# The influence of thinning intensity on stands of European ash (*Fraxinus excelsior* L.) affected by ash dieback – how should they be managed?

## - A case study based on observations in young stands of ash in Denmark


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Master Thesis no. 221

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# Table of content

All photos presented in this study were taken by André Ahlberg in the experimental stands on Jutland during the summer of 2013.

# 1. Abstract

European ash *Fraxinus excelsior* L. is a large deciduous tree species common throughout Europe. It can grow on a wide range of sites and is often found in mixed broadleaved forests. Ash rarely occurs in pure stands, which probably explains why silviculture of the species has received little attention in the past. If managed carefully, ash stands can produce a valuable timber on relatively short rotations. Ash has also been an important tree out of an ecological and cultural perspective since way back in time. But now the future of the ash is threatened by ash dieback, a disease first discovered in Poland 1992. Since then ash dieback has rapidly spread to most parts of Europe, causing high levels of mortality in all age classes. The understanding of the disease is still limited and there are only few guidelines suggesting how infected stands should be managed.

The main purpose of this study was therefore to investigate the influence of silviculture on ash dieback stands and provide guidelines on how these stands should be handled both from quality and health aspects. Measurements and assessments were carried out in four experimental stands with young ash in Denmark during the summer of 2013. During 2005-2007 the experimental plots were installed and thinned to following four stem densities: (1) unthinned control plots (1700-500 trees/ha), (2)1500 tr/ha, (3) 500 tr/ha and (4) 100-150 tr/ha. Results showed that no silvicultural treatment resulted in stands where most trees had small diameters, low yearly diameter growth, poor quality due to sweeps and crooks on the stem and primary crowns without leaves. Sample plots thinned to 1500 tr/ha gave the most optimal results, with a significantly higher share of trees with good quality, no epicormic shoots and good primary crown score compared to the other treatments. However, field observations strongly suggest that water drainage conditions play an important role for the results. In the majority of the plots a clear trend was seen with more dead and dying trees at the bottom of dips and healthier trees on slopes and on higher level ground.

Active management recommendations in stands with many healthy trees are selective thinnings of intermediate strength, where bad trees are removed. In stands with extensive attacks by ash dieback, it may be a good idea to replace pure ash stands with a mixed forest. A more passive approach where dead and dying trees are left could also be a good alternative. This increases the amount of dead wood, important for biodiversity and could possibly prevent rash fellings of ash dieback stands. Currently the future of the ash is very uncertain, but with more knowledge of ash dieback and how infected stands should be handled, the hope of saving this valuable broadleaved tree species increases.

Key words: European ash, Fraxinus excelsior, silviculture, thinning, ash dieback, guidelines

# 2. Introduction

This introductory part of the study will mainly focus on the ash as a tree, how we have managed and utilized its resources, its importance and the effect of ash dieback now threatening the future of the ash. The understanding of the disease is still limited and few guidelines on how to manage infected stands have been written. The main purpose of this study was to investigate the influence of thinning intensity on ash dieback stands and provide guidelines on how these stands should be handled, both from a quality and health aspect. In this introduction the following topics about the ash will be included: Ecology, Silviculture, Importance, Ash dieback and Objectives.

## 2.1 Ecology of ash

The European ash or common ash (*Fraxinus excelsior* L.) is one of the largest deciduous tree species native to Europe, able to reach a maximum height of 45 m and an age of 400 years (Kew, Royal Botanic Gardens 2013; Holeksa et. al 2009; Faliński 1986 ). Throughout most parts of Europe the European ash (referred to as ash from now on) is a common species with a natural distribution stretching from the British Isles, southern parts of Norway, Sweden and Finland to Italy, North Spain and Greece (Fig. 2) (Wardle 1961; Euforgen 2009). Ash also grows along the Black Sea and in the mountain regions of Caucasus and Elburz. At the Trondheim fjord in Norway (63 ° N) it reaches its northern most limits (Wardle 1961; Vedel et al. 2004). In Norway and around other parts of its northern range it usually grows in the lowlands, whereas in Central and Eastern Europe it occurs on altitudes up to 1600 m (Rubner 1953; Wardle 1961). In Denmark, where this study was carried out, ash is found almost all over the country, though most of the larger stands are located along riverbanks and in the beech dominated forests in Bornholm, Funen and SE Jutland as well as locally on Lolland, Falster and South Zealand (Ødum 1968).

Within its native range ash is usually found in mixed broadleaved forests or as associated species in forests dominated by beech, pedunculate oak, sycamore and alder (Dobrowolska et al 2011). Ash is a flexible species, able to establish on a variety of growing conditions (Evans 1984). It can be tolerant of drought and shade during early development, but sensitive to frost and acid soils. It has typical pioneer features such as a fast juvenile growth and almost yearly spreading of numerous wind-dispersed seeds, which has made it a gap specialist, able to be the first colonizer of gaps in the forest canopy (Emborg et al. 1996). Although ash is found on a wide range of site types, factors such as hydrology and soil conditions determine whether it becomes the dominant species (Kerr & Cahalan 2004). Ash is usually found as a dominant species on moist sites such as floodplain forests and along rivers, but may also dominate on dry calcareous soils in central Europe and around its northern most range (Dufour & Piegay 2008; Wardle 1961). This could partly be explained by many of these sites being unfavorable for beech, oak and to a certain degree alder, resulting in less competition (Ellenberg 1996). Out of an ecological perspective neither very dry nor very wet sites are optimal for the ash. Most favorable conditions are primarily moist but well-drained soils rich in silt or clay on calcareous substrate (Wardle 1961). Characteristics for these ash sites are fast decomposition of organic matter, high abundance of invertebrates and a rich nitrophilous ground flora often consisting of *Mercuralis perennis* L., *Alium ursinum* L., *Urtica dioca* L. *and Circaea lutetiana* L. (Loidi 2004; Wardle 1961; Evans 1984).

## 2.2 Silviculture of ash

In Scandinavia and in most parts of Europe ash is an important hardwood, highly attractive for its fast growth, production of high-quality timber and rarely being attacked by grey squirrel (Dobrowolska et al 2011; Bakys 2013; Kerr & Evans 1993). In spite of this, silviculture of ash has been paid little attention to in the past. This is mainly because ash is rarely found in pure stands (unless when planted), but occurs rather dispersed in the forest. Lately a number of silvicultural implications and reviews on ash have been written e.g. (Kerr 1995; Rytter 1998; Nicolescu & Simon 2002; Almgren et al 2003; Fraxigen 2005; Dobrowolska et al 2011), though many knowledge gaps still remain.

In order to successfully utilize the ability of ash to produce valuable timber, it is of great importance that potential stands are managed carefully (Kerr 1995). The following considerations should be made: (1) selection of site, (2) regeneration method, (3) weed control & plant protection and (4) clearings & thinning.

**2.2.1 Selection of site:** The ash is one of the more site demanding tree species and when aiming for production of high quality timber, the selection of suitable sites is crucial (Rytter 1998; Fenessy & Mclennan 2003). In order for ash to grow really well it requires fertile soils with high contents of available nitrogen and phosphorus. Deep, moist and base-rich soils (pH 7-8); preferably sandy calcareous loams that are well-drained create optimal growth conditions for ash. A common misbelief is that wetter parts and damp valley bottoms are suitable sites for ash when in reality well-drained alkaline soils are the best (Garfitt 1989; through Fraxigen 2005; Evans 1984). Even though it can withstand waterlogging to some extent, long term flooding will have a negative effect on growth and eventually kill it (Wardle 1961). Ash is also sensitive to compacted soils as they limit water and oxygen uptake, thus such sites should be avoided. The climatic influence on growth of ash is relatively small compared to that from the soil (Evans 1984). As long as the soil conditions are suitable, it can grow under various climatic conditions, though mild, moist and sheltered sites are ideal. Sites with risk of late frost should be avoided as they may cause forking, one of the most common defects among ash (Kerr & Boswell 2004).

**2.2.2 Regeneration method:** Establishment of ash is mainly done through natural regeneration, planting or a combination of the two (Dobrowolska et al 2008). On good sites the natural regeneration of ash might be very abundant. Though in many cases, especially on bare field, the quality of the seedlings worsens and many of them die due to competition with weeds or damage by frost (Fraxigen 2005; Rytter 1998). One way to increase the quality and seedling survival is by using groups of shelterwood. The ash is well suited to be used together with other tree species, often doing better in group mixtures than in pure stands. Cherry (*Prunus avium)* is one of the best species to use with ash, other alternatives that works well are group selection system with sycamore (*Acer pseudoplatanus)* and beech (*Fagus sylvatica)* (Fraxigen 2005; Pryor 1988; Evans 1984). In Denmark for example ash is grown scattered in beech stands and harvested after 70 years, while the beech is left to grow for additionally 30-40 years. Ash also grows well with black alder (*Alnus glutinosa)* on damp low-lying areas, decreasing frost risk and quality defects (Almgren et al 2003; Skovsgaard & Graversgaard 2004). In Belgium ash is often mixed with sycamore, cherry, oak, elm, birch and aspen (Fraxigen 2005; Pryor 1988).

When planting ash the recommendations on what planting densities should be used varies greatly between countries in Europe. In Germany, there are recommendations of planting between 4 000 and 6 000 plants per hectare (pl/ha), while in France much lower densities are recommended e.g. 400 -1 200 pl/ha (Landesforst Mecklenburg-Vorpommern 2004; Sachsenforst 2012; CRPF 2005; CRPF 2010). Swedish and English recommendations are mainly to use one meter high ash plants with a plant density of 2500-3000 pl/ha (Rytter 1998; Almgren et al .2003; Fenessy & Mclennan 2003). Results have shown that the greatest percentage of survival was achieved at wider spacing (2*2 m or 2.5*2.5 m), although the percentage of forking increased then as well (Espahbodi et al. 2003). Additionally wider spacing has also been connected with a decrease of diameter, height and stem volume. Closer spacing (1.0*1.0 m) resulted in a better growth and points towards closer spacing being a silvicultural characteristic of ash (Kerr 2003). Another alternative apart from natural regeneration and planting is to use a combination of the two e.g. by enrichment planting in between patches of natural regeneration.

**2.2.3 Weed control and plant protections:** Is crucial as it has great effect on the establishment of the stand (Davies 1985). Recommendations are that a minimum area of 1 $m^2$ should be kept clear from weeds for at least 3 years to increase water and nutrients available to the tree (Kerr 1995). Ash is browsed by animals like hares, voles and deer and to accomplish a successful establishment plant protection or fencing is often needed. Fencing is often connected with high costs but if high fences (≥2 m) or many small fenced areas are avoided, costs can be kept down (Kullberg 2001). There are also possibilities of getting subsidies for the costs needed to secure the regrowth of noble broadleaves (Skogsvårdslagstiftningen 2012).

**2.2.4 Cleaning and thinning:** Because ash easily forms a singular stem, it is possible to perform cleanings down to 2 m spacing, already at the height of 2 m (Almgren et al. 2003). In the early phase ash plants are very shade-tolerant but once they have reached heights of 6-7 m they become strongly light-demanding (Kerr & Cahalan 2003). From now on the main concern is ensuring a living crown constituting of about 50 % of the stem height. This is done through thinnings which should be heavy and frequent (every 5th to 7th year) in order to keep the crowns entirely free until final felling (Fenessy & Mclennan 2003; Rytter 1998). One of the most common mistakes made in ash silviculture is insufficient or delayed thinnings (Fraxigen 2005). Regular thinnings results in large diameters on relatively short rotations, but also reduces the risk and occurrence of black heart, a defect reducing timber value significantly (Rytter 1998; Oliver-Villanueva et al 1996a).

Another important silvicultural practice is pruning, made to prevent development of branches and epicormic shoots on the stems of potential future crop trees (Dobrowolska et al 2011). To ensure good quality it is recommended to prune before the stem reaches 7-10 cm at the lowest living branch. When the trees have reached 10-12 m in height, about 300 to 400 future stems should have been selected (Almgren et al 2003). These trees should have straight branch-free stem up to about 6-8 m. At the time of final felling there should be about 150 - 200 good quality trees with a dbh of 40-50 cm. Because ash grows faster than e.g. beech and oak, rotation periods are considerably shorter, usually between 60-80 years. According to Carbonnier (1947), ash had an average production of 7.3 $m^3$ska ha yr on the best sites with a rotation age of 60 years, a final number of stems of 170 tr/ha and an average dbh of 34 cm. The somewhat later Danish production overviews made by Möller & Nielsen (1959) showed a slightly higher average production of 7.7 $m^3$sk $ha^{-1}$ $yr^{-1}$ on the most productive sites.

## 2.3 Importance of ash

Since long ash has been an important tree from both an ecological and cultural, as well as economical perspective (Skovsgaard et al 2009; Quelch 2001; Bell 2008; Scheer 2001). In the Nordic mythology, Yggdrasil was a majestic ash tree described in the epic poem Edda, as the world tree holding the universe together with its mighty roots and branches (Marzell 1925; in Scheer 2001). The ash was also valued in herbal medicine, where e.g. a tonic made out of the bark was used against malaria (Fraxigen 2005; Bell et al 2008). In wooded rural areas “leaf-hay” harvesting of ash trees was of great importance, providing fuel wood, as well as fodder for livestock during winter and periods of drought (Slotte 2001; Quelch 2001; Moe & Botnen 1997). Today veteran pollarded ash trees, earlier used for leaf fodder production are being preserved, as they constitute an important part of the cultural landscape. They also provide a range of habitats for different organisms e.g. bark surfaces suitable for lichens and mosses, and nesting holes for bats and birds, making them valuable out of a biodiversity point of view. Ash is also said to have a positive effect on the soil as the litter is highly nutritious, pH neutralizing and has a fast turnover (Almgren et al 2003).

In Europe there is a large variation in the density of ash species in broadleaved forests (Fig. 1) (Skjøth et al 2008). Although they generally occur in low densities they are seen as valuable trees, able to produce high quality timber (Fodgaard 1978).The timber of ash is very hard, elastic and flexible, making it strong yet easy to work with (Pliura & Heuerz 2003; Villanueva et al 1996b). These features have made it very popular for making various handicrafts throughout Europe. Arrows for the English longbow, spears, tool handles, ladders, fences, wheels, hockey sticks, but also barns and houses were traditionally made out of ash wood (Bell et al 2008). Nowadays there is still a large demand for ash timber and it is considered to be of a high economic significance (Ballian et al 2008). Today ash wood is used mainly for producing furniture, parquet flooring, tool handles and sport equipments (Bell et al 2008). On average ash generates a market price higher than beech but lower than oak, for sawn timber logs and veneer[1]. The Swedish forest company Södra price of ash timber is 50 Euro per $m^3$fub (solid volume excluding bark) provided its diameter is within 18-80 cm and it meets the special requirements (Södra 2013).

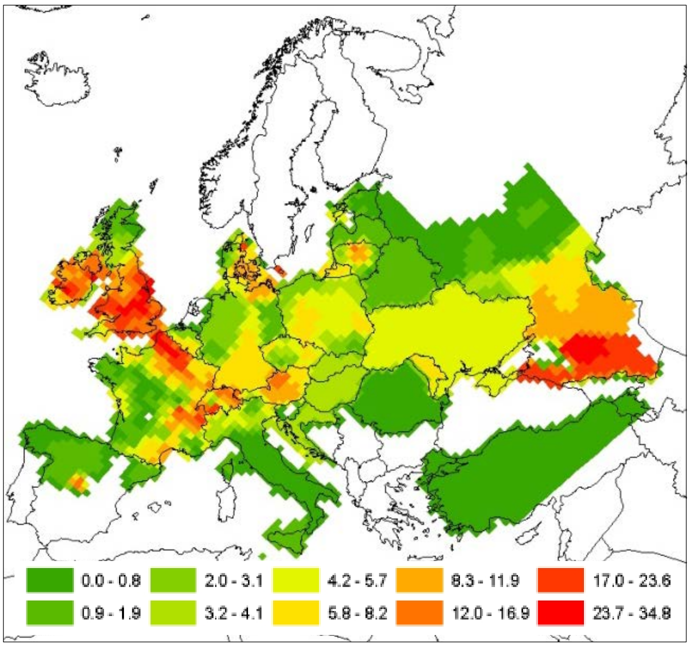


**Figure 1.** Density of Fraxinus (%) in broadleaved forests (Skjøth et al. 2008).

## 2.4 Ash dieback

In just a few years a severe disease has spread across Europe from east to west, now threatening the future of the ash (Kowalski & Holdenrieder 2008). The first large-scale observation of ash dieback was made in Poland and the Baltic Sea region in the 1990s (Przybyl 2002; Kowalski 2006; Bakys et al. 2009). Since then the disease has spread widely occurring in central, eastern and northern Europe. Initially there were a lot of open questions concerning the causal agent and its origin, abiotic factors like drought and frost were among the suggestions (Pukacki & Przybyl 2005; Thomsen & Skovsgaard 2007). More recent analysis revealed a fungus as the primary causal agent behind the dieback (Kowalski 2006; Kowalski & Holdenrieder 2009; Schumacher et al 2010). In 2009 an article was

[1] Jens Peter Skovsgaard Professor of Silviculture SLU, lecture: *Silviculture of temperate forests* 2013.

published arguing that the anamorphic state (asexual form) of the already known ascomycete *Hymenoscyphus albidus*, a harmless saprotrophic fungus found throughout Europe was the reason for the disease. The asexual form was described as a new species, *Chalara fraxinea*. However in 2010, shortly after the first report, results from another molecular investigation pointed out a previously undescribed fungus species closely related to *C.fraxinea*. It was a new cryptic species and the teleomorph (sexual form) of *C.fraxinea* and was named *Hymenoscyphus pseudoalbidus* (Queloz et al 2010). The fungus has its origin in Asia, wherefrom it somehow spread to Europe and became a lethal pathogen. Ash dieback has now been reported in more than 25 European countries (Fig. 2), where the UK is one of the most recently affected (Schumacher et al. 2007;Halmschlager & Kirisits 2008; Jankovski & Holdenrieder 2009;Dehnen-Schmutz et al 2010;Timmermann et al 2011;Ogris et al 2009; Ogris et al 2010;Koltay et al 2012;Ioos et al 2009; Rytkönen et al 2011;Engesser et al 2009;Husson et al 2011; Chandelier et al 2011;LNV 2010; BES 2013; Barklund 2005;Thomsen et al 2007; Talgø et al 2009; SNS 2013; Douglas 2012; Treštić & Mujezinović 2013).

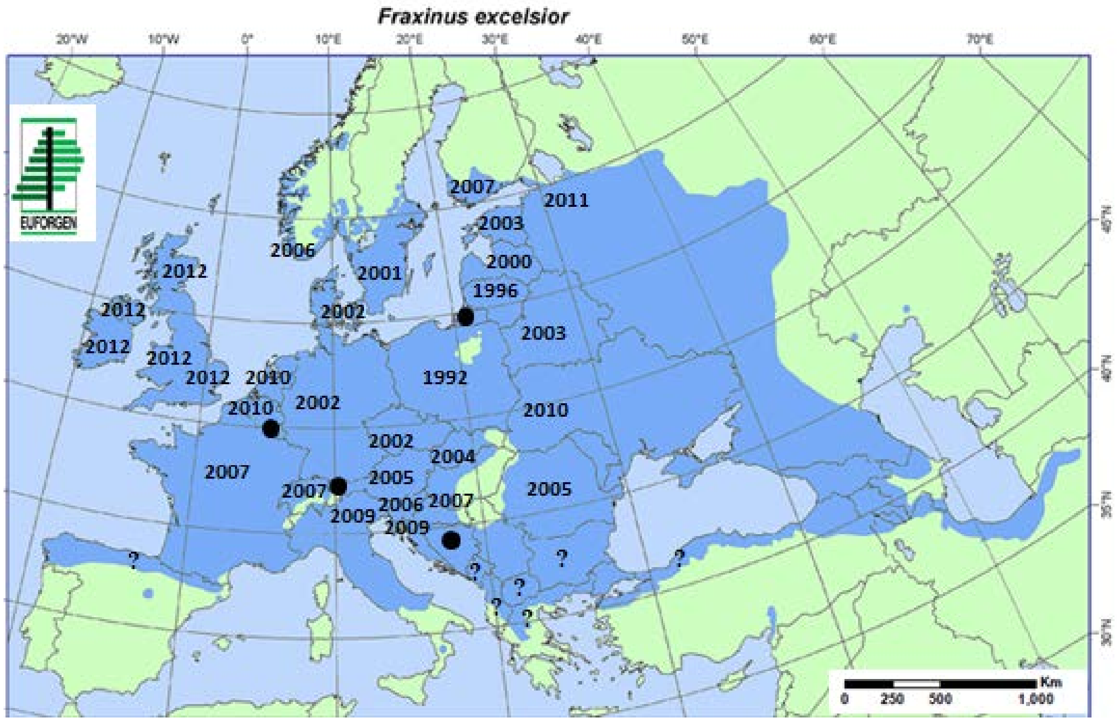


**Figure 2.** Year of first record of ash dieback in each region based on literature and distribution map of *Fraxinus excelsior* (blue shaded area) from Euforgen 2009, www.euforgen.org. Question marks are regions where the disease status is uncertain. For Kaliningrad Oblast of Russia, Luxemburg, Liechtenstein and Bosnia - Herzegovina (black dots) no first record is known but the disease occurs here as well.

Typical symptoms of the disease are eye shaped necrotic spots on leaves and bark of young shoots, elongated cankers on bark and stem, discoloration of leaves and petioles, and subsequent wilting of foliage (Fig. 3 picture A & D) and shoots (Kowalski & Holdenrieder 2009; Barklund 2005; Skovsgaard et al. 2010). These symptoms mostly occur in the tree crowns often resulting in a characteristic dieback of the upper parts of the crown, so called top-dry (Fig. 3 picture B & E). Repeated dieback typically results in tree tops with a bushy feature (Fig. 3 picture B & E) and ultimately death of the tree. A normal course of events is that trees first get weakened by ash dieback and then get attacked by secondary damaging agents, leading to death of the tree (Thomsen & Skovsgaard 2007; Skovsgaard et al. 2009). One example is the clear association found between the disease and symptoms of honey fungus *Armillaria* in ash dieback stands, often seen as red or brownish discoloration at the stem base of trees up to 40 years of age (Fig. 3 picture C).

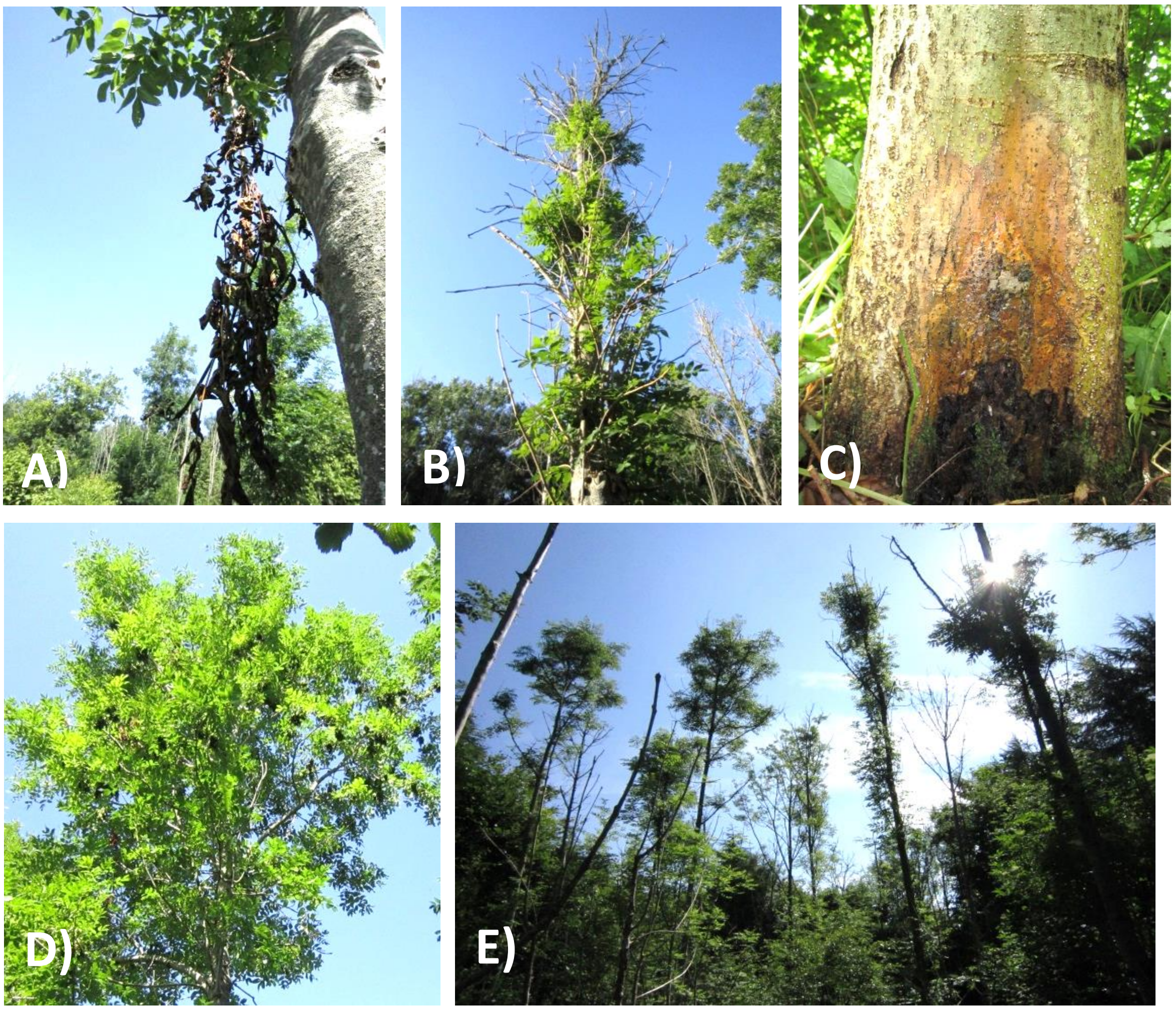


**Figure 3.** Pictures with symptoms characteristic for ash dieback stands, further explained in the main text.

In Denmark the first symptoms of ash dieback were observed in 2002 and the situation has worsened over the years (Lorenz et al 2008; Skovsgaard 2010). By 2005 the disease was relatively common; mainly occurring in young ash stands over the country. In 2008 the disease was reported as extensive on about one third of all monitored trees and presently ash trees all over Denmark are affected. In Sweden by 2002 ash dieback had only been observed locally in the southern parts, but by the summer of 2004 the disease had caused major damage and killed trees all over the country (Barklund 2005; Flykt 2009). This was confirmed by a national damage inventory made by SLU in Götaland during 2009 and 2010, showing that 50 % of all ash trees >10 cm dbh had thinned crowns and about 30 % were badly damaged or dead (Wulff & Hansson 2011). As a consequence the species is now Red-Listed in Sweden, assessed as vulnerable in the extinction risk classification (Gärdenfors 2010). Today the status of many ash stands is critical; the disease has spread over long distances and rapidly caused high levels of tree mortality in all age classes (Lorenz et al 2008; McKinney et al 2011; Skovsgaard et al 2010). The understanding of the pathogenesis is still limited, thus few practical guidelines on how to manage infected stands have been written (Dobrowolska et al 2011). Nonetheless there is no doubt that the consequences out of a forest and landscape perspective are very severe (Skovsgaard 2008). In many cases infected ash stands are cut down too rash, meaning that trees that could have survived for many years are felled, resulting in loss of wood value as well as genetic value (Flykt 2009, Skovsgaard et al 2009). Current guidelines for managing ash dieback stands differ between younger stands up to 40 years of age and older stands (Skovsgaard et al 2009). Younger stands with extensive attacks by ash dieback are often beyond hope, quickly getting killed by the honey fungus. The best solution is then final felling, perhaps saving some surviving trees, and then replanting with other tree species. However in young stands with plenty of healthy trees, selective thinning can be suitable, removing sick trees and choosing healthy trees as future crop trees. In older stands a prolonged forced final felling is desired to get an increase in stem diameter. It is important to have the right strategy because trees with severe crown damages have reduced diameter growth. Trees with epicormic shoots on stem, severe crown damages and almost no primary crown should be cut down, whereas trees with three quarters of their primary crown intact are healthy enough to be saved. It is recommended that stands are inspected every to every second year during growth season to assess their health status.

## 2.5 Objectives

The main purpose of this thesis is to investigate the influence of silviculture on ash dieback stands and to provide guidelines on how these stands should be handled both from a quality and a health aspect. The study is to conclude with a summary of silvicultural guidelines, alternatively suggest a revision of current silvicultural guidelines presented in Skovsgaard et al (2009). The specific objectives were:

- To investigate if there is an influence of thinning on the severity of ash dieback in the experimental plots?

- To identify whether soil conditions, topography and spatial position do have any influence on the frequency of ash dieback in the experimental plots?

- To evaluate if the methods used in this study are suitable for assessing the influence of Silviculture on tree quality and occurrence of ash dieback?

- To suggest how stands infected by ash dieback should be managed if the goal is to minimize loss of wood value and genetic value?

# 3. Material and method

## 3.1 The experimental stands

In the summer of 2013 (24th June – 10th July) measurements were carried out in four experimental stands in Denmark (Fig. 4). The stands are situated along the east coast of Jutland from North to South as following: No. 1425 in Saebygaard Skov (on ancient forest land), No. 1535 in Visborggaard (on ancient forest land), No. 1424 in Sebberup Skov (on former farmland) and No. 1423 in Haderslev Vesterskov (on former farmland). All stands were planted in 1992-1995 with two- to four- year-old saplings of European ash *F.excelsior* (Bakys et al. 2013).

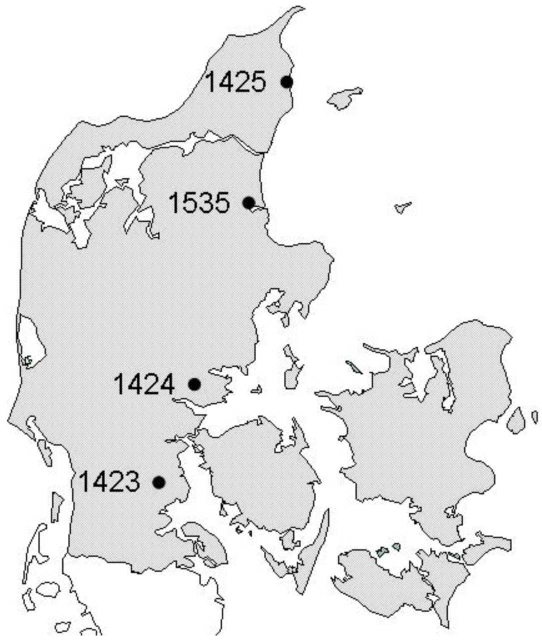


**Figure 4.** Location of the four thinning experiments on European ash (*F.excelsior*) on Jutland in Denmark.

The ash trees were planted in rows and given an individual number for monitoring of their condition. During 2005-2007 experimental plots were installed and thinned to following four stem densities: (1) unthinned control plots (1700-500 trees/ha), (2)1500 tr/ha, (3) 500 tr/ha and (4) 100-150 tr/ha.

**Table 1.** Sample sizes and no. of plots with different stem densities for each of the four experimental stands.

| Stand density (trees/ha) | No. of plots (no. measured/assessed trees) in experimental stands | | | |
|---|---|---|---|---|
| | 1425 | 1535 | 1424 | 1423 |
| 1700-5500 | 2 (224/98) | - | - | 1 (270/49) |
| 1500 | 2 (83/83) | - | - | 1 (63/62) |
| 500 | 2 (66/66) | 1 (61/13) | 1 (49/53) | 2 (56/67) |
| 100-150 | - | 1 (21/16) | 1 (12/11) | - |
| Total | 6 (373/247) | 2 (82/29) | 2 (61/64) | 4 (389/178) |

The main purpose when establishing the experiments was to see the effects of different tree densities on stem quality, no considerations were taken to ash dieback as it was newly discovered at that time. Thinning was mostly carried out from below and only few trees were thinned due to phytosanitary reasons. Since 2006 ash dieback has been observed in all four experimental stands, with consistent isolation of *H.pseudoalbidus* from symptomatic shoots (Johansson et al. 2009). In this study a total of 904 trees were measured and 520 trees were assessed for stem quality, primary crown condition, epicormic shoots, dead or alive status, damages, secondary crown condition and whether trees had foliage or not. For information about the number of sample plots of different stem densities, measured and assessed trees in each experimental stand (see table 1).

## 3.2 Inventory method

Measurements and assessments were made in the planted rows as long as they could be identified. In some plots the number of trees were so many that there was not enough time to measure and assess all trees. In those cases several tree rows were chosen, evenly spread across the area in order to obtain a representative sample. All measured data and the main part of the assessments were entered to excel files in an Allegro MX Rugged Handheld computer. Number of plots and the number of trees measured and assessed in each experimental stand can be seen in table 1. Information about the size of each sample plot is presented in (appendix 7.3).

## 3.3 Field measurements

Within each sample plot the diameter of ash trees was measured at breast height (1, 3 m) using a caliper. The number of epicormic shoots out from the stem from 0 to 6 meters up was counted. When the number of shoots was 20 or more, it was noted as 20.

## 3.4 Field assessments and observations

The following assessments and observations were executed in the sample plots:

- **Quality** – The quality of the trees was assessed as either Yes (good quality), Possible (decent quality) or No (bad quality). The outcome of the assessment was based on a number of factors such as the status of the tree, possible damages, thickness and straightness of the stem and number and size of branches and epicormic branches. The assessment was done from the stem and 6 meters up, due to this part being the most valuable out of a timber value standpoint (CRPF 2010).Trees that were assessed to have bad quality were indicated with at least one and a maximum of three reasons for the bad quality, where reason 1 was the main reason and reason 2 the second most important.

- **Primary crowns (P) –**The gradual leaf loss and crown dieback are symptoms of ash dieback largely visible (Skovsgaard et al. 2010). It was therefore appropriate to use a rated scale for the primary crown of the trees when I tried to determine the severity of the disease in different stands. Each tree was rated with one of the following scores 3, 2.5, 2, 1 or 0 depending on how leafed i.e. damaged the primary crown was (Fig. 5).

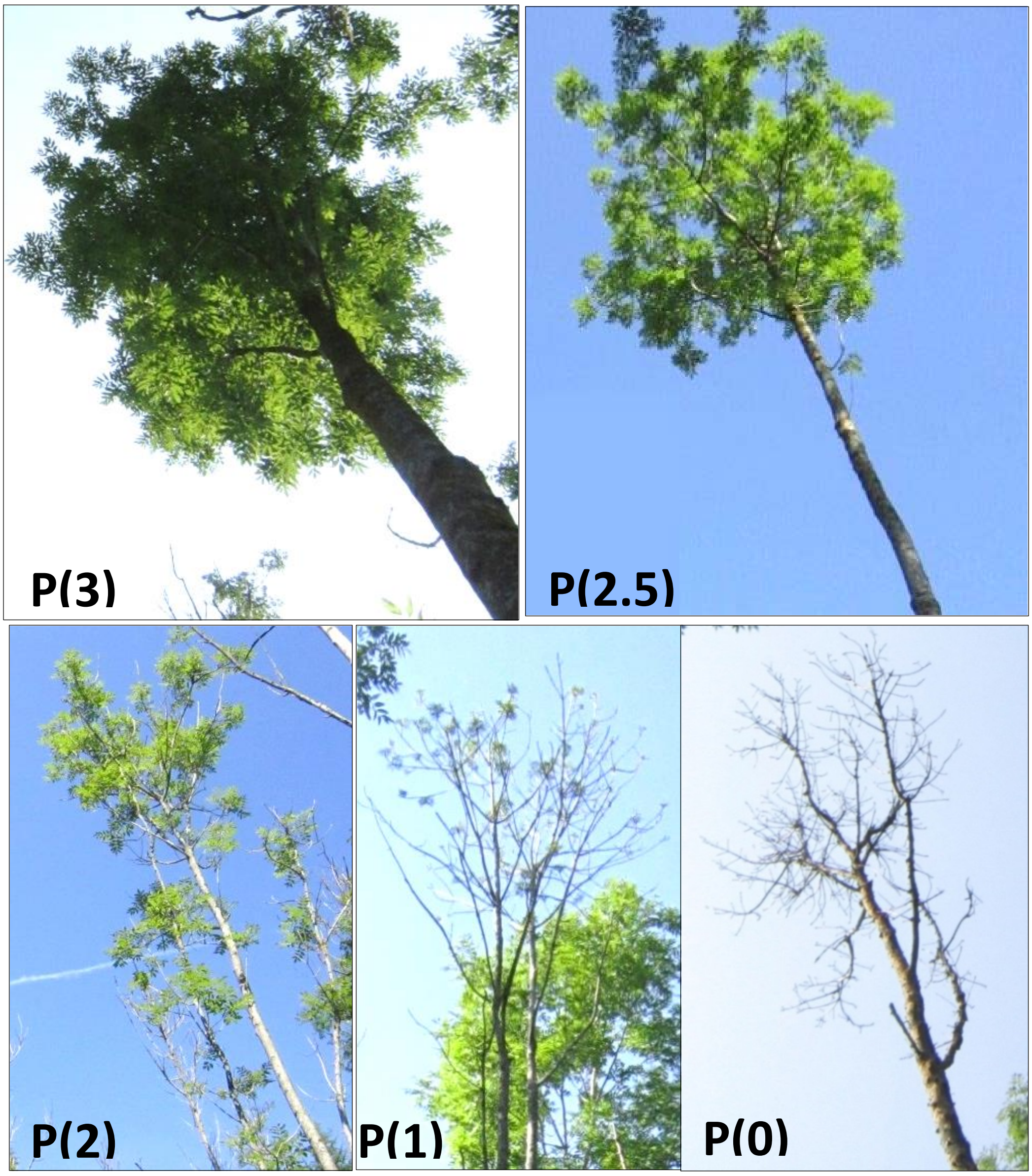


**Figure 5.** Examples of the scale for the primary crown of the trees used to assess the severity of ash dieback in different stands. Depending on foliage cover of the primary crown, trees were given one of five scores defined as: A dense full or largely full primary crown P (3), an almost full primary crown but somewhat sparse P (2.5), an intermediate sparse primary crown P (2), a primary crown with only few leaves P (1) or a primary crown without any leaves P (0).

- **Epicormic shoots** – Whether there were epicormic shoots coming from the stem or not was noted with a Yes, respectively No. Ash dieback is often associated with formation of prolific epicormic shoots on branches and the trunk (Halmschlager & Kirisits 2008; Forestry Commission 2013).

- **Potential future crop tree** - An assessment of trees as potential future crop trees (F-trees) was done, based on whether the tree was considered to have a good possibility to survive and be part of a future stand. The outcome was noted as Yes, Uncertain or No.

- **Dead/Alive status** - The status of the tree was observed and then a specific notification whether the tree was dead, dying or alive was made.

- **Damages** – If the tree had stem wounds, necrosis or bark beetle attacks causing notable damage, it was noted.

- **Secondary crowns** – An assessment of how large part of the trees foliage was part of a secondary crown was made, where the outcome was noted between 0 and 100 % (Fig. 6.). The secondary crown is the leafed parts (mostly epicormic shoots) not belonging to the primary crown. Trees that are largely or entirely made up by a secondary crown are often of bad health and severely attacked by ash dieback.

**Figure 6.** Example of a tree with a primary crown without any leaves P(0), where the whole foliage is made up by a secondary crown (100 %)

- **Foliage** – As the loss of leaves can be an indicator of severe ash dieback, a notification whether the tree had leaves on or not was made.

- **Soil sample** – A point for soil sampling was chosen in every parcel, the point was selected in between two individually marked trees and noted on a sketch. The soil sample was photographed and rolled to easier determine type and texture.

- **Photography** –Photos were taken with a digital camera in every sample plot for documentation.

- **Questionnaire** – In every plot a number questions were answered according to a questionnaire (see appendix).

## 3.5 Classification into different stem quality classes

Based on the assessment of stem quality made in field, different quality classes were created. Each tree was given one of the following quality classes A, A2, B, C, D or E depending on the feature of the stem (Fig. 7).

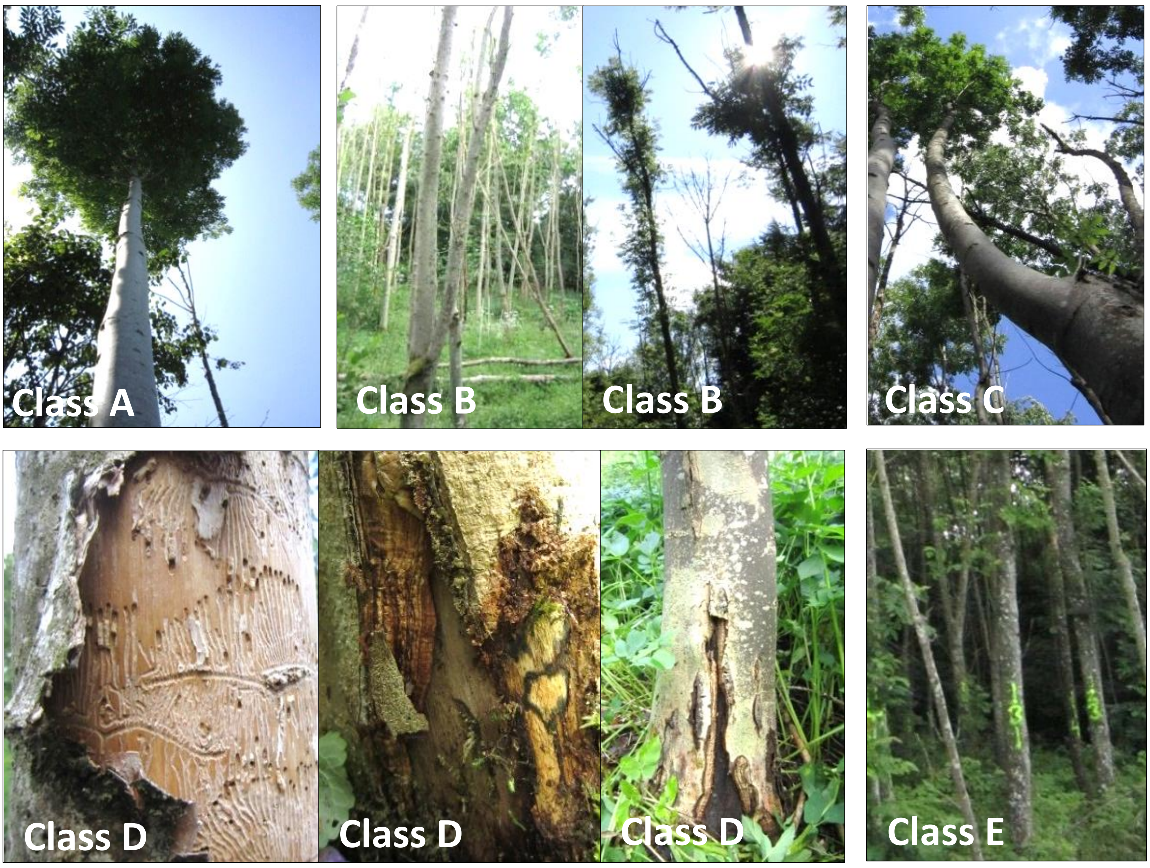


**Figure 7.** Examples of quality classes used to assess the quality of the stems in the different sample plots. Depending on the stem feature (0-6 m up), trees were given one of six classes defined as: Class **(A)** good quality with relatively straight and thick stem free from branches and epicormic shoots, **(A2)** possible good quality but due to some defect not meeting the requirements of class A, **(B)** bad quality due to multiple stems, branches or epicormic shoots, **(C)** bad quality due to sweeps or crooks in the stem, **(D)** bad quality due to bark beetles, rot, necrosis or poor health or **(E)** bad quality due to noticeable small diameter.

If trees placed in the bad quality classes (B, C, D or E) had 1 or 2 additional reason/s apart from the main reason causing the bad quality, number 2 respectively 3 was added to the letter. For example, a tree with epicormic shoots as main reason for its bad quality was placed in class B, if the tree had one further reason for bad quality it was indicated as B2.

## 3.6 Calculations and data analysis

The average diameters of living trees were calculated for each parcel. Dead trees and trees that no longer could be found (e.g. dead fallen trees) were sorted away. Average diameter growth for living trees between the years 2012 and 2013 was calculated. A maximum limit for yearly diameter growth was set at 50 mm/year; trees exceeding these limits were sorted away. Negative yearly diameter growths were also sorted away, as they indicate either measurement error or a dead tree (as bark fall off). In the cases where diameter growth was compared between different years, only trees with complete measurement series and values within the limits were chosen. One exception from this was made for parcels in Visborggaard due to lack of measurements during 2012. Measurements were taken 2008 and 2013, so in order to calculate an average yearly diameter growth the mean between the years was used (growth 2013 minus growth 2008 divided by 5).

Trees were divided into different classes based on their number of epicormic shoots from 0-6 m up the stem and then presented in a bar chart. For every parcel proportions of trees with and without leaves and epicormic shoots were calculated, as well as the share of the different quality classes and primary crown ratings. The average proportion of the secondary crown (%) was also calculated for each parcel. Regarding the potential future crop trees, the proportion of trees assessed to Yes, Uncertain or No was calculated for this year (2013) and a previous year for comparison. The comparison was only made for individual trees that were assessed both years. The share of living and dead ash trees was also calculated for every parcel.

## 3.7 Tree coordinate data

Previous tree coordinate data of sample plot 1 in Saebygaard Skov was imported to Arc Map © (version 10.1). By using the individual tree number, their spatial location and primary crown score was linked and presented in a distribution map. The position of dead trees was also included. In order to make identification of patterns easier, clusters of dead trees and trees with a primary crown score of 0 and 1 were encircled.

## 3.8 Statistical analyses

Comparisons between the different treatments for each experimental stand (controls, 1500 tr/ha, 500 tr/ha and 100 tr/ha) concerning quality class distribution, primary crown rating, epicormic shoot frequency and epicormic shoots on future trees were made using a Chi-Square Goodness of fit Test in Minitab© Statistical Software (version 16). Because I wanted to test whether a frequency distribution with many classes differed between the treatments, a Chi-square goodness of fit test was suitable to use (Bluman 1997). The tests were made with two treatments at the time for each experimental stand, where one treatment was set as the observed and the other as expected to see if there were any significant differences (for all runs see appendix 7.1). The probability value (p) for acceptance/rejection of hypothesis was set to 0, 05. Minitab was also used to calculate Standard Error and 95 % confidence interval for average diameter, average diameter growth per year and average number of epicormic shoots.

# 4. Results

## 4.1 Quality class distribution

**No. 1425 Saebygaard Skov:** The proportion of good and possibly good quality (class A & A2) was significantly higher ($P<0.05$) in the sample plots thinned to 1500 tr/ha, whereas the proportion of bad quality due to sweeps or crooks in the stem (class C) was much lower than in the controls (see table 2.). Plots thinned to 500 tr/ha had somewhat higher proportion of class A/A2 and lower proportion of class C compared to the control plots. In total thinned to 1500 tr/ha was the best plot out of a quality standpoint, a trend also seen when summarizing the results from all experimental stands (see fig. 8).

**No. 1535 Visborggaard:** In the sample plot thinned to 100 tr/ha there was a significantly higher ($P<0.05$) proportion of class A & A2 and much lower proportion of class C compared to thinned to 500 tr/ha (see table 2).

**No. 1424 Sebberup Skov:** No significant difference in the quality class distribution between sample plots thinned to 500 tr/ha and 100 tr/ha was seen (see table 2).

**No. 1423 Haderslev Vesterskov:** There was a significantly higher proportion of class A & A2 and lower proportion class B ($P<0.05$) in thinned to 1500 tr/ha compared to controls and thinned 500 tr/ha (see table 2). The control plot had somewhat higher proportion of class A/A2 and lower proportion of class B compared to thinned to 500 tr/ha. Thinned to 1500 tr/ha was the best plot out of a quality standpoint.

**Table 2.** Results presented as P- values, acquired from chi-square goodness of fit tests performed in Minitab, where quality class distributions are compared between different treatments in each experimental stand. Significant level was set to 0.05, P - values below this were considered as significant and marked with an asterisk.

| Experimental area | Compared treatments | Probability value (p) |
|---|---|---|
| No. 1425 Saebygaard Skov | Control vs thinned to 1500 tr/ha | <0.0001* |
| No. 1425 Saebygaard Skov | Control vs thinned to 500 tr/ha | 0.02* |
| No. 1425 Saebygaard Skov | Thinned to 1500 tr/ha vs 500 tr/ha | 0.013* |
| No 1535 Visborggaard | Thinned to 500 tr/ha vs 100 tr/ha | <0.0001* |
| No. 1424 Sebberup Skov | Thinned to 500 tr/ha vs 100 tr/ha | 0.392 |

| | | |
|---|---|---|
| No. 1423 Haderslev Vesterskov | Control vs thinned to 1500 tr/ha | 0.032* |
| No. 1423 Haderslev Vesterskov | Control vs thinned to 500 tr/ha | 0.043* |
| No. 1423 Haderslev Vesterskov | Thinned to 1500 tr/ha vs 500 tr/ha | <0.0001* |

**Summarized results:** Thinned to 1500 tr/ha had the highest proportion of good and possibly good quality trees (class A & A2) and among the lowest proportion of trees in the bad quality classes B & C (see fig. 8). Thinned to 500 tr/ha and controls had the lowest proportion of good quality trees and the highest proportion of bad quality trees due to sweeps and crooks on the stem (class C). Thinned to 100 tr/ha had a high proportion of good quality stems but also the highest proportion of bad quality trees due to branches and epicormic shoots (class B).

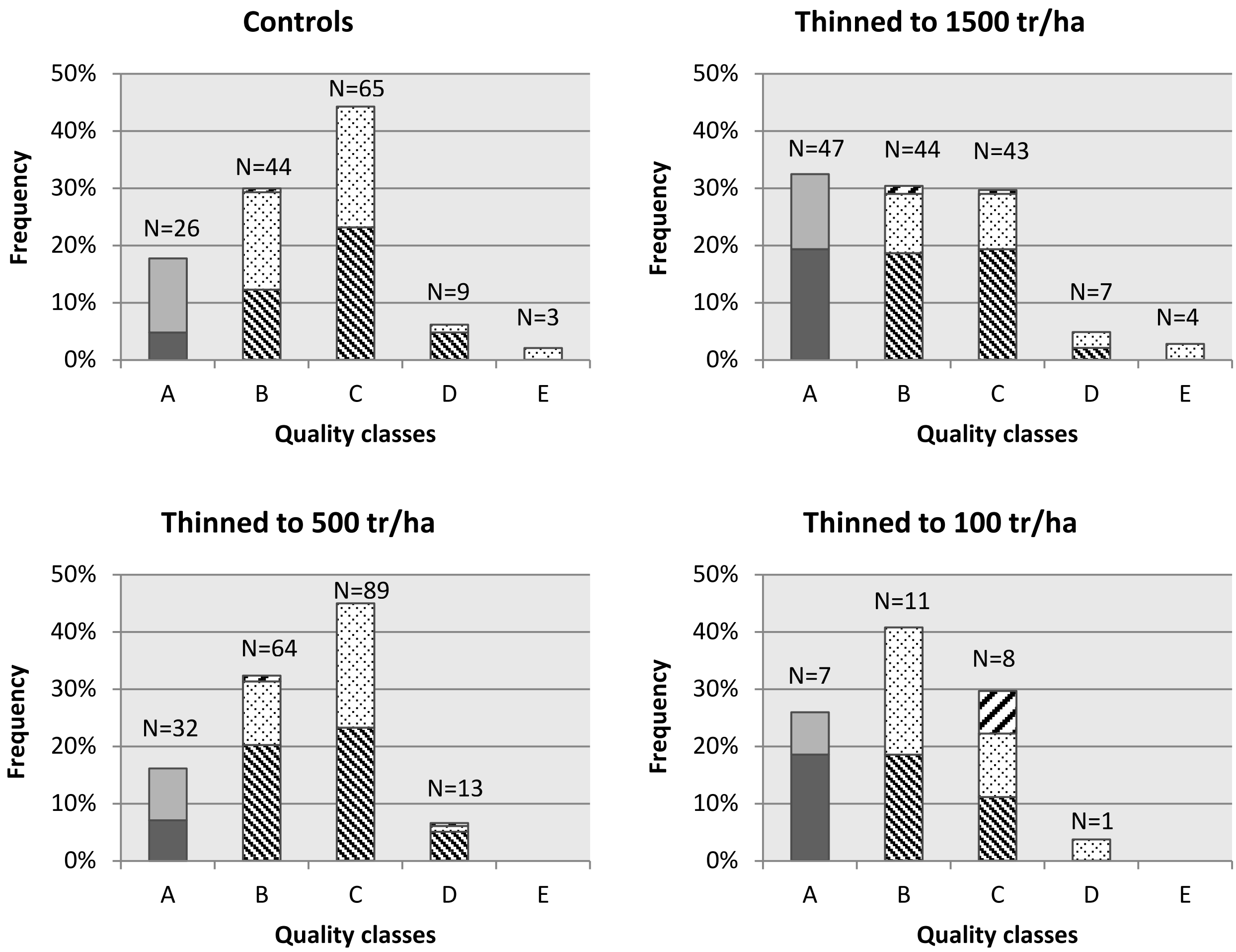


**Figure 8.** Distribution of quality classes (A/A2, B, C, D and E) for controls, thinned to 1500 tr/ha, 500 tr/ha and 100 tr/ha. The proportions (%) of the quality classes are based on the total number of trees in all sample plots for each treatment.

| | |
|---|---|
| A | = Good quality stem relatively free from branches and epicormic shoots |
| A2 | = Possible good quality, not meeting requirements for class A due to some defect |
| Reason 1 | =Bad quality stem (class B, C, D and E) with only one reason for bad quality |
| Reason 2 | =Bad quality stem (class B, C, D and E) with one additional reason for bad quality |
| Reason 3 | =Bad quality stem (class B, C, D and E) with two additional reasons for bad quality |

## 4.2 Primary crown ratings

**No. 1425 Sabeygaard Skov:** The distribution of primary crown ratings differed significantly between controls and sample plots thinned to 1500 tr/ha (see table 3). The proportion of primary crowns with the best rating P(3) was much higher in plots thinned to 1500 tr/ha. Thinned to 500 tr/ha had a higher proportion of P(3) and lower proportion of P(0) compared to control plots. Thinned to 500 tr/ha had a higher proportion of P(2.5) but lower proportion of P(3) compared to thinned to 1500 tr/ha. The thinned plots had much higher primary crown scores than the control plots, a trend also seen when summarizing the results from all experimental stands (see fig. 9).

**No 1535 Visborggaard:** The distribution of primary crown scores differed significantly between plots thinned to 500 tr/ha and plots thinned to 100 tr/ha (see table 3). Plots thinned to 500 tr/ha had a higher proportion of P(2) but lower proportion of P(3) compared to thinned to 100 tr/ha. The average primary crown score was somewhat higher for plots thinned to 100 tr/ha.

**No. 1424 Sebberup Skov:** Sample plot thinned to 100 tr/ha had a significantly higher proportion of P(3) and P(1) compared to thinned to 100 tr/ha(see table 3). Thinned to 500 tr/ha had more even and higher average primary crown score than 100 tr/ha, a trend seen when summarizing the results from all experimental stands as well (see fig. 9).

**No. 1423 Haderslev Vesterskov:** Thinned to 1500 tr/ha had a significantly higher proportion of P (3) & P(2.5) and much lower proportion of P(0) compared the control plots (see table 3). The proportion of P(0) and P(3) was higher in the controls than in thinned to 500 tr/ha. Sample plots thinned to 1500 tr/ha had the highest primary crown scores, with high proportions of P(3) & P(2.5) and lowest proportions of P(1) & P(0).

**Table 3.** Results presented as P- values, acquired from chi-square goodness of fit tests performed in Minitab, where primary crown ratings are compared between different treatments in each experimental stand. Significant level was set to 0.05, P - values below this were considered as significant and marked with an asterisk.

| Experimental area | Compared treatments | Probability value (p) |
|---|---|---|
| No. 1425 Saebygaard Skov | Control vs thinned to 1500 tr/ha | <0.0001* |
| No. 1425 Saebygaard Skov | Control vs thinned to 500 tr/ha | <0.0001* |
| No. 1425 Saebygaard Skov | Thinned to 1500 tr/ha vs 500 tr/ha | <0.0001* |
| No 1535 Visborggaard | Thinned to 500 tr/ha vs 100 tr/ha | 0.018* |
| No. 1424 Sebberup Skov | Thinned to 500 tr/ha vs 100 tr/ha | 0.005* |
| No. 1423 Haderslev Vesterskov | Control vs thinned to 1500 tr/ha | <0.0001* |
| No. 1423 Haderslev Vesterskov | Control vs thinned to 500 tr/ha | <0.0001* |
| No. 1423 Haderslev Vesterskov | Thinned to 1500 tr/ha vs 500 tr/ha | <0.0001* |

**Summarized results:** Thinned to 100 tr/ha had the highest proportion of fully leafed primary crowns P(3) but also one of the highest proportion of trees without leafed primary crowns P (0) (see fig. 9). Controls had the lowest proportion of P(3) & P (2.5) put together and the highest proportion P (0). Thinned to 1500 tr/ha and thinned to 500 tr/ha had the highest and most even distribution of the different primary crown ratings.

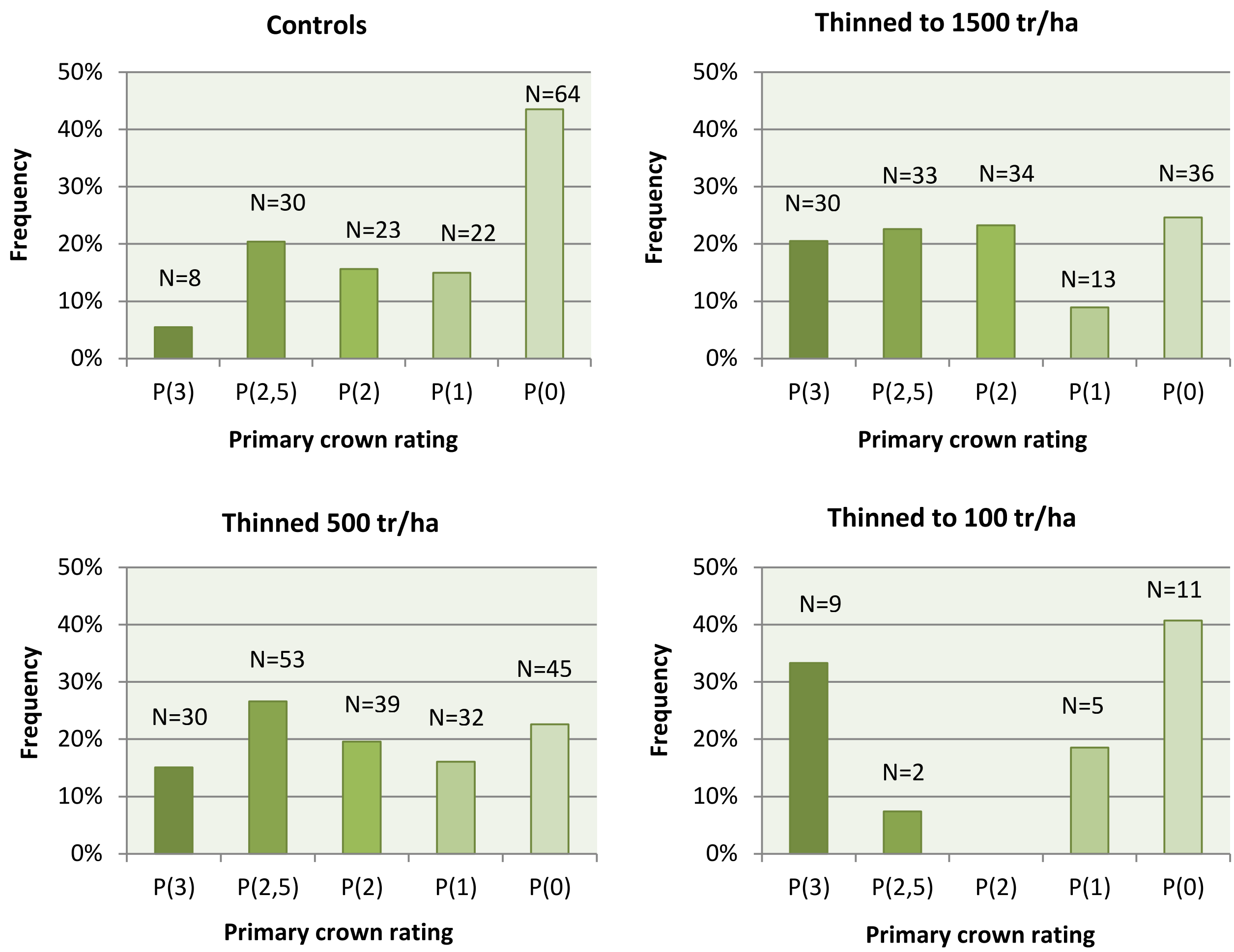


**Figure 9.** Distribution of primary crown ratings (3, 2.5, 2, 1, 0) for controls, thinning grade 1500 tr/ha, 500 tr/ha and 100 tr/ha. The proportions (%) of primary crown ratings are based on the total number of trees in all sample plots for each treatment.

P(3) = Dense, full or largely full primary crown

P(2,5) = Almost full primary crown, somewhat sparse

P(2) = Sparse intermediate primary crown

P(1) = Primary crown with only few leaves

P(0) = Primary crown without any leaves

## 4.3 Epicormic shoot frequency

**No. 1425 Saebygaard Skov:** A significant difference in the frequency of epicormic shoots between controls and thinned to 1500 tr/ha (see table 4). The sample plot thinned to 1500 tr/ha had a much lower proportion of the class 16-20 epicormic shoots. No significant difference between plots thinned to 500 tr/ha and controls, as well as thinned to 500 tr/ha and thinned to 1500 tr/ha was seen. Thinned plots had lower proportions of the class 16-20 epicormic shoots than control plots.

**No. 1535 Visborggaard:** A significant difference in epicormic shoot frequency between plots thinned to 500 tr/ha and 100 tr/ha was found (see table 4).Thinned to 500 tr/ha had much higher proportions of trees without epicormic shoots (class 0) compared to plots thinned to 100 tr/ha.

**No 1424 Sebberup Skov:** Frequency of epicomic shoots differed significantly between plots thinned to 500 tr/ha and 100 tr/ha (see table 4). The proportion of the class 16-20 epicormic shoots was higher in plots thinned to 100 tr/ha. The average number of epicormic shoots was lower in thinned to 500 tr/ha compared to thinned to 100 tr/ha.

**No. 1423 Haderslev Vesterskov:** A large significant difference in the proportion of epicormic shoots was seen when comparing controls with plots thinned to 1500 tr/ha (see table 4). Thinned to 1500 tr/ha had much higher proportion of trees without epicormic shoots (class 0) than the control plots. No difference was found when comparing controls and plots thinned to 500 tr/ha. Sample plots thinned to 1500 tr/ha had the lowest frequencies of epicormic shoots, where over 60 % of the trees were free from epicormic shoots (class 0). This was a trend also seen when summarizing the results from all experimental stands (see fig. 10).

**Table 4.** Results presented as P- values, acquired from chi-square goodness of fit tests performed in Minitab, where epicormic shoot frequencies are compared between different treatments in each experimental stand. Significant level was set to 0.05, P - values below this were considered as significant and marked with an asterisk.

| Experimental area | Compared treatments | Probability value (p) |
|---|---|---|
| No. 1425 Saebygaard Skov | Control vs thinned to 1500 tr/ha | 0.001* |
| No. 1425 Saebygaard Skov | Control vs thinned to 500 tr/ha | 0.311 |
| No. 1425 Saebygaard Skov | Thinned to 1500 tr/ha vs 500 tr/ha | 0.094 |
| No 1535 Visborggaard | Thinned to 500 tr/ha vs 100 tr/ha | <0.0001* |
| No. 1424 Sebberup Skov | Thinned to 500 tr/ha vs 100 tr/ha | <0.0001* |
| No. 1423 Haderslev Vesterskov | Control vs thinned to 1500 tr/ha | <0.0001* |
| No. 1423 Haderslev Vesterskov | Control vs thinned to 500 tr/ha | 0.062 |
| No. 1423 Haderslev Vesterskov | Thinned to 1500 tr/ha vs 500 tr/ha | <0.0001* |

**Summarized results:** Thinned to 1500 tr/ha had the highest frequency of trees without epicormic shoots (class 0) and lowest frequency in class 16-20 shoots (see fig. 10). Thinned to 100 tr/ha had the highest frequency of epicormic shoots in class 11-15 & 16-20 shoots and lowest frequency in class 0 & 1-5 shoots. Controls and thinned to 500 tr/ha had similar distribution of the different classes with the highest frequencies of class 1-5 shoots.

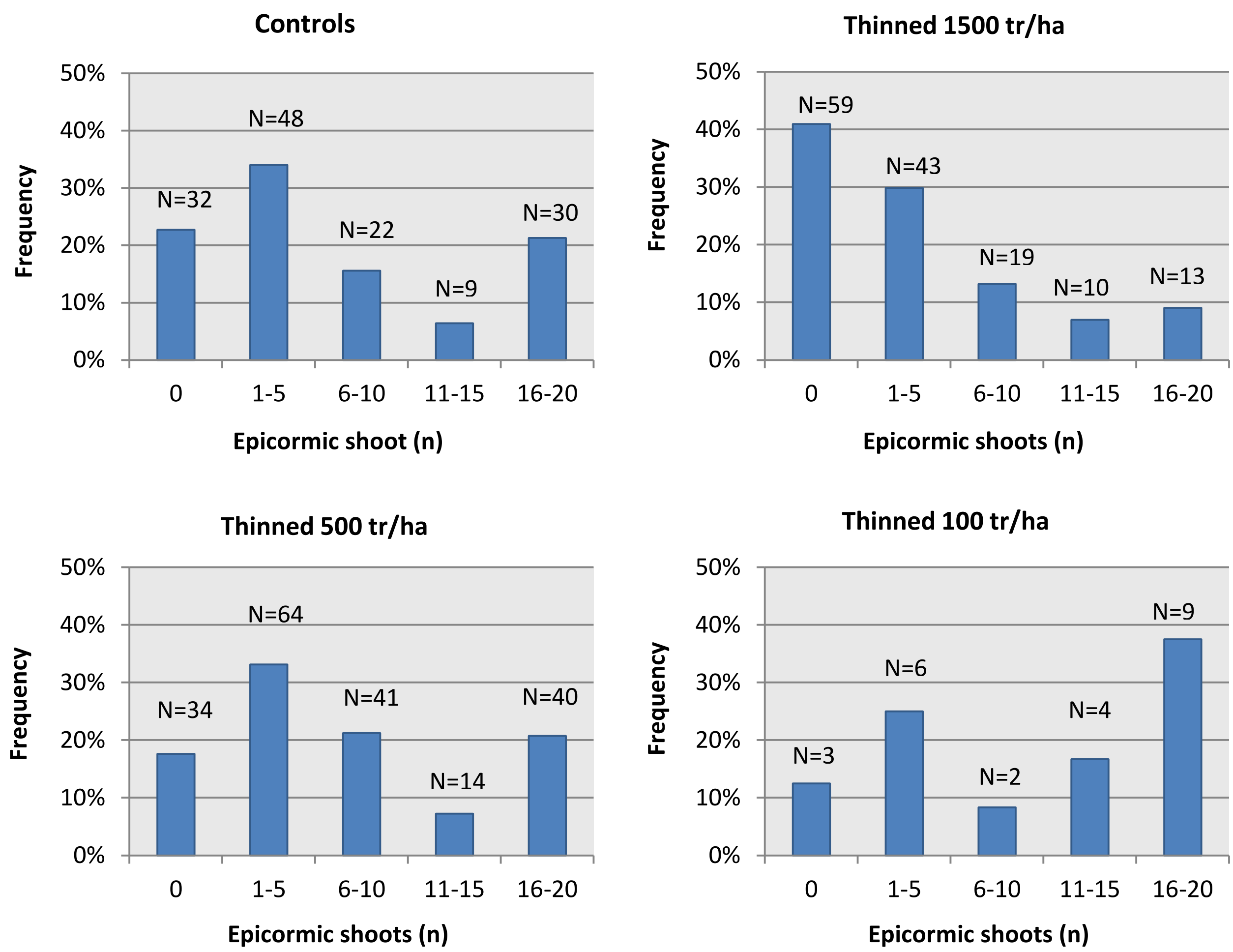


**Figure 10.** Frequency of epicormic shoots in different classes based on observed numbers 0 to 6 m up the tree stem, where control, thinning grade 1500 tr/ha, 500 tr/ha and 100 tr/ha are compared. The proportions (%) of epicormic shoot are based on the total number of trees in all sample plots for each treatment.

## 4.4 Summary of measurements and assessments made in field

**Table 5.** Summary of various variables measured and assessed in sample plots, where four different stem densities are compared. A & A2 are trees assessed as good and possibly good quality trees, P (3) & P (2.5) are trees with fully to almost fully leafed primary crowns. Values in parenthesis are standard error.

| Variables | Control | 1500 tr/ha | 500 tr/ha | 100 tr/ha |
|---|---|---|---|---|
| Measured plots (n) | 3 | 3 | 6 | 2 |
| Measured/Assessed trees (n) | 494/147 | 146/146 | 231/199 | 33/28 |
| Average proportion A & A2 (%) | 18 % | 32 % | 16 % | 26 % |
| Average diameter (mm) | 107 (±2,9) | 145 (±5,6) | 153 (±4,1) | 167 (±14,8) |
| Average diameter growth (mm/year) | 3.8 (±0,43) | 7.1 (±0,88) | 7.5 (±0,78) | 6. 2 (±1,75) |
| Average proportion of trees without epicormic shoots (%) | 13 % | 26 % | 9 % | 11 % |
| Average number of epicormic shoot (n) | 7 (±1,26) | 5 (±1,027) | 8 (±1,034) | 11 (±3,41) |
| Average proportion secondary crown (%) | 49 % | 28 % | 41 % | 50 % |
| Average proportion P(3) & P(2.5) | 26 % | 43 % | 42 % | 41 % |
| Average primary crown rating | 1.1 | 1.7 | 1.7 | 1.4 |
| Average proportion of trees with leaves (%) | 90 % | 89 % | 91 % | 93 % |
| Average proportion living trees (%) | 77 % | 84 % | 73 % | 59 % |

## 4.5 Potential future crop trees, development between years

### 4.5.1 Future crop trees 2013 compared to 2010 (thinned 1500 tr/ha)

The proportion of epicormic shoots in different classes on F - trees differed significantly between the years 2010 and 2013 ($P<0.05$). In 2010 the proportion of F - trees without epicormic shoots (class 0) was much higher than in 2013 (see fig. 11). In 2013 the F - trees had much higher proportion of trees in class 1-5 shoots and somewhat higher proportion in class 6-10. Results point towards an increase of epicormic shoots on trees between the years 2010 and 2013 in the sample plot thinned to 1500 tr/ha. Results from the F-tree status assessment showed a down going trend between the years, where 21 % of trees were no longer considered as F – trees in 2013 (see fig. 12).

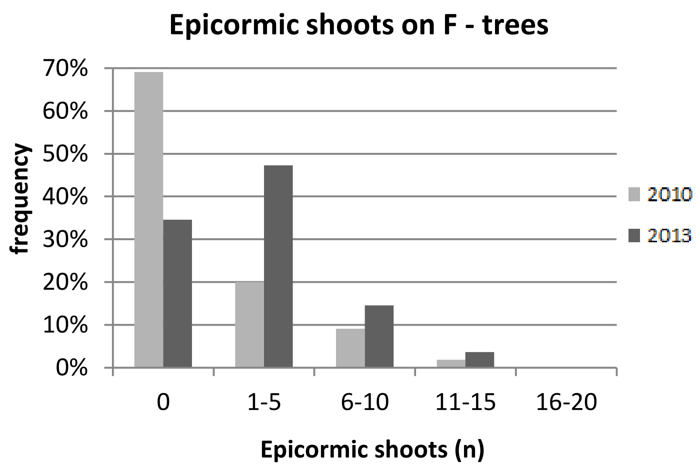


**Figure 11.** Frequency of epicormic shoots from stem 0-6 m on 58 future crop trees for the year 2010 and 2013 in two sample plots located in Saebygaard Skov, thinned to 1500.

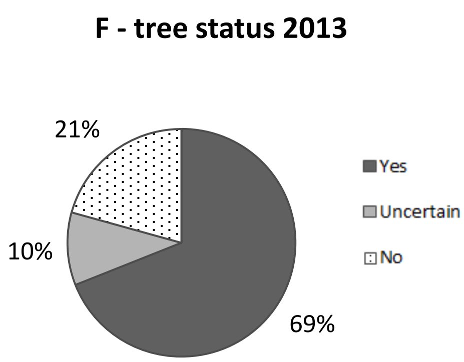


**Figure 12.** Development of original future crop trees (n=58) in two sample plots in Saebygaard Skov thinned to 1500 tr/ha, selected in 2010. The future crop trees were reassessed in 2013 and their status was noted as Yes, Uncertain or No, based on whether the trees still were considered to have a good possibility to survive and form a future stand.

### 4.5.2 Future trees 2013 compared to 2012 (thinned 500 tr/ha)

No significant difference (P>0.05) in the proportion of epicormic shoots on F - trees between 2012 and 2013 was found in the sample plot thinned to 500 tr/ha (see fig. 13). Results from the F-tree status assessment showed a down going trend between the years, where 23 % of trees were no longer considered as F – trees in 2013, compared to 10 % in 2012 (see fig. 14).

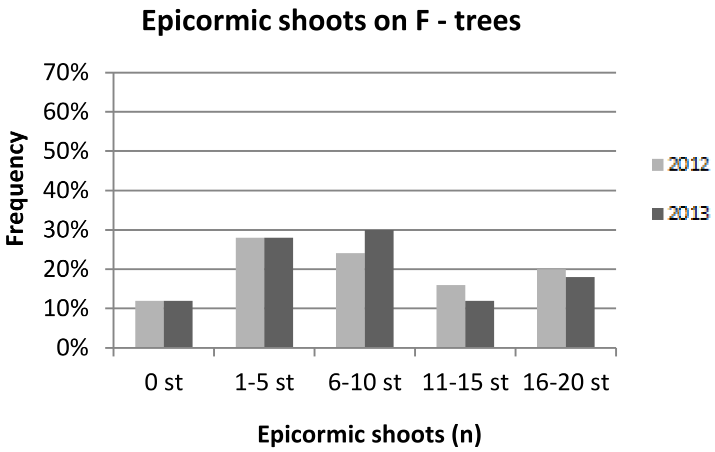


**Figure 13.** Frequency of epicormic shoots from stem 0-6 m on future crop trees (n=53) for the year 2012 and 2013 in one sample plot in Sebberup thinned to 500 tr/ha.

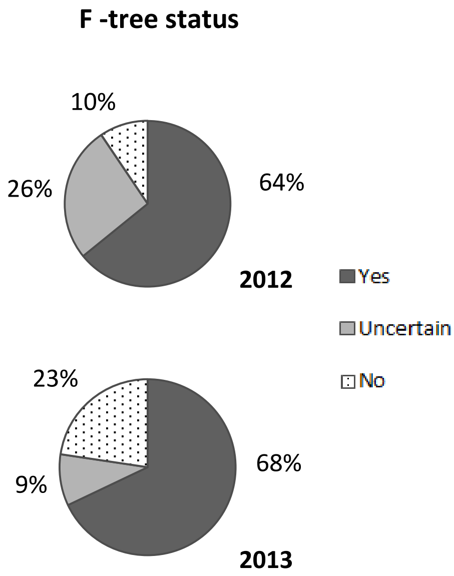


**Figure 14.** Development of future crop trees (n=53) from 2012 to 2013 in one sample plot in Sebberup. The future crop trees were reassessed in 2013 and their status was noted as Yes, Uncertain or No, based on whether the trees still were considered to have a good possibility to survive and form a future stand.

### 4.5.3 Future trees 2013 compared to 2012 (thinned 100 tr/ha)

No significant difference (P>0.05) in the proportion of epicormic shoots on F - trees between 2012 and 2013 was found in the sample plot thinned to 100 tr/ha (see fig. 15). Results from the F-tree status assessment showed a down going trend between the years, where 33 % of trees were no longer considered as F – trees in 2013, compared to 16 % in 2012 (see fig. 16).

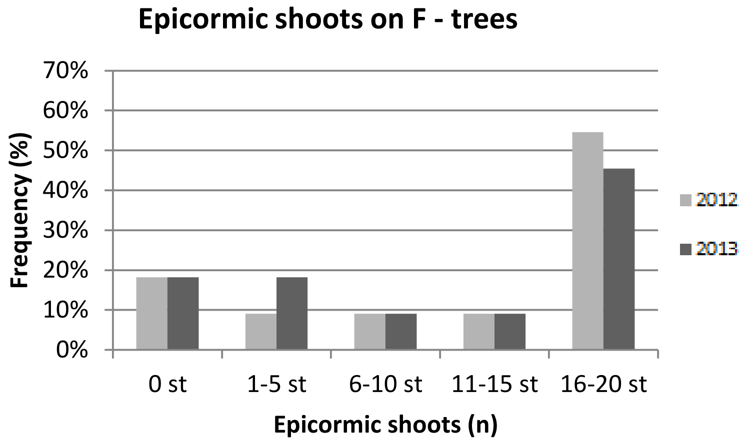


**Figure 15.** Frequency of epicormic shoots from stem 0-6 m on 12 future crop trees in one sample plot in Sebberup thinned to 100 tr/ha for the year 2012 and 2013.

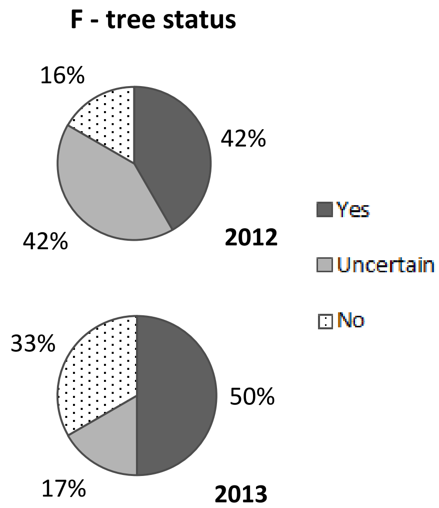


**Figure 16.** Development of future crop trees (n=12) from 2012 to 2013 in one sample plot in Sebberup. The future crop trees were reassessed in 2013 and their status was noted as Yes, Uncertain or No, based on whether the trees were considered to have a good possibility to survive and form a future stand.

## 4.6 Spatial position of healthy and diseased trees in Saebygaard Skov plot 1

A clear trend of grouping of diseased and dying trees with primary crown ratings 0 and 1, as well as trees that died between 2012 and 2013 is seen.

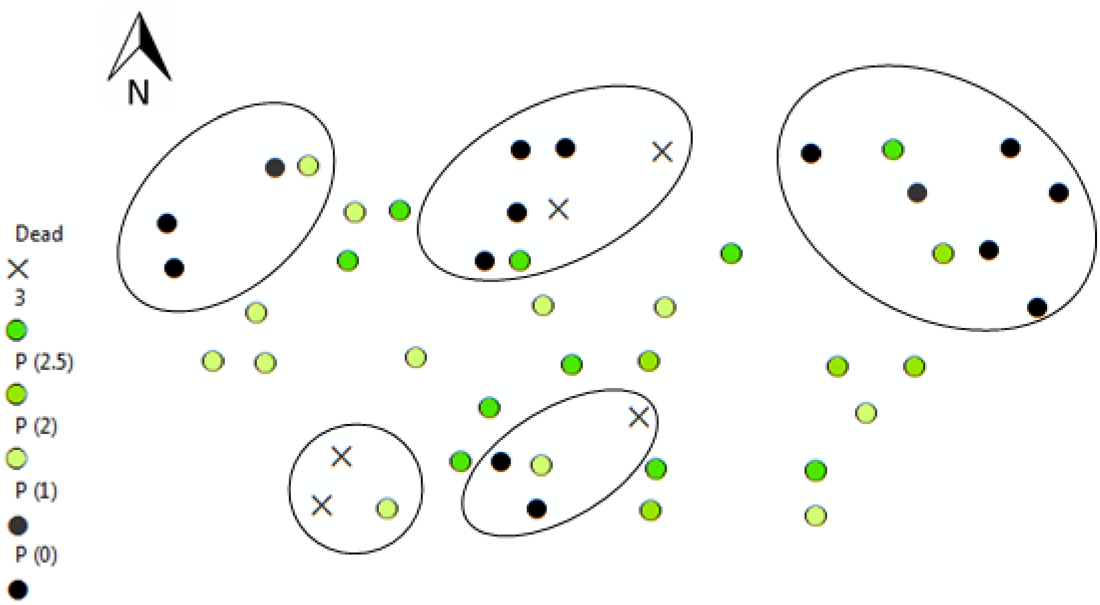


**Figure 17.** Spatial distribution of healthy and diseased trees constructed in Arc GIS, based on primary crown ratings (Saebygaard Skov No. 1425 sample plot 1) made in field. Trees that died between 2012 and 2013 were also included. To make identification of patterns easier, clusters of dead trees (X) and trees with a primary crown (P) score of 0 (no leaves) and 1 (few leaves) were encircled.

# 5. Discussion

## 5.1 Quality class distribution

The definition of stem quality can differ a lot, but generally trees with relatively thick, straight and branch free stems are considered to be of good quality (Dobrowolska et al. 2011). In order to get trees of high quality it is important that they have enough growing space (Kerr 1998). If thinnings are delayed, the crowns get small and the risk of black heart increases. The low proportion of good and possibly good quality (A & A2) in the control plots was therefore expected. Ash is a very light demanding species once it has reached a height of 6-7 m (Kerr & Cahalan 2003). The control plots were very dense, resulting in high competition for light. This could probably explain the high proportion of trees with sweeps and crooks on their stem (class C), as they have grown trying to reach an opening in the closing canopy.

Results showed that plots thinned to 1500 tr/ha had the highest proportion of trees in the good quality classes A & A2 and among the lowest proportion of trees in the bad quality classes B & C. This is interesting, because heavy thinnings are often recommended when aiming for a production of high quality ash timber (Rytter 1998). But in these results the heavier thinning (500 tr/ha) had a much lower proportion of trees in class A & A2, equal that of the control plots. However the heaviest thinned plots (100 tr/ha) had a high proportion of good quality trees (A) but also the highest proportion of bad quality trees due to branches and epicormic shoots (class B). This indicates that there might be other factors besides thinning affecting the quality of the trees. Factors such as frequency of ash dieback, drainage conditions, exposure to wind etc. may differ between plots and will be discussed further in the spatial position of healthy/diseased trees and observations in field.

## 5.2 Primary crown ratings

The low proportion of fully leafed primary crowns (3) in the control plots was expected, due to the dense conditions with high competition for light. The reason why the control plots had the highest proportion of primary crowns without any leaves (0) is probably severe intraspecific competition. However ash dieback could also be an important factor, as a lot of the trees were of small diameter, making them more susceptible to the disease (Skovsgaard et al. 2010). Sample plots thinned to 100 tr/ha had the highest share of fully leafed crowns, which seem reasonable as the trees are given plenty of space to develop their crowns. Heavy thinned plots to 100 tr/ha also had among the largest share of crowns without leaves. One explanation could be the tough selection, where the sick and weaker trees gets worse by increased stress and the healthier trees gets increased space to grow. Thinnings to 1500 tr/ha and 500 tr/ha gave the best result, these stands seem to be more healthier with more trees having primary crown ratings of 3, 2.5 and 2.

## 5.3 Epicormic shoots

Normally, ash has a lower tendency of developing epicormic shoots than for example oak (Kuehne et al. 2013). Trees in sample plots thinned to 1500 tr/ha had the lowest number of epicormic shoots, with over 40 % of the trees with 0 shoots. Whereas plots thinned to 100 tr/ha had a very high proportion of trees in the class 16-20 shoots. It is interesting as studies have shown that increased spacing rather leads to fewer epicormic shoots than increased. One probable reason is that the much heavier thinning causes increased stress. Stressed trees are possibly more easily attacked by ash dieback, which is known to cause leaf loss in the upper crown (Skovsgaard et al. 2010). To sustain their photosynthesis, trees then produce epicormic shoots along the stem. Additionally, trees affected by ash dieback are often associated with formation of prolific epicormic shoots on their stem (Halmschlager & Kirisits 2008; Forestry Commission 2013). With this in mind, the results are exciting as they show an almost similar distribution of epicormic shoots for thinned to 500 tr/ha and the control plots. It indicates that factors other than thinning play an important role in the occurrence of epicormic shoots, e.g. site conditions and frequency of ash dieback. This will be further discussed in spatial position of healthy/diseased trees and observations in field.

## 5.4 Potential future crop trees

The results concerning the potential future crop trees are interesting as they show the development of individual trees between years, perhaps revealing what factors affect tree health. Comparisons between years within one treatment but also between the different treatments can be made.

In 2013 compared to 2010 in Saebygaard Skov sample plot 1 (thinned to 1500 tr/ha), about 12 trees out of 58 future crop trees (21 %) were considered to not have a good possibility to survive and form a future stand anymore. Similar results are seen in the two other plots; with about 15 % more trees in the class no potential future crop trees in 2013 compared to 2012. All assessed plots point towards same down going trend regardless of the treatment, a yearly change where about 10-15 % of the trees are no longer considered as potential future crop trees. These results points towards a rapid deterioration of the health of the trees, indicating the severity and large scale effect of ash dieback.

When comparing the frequency of epicormic shoots on the future crop trees between the three sample plots some differences were found. In the plot thinned to 1500 tr/ha there was a clear increase in the frequency of epicormic shoots, whereas in the two other plots thinned to 500 tr/ha and thinned to 100 tr/ha no such trend was seen. It is very hard to point out one single factor as the main reason, as there could be several explanations. Less severe attacks between 2012 and 2013, old epicormic shoots die and fall off or just simply the shorter time span of one year instead of three years are possible explanations to why there is no increase in epicormic shoots.

## 5.5 Summarized results of measurements and assessments

The summarized results show that no silvicultural management i.e. control plots results in stands with a high proportion of the trees with small diameters, low yearly diameter growth, bad quality due to sweeps and crooks on stem and primary crowns without leaves. Even though the control plots had relatively low frequencies of epicormic shoots it is obvious that no silviculture is a bad option if good tree health and quality is the aim.

Compared to the control plots, really heavy thinnings down to a stem density of 100 tr/ha, results in stands with a high proportion of trees of good quality but also of bad quality due to multiple reasons mainly epicormic shoots, branches and stem sweeps. The same tendency is seen in the primary crown score distribution where thinned to 100 tr/ha had many trees with full crown foliage but also many without any leaves. A probable explanation could be the increased stress caused by the heavy thinning, perhaps increasing attacks by ash dieback. This would lead to a strong selection where stronger more resistant trees are favored and already diseased and weakened trees quickly die. Very heavy thinnings such as 100 tr/ha is probably not suitable in stands with ash dieback (nor in healthy stands), as they most likely increase tree mortality and leave behind very sparse stands.

The heavy thinning of 500 tr/ha resulted in very low proportion of good quality stems and high proportions of bad quality stems. Out of a quality stand point the sample plots thinned to 500 tr/ha were among the worst together with the control plots.

Sample plots thinned to 1500 tr/ha gave the most optimal results with many trees with good quality, no epicormic shoots and high primary crown score. Although the thinning strength of 1500 tr/ha gave the best result out of a quality and health perspective, there could be other factors besides thinning affecting the results. These factors will be further discussed in the next session.

All assessments of potential future crop trees showed the same down going trend regardless of treatment, a yearly change where about 10-15 % of the trees are no longer considered as potential future crop trees. These results points towards a rapid deterioration of the health of the trees, indicating the severity and large scale effect of ash dieback.

## 5.6 Spatial position of healthy/diseased trees and observations in field

One interesting question to ask is if similar results had been seen in stands without ash dieback and whether there are differences between sites. Based on the results and observations in field it seems likely they would differ. The fact that plots thinned to 500 tr/ha and control plots had equal proportions of good and bad quality trees as well almost the same frequencies of epicormic shoots supports this idea. One or several factors affecting the results are possible but to identify or even quantify these can be difficult. However in this case the observations in field strongly suggest that water drainage conditions play an important role. Personal observations made in field from the majority of the plots indicated a clear trend, with more dead and dying trees in the bottom of dips and healthier trees on slopes and on higher flatter ground. A good example of this observation can be seen on the photos taken in control plot 6 in Haderslev Vesterskov (appendix 7.3). The grouping of dead and dying trees in dips was made even clearer in the map constructed for Saebygaard Skov based on tree coordinates (Fig. 17).

The most likely explanation is that trees growing in the dips and lower ground are more stressed due to poor drainage and maybe also more severely attacked by ash dieback. Many plots were also located on clay soils which often have problems with water-saturation and strongly retained water, causing lack of oxygen and plant available water (Magnusson 2009). Even though ash can survive waterlogging to some extent it is certainly not optimal conditions and prolonged periods will eventually kill the tree (Wardle 1961). Sudden changes in water level could also be an effect to be reckoned with, causing stress to trees adapted to more stable conditions. It may also be so that the physiological amplitude of ash, once described by Ellenberg (1996), changes due to ash dieback (Fig. 18). Further studies are needed to clarify the relationship between host, pathogen and environmental factors.

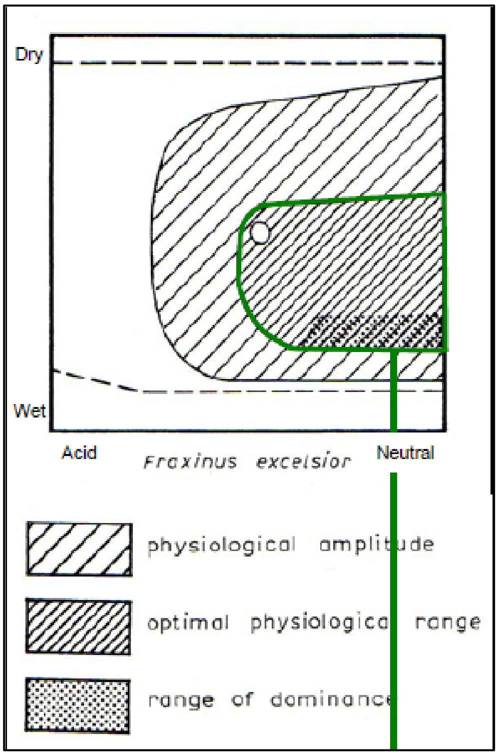


**Figure 18.** Ecological site requirements for European ash *Fraxinus excelsior* (Ellenberg 1996).

Ash dieback has caused major damage to ash stands all over Europe with high mortality. Since ash dieback has been observed in all of the experimental stands visited, self-thinning due to ash dieback could definitely be a factor worth of considering (Johansson et al. 2009). If trees die off frequently every year, stands will be sparser and this will correspond to a heavier thinning, possibly with increasing stress as the result. To determine what local factors affect these ash dieback stands is very important, when main focus is on good tree quality and health (Bakys et al. 2013). In this case where site factors seem very important for tree health and water conditions in particular, they should be considered with extra care.

## 5.7 Sources of error and evaluation of method

Some of the measurements and assessments carried out in field were connected with certain weaknesses and difficulties. One example was the difficulty of determining whether trees were dead or not, as they may lose all foliage but still be alive. In case of uncertainty I checked the branches and epicormic shoots, if they snap off the tree was dead and if they were flexible the tree was still alive. Another difficulty that I experienced in some of these ash stands was that stems were hidden by high undergrowth of bushes and stinging nettles, making assessments difficult. In some stands there was also plenty of lying dead trees, making it hard to move.

The fact that the measurements were only carried out in young even aged stands is a limitation, to measure in both young and old stand would have been preferred. Sample plots thinned to 100 tr/ha had a smaller sample than the other treatments, a factor that may have affect the results. Another factor that could have influenced my results was the differences in site condition within and between sample plots. However, due to field observations and notes, site factors were taken into considerations to some extent.

The use of assessments can often be connected with certain weaknesses as they may differ depending on the person. One example is the assessment of trees as potential future crop trees carried out by different persons. But in most cases the assessments were relatively easy to make, even though e.g. some trees had primary crowns between two ratings, they were so few it probably did not affect the result very much.

Many of the methods I used can be seen as fairly simple but they can be very useful to get a quick overview of the status in ash dieback stand. Methods like quality assessments, primary crown ratings, counting of epicormic shoots and identification of potential future crop trees, I find suitable to be used by e.g. forest owners dealing with these stands. If the methods are used each or every two years, it will give information on current and possibly also the expected future stand development. Knowledge that can be useful when planning how to manage ash dieback stands, where conditions can change swiftly.

Regardless whether field observations lead to statistically reliable results, I see them as a good way of discovering interesting things that otherwise could have been missed. In my study the observations I made in field gave indications that site factors seemed to largely affect my results and not just thinning strength. This gave me possibilities to better interpret my results. Another easy and useful method is to take photos in the stand, perhaps from selected spots or on potential future crop trees, making it easier to assess the development of the trees as well as sharing observations between parties.

## 5.8 Silvicultural guidelines

Based on the results and observations in this study complemented with Skovsgaard et al (2009), I here present some silvicultural guidelines on how to manage young to middle-aged ash stands infected by ash dieback. Because of the severity of disease and its influence on management, I distinguish between dying stands with extensive attacks and stands with many apparently “healthy or somewhat healthy trees”.

**5.8.1 Stands with extensive attacks:** In young stands up to about 40 years with extensive attacks by ash dieback, there is sadly not much to do. When the honey fungus attacks the weakened trees they will quickly die (Thomsen & Skovsgaard 2007). In such cases final felling followed by chipping is often the best option (Skovsgaard et al. 2009). An alternative can be to let the dying stand act as shelter for planting with other tree species.  Another possible option if there are some healthier looking trees is to save them, giving them a chance of producing resistant individuals and then replacing with other species in the gaps either by planting or natural regeneration. Hopefully with the ongoing project of selecting for tolerant clones e.g. in Denmark, there will be resistant ash available for planting quite soon (Skovsgaard 2013). Most ash sites I visited also had a good natural regeneration of broadleaves like lime, maple, alder, oak as well as ash, gradually filling the gaps. Native species are not the only alternative, replanting with species like Sitka spruce, sycamore, walnut and hybrid aspen can also be a suitable option. To favor other species can be a good idea in many ways, as it for example has been indicated that ash in mixed stands suffers less from ash dieback (Skovsgaard 2013). Having another tree species ensures you economically as well, in case most ash trees would die.

Selection of site is always very important in forestry, but possibly more important in ash dieback stands, where many trees already have poor health. Even though ash can grow on wet sites, it should not be established on waterlogged sites or sites with bad drainage, leading to more stress and poorer health (Wardle 1961). This was clearly seen in the stands visited in this study, where there always were more dead and dying trees in the dips than on higher ground or on the slopes. In these cases where some areas in the stands are at the risk of bad drainage or even waterlogging, it is wiser to replace the ash with black alder or other species more suitable. To have black alder on the wetter parts and ash on better drained areas creates a mix proven to work really well (Almgren et al. 2003; Skovsgaard & Graversgaard 2004). The black alder can improve drainage conditions as well as decreasing the risk of frost on the regeneration. Preferably ash should be established on moist, fertile and well-drained soils (Dobrowolska et al 2011).

**5.8.2 Stands with many healthy trees:** If the stand seems to have a fair chance of survival, a long term conservation strategy should be established. Thinnings of intermediate strength around 1500 tr/ha (not as heavy as 500 tr/ha), where the healthier trees are saved and dead or dying trees are removed is recommended, provided that there are enough healthy trees. This type of selective thinning seems most rational both out of a wood value and conservation standpoint. The remaining stems are given more time and space to increase in diameter and there are possibilities of taking genetic samples to find resistant individuals. Removing the dead and dying trees also makes it easier to monitor and manage the stand, as there will be less dead fallen trees in the way and focus can be on the healthier individuals. Very heavy thinning should be avoided (100 tr/ha or lower) as the stress will increase and there will only be a small selection of trees left. Self-thinning is also a factor worth taken into account, as it increases the strength of performed thinnings. On the other hand if thinnings are made too weak or not at all, it will result in bad quality, small diameters and increased attacks by ash dieback (Bakys et al 2013; Skovsgaard et al 2010).

To make frequent health surveillance during growth seasons is possibly the most important measure dealing with these stands. Surveillance every to every two years is recommended as the health status of the trees can shift quickly, something which also was seen in my results for the potential future crop trees. During surveys, trees of good health and quality should be marked out e.g. with alkyd color and dying trees is to be removed continuously. Simple inventory methods like quality assessment, primary crown rating and future crop tree assessment can preferable be used to get a quick overview of the status of the stand. Trees with bad primary crown ratings (1 and 0) should be removed to favor trees with better ratings (2.5 and 3). As these stands are quite young with long remaining time to harvest, the tolerance to epicormic shoots can be higher. Though, trees with abundant number of epicormic shoots on their stem should preferable be removed as the fungus (*H.pseudoalbidus*) may attack them and cause discoloration in the wood (Skovsgaard et al 2009). The main concern should be on managing the remaining trees of good health so they have best possible growth conditions with good supply of nutrients, light and movable soil water etc.

An alternative to the active management described above is a more passive approach, where the dead and dying ash trees are left. Out of a biodiversity aspect this could be a good strategy, as there will be an increase in dead wood, important for a great variety of species (Pautasso et al 2013). Dead wood and biodiversity could also prevent rash fellings of ash dieback stands or at least prolong the time to final felling. Additionally, leaving the dead and dying trees could increase the time for establishment of other tree species that may outcompete the ash.

The many similarities found comparing my silvicultural guidelines with those presented in Skovsgaard et al. (2009), further supports their suitability to be used when managing ash dieback stands. Since my study was only carried out in stands younger than 40 years, I cannot make any comments on older stands. The main recommendations presented here and by the other report are summarized as follows:

- Favor mixed forests with several species in stands with extensive attacks
- Perform surveillances of the ash stand each or every two years during growth season, to evaluate health status of the trees
- Mark out trees of good health and quality
- Perform thinnings with intermediate strength (to about 1500 tr/ha) and selectively, where bad trees are removed and healthier saved
- Remove trees with bad primary crown ratings (0 and 1) and save trees with better ratings (2.5 and 3)
- Trees with more than half of the primary crown dead (rating 2 or less) should be considered to be cut down
- Remove trees with abundant number of epicormic shoots on the stem
- Alternatively a more passive approach, leave dead and dying trees for biodiversity

## 5.9 The future of the ash

Currently, the future of the ash is very much uncertain as more threats arise following ash dieback. The species has already decreased a lot and will probably continue to do so, partly because of the disease virulence and rapid spreading and partly because stands are cut down and replaced with other tree species. In some parts of Germany for example, current recommendations are to favor alternative species and no longer plant ash, select ash as target crop trees or invest money in ash (Metzler 2013). However the problem is complex, as each country has different conditions, differing in the occurrence of ash, severity of the disease and so on. Another concern is the fact that young ash is more severely affected by the disease, which results in a serious regeneration problem (Halmschlager & Kirisits 2008). All this put together points towards ash being a rarer species and in Sweden it is now Red-Listed, assessed as vulnerable in the extinction risk category (Gärdenfors 2010). The ash will most likely remain as a species, though to a lesser extent, found as an admixture component in broadleaved forests and seldom in pure stands. Although the prospects are seemingly bad there is still hope. In Denmark and several other countries, efforts are made to select for resistant genotypes, more information about ash dieback is spread to the public and several ash dieback conferences (FRAXBACK) has been held during 2013, gathering research from all around the world. In Sweden there is an ongoing national project during 2013-2015, where the public is asked for help to identify and report the location of healthy ash (Aronsson et al. 2013). Grafts from the healthy trees will then be collected for analyses, investigating why some trees are resistant to the disease as well as creating a gene pool of resistant ash. These examples show that there is at least a will and an engagement of trying to save the ash, bringing hope for the future.

**5.9.1 Final comments:** Although it has been tough at times I must say it has been very interesting to work with ash dieback, especially to be out in field and really see and assess these stands. Many uncertainties about the effects of ash dieback still remain and more research is therefore needed on this hot topic, as most parts of Europe are afflicted. It is my hope that the results and guidelines presented in this study can be of use when managing stands of ash infected by ash dieback. With more knowledge of ash dieback and how infected stands should be handled, the hope of saving this valuable broadleaved tree species increases.

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# 7. Appendix

## 7.1 Chi-square goodness-of-fit test for observed counts in variable

Results from a Chi-square goodness of fit test in Minitab, where distributions of quality classes, primary crown ratings and epicormic frequencies are compared two treatments at the time for each experimental area. Based on the number of trees in each class in one of the treatments (observed) and the proportion and number of trees in each class in the other treatment, Minitab could calculate an expected distribution. Probability values (p) lower than 0.05 indicate a significant difference in the distribution. The contribution to chi-square from each of the five classes or scores can be seen in the right most columns. Classes that contribute to almost the whole total chi-square (bottom line third column) differs more between the compared treatments than classes with low contribution.

### 7.1.1 Quality classes

No. 1425 Saebygaard Skov

Controls vs 1500 tr/ha

| Class | 1500 tr/ha | Control | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 28 | 0,15 | 12,45 | 19,4219 |
| B | 35 | 0,34 | 28,22 | 1,6289 |
| C | 15 | 0,43 | 35,69 | 11,9943 |
| D | 5 | 0,06 | 4,98 | 0,0001 |
| E | 0 | 0,02 | 1,66 | 1,6600 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 83 | 4 | 34,7052 | 0,000 |

Control vs 500 tr/ha

| Class | controls | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 15 | 0,23 | 22,54 | 2,52225 |
| B | 33 | 0,41 | 40,18 | 1,28304 |
| C | 42 | 0,32 | 31,36 | 3,61000 |
| D | 6 | 0,03 | 2,94 | 3,18490 |
| E | 2 | 0,01 | 0,98 | 1,06163 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 98 | 4 | 11,6618 | 0,020 |

1500 tr/ha vs 500 tr/ha

| Class | 1500 tr/ha | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 28 | 0,23 | 18,9010 | 4,38030 |
| B | 35 | 0,42 | 34,5149 | 0,00682 |
| C | 15 | 0,32 | 26,2970 | 4,85313 |
| D | 5 | 0,03 | 2,4653 | 2,60591 |
| E | 0 | 0,01 | 0,8218 | 0,82178 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 83 | 4 | 12,6679 | 0,013 |

## No. 1535 Visborggard

500 tr/ha vs 100 tr/ha

| Class | 500 tr/ha | 100 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 0 | 0,31 | 4,03 | 4,0300 |
| B | 2 | 0,38 | 4,94 | 1,7497 |
| C | 11 | 0,25 | 3,25 | 18,4808 |
| D | 0 | 0,05 | 0,65 | 0,6500 |
| E | 0 | 0,01 | 0,13 | 0,1300 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 13 | 4 | 25,0405 | 0,000 |

## No. 1424 Sebberup Skov

500 tr/ha vs 100 tr/ha

| Class | 100 tr/ha | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 1 | 2 | 0,19 | 2,09 | 0,00388 |
| 2 | 5 | 0,23 | 2,53 | 2,41142 |
| 3 | 4 | 0,44 | 4,84 | 0,14579 |
| 4 | 0 | 0,13 | 1,43 | 1,43000 |
| 5 | 0 | 0,01 | 0,11 | 0,11000 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 11 | 4 | 4,10108 | 0,392 |

## No. 1423 Haderslev Vesterskov

Control vs 1500 tr/ha

| Class | 1500 tr/ha | Control | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 19 | 0,225 | 13,95 | 1,82814 |
| B | 9 | 0,225 | 13,95 | 1,75645 |
| C | 28 | 0,470 | 29,14 | 0,04460 |
| D | 2 | 0,060 | 3,72 | 0,79527 |
| E | 4 | 0,020 | 1,24 | 6,14323 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 62 | 4 | 10,5677 | 0,032 |

Control vs 500 tr/ha

| Class | Control | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| A/A2 | 11 | 0,10 | 4,90 | 7,59388 |
| B | 11 | 0,33 | 16,17 | 1,65299 |
| C | 23 | 0,50 | 24,50 | 0,09184 |
| D | 3 | 0,06 | 2,94 | 0,00122 |
| E | 1 | 0,01 | 0,49 | 0,53082 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 49 | 4 | 9,87075 | 0,043 |

1500 tr/ha vs 500 tr/ha

| Class | 500 tr/ha | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 1 | 7 | 0,31 | 20,46 | 8,8549 |
| 2 | 22 | 0,15 | 9,90 | 14,7889 |
| 3 | 33 | 0,45 | 29,70 | 0,3667 |
| 4 | 4 | 0,03 | 1,98 | 2,0608 |
| 5 | 0 | 0,06 | 3,96 | 3,9600 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 66 | 4 | 30,0313 | 0,000 |

### 7.1.2 Primary crowns

<u>No. 1425 Saebygaard Skov</u>

Control vs 1500 tr/ha

| Crown score | controls | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 3 | 0,20 | 19,60 | 14,0592 |
| P(2.5) | 20 | 0,12 | 11,76 | 5,7736 |
| P(2) | 15 | 0,28 | 27,44 | 5,6397 |
| P(1) | 19 | 0,11 | 10,78 | 6,2679 |
| P(0) | 41 | 0,29 | 28,42 | 5,5685 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 98 | 4 | 37,3089 | 0,000 |

Control vs 500 tr/ha

| Crown score | 500 tr/ha | Control | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 10 | 0,03 | 1,98 | 32,4851 |
| P(2.5) | 23 | 0,20 | 13,20 | 7,2758 |
| P(2) | 10 | 0,15 | 9,90 | 0,0010 |
| P(1) | 8 | 0,20 | 13,20 | 2,0485 |
| P(0) | 15 | 0,42 | 27,72 | 5,8369 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 66 | 4 | 47,6472 | 0,000 |

1500 tr/ha vs 500 tr/ha

| Crown score | 500 tr/ha | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 10 | 0,20 | 13,20 | 0,7758 |
| P(2.5) | 23 | 0,12 | 7,92 | 28,7129 |
| P(2) | 10 | 0,28 | 18,48 | 3,8913 |
| P(1) | 8 | 0,11 | 7,26 | 0,0754 |
| P(0) | 15 | 0,29 | 19,14 | 0,8955 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 66 | 4 | 34,3509 | 0,000 |

## No. 1535 Visborggaard

500 tr/ha vs 100 tr/ha

| Crown score | 100 tr/ha | Test Proportion | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 4 | 0,07 | 1,12 | 7,40571 |
| P(2.5) | 2 | 0,21 | 3,36 | 0,55048 |
| P(2) | 0 | 0,21 | 3,36 | 3,36000 |
| P(1) | 1 | 0,07 | 1,12 | 0,01286 |
| P(0) | 9 | 0,44 | 7,04 | 0,54568 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 16 | 4 | 11,8747 | 0,018 |

## No. 1423 Ny Sebberup

500 tr/ha vs 100 tr/ha

| Crown score | 100 tr/ha | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 5 | 0,32 | 3,52 | 0,62227 |
| P(2.5) | 0 | 0,25 | 2,75 | 2,75000 |
| P(2) | 0 | 0,21 | 2,31 | 2,31000 |
| P(1) | 4 | 0,09 | 0,99 | 9,15162 |
| P(0) | 2 | 0,13 | 1,43 | 0,22720 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 11 | 4 | 15,0611 | 0,005 |

## No. 1423 Haderslev Vesterskov

Control vs 1500 tr/ha

| Crown score | control | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 1 | 5 | 0,21 | 10,29 | 2,7195 |
| 2 | 10 | 0,37 | 18,13 | 3,6457 |
| 3 | 8 | 0,17 | 8,33 | 0,0131 |
| 4 | 3 | 0,06 | 2,94 | 0,0012 |
| 5 | 23 | 0,19 | 9,31 | 20,1306 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 49 | 4 | 26,5102 | 0,000 |

Control vs 500 tr/ha

| Crown score | control | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 5 | 0,05 | 2,45 | 2,65408 |
| P(2.5) | 10 | 0,21 | 10,29 | 0,00817 |
| P(2) | 8 | 0,22 | 10,78 | 0,71692 |
| P(1) | 3 | 0,27 | 13,23 | 7,91027 |
| P(0) | 23 | 0,25 | 12,25 | 9,43367 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 49 | 4 | 20,7231 | 0,000 |

1500 tr/ha vs 500 tr/ha

| Crown score | 500 tr/ha | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| P(3) | 3 | 0,21 | 14,07 | 8,7097 |
| P(2.5) | 14 | 0,37 | 24,79 | 4,6964 |
| P(2) | 15 | 0,17 | 11,39 | 1,1442 |
| P(1) | 18 | 0,06 | 4,02 | 48,6170 |
| P(0) | 17 | 0,19 | 12,73 | 1,4323 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 67 | 4 | 64,5995 | 0,000 |

### 7.1.3 Epicormic shoots

## No. 1425 Saebygaard skov

Control vs 1500 tr/ha

| Ep.shoot | controls | 1500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 21 | 0,24 | 22,56 | 0,1079 |
| 1-5 | 31 | 0,37 | 34,78 | 0,4108 |
| 6-10 | 15 | 0,18 | 16,92 | 0,2179 |
| 11-15 | 7 | 0,12 | 11,28 | 1,6240 |
| 16-20 | 20 | 0,09 | 8,46 | 15,7413 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 94 | 4 | 18,1019 | 0,001 |

Control vs 500 tr/ha

| Ep.shoot | 500 tr/ha | control | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 15 | 0,22 | 13,86 | 0,09377 |
| 1-5 | 21 | 0,33 | 20,79 | 0,00212 |
| 6-10 | 15 | 0,16 | 10,08 | 2,40143 |
| 11-15 | 4 | 0,08 | 5,04 | 0,21460 |
| 16-20 | 8 | 0,21 | 13,23 | 2,06749 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 63 | 4 | 4,77941 | 0,311 |

1500 tr/ha vs 500 tr/ha

| Ep.shoot | 1500 tr/ha | 500 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 20 | 0,24 | 19,68 | 0,00520 |
| 1-5 | 30 | 0,33 | 27,06 | 0,31942 |
| 6-10 | 15 | 0,24 | 19,68 | 1,11293 |
| 11-15 | 10 | 0,06 | 4,92 | 5,24520 |
| 16-20 | 7 | 0,13 | 10,66 | 1,25662 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 82 | 4 | 7,93938 | 0,094 |

## No. 1535 Visborggaard

500 tr/ha vs 100 tr/ha

| Ep.shoot | 500 tr/ha | 100 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 6 | 0,08 | 1,04 | 23,6554 |
| 1-5 | 4 | 0,30 | 3,90 | 0,0026 |
| 6-10 | 0 | 0,08 | 1,04 | 1,0400 |
| 11-15 | 2 | 0,23 | 2,99 | 0,3278 |
| 16-20 | 1 | 0,31 | 4,03 | 2,2781 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 13 | 4 | 27,3039 | 0,000 |

## No. 1424 Ny Sebberup

500 tr/ha vs 100 tr/ha

| Ep.shoot | 500 tr/ha | 100 tr/ha | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 6 | 0,18 | 9,18 | 1,1016 |
| 1-5 | 14 | 0,18 | 9,18 | 2,5308 |
| 6-10 | 15 | 0,09 | 4,59 | 23,6096 |
| 11-15 | 6 | 0,09 | 4,59 | 0,4331 |
| 16-20 | 10 | 0,46 | 23,46 | 7,7226 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 51 | 4 | 35,3977 | 0,000 |

## Haderslev Vesterkov 1423

Controls vs 1500 tr/ha

| Ep.shoot | 1500 tr/ha | control | Expected | Contribution to Chi-Sq |
|---|---|---|---|---|
| 0 | 39 | 0,24 | 14,88 | 39,0977 |
| 1-5 | 13 | 0,36 | 22,32 | 3,8917 |
| 6-10 | 4 | 0,15 | 9,30 | 3,0204 |
| 11-15 | 0 | 0,04 | 2,48 | 2,4800 |
| 16-20 | 6 | 0,21 | 13,02 | 3,7850 |

| N | DF | Chi-Sq | P-Value |
|---|---|---|---|
| 62 | 4 | 52,2748 | 0,000 |

Control vs 500 tr/ha

```
                                            Contribution
Ep.shoot  500 tr/ha     control   Expected    to Chi-Sq
0          7             0,24      15,84      4,93343
1-5        25            0,36      23,76      0,06471
6-10       11            0,15      9,90       0,12222
11-15      2             0,04      2,64       0,15515
16-20      21            0,21      13,86      3,67818


 N  DF   Chi-Sq  P-Value
66   4  8,95370    0,062
```

1500 tr/ha vs 500 tr/h

```
                                             Contribution
Ep.shoot    1500 tr/ha  500 tr/ha   Expected    to Chi-Sq
0             39        0,11         6,82       151,841
1-5           13        0,38         23,56      4,733
6-10          4         0,17         10,54      4,058
11-15         0         0,03         1,86       1,860
16-20         6         0,31         19,22      9,093


 N  DF   Chi-Sq  P-Value
62   4  171,585    0,000
```

## 7.2 Summary of observations and suggestions for all plots

**Table 6.** Summary of observations and suggestions made in field in each sample plot. More details and photos in (appendix 7.3).

| Treatment | Exp. Area | Site condition | Dead/Living trees | Suggestion |
|---|---|---|---|---|
| Control | Saebygaard Skov plot 4 | Flat to slight slope, good drainage,forest land, sandy soil | Dead trees on flat ground, healthier on the better drained area | Thinning now, select future stems |
| Control | Saebygaard Skov plot 5 | Relatively flat, poor drainage, dark organic soil | Dead/healthy trees in groups, many storm felled | Selective thinning or leave it |
| Control | Haderslev Vesterskov plot 6 | Flat with two large dips, bad drainage, clay soil | Healthier trees around edges, all dead in the dips | Replace with black alder in the dips, too wet! |
| Thinned to 1500 tr/ha | Sabygaard Skov plot 1 | Flat to slight slope, good drainage, forest land, sandy soil | Dead trees on the flat ground, healthier on the better drained area | Remove dead/dying trees, replace with maple |

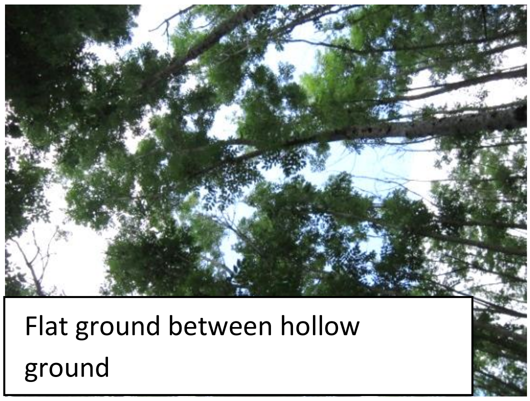
| | | | | |
|---|---|---|---|---|
| Thinned to 1500 tr/ha | Saebygaard Skov plot 6 | Flat to slight slope, good drainage, moist organic soil | Some dead trees in groups, otherwise quite healthy | Final fell 5-10 years, replace with black alder |
| Thinned to 1500 tr/ha | Haderslev Vesterskov plot 2 | Flat, good drainage, clay soil | Many healthy looking trees, mostly around the edges | Observe, perhaps final fell in 10-15 years |
| Thinned to 500 tr/ha | Saebygaard Skov plot 2 | Flat to slight slope, good drainage, forest land, sandy soil | Dead trees on the flat ground, healthier on the better drained area | Final fell in 5-10 years, replace with maple |
| Thinned to 500 tr/ha | Saebygaard Skov plot 7 | Flat to slight slope, good drainage, organic silty soil | Some dead trees mostly around edges, otherwise healthy looking | Final fell 5-10 years, replace or mix with black alder |
| Thinned to 500 tr/ha | Visborggaard plot 4 | Flat with some dips, bad drainage, moist clay soil | Dead trees in groups, healthier trees around edges | Final fell in 10 years, replace with black alder |
| Thinned to 500 tr/ha | Sebberup Skov plot 6 | Flat, some dips and slight slopes, drainage varies, forest land sandy soil | Dead trees on flat ground around edges, otherwise many healthy trees | Replace with black alder in dips, final fell in 10 years |
| Thinned to 500 tr/ha | Haderslev Vesterskov plot 3 | Almost entire plot in a dip, bad drainage, moist clay soil | Many dead trees in the middle, healthier around edges on higher ground | Final fell in the middle, replace with black alder |
| Thinned to 500 tr/ha | Haderslev Vesterskov plot 4 | Almost entire plot in a dip, bad drainage, moist clay soil | Many dead trees in NW where the dip is deepest, healthier in S on higher ground | Final fell now, replace with black alder, sitka spruce |
| Thinned to 100 tr/ha | Visborggard plot 3 | Relatively flat with some dips, bad drainage, moist dark clay | Many dead trees spread out all over, but a few tree of really good quality | Final fell now, replace with black alder |
| Thinned to 100 tr/ha | Sebberup Skov plot 2 | Slight slope, good drainage, forest land, sandy soil | Many dead trees on flat ground, healthier in the slope, a few good quality stems | Manually cut good quality stems, natural reg. of lime or plant larch |

## 7.3 Summary of questionnaire answers and observations in field

### 7.3.1 Controls

Sample plot 4 Saebygaard Skov

Sample plot 5 Saebygaard Skov


Sample plot 6 Haderslev Vesterskov

**Sample plot 4 Saebygaard Skov** – flat to slight slope, relatively good drainage, forest land Sandy soil. Sample plot size: 0.051 ha (Jakobsen 2011). Dying and dead trees located in the middle towards north, healthier trees towards the road were the ground is higher. A lot of trees are alive, though many have stem crooks or small diameter. Almost all trees of small diameter (5-8 cm dbh) are dead. Thinning is needed. Suggestion is thinning and selection of good stems alt. final fell and replace with e.g. maple.

**Sample plot 5 Saebygaard Skov** – relatively flat, some dips, dark organic soil, between a ravine and small river, poor drainage, risk of high water levels. Sample plot size: 0.066 ha (Jakobsen 2011). Healthy and dead/dying trees in groups, many storm felled/leaning trees, *Armellaria* fungi found on several stems, bad quality trees. Suggestion is to final fell and replace with black alder.

**Sample plot 6 Haderslev Vesterskov** – two large hollows/dips area (NE & SW) with very poor drainage, wet clay soil, flat ground in between. Sample plot size: 0.136 ha (Jakobsen 2011) Healthier trees located around the edges and on flatter ground, probably due to better drainage. In the dips almost all trees are dead or of very poor health. Many of the trees are of bad quality. Suggestion is final felling and to replace with black alder in the dips at least.

### 7.3.2 Thinned to 1500 tr/ha

Sample plot 1 Saebygaard skov

Sample plot 6 Saebygaard skov

Sample plot 2 Haderslev Vesterskov

**Sample plot 1 Saebygaard Skov** – flat to slight slope, relatively good drainage, forest land Sandy soil. Sample plot size: 0.057 ha (Jakobsen 2011). Dying and dead trees in the middle towards north, healthier trees towards the road were the ground is higher (better drainage). There is a rich undergrowth of nettles, as well as young elm and maple. Maple could be a suitable replacement for ash.

**Sample plot 6 Saebygaard Skov** – flat to slight slope, moist organic soil, between a ravine and small river, drainage relatively good. Sample plot size: 0.066 ha (Jakobsen 2011). Dead trees are standing group wise. Trees are quite large and proportions of good quality stems are higher than in Saebygaard Skov sample plot 5, though most trees are infected. Suggestion is final fell in 5-10 years, replace with black alder which already grows in the stand.

**Sample plot 2 Haderslev Vesterskov –** flat ground, even distribution, good drainage, clay soil. Sample plot size: 0.094 ha (Jakobsen 2011) Healthier trees around the edges maybe due to other species or better drainage.best plot in Haderslev many relatively healthy trees of good quality. Final felling in 10-15 years, depending on development.

### 7.3.3 Thinned to 500 tr/ha


Sample plot 2 Saebygaard skov


Sample plot 7 Saebygaard Skov


Sample plot 4 Visborggaard


Sample plot 6 Sebberup Skov


Sample plot 3 Haderslev Vesterskov


Sample plot 4 Haderslev Vesterskov

**Sample plot 2 Saebygaard Skov** – flat to slight slope, relatively good drainage, forest land Sandy soil. Sample plot size: 0.073 ha (Jakobsen 2011). Dying and dead trees in the middle towards north, healthier trees towards the road were the ground is higher (better drainage). There is a rich undergrowth of nettles, as well as young elm and maple. Maple could be a suitable replacement for ash.

**Sample plot 7 Saebygaard Skov** – flat to slight slope, relatively good drainage, organic silty soil, between a ravine and small river. Sample plot size: 0.092 ha (Jakobsen 2011). Dying and dead trees group wise, mostly around the edges but no strong direction health connection observed. More healthier and better quality trees than in plot 6 Saeby. Final fell 5-10 years and replace with black alder, maybe leave some ash trees to establish a mixed stand.

**Sample plot 4 Visborggaard** – flat ground with some dips, vegetation mostly nettle and hogweed, moist dark organic soil, poor drainage, dead trees in groups, healthier trees around the edges, plenty of dead trees in the southern edge. Await and see how the stand develops, some trees are of good quality, final fell in 10 years and replace with black alder.

**Sample plot 6 Sebberup Skov –** relatively flat ground with some dips and small slopes. Sample plot size: 0.066 ha (Jakobsen 2011).Drainage conditions variates, fores land sandy soil, best plot in Sebberup Skov, plenty of healty looking trees of relatively good quality. Dead trees mostly around the edges where the drainage was poorer. Suggestion to cut down ash in the flats and dips where drainage is poor and replace with black alder, rest of the stand final fell in about 10 years.

**Sample plot 3 Haderslev Vesterskov –** almost entire plot in a dip, drainage is very poor, wet clay soil, rich vegetation of nettles. Sample plot size: 0.110 ha (Jakobsen 2011). Dead and dying trees in the middle where drainage is poorer, healthier trees in the edges on better drained ground. Final fell all dead dying ash trees in the dip, replace with black alder, keep some better looking ash around the edges.

**Sample plot 4 Haderslev Vesterskov –** almost entire plot in a dip, poor drainage, wet clay soil. Sample plot size: 0.071 ha (Jakobsen 2011). Dead and dying trees in NW where the dip is deeper, more healthier trees in S with higher flatter ground. Plenty of dead trees, and trees with bushy features a lot of epicormic shoots, poor quality. Final fell stand now, no future, replace with black alder, lark or perhaps Sitka spruce.

### 7.3.4 Thinned to 100 tr/ha


Sample plot 3 Visborggaard


Sample plot 2 Sebberup Skov

**Sample plot 3 Visborggaard –** relatively flat ground with some dips, black fine organic soil, moist to wet soil with poor drainage, connection with tree health and position. Group wise dying tendency could be seen. Many trees are dead or dying maybe due to water and wind stress + disease, though some trees are of very good quality thick and straight. Final fell the ash trees now; they are thick enough, wait and risk of storm felling. Alternative to leave the best looking trees for genetic tests for 5 years. Replace with black alder which already exists in the plot.

**Sample plot 2 Sebberup Skov -** sligth slope with flat areas, good drainage conditions on forest soil. Sample plot size: 0.238 ha (Jakobsen 2011). Dead dying trees most on the flat areas where the drainage is poorer, very few trees in the plot, many trees are dead and dying but a few look really good, outside the plot towards SO is a deep dip where almost 100 % of the ash trees are dead. Suggestion is to leave the ash and let other species mix in e.g. lime which seem to grow well in the understory, Sitka spruce could also work. Alternative leave the stand for biodiversity.

## 7.4 Questionnaire

1. Describe the sample plot regarding topography, water condition and vegetation

2. If possible to determine, in what direction are the healthy respective dying trees located?

3. Are the healthier trees located around the edges? Can a positive neighbor effect from other species be seen?

4. Assess type of soil and texture by digging a hole in the plot

5. How does the ash stand look like? Approximately how large share of ashes are healthy, dying and dead? How is the quality of the living ash trees?

6. Suggest a management for the sample plot, should the ash trees be final felled now, later or be left standing? If cut down what species should the future stand consist of? Motivate!