External timber quality of birch in birch-spruce mixtures

Fredrik Hörnsten
Supervisor: Emma Holmström, SLU Southern Swedish Forest Research Centre

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Examiner: Eric Agestam, SLU Southern Swedish Forest Research Centre

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Abstract

The Swedish forest management model, largely based on monocultures of conifer species, has increasingly come under scrutiny. Its disadvantages to biodiversity, recreation and climate change susceptibility incentivize alternative ways of forest production. Mixtures with a secondary species is one such alternative. Birch and spruce, two species native to Sweden, are well-known to function together. Mixtures of the two exist today already, although the species are usually treated with different goals in mind. Further encouragement of forest owners is necessary for the practice to become more widespread.

This thesis attempts to reflect upon whether naturally regenerated birch in birch-spruce mixtures have a high enough timber quality to make the birch valuable from an economic perspective. The aim of the study was therefore to assess external timber quality of naturally regenerated birch in birch-spruce mixtures in southern Sweden. The hypotheses to be addressed was a) that naturally regenerated birch trees in Norway spruce plantations fulfill the requirements for high quality saw timber and b) that the quality of the future crop trees of birch is lower when the surrounding competition is of Norway spruce instead of other birches. Birch quality was assessed externally in 27 birch-spruce mixture stands in Götaland. Straightness, leaning, stem damage, spike knots and forks were among the studied variables.

The result showed that naturally regenerated birch trees in Norway spruce plantations generally did not fulfill the requirements for high quality saw timber, but had a potential for intermediate quality saw timber.

Furthermore, the quality of the future crop trees of birch was lower when the surrounding competition was Norway spruce instead of other birches.

The actual cause for the differences is not possible to state with this type of forest survey, where the earlier management is uncertain and the objectives of the different forest owners are unknown. Further research is needed to clarify this, and to determine how to achieve an optimization of birch-spruce mixtures, with yields of both high quality birch timber and spruce timber.

Keywords: mixed-species forestry, birch-spruce mixtures, external timber quality, birch

Svensk sammanfattning

Svensk skogsskötsel och dess traditionella fokus på monokulturer av barrträd, har mer och mer ifrågasatts. Dess nackdelar för biodiversitet, rekreation samt känslighet för klimatförändringar ger skäl att undersöka alternativa system för skogsskötsel. Blandskogar, där ett sekundärt trädslag introduceras, är ett sådant alternativ. Björk och gran är inhemska arter i Sverige, och är väl kända att fungera tillsammans. Blandningar av de två existerar redan idag, om än oftast med olika mål för trädslagen. Skogsägare tycks dock behöver ytterligare uppmuntring för att dessa blandskogar ska bli vanligare.

Denna uppsats försöker begrunda huruvida björk i björk-gran-blandskogar är av tillräckligt god kvalitet för att den ska vara lönsam ur ett ekonomiskt perspektiv. Målet med undersökningen var därför att skatta extern virkeskvalitet hos naturligt föryngrad björk i björk-gran-blandskogar i Götaland. Hypoteserna var a) att naturligt föryngrad björk i granbestånd når kvalitetskraven för hög virkeskvalitet och b) att kvaliteten hos framtida huvudstammar är lägre när den omgivande konkurrensen är av gran snarare än björk.

Björkkvalitet skattades externt i 27 björk-gran-bestånd i Götaland. Stammars rakhet och lutning, samt stamskador, torrkvistar och stamklykor var variabler som registrerades.

Resultatet visade att naturligt föryngrad björk i björk-gran-bestånd generellt inte uppfyllde kvalitetskraven för hög virkeskvalitet. Dock tycks det finnas viss potential för sågtimmer av intermediär kvalitet. Dessutom var kvaliteten av de framtida huvudstammarna lägre när den omgivande konkurrensen var av gran snarare än björk.

De faktiska skälen bakom dessa skillnader är ej möjliga att utröna med denna typ av undersökning, där beståndens tidigare skötsel samt skogsägarnas mål är okända. Ytterligare forskning behövs för att klargöra detta, samt för att optimera björk-gran-skogsskötsel generellt

Contents

Abbreviations and definitions

Age class	Approximate stand age according to previous selection, where class name = lower threshold of category
Birch	Downy birch (*Betula pubescens*) & silver birch (*Betula pendula*)
Future crop tree	25 largest birches per sample plot, by diameter in breast height
Plot tree	Trees within sample plot, used for stand variables (n=9212)
Sample plot	Circular area (10 m radius, n=212) within which the trees were sampled
Sample tree	All birches measured in 2017 (n=784)
Sampled spruces	All spruces sampled for heights & diameter in 2017 (n=520)
SLU	Sveriges lantbruksuniversitet, Swedish University of Agricultural Sciences
Spruce	Norway spruce (*Picea abies*)
Stand	Forest stands (n=27), within which up to 10 sample plots

Introduction

This survey belongs to a larger research project aimed at studying the establishment and management of mixed forests in southern Sweden. In the phase of sampling and data collection we were two master students (Fredrik Hörnsten and Damiano Cilio, University of Florence, Italy) who worked together pairwise. The analysis and writing of the master thesis has though been performed individually, each with a different subject and angle. Stand developments, birch vitality and species competition is not investigated in-depth in this thesis since it is the focus of study for Damiano Cilio.

Background

Changes in Swedish forestry

During the 1900s, the goal of Swedish forestry has been to achieve maximized economic profit from the wood resources. The means to achieve this was through major promotions of clear-cutting and monocultures of conifer trees, mainly Scots pine (Pinus sylvestris) and Norway spruce (Picea abies), which have been very popular for decades (Matthews, 1989, Lindblad & Bradshaw, 1998). The general goal of European forest policy has though shifted since the 1970s from only provisioning of timber, the so-called *sustained yield* management (Chikumbo et al., 2000), towards the last decades' *multiple-use* and *sustainable* forest management, which includes broader economic goals, but also social as well as environmental goals (Kankaanpää and Carter, 2004).

The reason for monoculture forestry has been that it has proven to be beneficial in order to provide large quantities of wood per unit area, however, this has often come at the expense of biodiversity (Lindenmayer and Franklin, 2002). Other disadvantages with monoculture forestry compared to mixed species forestry are for example increased risk for pests and an increased susceptibility to the impacts of climate change (Schlyter et al., 2006, Jactel et al., 2011).

The inherent disadvantages incentivize alternative ways of production. In traditional literature, the emphasized advantage of monocultural forest management has been that it is more profitable (Matthew, 1989). However, this notion has been more and more challenged whereby introductions of a second deciduous forest tree species in conifer tree forests has increased (Egnell, 2011). This has also had economic incentives, since it has been found to be more resilient and positive for the conifer trees (Lindbladh et al., 2014 Thompson et al., 2009).

The previous quite streamlined way of forest management has been dominant in Sweden with 75 % of the tree volume in southern Sweden consisting of the two species Norway spruce and Scots pine (Lindbladh et al., 2014). This master thesis will focus on mixed species forests, where birch has been introduced into spruce production, and focus lies on birch timber quality.

Common species in Swedish mixed forests

Norway spruce

Norway spruce is a conifer tree native to Europe. In the north it forms a continuum covering Fennoscandia, the Baltic states, Belarus, northern Poland and European Russia. In the south, the species occurs along mountainous regions such as the Alps, Carpathians and the Balkan mountain range. As with many other species, its migration to northern Europe was likely preceded by the retreating Scandinavian ice sheet after the last ice age (Aarrestad et al., 2014).

Norway spruce is the far most common timber species in Europe and Sweden (Spieker 2000; Nilsson, 2013; Bergquist et al., 2011). It is also a very important key species in mountainous and boreal forest ecosystems. In the north, the altitudinal limit, temperature and photoperiodic constraints, a natural selection has developed several traits in Norway spruce (Trujillo-Moya et al., 2012), regarding bud burst, bud set, frost hardiness and growth (Skrøppa, 1991; Pulkkinen, 1993; Hannerz et al., 1999, Sundheim Fløjstad & Granhus, 2010; Søgaard et al., 2007; Leinonen & Hänninen, 2002).

Birch (Betula pendula; Betula pubescens)

Both commonly abbreviated as just birch, Silver birch *(Betula pendula)* and downy birch *(Betula pubescens)* are broadleaved trees that occur throughout most of Europe, but particularly in northern or mountainous areas since they do not tolerate prolonged summer drought. In northern regions, birch trees often dominate the landscape up to the tree line. They often occur early in secondary succession because of their abundant seed production, low demands on soil quality, and intolerance of shade (Beck et al., 2016; Nylinder et al., 2006). Silver birch is known to be a good raw material for high quality and highly prices veneers and many other wood products (Luostarinen & Verkasalo, 2000; Verkasalo et al., 2017) while downy birch is more used for pulp and fire wood (Beck et al., 2016). Regarding the wood properties however, the species are very similar (Krames and Krenn, 1986), although silver birch is about 80 % smaller in height and stem diameter compared to downy birch (Viherä-Arnio & Velling, 2017). Birch wood is of medium density compared to other European hardwoods (Viherä-Arnio & Velling, 2017). In this survey, the birch species have not been differentiated, instead both being referred to as just *birch*.

Assessing birch timber quality

Although birch yields pulp of high quality, the most valuable birches are those that produce high quality timber, such as furniture-wood and veneers (Cameron, 1996). What is sought-after by the veneering and furniture industries are straight stems of large diameters without irregularities (Hynynen et al. 2010). The timber quality cannot be fully determined without cutting down and sawing the stem. Approximate birch timber quality can however be evaluated using various methods, where an external assessment of the stems is one. Commonly used external variables include stem straightness, leaning, crown height and ratio, cross diameter, knots and stem damage (Cameron, 1996 & Mäkinen et al., 2003). The market for birch timber is however small in Sweden, and assessments of timber quality based on stem characteristics are thus lacking in practice. In this thesis, high quality saw timber is defined with inspiration from Finnish birch timber standards. See Table 1.

Table 1. Finnish timber and veneer standards for birch (Keskusmetsölautakunta Tapio, 1991)

Log minimum top end over bark	**18 cm**
Log lengt h	3.1 m minimum to 7.0 m maximum (by 30 cm intervals)
Branch and knot number (per 150cm length)	
live branches	no limit
dead branches	5
Maximum branch thickness and knot size	
live branches	7 cm
dead or decayed	4 cm
Stem bend (per log) measured on one side (dependent on top diameter)	
18-23cm	2 cm
24-35cm	4 cm
36cm+	5 cm
Firm wounds	On one side up to 90 cm in length, and depending on top diameter, 2-4 cm deep or 10% in diameter.
Decayed wounds are not permitted	
If there are more than two quality defects then that log is not acceptable	

Note: Table from Cameron (1996).

Mixed forestry and its benefits

The definition of a mixed stand varies between countries and contexts. A Swedish definition of a mixed broadleaved and coniferous stand has been made by Johansson (2003), considering it as “a type of stand in which the total percentage of broadleaved species is 30-70 % of the growing stock”. Drössler (2010) further elaborates on the Swedish context, whereas both the thresholds of 30 and 10 percent of the basal area can be used. A stricter definition of mixed stands in which a plurality of tree species always equals a mixed stand, regardless of proportions, is suggested (Drössler, 2010). In Norway and Finland, it is defined as mixed if 20 % is broadleaved species (Frivold, 1982; Frivold and Groven, 1986).

Using a mixture of species in forest management has become more and more common in Europe for the last three decades. Also globally, mixed stands has been seen as important for a developed and sustainable forestry (Hegre and Langhammer, 1967; Stewart et al., 2000).

Previous monoculture forest management models have firstly been adopted to enhance timber production, often to the detriment of other forest services. A wide range of other beneficial services comes with forest production. Examples are regulatory services such as forests as a storage and sequestration of atmospheric carbon, and development of wood for building and for energy but also psychosocial benefits for the population, offering societal, recreational and cultural values (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). From a human perspective, a mixture of species in forests has shown to be a particularly beneficial for recreation and for example berry and mushroom picking (Lindhagen and Bladh, 2013).

Benefits with mixed-species forestry compared to monocultures have increasingly been reported regarding biodiversity in ecosystems (Felton et al., 2010; 2016). A challenge for the future is to identify forest production alternatives that are better suited to sustainability, providing a width of services useful for a growing population (Gustafsson et al., 2012). Even if mixtures come with a range of benefits compared to monocultures, the forest owner perspective and the economic implications might need to be addressed before mixtures can be presented as an alternative to monocultures. With a focus on birch-spruce-mixtures specifically, a primary issue within this master thesis is whether or not high quality birch timber and productive spruces can be achieved in the same stands simultaneously. The feasibility of this is not yet clear, which provides a motive for this survey.

Conclusively, there are usually different goals for the species in contemporary birch-spruce mixtures in southern Sweden. Whereas spruce timber is seen as a secure economic investment, the birch is to account for other values (Felton et al. 2016). As such, the birch is usually not managed for quality (Holmström, 2015). Nevertheless, the question remains to be answered whether birches in these mixtures are of sufficient quality to have an economic value in addition. If so, forest owners could have an additional motive to adopt birch-spruce mixtures. This provides a motive for this survey. An important motive for the study is to problematize the economic potential of naturally generated birch in birch-spruce mixtures. An indication of economic potential is based on external timber quality, as assessed in the field.

Aim

The aim of this survey was to assess the contemporary external timber quality of naturally regenerated birch in birch-spruce mixtures in southern Sweden. Retaining a mixture of the two species is usually primarily motivated as a mean to meet goals of enhanced biodiversity or recreational values. However, if the birch timber could be sold as valuable saw-timber, it could possibly increase the commercial gain in thinnings and final harvest.

The hypotheses to be addressed were the following:
a) The naturally regenerated birch in Norway spruce plantations meet the requirements for high quality saw timber.
b) The quality of the future crop trees of birch is lower when the surrounding competition is of Norway spruce instead of other birches.

Method and material

Design

Quality assessment was conducted on individual birch trees in 27 randomly selected stands in southern Sweden (Figure 1). Within a larger research project at Southern Swedish Forest Research Centre, SLU, with the purpose to examine the potential of mixed species forestry in Götaland, southern Sweden, two previous data collections in 2016 and 2017 have been made prior to this study. Data on the stands before that has been provided by the forest owners themselves. In the data collection from 2016, 60 randomly selected stands in Götaland were surveyed. That survey was stratified on equal amount of stands in age categories between 20 and 60 years and in monocultures of Norway spruce, birch and mixture of Norway spruce and birch. In all stands five sample plots with 10 m radius were established, where all trees were calipered, heights of dominant and sample trees were measured and stand and site properties was registered. Its assessment of stand age and categorization of stand structure was used in this study as background data regarding stand-level variables.

From the survey performed in 2017, 27 stands were selected and further measured where data on ten gridded sample plots per stand was collected (Figure 1). The ten sample plots were by design stratified to cover the range of species mixture within the stands (ongoing research, Hedwall & Felton, SLU). Within that data collection, the sample plot centers and all trees within a ten-meter radius were marked and mapped, and diameters were measured on the trees. These data collections formed the basis for the current survey, as the same sample plots and plot trees were used.

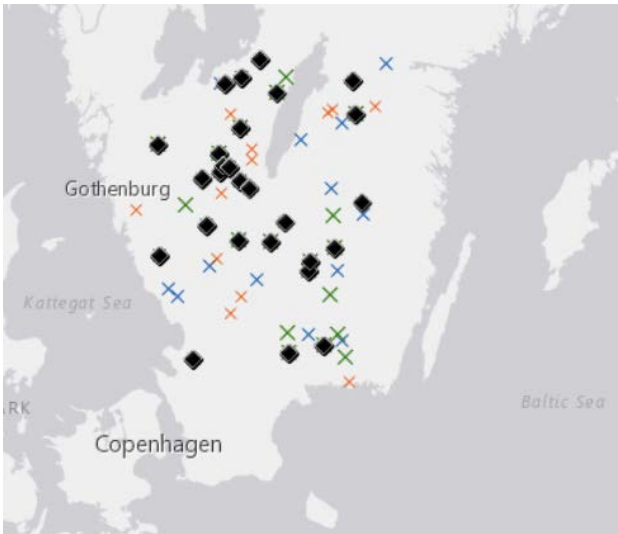

Figure 1. Locations of the 27 stands evaluated in this survey (black squared symbol) and the remaining 33 stands from the survey 2016 (colored X symbols).

Sampling

The selection of quality trees, for evaluation in the survey sample plots, were systematically prepared before visiting the stands based on the previous data collections and registered diameters of the trees. A goal was to achieve a sample of sufficient size, and was set to 50 birches per stand. They were evenly distributed, with approximately five per sample plot. A selection of 20 spruce stems was also made in all stands. In total, 27 stands with 212 sample plots were included in the study, where 784 birches and 520 spruces were measured respectively. The focus in this study was to describe birch quality in 27 birch-spruce mixture stands. External quality evaluation of birches included measures on height, cross diameter at breast height (1.3 m), straightness, leaning, stem damages, knots, forks and branch thickness.

Choice of birch sample

Selection of birch sample trees

On the sample plots, our systematic approach to the choice of birch sample was as follows:

- the two birches closest to the average diameter
- the two birches with largest diameter
- the smallest birch of those > 9 cm in diameter

Nine centimeters was set as a threshold under which quality assessments were deemed difficult and unreliable. It was assumed that we would often have fewer than five birches to measure, and occasionally most or all of them under the 9 cm threshold. Due to the birch-focused nature of this study, the stands and sample plots with little or no birch were discarded beforehand.

Selection of Norway spruce sample trees

Approximately 20 spruces were chosen per stand and was based on the sample plot tree numbering in the data collection performed 2016. Per sample plot, the systematical approach for this was:

- the first spruce
- the fifth spruce
- the seventh (and the third spruce if needed to achieve 20 spruces per stand)

Data collection

The ambition of the quality assessment was to examine the external timber quality of the birches. For spruces, therefore, only height and cross diameter was assessed while data collection on birch concerned height, cross diameter, straightness, leaning, stem damages, knots, forks and branch thickness. The variables were both discrete, continuous and categorical, and the latter ones needed to be defined by ourselves. To make the subjective assessment of the categorical data easier and more coherent, we limited the amount of categories to a maximum of three per variable. The variables and categories used in the data collection regarding external quality are described more detailed below.
The height of a tree is dependent on age and other variables and has been used only to calculate tree volume, volume density, crown ratio and dead branch ratio. Heights were measured with the following three measurements:

- Top height, the height of the tree top, in meter (*m)*
- Crown height, the height where the crown begins, (*m)*
- Branch-free height, the height from which dead branches continuously occur - measured for birch only, (*m)*

Cross-diameters were measured on stems in breast height. Birches with a diameter 9 cm or less were excluded. Diameters has been used to calculate tree area and areal density. The definition for the measurement of cross-diameters were as follows:

- Diameter 1 - diameter in the sample plot center direction, in centimeter (*cm)*
- Diameter 2 - diameter 90° from the sample plot center direction, (c*m)*

Stem straightness was assessed subjectively based on the following criteria:

- 1 - No or negligible amount and amplitude of crooks
- 2 - Somewhat crooked, with small areas affected
- 3 - Severely crooked, e.g. in more than one direction and affecting significant parts of the stem

Stem leaning was assessed subjectively based on the following criteria:

1 - Upright stem – approximately 85-90°

2 - Slightly leaning – approximately 75-85°

3 - Very leaning – approximately less than 75°

Stem damage was assessed within the first four meters of the stem

- Stem damage, *yes or no*

Furthermore, the following quality measures were included and assessed.

- Forks below 4 meters, where fork is > 0,75*stem diameter, *yes or no*
- Spike knots below 4 meters, i.e. knots not fully enclosed by stem, *number*
- Branch thickness i.e. diameter of largest branch below 4 meters, in centimeter (*cm)*

Photographed examples of three assessed stems can be found in the Appendix, Figures 7-9.

Analysis

Initially, in order to analyze the external timber quality of birch, all variables including their categories were analyzed descriptively by min-max, means, medians, as well as standard deviations. Thereafter, birches in the 27 stands were compared with regards to quality. To answer hypothesis A, the total sample tree population and surveyed stand means was used. To answer hypothesis B, the relation between species mixture and quality traits, and the sample plot was used as unit of mixture proportion.

Tree volumes and volume density was calculated based on height (H) and diameters (D), according to Näslund's model for volume functions for spruce and birch in southern Sweden (Näslund, 1947).

$$Vspruce = 10^{1,02039} \times D^{2,00128} \times (D + 20,0)^{-0,047473} \times H^{2,87138} \times (H - 1,3)^{-1,61803}$$

$$Vbirch = 10^{-0,89363} \times D^{2,23818} \times (D + 20,0)^{-1,06930} \times H^{6,02015} \times (H - 1,3)^{-4,51472}$$

From the collected tree heights, height curves were approximated for both species on each stand. These heights and/or estimated heights provided a means to calculate approximate volumes based on Näslunds model (Näslund, 1947).

Crown ratio ($\frac{total\ height - crown\ height}{total\ height}$) and branch free height (height to first continuous branches, living or dead) were calculated based on the height data collected in the field. Cross-diameter difference as well ($Diameter\ 1 - diameter\ 2, positivized$). Basal area, sample plot basal area and species basal area proportion were calculated using the diameters from the previous data collection. Analyses for the quality variables were performed on several variables for each sample plot, e.g. the total basal area, the areal proportion of birch and the age. Categorical variables were "straightness", "leaning", "forks" and "stem damage", and the rest were numerical.

For each sample plot, the birch trees were ranked based on their respective volumes and diameters. The ranking was used e.g. for analyzing the quality of the 2 and 25 largest trees, whereas the latter is defined as future crop trees in this survey.

Using the quality variables, high quality timber birches were defined. The criteria used, inspired by Finnish birch timber standards (Keskusmetsölautakunta Tapio, 1991), were:

- Straightness - No or negligible amount and amplitude of crooks
- Leaning - Upright stem
- No stem damage
- No forks
- Spike knots fewer than 10
- Branch diameter lower than 7cm

From the criteria above, three quality categories were defined. Each of these represent different degrees of fulfillment of the criteria.

A. Highest quality timber – no defects allowed / fulfillment of criteria (Figure 7)
B. Medium quality timber – somewhat crooked & slightly leaning stems allowed, no other defects. Accepted as potential saw timber in this survey.
C. Less valuable timber – everything else, i.e. severely crooked, very leaning, stem damage, forks, many spike knots & large branches (Figure 9)

The lower age classes, 20 & 30, were omitted in the analysis of the second hypothesis. A threshold was also set at the diameter 10 cm, under which birches were not included. All of the remaining trees fell within the definition of future crop trees, i.e. all of them were ranked at lower than 26 - in terms of diameter of birches per sample plot.

To see how the quality variables were affected by stem density, the quality variables were also tested against the total basal area of the sample plots.

With an exception in crown ratio, a consistent lack of normal distributions within the data obliged non-parametric tests throughout the analysis. Different statistical tests were chosen depending on data types (Nayak and Hazra, 2011). Kruskal Wallis rank sum test was used for the numeric vs categorical analysis and Kendall test used for the numeric vs numeric. All calculations and analyses were performed in R-studio, version 1.0.153 for macOS X High Sierra, version 10.13.4.

Results

Stand structure of the surveyed sites and sample plots

On average, including all stems per sample plot, diameter at breast height was somewhat larger for birches than spruces in all four age classes. However, throughout the age classes, and in 21 of the 27 stands, the mixture proportion was such that the stem density was higher for spruce, especially in the younger stands. This is also reflected in the larger basal area per hectare for spruce. The measured heights ranged from 7,3 to 27,3 for birch sample trees and 3,40 to 29,5 for spruce sample trees, and the sampled birches were taller than measured mean spruce height in older stands. Since they are based on just the sampled trees, however, the heights might not be representative of the actual upper heights of the stands (Table 2).

Table 2. Stand variables, a comparison of mean values for birch (left) and spruce (right) per age class

Birch / Spruce	**Age class 20**	**Age class 30**	**Age class 40**	**Age class 50**
Stem density* (st/ha)	276 / 1089	298 / 885	362 / 764	285 / 490
Diameter* (mm)	112,6 / 131,3	135,7 / 157,3	146,4 / 154,5	191,1 / 210,7
Basal area* (m2/ha)	3,17 / 16,5	4,80 / 19,7	6,77 / 17,0	9,66 / 20,3
Height** (m)	13,3 / 12,9	14,4 / 15,1	16,0 / 14,6	19,9 / 15,6
Tree volume*** (dm3sk)	89 / 127	119 / 224	155 / 219	331 / 381
Stand volume*** (m3sk/ha)	59,6 / 210,7	50,3 / 158,9	65,6 / 136,9	45,9 / 75,3

*means of measurements from all plot trees, from previous survey
**based on heights measurements of the sample trees
***estimated with height curves that have been produced for each stand, based on heights from sample trees

Only six (22 %) of the 27 stands had more than 40 % birch. Nine (33 %) had less than 10 %. The age distribution was 5 (19 %), 10 (37 %), 6 (22 %) and 6 (22 %) stands with 20, 30, 40 and 50 years respectively. Birch basal area proportion differed substantially between sample plots and age classes (Table 2 & Figure 2) and younger age classes had lower birch proportion while the opposite was true for the older.

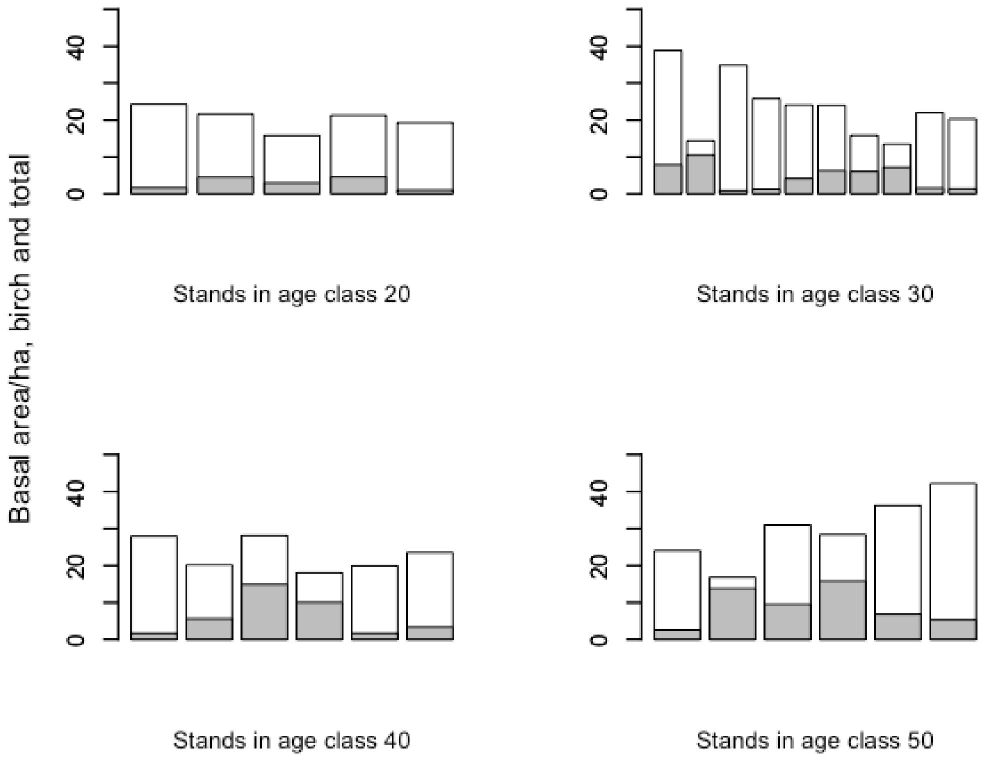

Figure 2. Birch (grey) and total (white) basal area per hectare, as distributed over age classes and individual stands. Calculated per sample plot.

High quality timber was a rare occurrence, although potential saw timber was common.

Based on all birch sample trees, only 6 % (n=46 of total 784) of the stems were categorized as high quality saw timber (quality category A) with regards to straightness, leaning, damages (Figures 3-5), forks, spike knots and branch diameter. Most birches were somewhat or severely crooked. Analyzing only the future crop trees, i.e. the 25 largest birches by diameter per sample plot, also resulted in 6 % (n=35) fulfilling the criteria.

For all sample trees, the high quality timber trees were distributed in 17 (63 %) stands, whereas 10 (37 %) of the stands had none. The stand with most high quality trees had 6, while 10 stands had less than 3 high quality timber trees according to the definition used in this survey. Looking only at older stands, 25 % had no high quality trees (n=3 of total 12).

The distribution of the categorical quality variables remained roughly the same throughout the age classes. At most, in 30 % of trees, severe crookedness was found in age class 30 (Figure 3). Upright stems varied in occurrence between 28 % and 45 % (Figure 4), while stem damage varied from 12 % to 18 % within the age classes (Figure 5). Forks were uncommon in all age classes, and not found at all in the 50-year-old stands.

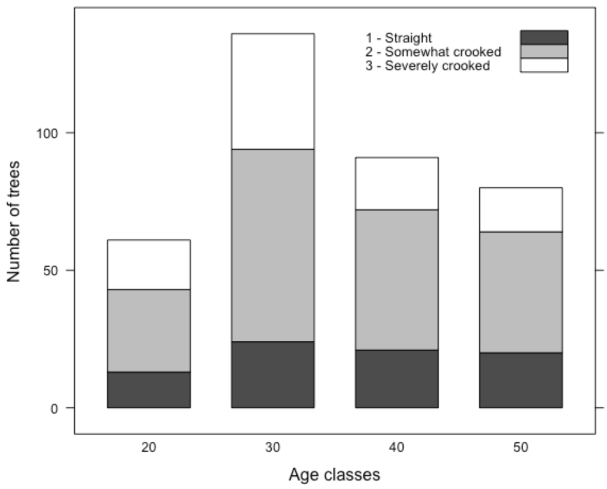

Figure 3. Straightness variable as distributed within age classes

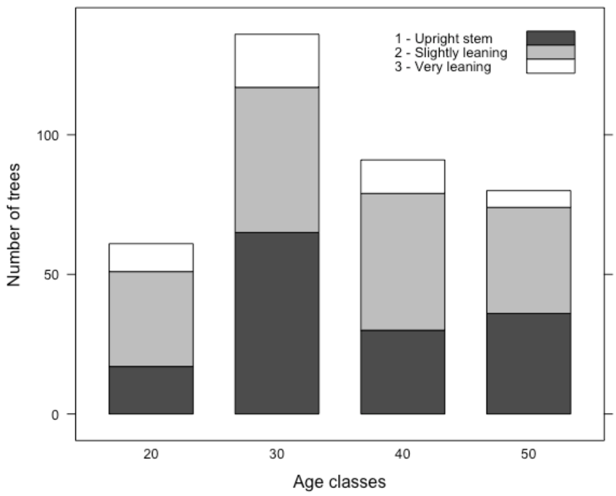

Figure 4. Leaning variable as distributed within age classes

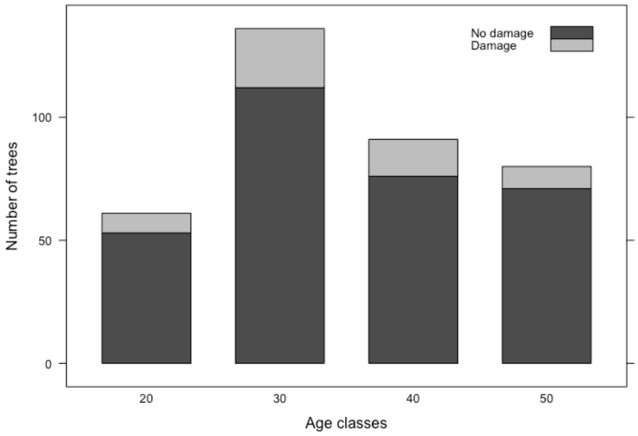

Figure 5. Number of stems with & without stem damage, divided in age classes

In total, the sample trees showed mixed results with regards to quality. Almost half (48 %) of the trees fell into the intermediate category of straightness or leaning. Severe crookedness (29 %) was more common than very leaning trees (13 %). Most stems (83 %) were undamaged. Forks and living branches were rarely found below the 4-meter threshold. Spike knots were a common occurrence, although mostly (60 %) within the 1-10 interval. Given relatively low turnouts of spike knots, stem damages and forks, most deficiencies in stem quality were manifested in the straightness and leaning variables (Table 3).

Table 3. Summary of the quality measures of birch in the survey, total=785 sample trees

Height (m)	**Crown ratio Mean: 0.45, SD 0.12**	**Branch-free height* Mean: 5.28 SD 2.48**	
Cross diameter difference** (cm)	Mean: 0.82 SD 0.74		
Stem straightness (n, *%*)	Not crooked (178, *23*)	Somewhat crooked (381, *48*)	Severely crooked (225, *29*)
Leaning, (n, *%*)	Upright stem (308, *39*)	Slightly leaning (376, *48*)	Very leaning (101,*13*)
Stem damage, (n, %)	Yes (134, *17*)	No (651, *83*)	
Forks*** **(n, *%*)**	Yes (23, *3*)	No (762, *97*)	
Spike knots, (n, *%*)	No (195, *25*)	1-10 (476, *60*)	10+ (114,*15*)
Largest branch diameter**** (cm)	Mean: 5.95 SD 4.26	No (n,%) (736, *94*)	

* = height to first continuous branches, living or dead
**only birches with a diameter >9 cm
***where fork >0,75 stem
****living, below 4m threshold

While few sample trees had the highest quality, many were intermediate when taking into account the several variables for each stem. This is visualized in Figure 6, which is referring to the previously defined categorization of quality, based on Keskusmetsölautakunta Tapio, 1991. High quality trees, i.e. those within category A, are few in all age classes. The category for slight defects, B, is the largest – somewhat larger than the lowest category, C, throughout. Within this survey, category B is defined as potential saw timber.

Hypothesis A stated that naturally regenerated birch in Norway spruce plantations meet the requirements for high quality saw timber. Because of the low outcome of sample trees fulfilling the set criteria for high quality saw timber, this hypothesis is rejected. However, given the large amount of potential saw timber trees (category B), there might still be a potential in birch saw timber in birch-spruce mixtures.

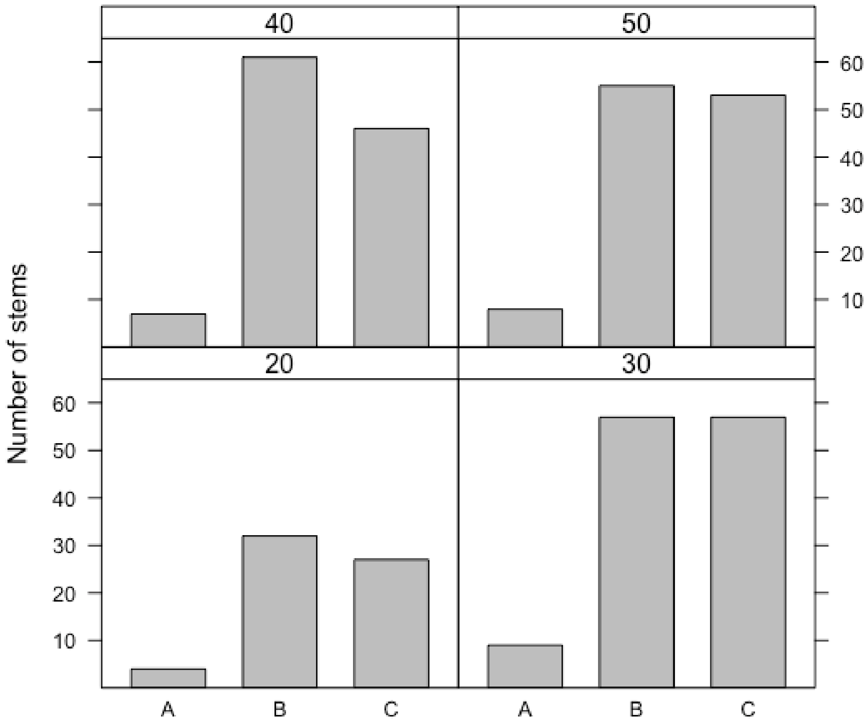

Figure 6. Total number of sample trees in each quality category A-C. The panels represent the age classes of the surveyed stands, 20, 30, 40 and 50 years old.

Timber quality was lower when spruce proportion was higher

The mixtures in sample plots varied in birch proportion between 1 % and 100 % birch, of the total basal area of the sample plot. Using the range of mixed proportion from the survey sampling design, the hypothesis that the quality of the future crop trees of birch was lower when the surrounding competition is of Norway spruce instead of birches can not be completely rejected. Stem damages were more common when birch proportion was lower, and spike knots were plentier and branch diameter higher. The crown ratio was higher and thereby branch-free height was also lower. A significant result in the other direction can also be found with cross-diameter difference, which is smaller when birch proportion was lower. The same results, except for stem damage, was found for the largest trees (Table 4).

Quality was also tested as a whole, with the multi-faceted categories A, B & C, although without significant results, as seen in Table 4. See Appendix for more in-depth statistics on the tests.

Table 4. Relationship between quality variables and birch basal area proportion (per sample plot) within age classes 40 & 50, for sample trees and a ranked group. Cats = categories of categorical variables, p = p-values, corr = correlation coefficients, cat means = mean values of birch basal area proportion per category

		Birch basal area proportion Sample trees* n=376			Birch basal area proportion Largest of sample trees** n=173		
	cats	p	corr	cat means	p	corr	cat means
Straightness	1			0.489	0.365		0.489
	2			0.506			0.325
	3	0.177		0.320			0.245
Leaning	1			0.394	0.638		0.314
	2			0.489			0.321
	3	0.738		0.528			0.432
Stem damage	Yes	0.015		0.306	0.351		0.314
	No			0.506			0.330
Forks	Yes	0.376		0.219	0.788		0.342
	No			0.469			0.321
Quality	A	0.394		0.394	0.998		0.246
	B			0.514			0.306
	C			0.332			0.325
Spike knots		<0.001	0.021		<0.001	0.038	
Branch-free height		0.012	0.065		0.024	0.072	
Crown ratio		<0.001	0.113		<0.001	0.139	
Cross-diameter difference		<0.001	0.004		<0.001	-0.088	
Branch diameter		0.348	-0.011		0.214	-0.308	

The quality variables were also affected by total stand density, but significant response (p=0,001 & 0,007) was only found for crown ratio, which was larger with higher densities.

Discussion

The analysis of the sample trees revealed that there is a potential for quality saw timber among naturally regenerated birch trees in Norway spruce plantations. Although sample trees rarely fulfilled all of the criteria for high quality timber (A), it cannot be ignored that plenty of sample trees (48 %) were included in the category for potential saw timber (B), i.e. stems that fulfill the criteria for saw timber according to the interpretation of Keskusmetsölautakunta Tapio (1991). Despite these trees might not have the highest economic value, they could perhaps be of commercial interests as saw timber if there was a market and logistical infrastructure for the product in southern Sweden. Especially since the only traits differing them from high quality stems were that they were either somewhat crooked or slightly leaning.

This is a survey on a random selection of mixed Norway spruce and birch stands in southern Sweden. No management history of the stands was assessed prior to the survey and no intentions is made to state a causality between species mixture and quality traits. However, all stands are sampled from forest plans which indicated that most stands were managed with strip rows and harvested stumps from thinnings. This was furthermore confirmed in most field observations.

It’s reasonable to assume that the quality is on average higher in the thinned stands due to an active selection to remove bad quality trees. Probably, the forest harvester operators make selections between birches based on stem straightness, leaning, forks and vitality. On the other hand, if the forest owner has an interest in, and set-out goals for biodiversity, and has been outspoken about it, the opposite result could be expected regarding the supposed relationship between quality and thinnings. This is due to the positive implications for biodiversity from traits that generally lower the saw timber quality, e.g. thick branches, forks and crooked stems (Ishi et al. 2003). Nonetheless, merely the addition of a broadleaved species in a Norway spruce plantation has proven to increase biodiversity values in several studies (Felton et al. 2016).

As for variation in birch proportions between the sample plots, thinning operations might have affected that as well. In both directions probably, depending on the owners’ objectives.

When committing to mixed-species forestry, the forest owners might have actively prioritized keeping more birches throughout the management cycle.

Although one could think that the larger future crop trees would be of higher quality than all sample trees, no significant difference was found. This could likely also be the result of previous thinnings, where selection of retained birches has possibly been made regardless of stem diameter.

The low percentage of sample trees fulfilling the criteria for high quality timber, within this survey, is perhaps unsurprising. In few or perhaps none of the stands, given impressions and experience from the field, had the birches been managed for the production of high quality saw timber, a goal which requires consistent and specific management (Cameron, 1996). If that goal is to be achieved in mixtures under these circumstances, further attention would have to be given to the birches, with an emphasis on the reduction of stem density for the benefit of the future crop trees.

To notice, for birch the recommended stem density in mature stands is also much lower than for Norway spruce (Hynynen et al., 2010). This could make for a potential challenge in optimizing birch-spruce mixtures for maximum timber quality of both species. Interestingly in this survey, however, stem density did not seem to affect the quality as significantly as the proportion of birch/spruce. For the sample trees, only crown ratio showed a significant correlation with stem density – two variables known to be closely related.

Moreover, stem density is commonly used and referred to in Swedish forest management. An example, given by Holmström (2015), is the thinning guides used in Swedish forestry that are based on density. These aim to maximize the harvestable yield for the target species. In this survey for example, the mean crown ratio, which is closely related to stem density, was below 0,5 for the birches (Table 2). According to Swedish forest practices, this is an indication that a thinning operation would be positive for the vitality of the individual stem (Almgren, 1990; Cameron, 1996). In the surveyed stands, spruce was probably the target crop species. As such, in addition to probably not being managed for quality, the birch was often times not properly managed for maximum yield either. New management practices and guidelines for mixtures, with equal trade-offs for both species, could perhaps be introduced. Nevertheless, from the forest owner perspective, the economic incentives needed to make birch a more viable addition in Norway spruce plantations remain to be found.

In explaining the perceived correlation between birch proportion and different potential in quality, several potential factors need to be taken into account. It could possibly be related to the dynamic in-between the species, and their respective abilities and limitations with regards to competitiveness. Sample plots with higher birch proportion could also have been deemed too unproductive for planting of Norway spruce at all. The species show different performances depending on site variables, such as soil moisture conditions, soil type and texture and frost resistance in early growth (Almgren, 1990). In addition to management practices, this is likely some of the main factors behind the result. In order to test the causal effect to the difference in birch quality, depending on species mixture or monoculture, experiments have to be conducted with random distribution of treatments on sites.

Assuming that the species suffered from competition in the high densities of Norway spruce, the vitality of the birches could probably have been raised with more frequent thinnings on most sites. In addition, pruning could have increased the quality and wood properties, although adding further costs to the management. In mixtures, implementations of such practices would probably only be viable if enough quality saw timber was assured, if the forest owner had a special interest in that goal and/or there was a present market for the product in southern Sweden. Whether that would be the case in mixtures such as these is still unclear. (Almgren, 1990).

Methodological discussion and limitations

Although this master thesis is part of a larger research project, the work itself is a survey. This makes for inherent advantages and disadvantages. Surveys are important in that they can result in indications or trends to be further studied through research. They are also relatively efficient in costs and time consumption, which is due to their limited nature. The latter is however the main disadvantage, as the limitations of the data limits how large a picture can be painted from it. As for this survey, the data suggests that there could be potential for high quality saw timber of birch in mixtures with spruce. To grasp the full effects of the variables, however, further research would have to be performed. This includes gathering new data on the same or similar stands, also taking into account recent management operations and the management goals of the individual forest owners. Broadened knowledge on the effects of thinnings on quality would be a valuable addition to contemporary research.

The variables were both discrete, continuous and categorical, whereas the latter ones were defined by ourselves. To make the subjective assessment of the categorical data easier and more coherent, we limited the amount of categories to a maximum of three per variable. In retrospect, this could be a limitation in not making the data specific enough. There were two subjective measurements included, stem straightness and leaning, which could be discussed regarding reliability. For example, tools could have been brought to further describe these measurements. This was decided against though, as time was a limitation and we already had many measurements to collect per sample plot.

Sampling and data collection

The choice of stands was mostly made before the data collection. Although not perfectly distributed, as seen in Figure 2, only stands with no or almost no birch were disregarded. No stands had birch comprise more than 80 % of the basal area, which can be discussed. Including stands with more birch could possibly have added to the analysis of birch proportion as a variable. There were no such stands available, however, and even without the analysis bore results.

Also, the choice of sample trees, i.e. trees evaluated for external quality, could be discussed. It was based on previously calipered diameters, with an aspiration to have a wide and fair representation of the birch quality within the stands. Another way would have been to assess only the higher quality trees, i.e. the maximum quality potential, which was deemed too subjective and time-consuming at the time.

Furthermore, concerning the inclusion based on size, a nine centimeter stem diameter threshold was set, under which quality assessments were deemed difficult and unreliable. The legitimacy of this selection system came into question in a few instances where, although there were five or more birches on the sample plot, fewer were included. This happened e.g. where the largest trees were also closest to the average. Although probably irrelevant to the results, because of the low occurrence, it points out an obvious error to the sample selection.

A third way would have been to assess the five largest trees, by diameter, on each sample plot. It retrospect, this method would have been preferred, as these would have made up a better representation of the future crop trees.

Because of practical reasons, several of the quality measurements were confined to the first four meters of the tree stem. This is important to note, however, as it limits the possible interpretations of the results regarding quality potential. In other words, they only concern the lower part of the stems.

Analysis

For parts of the analysis, especially in testing hypothesis B, the data was reduced to only amount for the older age classes. Younger stands, being too distant from the end of the rotation age, were deemed less representative with regards to timber quality. Also, several of the younger stands had not yet been thinned, and thus distorted the data additionally. For the same reason, stems thinner than 10 cm in diameter were excluded.

The categorization of quality variables (A, B & C) can perhaps be scrutinized. Because of their greater experience with the assortment compared with Sweden, the criteria are based on Finnish birch timber standards (Keskusmetsölautakunta Tapio, 1991). However, while that standard is for cut-down timber, this survey had to resort to asses the stems externally in the forest. External quality assessment has its flaws inherently, and perceived flaws of the quality categorization are arguably just reflections of that. The categorization was however necessary to estimate the quality at large. In other words, the quality as assessed within this rather limited survey is not fully representative of the actual stem quality. Rather, it’s a rough assessment.

A possible further study of the survey data could include multivariate analysis on all available variables, which could provide further indicators. Although to grasp the whole picture, new data studying cause and effect specifically between variables would have to be collected.

Conclusion

In Götaland under these circumstances, high quality birch timber was a rare occurrence. However, there is possibly a potential for birches of sufficient quality for saw timber. The data showed that spruce proportion affected the birch timber quality negatively, although further research is needed to study covariates possibly affecting this. Thinning, management goals and site prerequisites might be such variables that are unaccounted for in this survey.

To better optimize birch-spruce mixtures, yielding profits from both species, the management system would also have to be studied in general. Increased knowledge on this could incentivize forest owners to take up birch-spruce mixtures in place of monocultures. As of today, however, the lack of industrial infrastructure and demand for Swedish birch saw timber is an obstacle needed to break through at first.

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Appendix

Figure 7. This stem was assessed as 3 & 3 in straightness & leaning variables

Figure 8. This stem was assessed as 1 & 1 in straightness & leaning variables

Figure 9. This stem was assessed as 2 & 2 in straightness & leaning variables