volume of the stand. Kennel (1965) cited by Burkhart and Tham (1992) found that beech grows better in monocultures than in mixtures with spruce, but an admixture of beech has positive impact on spruce growth. Assmann (1970) concluded that mixtures result in increased total productivity of the stands. Beech growing in open conditions (monoculture) have similar mean diameter to beech growing under shelterwood of fast growing species. In mixtures with slower growth rate species, the diameter of beech is slightly bigger than in monoculture but the differences between the stands are not significant. From the other hand Kelty 1992 stated that mixtures will not always exceed the production of monocultures.

In this study fast growing species do not hamper the volume development of beech in mixtures. However, Knoke and Seifert (2008) found a reduction of beech volume growth in mixture with spruce. On the other hand, the total volume of the stand was higher in mixtures than in monoculture especially in the HS group. The occurrence of fast growing species in the initial stages of the stand could give an early income and contribute to overall profitability. Kerr et al. 1992 indicate that conifer/broadleaves mixtures give a return earlier then a monoculture of broadleaves. Klang 1999 found the mixture of spruce and birch more productive then monocultures of those species. Other studies concerning mixture of spruce and birch show that spruce stands with a slight birch admixture have positive influence on the income from cuttings (Agestam, 1985;). This fact could be an interesting incentive for forest owners who are going to establish beech stands, as establishment of pure beech stand is regarded as a not profitable due to that it takes a long time before the stand generates any income (Holgén and Bostedt, 2004). In the initial stage of the stand the beech production is not important because quite much of the beech individuals will be removed in pre-commercial thinning.

5.2. Quality properties

In the examined stands, the commercial quality and a stem shape were affected more than the other quality traits by the presence of the shelterwood.

5.2.1. Diameter of the thickest branch

In the study small differences between stands were found concerning the diameter of the thickest branch. The differences between the study groups are not statistically significant. The former Czech (Veseleý, 1980) investigations focused on branch diameter. The study indicates that it is worth to grow beech with smaller stem diameter and with a medium diameter of the branch. It gives a greater economic return because of the increased value per cubic meter (Veseleý, 1980). This fact, in connection with a prerequisite for quick natural pruning of beech (Nicolescu, 2006) indicates that mixture with fast growing species and monocultures should be chosen for future production.

5.2.2. Stem shape and stem defects

There is a substantial difference between the share of forked trees between group HS and groups NS and LS. The presence of an over story composed with fast growing tree species seems to hamper double top formation. The difference between the shares of double tops in different mixtures could be caused by interaction between tree crowns. In stands where interaction has already started (LS group), examples of a whipping process were observed. The biggest share of double top trees was found in pure beech stand – 70%, so the influence of frost could not be excluded.

Ekö at el. (1995) found 40% of forked trees in monocultures of beech. The formation of double tops continues through all stages of stand development and is influenced by genetic factors and silvicultural treatments (Veseleý, 1980; Ekö, 1995; Zing and Ramp, 2006).

The occurrence of spike knots is similar in all stands and it is always more frequent in the bottom part of the stem.

5.2.3. Crookedness

There are obvious differences in relative frequency of straight trees between group HS and pure beech stand. In the HS group about 60% of the individuals were classified as a straight. In the NS and LS the frequency was about 40%. The percentage of straight and slightly crooked trees does not differ among the stands.

According to the Holmsgaard (1985) cited by Ekö at el. (1995), the straightness of the tree can increase during the life span of the stand, so this property can change in the further stages of the stands. The crooks will however be present in the juvenile part of the tree and will thus have a negative impact on the wood quality. Nicolescu at el. (2006) suggests keeping the stand dense to allow for the formation of straight trees.

5.2.4. Commercial quality

There are substantial differences between commercial quality of trees belonging to group HS and NS and LS. In the HS group the percentage of the A quality class is close to 40%, in the LS is below 20% and in the NS is close to 30%. In mixtures with fast growing species the nursing influence of the over story layer seems to have a positive impact on beech quality formation. The poorer quality of other mixtures (group NS and LS) especially among the dominant and co-dominant groups of trees could be caused by a stronger interaction between the tree crowns. The height of beech and admixture species in groups NS and LS is more even then in HS. It can negatively affect the quality of beech individuals. The poorest proportion of the best quality trees is found in pure beech stand. The process of whipping could be proved by observation on the field but the whipping was not analyzed in the study. In mixtures of beech/larch and beech/birch where beech has started to interact with larch crowns, due to the whipping, forks of the beech started to appear (Appendix 1). Previous investigations focused on beech mixtures are rare. According to Zingg and Ramp (2006) beech in mixed stands has better quality than in monocultures with an exception of mixture with coniferous.

The results of commercial quality assessment correspond with the results of the objective assessment of quality properties. The biggest share of potential final crop trees is found in group HS. It can be said that in other groups the percentage of the best classes trees is substantially lower due to results referred to above.

The results concerning the commercial quality of beech in mixture with spruce showed by Karlsson at el. (2006) correspond to results of the study.

5.3. The overall value of mixtures

Overall results are presented in a Table 7. The results in the table suggest the most desired quality of beech to be formed in the stands belonging to the HS group (mixture with fast growing species). All wood quality properties studied were positively affected by the presence of fast growing species shelterwood (group HS). However the influence on growth properties was not significant. Based on these results it can be concluded that shelterwood doesn't affect beech growth but its presence positively affects beech quality formation in the initial stages of the stand. Furthermore the presence of shelterwood will increase the total volume production. At the time of field measurements, the negative impact of interaction between crowns in group HS mixtures was minor. As a result of lack of competition between the crowns a smaller amount of forked trees can be obtained. It must be stressed that there is a need of constant observation of interaction between tree crowns and to make adjustments when necessary (reducing the density of the stand and perhaps pruning).

Artificially planted monocultures of beech in open land conditions should not be recommended as a method of a stand establishment or regeneration. In this stand trees are not protected by nursing trees, their quality will likely become low. Knoke and Seifert (2008) suggest that small amount of beech (even 20%) in spruce stands has a beneficial influence for wind resistance of the stand. An introduction of second species will also decrease the stand establishment costs.

Table 8. The value of mixed beech stands in comparison to the pure beech stand. + positive effect of mixture, 0 - no difference, (-) - negative influence of mixture on wood quality.

Stand	Property									
	Diameter	Height	Stand volume	Diameter of the thickest branch	Crookedness	Spike knots	Shape of the tree	Commercial quality	Silvicultural value	Total points
Beech Alder	+	+	0	-	+	0	0	-	0	1
Beech Hornbeam	0	0	+	0	+	0	0	-	0	1
Beech Spruce	0	+	+	0	0	0	0	-	0	1
Beech Aspen	+	+	+	0	0	-	+	-	0	2
Beech Larch	0	0	+	0	+	+	+	+	+	6
Beech Birch	0	0	+	0	+	+	+	+	+	6
Beech H.Aspen	0	0	+	0	+	0	+	+	+	5

5.4. Is it worthwhile to plant beech in a mixture under the shelterwood?

The present study to a certain extent confirmed the importance of shelterwood in a beech stand management. The presence of shelter trees does not influence the dimension of beech trees but is positive for the formation of timber quality. The species of shelter layer doesn't either have an influence. This fact confirms the results showed by Prévosto and Curt (2004) who found no differences between growth traits of beech growing under a shelter of pine and birch. Shelterwood protect beech seedlings against hazardous factors as: late spring frosts especially on the large open lands. From the ecological point of view mixed stands are more resistance for pathogenic disease and pests outbreaks (Kelty 1992; Jactel 2005 cited by Knoke and Seifert 2008). Mixed stands can make a better use of the site potential, so the total yield could be higher in comparison with monocultures (ecological niche theory) (Kelty 1992; Lindén, 2003).

Planting mixed stands could also have a positive influence on a stand stability against wind damages (Kelty 1992; Knoke and Seifert, 2008). Artificially regenerated mixed beech stands can be an interesting alternative from the economic point of view. As the survey show it is possible to achieve good quality beech timber without hampering the growth. An early initial crop of fast growing species could increase the profitability of beech enterprise and positively influence the creation of good quality beech timber (Kelty, 1992; Burkhart & Tham, 1992; Kerr at el., 1992).

Planting mixed beech stands has more positive reasons than given above. The worldwide tendency to restore the area of broadleaves forest is observed in Sweden also. Increasing and protecting biodiversity, improvement of water quality, meeting social demands are the main reasons behind planting mixed and noble broadleaves forest. It is also an assumption of the concept of a multifunctional forestry which is currently dominating in Europe. The Swedish Forestry Act (1994) and international forest certification organizations (FSC, PEFC) advocate restoration and retention of broadleaved forest.

Nevertheless, still not so many forest owners in southern Sweden have decided to change traditional forest management of coniferous monocultures into the broadleaves forest management. The knowledge of mixed forestry is rather small in comparison with the knowledge of monocultures and it does not countenance rapid changes. Kelty (1992), Burkhart and Tham (1992) show the need of better understanding of ecological relationships in mixed-species stands and lack of proper harvesting system for various models of mixed stands. Linden (2003), Burkhart and Tham (1992) point out the problems with prediction and management operation in mixed stands.

5.5. Considerations for practical applications

Karlsson at el. (2006) regards row-wise mixture of beech and spruce as a commercially interesting option for establishing beech stand, so other examined mixtures could be also interesting options.

It needs to be said that the patterns of planting used in this study will not lead to multi-storeyed stand. Because of competition between the species, the admixture must be removed at some stage and the final stand will be a monoculture of beech. In such mixtures problem of removing admixture trees could be a serious problem. The removal of big dimension trees could cause serious damages of beech individuals. To keep the admixture species in a long term in artificially planted stands different pattern of planting should be designed (group planting, planting over the story in advance to beech, wider rows etc.).

5.6. Shortcomings of studies

The investigated stands are not located in homogenous terrain and are without any true replications. It is likely that growing conditions varies between stands due to a hilly terrain. The influence of soil conditions for growth of stands were not investigated in the survey, the same as climatic factors e.g. risk of frost.

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5.7. Field of future studies

The problem of growing beech stands must be studied further. Major problems which have to be solved are: choosing appropriate provenance of seedlings and method of regeneration which have a great influence on the quality of the final stand. The present study only superficially gives ideas of how the stand establishment might influence the development.

Forest management of beech can not be regarded with focus on economical aspects. Planting beech with fast growing species seems to be a good opportunity to increase profitability of beech and a way to increase the share of beech stands in Sweden. As surveys show beech monoculture is not profitable in a long term perspective (Holgén and Bostedt, 2004). Thus there is a need for future analysis of growing mixed beech stands and mixed stands in general (Kelty, 1992; Lindén, 2003). In the authors opinion the Snogeholm plantation is a good place for studies concerning management of mixed and broadleaves stands.

6. Literature

1. Agestam E.; 1985. En productions model for bland testand av tall, gran och bjork i Sverige (summary: A growth simulation for mixed stands of pine, spruce and birch in Sweden). Swed. Univ. of Agri. Sciences. Department Of Forestry Yield Research Report No 15.
2. Assmann E., 1970 “The principles of forest yield study. Pergamon Press, Oxford p. 506.
3. Bolvanskŷ M., 1980-1981. “Some causes of steam dichotomy of young beech individuals in the growth phase of thickest”, Acta dendrobiologica Ĉ. 3-4 “Aroborĕtum Mlyňany” – Ŭstav dendrobiologie”, Sav Bratislava.
4. Burkhart H.E., Tham Å., 1992. “Predictions from growth and yield models of the performance of mixed-species stand”. The Ecology of Mixed-Species Stands of Trees, Oxford 1992.
5. Chodziki E., 1930 „Badania mikrobiologiczne nad wpływem zmiany składu gatunkowego drzewostanów na stan gleby (Buk w sośninach)” Warszawa, 1933, 298 s., il. ; 23 cm, Sygnatura(y): 35680; 2272 (MON-009142). In Polish.
6. Chojecka-Ożga L. 2002, “The rhythm of radial increments of the European beech (Fagus silvatica L.)”, The Polish Forest Society – Sylwan nr 4/2002 p. 51. In Polish. Abstract in English.

7. Dietmar C., Zech W., Wolfram E., 2003. „Growth variation of Common beech (*Fagus sylvatica* L.) under different climatic and environmental conditions in Europe - a dendroecological study", Forest Ecology and Management 173 (2003), p 63-78.
8. Ekö P.M., Petterson N., Bjerregaard J., 1995. "Pre-commercial Thinning in European Beech (*Fagus sylvatica* L.). Results from field trial." For.&Landsc. Res. 1995: 1: 207-226.
9. Evans, J.1984. Silviculture of Broadleaved Woodland. Forest Commision Bulletin no 62.
10. Fanta J., 2006, "European beech forests and their management" – Proceedings International Conference "Beech silviculture in Europe's largest beech country" – IUFRO WP 1.01.07 Ecology and silviculture of beech, 4-8 September 2006, p.52-54.
11. Giertych M., 1990 „Genetyka" Buk zwyczajny Fagus sylvatica L. Nasze Drzewa Leśne, PWN Warszawa-Poznań 1990. In Polish.
12. Hahn K., 2001. History and management of beech in Northern European Lowland Denmark, south Sweden, north Poland and north Germany, The Royal Veterinary and Agriculture University, Denmark, 2001.
13. Hansen J.K., Jorgensen B.B., Stoltze P., 2003. "Variation of Quality and Predicted Economic Returns between European beech (*Fagus sylvatica* L.) Provenances", Silvae Genetica vol. 52, 5-6(2003) p. 185-197.
14. Holgén P, Bostedt G., 2004. "Should planting of broad-leaved species be encourage at the expense of spruce? An economic approach to a current southern Swedish forestry issue". Journal of Forest Economics Vol 10(2004) p. 123-134.
15. Jahn G., 1991. "Temperate decidous forest of Europe" – Tempered Deciduous Forests, Ecosystems of the world 7 edited by Röhrig E. & Urlich B., Amsterdam 1991, p. 377-423.
16. Jaworski A., 1995. "Charakterystyka hodowlana drzew leśnych", Wydawnictwo Gutenberg, Kraków 1995 In Polish.
17. Johansson K. 1997, "Effeect of early competition on wood properties of Norway spruce", Acta Universitatis Agriculturae Sueciae, Silvestria 19, SLU 1997.

18. Karllson M., Johansson U., Ekö P.M., Jorgensen B., 2006, "Establishment and early growth of mixed beech and spruce stands" – Proceedings International Conference "Beech silviculture in Europe's largest beech country" – IUFRO WP 1.01.07 Ecology and silviculture of beech, 4-8 September 2006, p.70-73.
19. Kelty M. J.; 1992. "Comperative productivity of monocultures and mixed-species stands" The Ecology and Silviculture of Mixed-Species Forests, p.125-141.
20. Kerr G., Nixon C.J., Matthews R.W., 1992. "Silviculture and yield of mixed-species stands: the UK experience". The Ecology of Mixed-Species Stands of Trees, Oxford 1992.
21. Kinka W., 1948. "Wprowadzanie buka i innych rodzajów cienioznośnych w drzewostanahc sosnowych". Instytut Badawczy Leśnictwa 1948. In Polish.
22. Klang F., 1999. "Tree properties and yield of Picea abies planted in shelterwoods" Scandinavian Journal of Forest Research 1999, v. 14(3), p. 262-269.
23. Klang F., 2000. "The influence of Silvicultural Practices on Tree Properties in Norway spruce". Doctoral thesis Swedish University of Agricultural Sciences, Alnarp 2000.
24. Knoke T., 2003. "Predicting red heartwood formation in beech trees (*Fagus sylvatica* L.), Ecological Modelling, Volume 169, Issues 2-3, 15 November 2003, p. 295-312
25. Knoke T., Seifert T.; 2008. „Integrating selected ecological effects of mixed European beech – Norway Spruce stands in bioeconomic modeling", Ecological Modeling 210(2008) p. 487-498.
26. Krahl-Urban 1955 Erfahrungen bei Eichen- und Buchenpfropfungen. Zeitschrift f. Forstgenetik und Forstpflanzenzuchtung
27. Leclercq A., 1979. "Effect of site quality on beech wood (*Fagus silvatica* L.) physiomechanical properties", Bull-Rech-Agron-Gembloux, Presses agronomiques de Gemboloux v. 14, p. 213 – 240. Abstract in English
28. Lindén M., 2003. "Increment and yield in mixed stands with Norway Spruce in southern Sweden". Acta Universitatis Agriculturae Sueciae. Silvestria 260. Swed. Uni. of Agri. Sciences. Doctoral thesis.

29. Löf M., Thomsen A., Madsen P., 2004. "Sowing and transplanting of broadleaves (*Fagus sylvatica* L., *Quercus robur* L., *Prunus avium* L. and *Crataegus monogyana* Jacq.) for afforestation of farmland. Forest Ecology and Management 188 (2004) p. 113-123.
30. Madsen P., Bensten N., Madsen T., Olesen C., 2006, „Artificial beech regeneration in Denmark – developement of direct seeding and plantng methods" – Proceedings International Conference "Beech silviculture in Europe's largest beech country" – IUFRO WP 1.01.07 Ecology and silviculture of beech, 4-8 September 2006, p.64-66.
31. Madsen P., Larsen J.B. 1997. "Natural regeneration of beech (*Fagus Sylvatica* L.) with respect to canopy density, soil moisture and soil carbon content", Forest Ecology and Management 97 (1997) p. 95-105.
32. Ministry of Agriculture & Food of Irland, accessed 21-May-05 www.agriculture.gov.ie/forestry.
33. Murat E., 1999. "Poradnik Hodowcy Lasu" , Wydawnictwo Świat, 1999. In Polish.
34. National Atlas of Sweden, 1996. The Forests. SNA. Bra Bocker, Hoganas. In English.
35. NFI 2003. Swedish National Forest Inventory. Forestry statistics available at http://www-nfi.slu.se/ in January 2008. In English.
36. NFI, 2001-2005. Swedish National Forest Inventory. Forestry statistics available at http://www-nfi.slu.se/Resultat/01_05/T22_0105.xls accesed 16.10.2008..
37. Nicolescu N.-V., Petrițan1 I.C., Filipescu C.-N., Vasilescu M.-M., Pãcurar V.-D., Radu N., Simon D.-C., Tereºneu C., 2004 "Silvicultural interventions in young European beech (*Fagus sylvatica* l.) stands of Romania - a new approach" Proceedings from the 7th International Beech Symposium IUFRO Research Group 1.10.00 10-20 May 2004, Tehran, Iran, p. 90-96
38. Nicolescu V.-N., Pátráucean A., Ionescu I.-C., Filipescu C.-N., Pribeagu R.-A., Simca I., 2006. "Effect of European beech artificial pruning on wound occlusion and wood quality" Proceedings International Conference "Beech silviculture in

Europe's largest beech country" – IUFRO WP 1.01.07 Ecology and silviculture of beech, 4-8 September 2006, p.64-66

39. Nicolescu1 N.-V., Petrițan1 I.C., Vasilescu1 M.-M., 2004. "The early and heavy snowfalls, a major threat to the young European beech (Fagus sylvatica L.) stands" Proceedings from the 7th International Beech Symposium IUFRO Research Group 1.10.00 10-20 May 2004, Tehran, Iran, p. 96-101
40. Prevosto B., Curt T., 2004. Dimensional relationship of naturally established European beech trees beneath Scots pine and Silver birch canopy. Forest Ecology and Management 194 (2004), 335-348.
41. Račko J., 1985. "Forking – an undesirable quality factor of the beech forests in Slovakia" – summary in English, Lesnicky čaopis 3/1985, p. 161-177.
42. Skovsgaard J.P., Nordfjell T.&IB Holmgård Sorensen 2006, "Precommercial thinning of beech (Fagus Silvatica L.): Early effects of stump height on growth and natural pruning of potential crop trees." Scandinavian Journal of Forest Research, 21, 2006, p. 380-387.
43. Swedish Forest Agency 2008 – Four vegetation zones. Available at http://www.svo.se/episerver4/templates/SNormalPage.aspx?id=11505 in January 2008. In English
44. Swedish Forest Agency, accessed 21.01.2008 http://www.svo.se/episerver4/templates/SNormalPage.aspx?id=11505
45. Swedish Forestry Act.1994. Full version available at http://www.svo.se/episerver4/templates/SNormalPage.aspx?id=11303 in January 2008. In English.
46. Tarp P., Helles F., Holten-Andersen P., Larsen J.B., Strange N., 2000. Modeling near-natural silvicaltural regimes for beech – an economic sensitivity analysis. Forest Ecology and Management 130 (2000), 187-198.
47. Tomanek J., 1997. Botanika leśna, PWRiL Warszawa 1997.
48. Wijdeven S.M.J., 2003. Natural regeneration of beech forests in Europe – Netherlands: approaches, problems, recent advances and recommendations. Report from research on approaches to naturally regenerate beech managed forests (D22).

49. Zasady Hodowli Lasu, 2003. In Polish.
50. Zell J., Hanewinkel M., Seeling U., 2004. "Financial optimization of target iameter harvest of European beech (*Fagus sylvatica*) considering the risk of decrease oftimber quality due to red heartwood", Forest Policy and Econimics vol. 6(2004) p. 579-593.
51. Zerbe S., 2002. "Restoration of natural broad-leaved woodland in Central Europe on sites with coniferous forest plantation", Forest Ecology and Management 167 (2002) p. 27-42.
52. Zingg A. and Ramp B., 2004. "Thinning and Stem Quality in Pure and Mixed Beech (Fagus sylvatica L.) Stands" Proceedings from the 7th International Beech Symposium IUFRO Research Group 1.10.00 10-20 May 2004, Tehran, Iran, p.169- Surmiński J., 1990 "Właściwości techniczne i możliwości zastosowania drewna" Buk zwyczajny Fagus sylvatica L. Nasze Drzewa Leśne, PWN Warszawa-Poznań 1990. In Polish

7. Appendix

Pictures from the survey area in Snogeholm

7. 1. Beech monoculture

Pic. 1 Beech monoculture

Pic. 2 Bottom fork

Pic. 3 Double top

Pic. 4 Spike knot

7.2. Beech and alder mixture

Pic. 5 Beech and alder, bottom fork

Pic. 6 Beech and alder

Pic. 7 Wolf tree

7.3. Beech and hornbeam



Pic. 8, 9, 10 Mixture of beech and hornbeam

7.4. Beech and spruce

Pic. 11 Beech rows in spruce stand, foreground – bottom fork of beech

Pic. 12 Interaction between spruce and beech

Pic. 13 Severe damages of beech

7.5. Beech and aspen

Pic. 14 Beech in the aspen stand

Pic. 15 Bottom fork

Pic. 16 Upper fork and spike knot

7.6. Beech and larch

Pic. 17 Beech and larch rows

Pic. 18, 19 Interaction between beech and larch (whipping) – creation of double tops

7.7. Beech and birch

Pic. 20 Beech rows between the birch

Pic. 21 Double top and spike knot

Pic. 22 Bottom fork

7.8. Beech and hybrid aspen

Pic. 23 Proper shape tree

Pic. 24 Shelterwood of H.aspen creates the most beneficial conditions for beech regeneration