Examensarbeten **2009:1**
Institutionen för skogens ekologi och skötsel

Influence of light competition on vitality in old aspen

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Sveriges Lantbruksuniversitet Skogligt magisterprogram/Jägmästarprogrammet
Examensarbete i skogshushållning, 30 hp, avancerad D
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I denna rapport redovisas ett examensarbete utfört vid Institutionen för skogens ekologi och skötsel, Skogsvetenskapliga fakulteten, SLU. Arbetet har handletts och granskats av handledaren, och godkänts av examinator. För rapportens slutliga innehåll är dock författaren ensam ansvarig.

This report presents an MSc/BSc thesis at the Department of Forest Ecology and Management, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by the supervisor, and been approved by the examinator. However, the author is the sole responsible for the content.

Abstract

European aspen (*Populus tremula*) is a pioneer tree species that has a high importance for biodiversity. In Sweden, the number of long-continuity aspen stands has decreased during the last century. However, the awareness of the importance of aspen for other species has increased recently, and in many areas the current goal is to increase the number of old, large aspens. In order to do so, one common method is lower stand density by cutting trivial tree specimens intermingled within aspen clones, in order to reduce competition with surrounding trees.

The aim of this study was to investigate how light competition affects vitality in old aspens. In a study area located in Norrbotten, Sweden, 5 sites were chosen with the objective of obtaining a wide range of stand density values. 4 sites were located in an old spruce-aspen stand, and one site was located on a 7 years old clear-cut. On each site, 3 old aspens were cut down, and wood discs were taken out from their trunks at the heights 1,3 m; 50% of tree height and 75% of tree height. The age of each felled aspen was determined, and growth during the last 20 years was calculated and used as an indicator of vitality. Furthermore, the health state of the trees was measured using a novel index based mainly on rot occurrence. Fisheye photos were also taken of the canopy above each aspen, and variables such as basal area, age of surrounding spruces, diameter and general stand characteristics were collected and analyzed.

Results indicate that age is the main factor affecting vitality in old aspens. Significant correlations could be found between age and health index as well as between age and the variable representing growth during the last 20 years. No significant correlation could be found between stand density and the parameters representing vitality. However, the results show that in the trees on the clear-cut, a growth increase occurred after the old stand was harvested. This indicates that creating more space around old aspens is a useful method for inducing larger diameters in stands where the growth has stagnated.

Sammanfattning

Europeisk asp (*Populus tremula)* är ett pionärträdslag som har ett högt värde för den biologiska mångfalden. I Sverige har antalet aspbestånd med lång kontinuitet minskat under de senaste hundra åren. På senare tid har man dock fått ökad kunskap om aspens höga värde för andra arter, och i många områden finns nu ett mål att öka antalet gamla, stora aspar. En vanlig metod för att göra detta innebär att man genom att friställa aspar som förväntas ha goda utsikter att utveckla större dimensioner minskar konkurrensen med omgivande träd.

Syftet med den här studien var att undersöka hur ljuskonkurrens påverkar vitalitet i gamla aspar. I ett område beläget i Norrbotten, Sverige, valdes 5 ytor ut i syfte att erhålla ett så brett spektrum av olika beståndstäthet som möjligt. 4 ytor var belägna i ett gammalt asp-gran-bestånd, och en yta låg på ett 7 år gammalt hygge. På varje yta togs 3 gamla aspar ner, och vedtrissor höggs ut ur stammarna på höjderna 1,3 m; 50 % av trädhöjd och 75 % av trädhöjd. Åldern på var och en av de nedhuggna asparna bestämdes, och tillväxten under de senaste 20 åren beräknades och användes som en indikator på vitalitet. Vidare mättes trädens hälsotillstånd med hjälp av ett eget utvecklat index som huvudsakligen var baserat på rötförekomst. Fisheyefoton togs också av krontäcket över varje asp, och variabler såsom grundyta, ålder på omgivande granar, diameter och generella ståndortsegenskaper samlades in och analyserades.

Resultaten indikerar att ålder är den faktor som har störst påverkan på vitaliteten i gamla aspar. Signifikanta korrelationer hittades mellan ålder och hälsoindex, och också mellan ålder och den variabel som representerade tillväxt under de senaste 20 åren. Ingen signifikant korrelation gick att hitta mellan beståndstäthet och de parametrar som representerade vitalitet. Resultaten visade emellertid att en tillväxtökning skedde i de träd som växte på hygget efter att det gamla beståndet slutavverkades. Detta indikerar att friställning av gamla aspar är en väl fungerande metod för att skapa träd med grövre diametrar i bestånd som har stagnerat i tillväxt.

Contents

1. Introduction

1.1 Populus tremula (Aspen) - distribution and regeneration

In the Northern Hemisphere, European aspen (*Populus tremula L.*) is a widely distributed tree species (Johansson 2002). Its latitudinal range stretches from the north of Norway down to northern Africa, while its longitudinal range covers Western Europe and the major part of northern Asia, all the way to Japan (Hazell 1999). In Sweden, aspen can be found throughout the country with the exception of the alpine region, but it seldom forms large stands (Hazell 1999, Johansson 2002). The mean standing volume of aspen on productive forest land in Sweden is 1,6 m^3 ha^{-1}, which constitutes approximately 1,3% of the total standing volume (Hazell 1999). Aspen is a pioneer tree species, but also rather persistent once it has established in an area (Delin 2004).

Aspen can regenerate either sexually or vegetatively. Sexual regeneration results in seeds being spread by the wind in the spring or early summer (Delin 2004). However, only a very small percentage of the seeds usually get the chance to germinate, since they need to be held constantly moist during the first weeks after they have landed on the ground. Vegetative regeneration by suckering is much more common. Aspen stands generally consist of a single clone that is composed of genetically identical stems that originated from a seedling (Smith & Smith 2005). From the root system of the clone, new suckers are produced (Hazell 1999). This kind of regeneration is triggered by hormonal stimulation of underground root buds, and it is primarily initiated by disturbance, e.g., a forest fire that kills the mature trees (Jones *et al*. 2005). Even if the parent tree disappears, the root system of a clone may remain alive for a very long period by frequently producing new suckers (Hazell 1999).

Throughout its range, aspen shows a great variety of adaption to various climatic conditions and site characteristics (Hazell 1999). It can grow on a wide range of sites, and reaches its largest dimensions on fertile, well-drained mineral soils on fine sand- or clay-moraine material (Hazell 1999). On dry and nutrient-poor sites the growth rate is low, and aspens that grow on these kinds of sites also tend to develop curved stems and bushy shapes (Johansson 2002). Since all trees constituting the parts of a clone are intertwined through their root systems, individual aspen trees usually have good resistance against drought as well as drowning (Delin 2004). Due to this, aspen manages to grow successfully on shores, near rivers and on other sites where the water level tends to fluctuate a lot. On wet sites, the parts of the root system that are located in well drained soil ensure oxygen supply for the drenched parts of the root system, even if the drowning remains for a long time (months or even years). Correspondingly, roots reaching moist soil provide the clone with water on very dry sites.

1.2 Importance of P. tremula as a keystone species

Aspen holds a very high value for biodiversity, and can be considered as a keystone species for many other species groups (Bartos 2001). The term “keystone species” has been defined by Wilson (1992), who states that “the removal of a keystone species causes a substantial part of the community to change drastically”. For instance, the bark of aspen trees is rich in nutrients and constitutes an important substrate for a wide variety of insects

(Stokland *et al*. 2003), lichens, bryophytes, (*i.e.* mosses, liverworts, hornworts (UNB Faculty of Forestry and Environmental Management 1998)) and macrofungi (Hazell & Gustafsson 1999). Aspen forests also offer habitat for many birds and mammals, for instance by providing hollow tree trunks where birds can nest (Delin 2004; Smith & Smith 2005). Early-successional stands dominated by aspen and birch are often regarded as one of the most species-rich forest types in the boreal parts of the Nordic countries (Hazell 1999). The importance of aspen for biodiversity varies between different habitats, and is larger in old-growth forests with long continuity than on old overgrown fields and pastures where aspen only has existed for perhaps half a century (Delin 2004). In general it can be said that for most rare species, habitat continuity is more important than substrate availability.

Aspen is vulnerable to damage by insect and fungal pests (Anderson *et al.* 1997). For example, a large part of all the Swedish aspens are infected by White heartwood rot, *Phellinus tremulae* (Delin 2004, Rönnberg *et al.* 2006). This wood fungus grows on the underside of branches and in scars from branches that have fallen off the tree (Delin 2004). It spreads via spores, and several genetically different fungus individuals can usually be found on the same tree. There is no evidence so far that the fungi would spread via the roots of the trees. The fungus does not destroy the sapwood, but it causes heartwood rot and eventually results in a tree with a hollow trunk. Despite this, aspens can grow to maturity and become very old with the mycelium inside without being killed by the fungus (Delin 2004).

Since old aspens usually are infected by fungi that destroy the wood and make the trunks hollow, their exact age is difficult to determine. Although the general belief has been that aspen rarely reaches a higher age than 150 years (cf. e.g. Almgren 1990), this is disputed by Delin (2004), who asserts that it might live much longer than that.

1.3 Stand development and light competition

Aspen is strongly adapted to ecosystems where forest fire occurs as a frequent disturbance (Hazell 1999). When boreal ecosystems are moulded by natural fire regimes, the main effect of a fire is that many trees die and either are consumed by the fire or become slowly decaying dead wood (Delin 2004). After the fire, aspen and birch quickly re-establish on the burnt site. Consequently, in many newly burnt areas, deciduous species come to dominate the site for up to half a century, with the late-successional Norway spruce gradually entering the stand and ultimately replacing the broadleaved trees to become the predominating species. However, aspen may persist in a stand for a long time after the spruce has established. On some sites it successfully competes with spruce even when the forest has reached maturity, and in certain areas aspen might even outnumber the spruce. For instance, in Russian virgin forest with long continuity and low fire frequency there are sites where aspen dominates over spruce as well as over Siberian Pine (Delin 2004).

Light availability is a very important factor affecting vitality and growth rate throughout the development of a forest stand containing aspen (Johansson 1989). The degree of light influences the potential for vegetative reproduction, as well as the growth of understory plants and ground vegetation. In an aspen stand, the leaf area will increase during the initial 15 to 25 years of its development, until the stand becomes so dense that self-thinning occurs (Pritchard & Comeau 2004). At this point, understory light levels may be only about 5% of open sky values, but more typical values are usually found in the range 10–20%. In aspen-dominated stands, Lieffers and Stadt (1994) found that an overstory resulting in 15-40% transmitted light at 1,3 m. above the forest floor normally allowed acceptable growth of white spruce saplings in the understory (Constabel & Lieffers 1995). Among the species that are dependent on aspen, there is a wide range of different light demands (Delin 2004). For instance, mosses and some lichens tend to prefer dark and moist sites, while other lichen species and insects are more light-demanding.

1.4 Aspen in managed boreal landscapes

During the last centuries, large changes have taken place in the Swedish boreal ecosystems, mainly due to the transition from primarily natural to human disturbance regimes (Axelsson *et al.* 2002). These changes have had a profound influence on the distribution of aspen in the landscape. Between the 1950s and the 1990s, birch and aspen were viewed upon as serious threats to coniferous plantations. Thus, many silvicultural methods, *i.e.* girdling and herbicide spraying, were used to reduce the amount of broadleaved trees. In addition to this, much effort was put into eliminating natural forest fires (Hazell 1999). These actions altogether significantly reduced the number of virgin aspen stands.

Data from the Official Statistics of Sweden (SNFI) show that the total volume of deciduous trees in Sweden has increased since the 1920s (Hellberg 2004). However, the majority of the present deciduous forests are found either on land that has been used for agriculture in the past (Axelsson *et al.* 2002), or in forest areas that were clear-cut 10-20 years ago (Axelsson & Östlund 2001). In other words, most of today's broadleaved forests in Sweden are relatively young. Compared to the clustered, site-specific deciduous stands that were common 200 years ago, they are probably also distributed more evenly in the landscape. Past forest management has resulted in a lack of old and dead deciduous trees and broadleaf-dominated forests with long continuity in the Swedish boreal zone (Axelsson *et al.* 2002). However, during the last couple of decades management of aspen has attracted rising attention, partially due to increased awareness of the importance of deciduous forests for many rare species (Hazell 1999). One important goal today is to create forest stands with a high proportion of old and dead deciduous trees, and to increase the occurrence of trees with large diameters which have many associated species (Axelsson *et al.* 2002, Hazell 1999). To serve this purpose, one method is to create more open space around trees in order to alleviate light competition around trees that seem suitable for developing larger dimensions (Forsmark 2007). Hitherto, however, few studies have addressed the question of how mature aspens react to liberation. Although there is a growing interest in active management of aspen for biodiversity purposes in Sweden today, we still know little about how to manage aspen stands, e.g. with respect to light competition, in ways that increases longevity, dimension development and vitality of individual trees.

The aim of this study is to investigate how light competition affects vitality in old aspen trees. Furthermore, the possibilities of prolonging the lives of old aspens by creating more open space around the trees will be examined. Finally, some general management advice for enhancing vitality in old aspens will be given.

2. Materials and methods

The study was conducted in two forest stands located in the county of Norrbotten, Sweden (Fig. 1). One of the stands was an old, mixed spruce-aspen stand in which no large-scale silvicultural activities had taken place since the current forest established. The second stand was an adjacent clear-cut where the main stand was harvested 7 years ago, but where several broadleaf trees (aspens, birches and Salix), some old pines and a few groups of Norway spruce had been left when the cutting was made.

Fig. 1. Location of the study area.

In the stands, a total of five sites were selected with the objective of obtaining the widest possible range of stand density and incoming light values. 4 sites were chosen in the mature stand and one site was chosen on the clear-cut (Fig. 2). The selections were based on estimated basal area and density of the canopy cover on the site. In order to minimise the occurrence of covariation with other stand characteristics, the aim was to find sites that were as similar as possible with respect to e.g. tree age, vegetation type and elevation.

Fig. 2. The selected sites. Site 1 is the clear-cut area.

With the exception of the studied variables basal area and canopy density, general characteristics related to ground conditions, structure of the surface and slope were very similar among the sites. The four sites in the mature stand (Fig. 3) all had a fresh soil moisture class, moraine soil, and vegetation that was dominated by *Vaccinium myrtillus* and *Vaccinium vitis-idaea*. On the clear-cut (Fig. 4), *Deschampsia flexuosa* also represented a rather large percentage of the vegetation cover. The darkest site had very sparse vegetation, since the ground was covered by fallen leaves.


Fig. 3. Photo from the old spruce-aspen stand.


Fig. 4. Photo from the clear-cut.

On each site, 3 old and relatively large aspens were randomly selected within 40 meters distance from each other, in order to increase the possibility of choosing trees from the same aspen clone. The selected aspens on each site were motor-manually harvested. From three different height levels; 1.3 m, 50% and 75% of tree height, as measured with measuring tape on the felled trees, 20 cm thick wood discs were sampled from the stems.

The tree stumps and the wood discs were labelled with the numbers of the site and the tree, and GPS coordinates were registered for each stump. Furthermore, the diameter at 1, 3 m. and the green crown border was measured on each tree. In order to determine the total age for each tree and height level, the transverse surfaces of each wood disc was planed using a bench planer, and the number of annual rings in the upper transverse cut was counted. In the cases were part of the disc was rotten due to wood fungus the number of annual rings was estimated as accurately as possible.

Drill cores were taken from at least two large spruces on each site. On the clear-cut, no dominating spruces had been left when the harvesting was made. Instead, drill cores were taken from an old pine and two medium-sized spruces. The annual rings from each drill core were counted, in order to get age data that could be compared to the data from the aspens.

On each site, 3 circular plots (radius 8 m.) were placed, using the aspen stumps as centre points. For each plot, the number and diameter of stems for different species were registered. Trees with a diameter less than 8 cm were considered not important for the light influence on the aspen clone, and therefore excluded. The majority of these excluded trees were small spruces. Results from the plots were used for calculating the basal area surrounding each cut down aspen. All calculations in this study, with the exception of the ones made in Gap Light Analyzer (see below), were made using Microsoft Excel.

In order to measure the amount of incoming light on the sites, fisheye photos were taken of the forest canopy above the point where each of the cut down aspens had been growing. A Nikon Coolpix 4500 digital camera with a Nikon fisheye converter lens (FC-E8) and an automatic trigger was set up using a tripod. The camera was fixed at 1, 4 m. above the centre of the aspen stump, and the north-south direction was determined using a compass. 3 photos were taken above each stump.

The fisheye photos were analyzed using the software Gap Light Analyzer (Frazer & Canham 1999). Initially, the brightness of each picture was adjusted, and suitable threshold values were chosen with the objective of obtaining the best possible contrast between canopy cover and sky. When the contrast values had been set, calculations of the site openness in each photo were run.

On the upper transverse cut of each wood disc, the average width of the annual rings from the recent 20 years was measured using a ruler (Fig. 5). The measured width and the total diameter were used for calculating the area of the 20 most recent annual rings (Fig. 6).

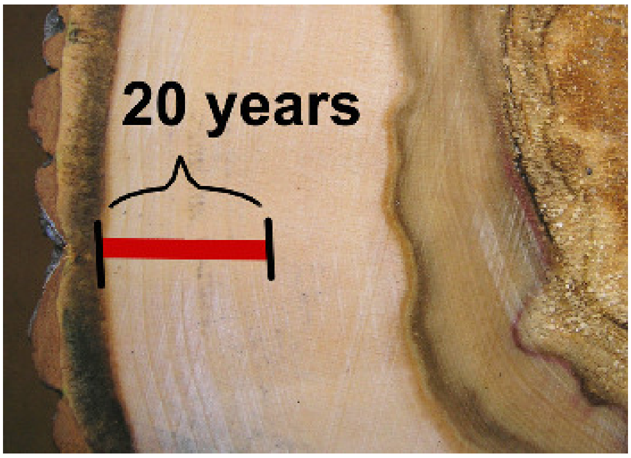

Fig. 5. Photo showing how the width of the 20 most recent annual rings was measured.

Fig. 6. The red (patterned) area represents the area of the 20 most recent annual rings in a transverse cut, as it was used in the calculations.

In order to create a parameter that could represent relative growth for the last 20 years, the width variable was transformed using the formula
$\boldsymbol{W20_n = (((A_{b20}/A_{tot})*100) * 1/(K_n - 20))}$, where
$\mathbf{W20_n}$ = The relative width of the 20 most recent annual rings at level n
$\mathbf{A_{tot}}$ = Total area of all annual rings in the transverse cut at level n,
$\mathbf{A_{b20}}$ = Total area of the last 20 annual rings in the transverse cut at level n,
$\mathbf{K_n}$= total tree age at level n, and
n = tree height level (1,3 m; 50% of tree height or 75% of tree height).

This novel W20 variable was used as an indicator of vitality.

For each cut-down aspen, the tree's overall health state was examined and described in a healt index (HI), which was determined subjectively on a scale from 1 to 10, with the highest value representing optimal vitality. HI was based on ten criteria, of which eight were related to rot occurrence and discolouration in the trunk, which usually is a preliminary state of rot (Anderson *et al.* 1997). Presence of rot or discolouration at 1,3m; 50% of tree height and 75% of tree height was registered, and the width of the rotten or discoloured area at 1,3 m. was measured and compared to the total stem diameter. Further, one criteria was the presence of fungi conks, and one included the presence of other noteworthy observations such as insects or different forms of external damages and growth irregulatities. More fulfilled criteria resulted in a lower HI, and vice versa. Rotten wood was given a higher influence on the HI than wood discolouration (*i.e.* a tree with rotten wood at one specific height level was considered less healthy than a tree where discoloured wood (but no rot) could be found at the same level). Similarly, if the average diameter of the rot infected or discoloured area exceeded 50% of the diameter in the transverse cut at 1, 3 m. of the height (Fig. 7), the tree was viewed upon as less healthy than a tree where the average diameter of the rot infected or discoloured area was less than 50% of the diameter at this level (Fig. 8).

Fig. 7. Trunk where the diameter of the rotten wood (the white line) makes up more than 50% of the total diameter of the transverse cut (the black line).

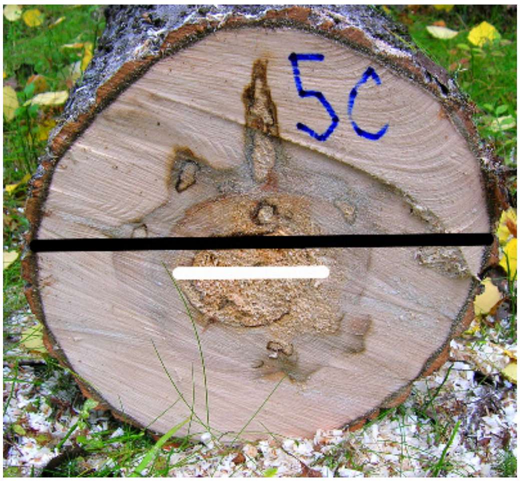

Fig. 8. Trunk where the diameter of the rotten wood (the white line) makes up less than 50% of the total diameter of the transverse cut (the black line).

Statistical analyses were conducted using Minitab. For comparing the variables and describing significant differences, one-way analysis of variance (ANOVA) was used. The data for age at 1,3 m, basal area and W20 at 1,3 m. were divided into 3 statistically different classes, respectively. The other variables were used as respondents. Furthermore, regression analyses were applied to examine the relationships between the vitality parameters (growth during the last 20 years and health index) and the variables describing basal area, age and growth. A significance level of 0.05 was used in all the analyses.

3. Results

3.1 Height

The heights of the selected aspen clones ranged between 16, 5 and 24 m. The height distribution was rather even throughout the stand, but 2 of the 3 highest trees could be found on the darkest site. The heights of the green crown border varied a lot between the clones, and did not show any significant correlation with the other variables in the study. The individual height distribution and the heights of the green crown border of each tree can be seen in fig. 9.

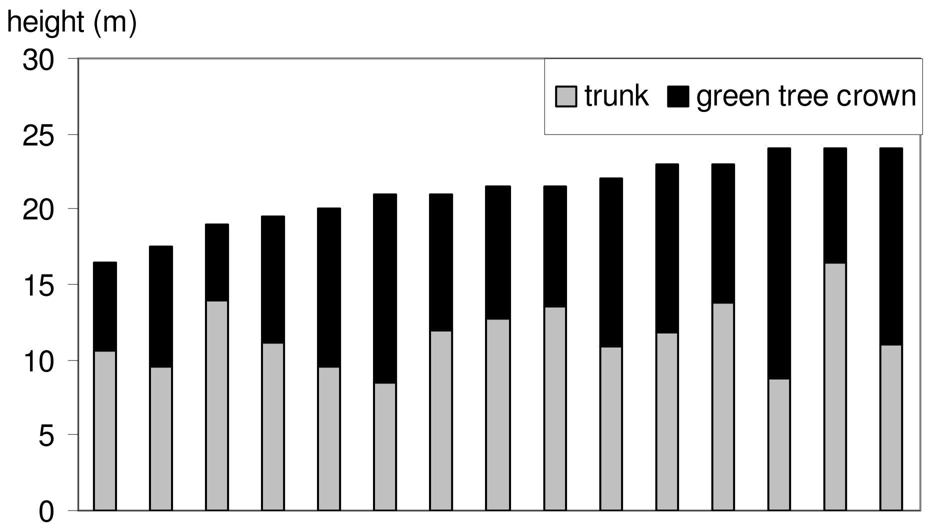

Fig. 9. Height distribution, sorted by individual height. The figure shows the total heights of all the studied trees, and the heights of their green crown bases.

3.2 Age

The results from the annual ring analyses showed that the total age at 1, 3 m. height for the cut-down aspens varied between 84 and 124 years (Fig. 10). 11 trees were younger than 100 years and 4 trees were older than 100 years.

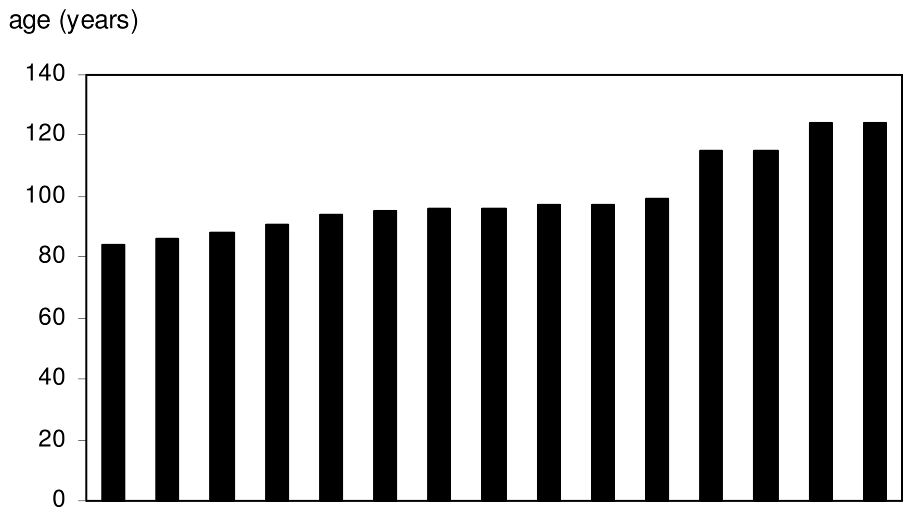

Fig. 10. Age distribution of the studied trees, sorted by individual age.

In the statistical analyses, the age data from 1, 3 m. was divided into 3 different classes. These classes, their intervals and the number of values in each class can be seen in table 1.

Table 1. Classification of the age data, and the number of values in each class

Age class	Age (1,3 m) interval (years)	Number of values
1	84-91	4
2	92-99	7
3	110-124	4

3.3 Drill cores

The drill cores taken from old spruces and one pine that were growing on the sites showed that most of these coniferous trees were in average 11 years younger than the studied aspen clones. Only one spruce could be found that was older than the aspens (160 years). The pine that was growing on the clear-cut was older than the aspens as well, but the total age of this tree could not be determined due to its large diameter. However, its age was estimated to be at least 120 years, but more probably somewhere in the range of 130-150 years. Fig. 11 shows the age distribution of the aspens and the spruces.

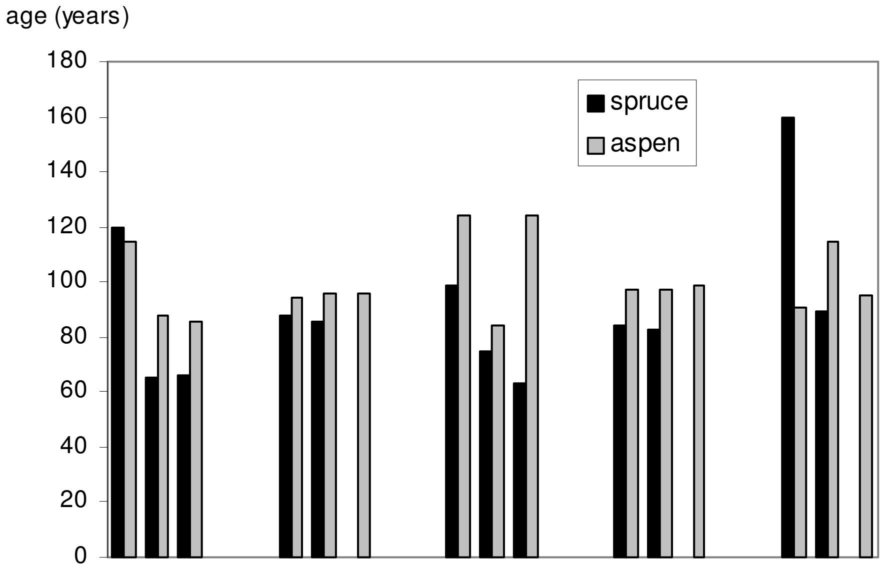

Fig. 11. Age distribution of spruce and aspen, sorted site-specifically.

3.4 Basal area

The basal areas surrounding the 15 cut down aspens ranged from 1 m^2 ha^{-1} to 63 m^2 ha^{-1} , as can be seen in fig. 12. The distribution was rather even. No noteworthy correlation could be found between age and basal area, or between basal area and diameter of the aspen clones (not further presented).

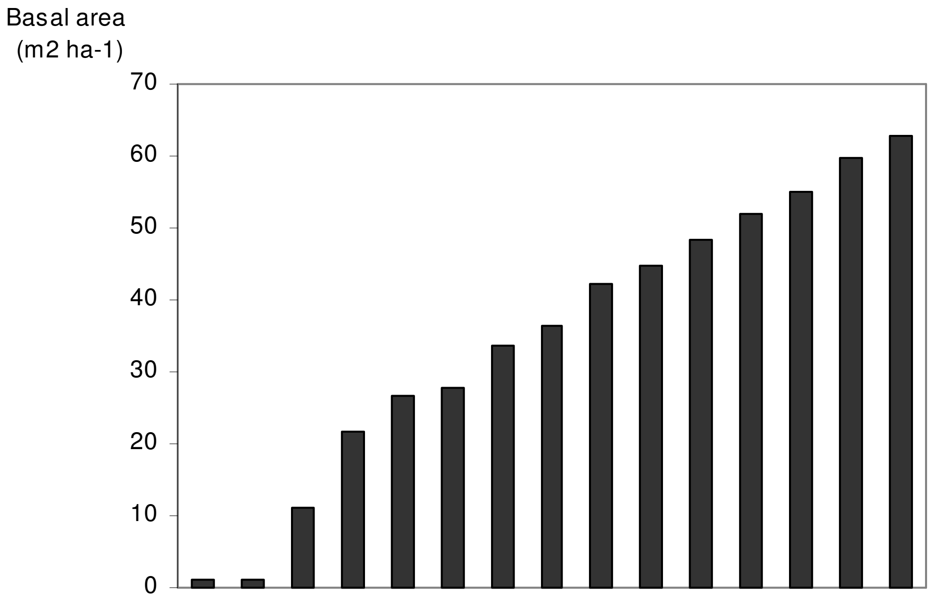

Fig. 12. Distribution of the basal area surrounding each studied tree (sorted by individual basal area).

In the statistical analyses, the basal area data was divided into 3 different classes, as can be seen in table 2.

Table 2. Classification of the basal area data, and the number of values in each class

Basal area class	Basal area interval ($m^2 ha^{-1}$)	Number of values
1	0-22	4
2	23-45	6
3	46-63	5

No statistically significant correlation (p=0.188) could be found between height and basal area, even if a very weak trend seemed to indicate that trees that grew in dense stands tended to be higher (fig. 13).

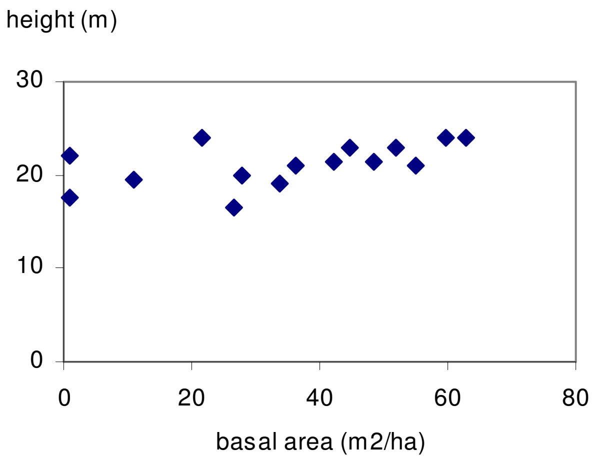

Fig. 13. Height vs. basal area.

3.5 Site openness

The result from the fisheye photo analyses showed that the individual site openness (SO) values for the 15 aspen clones ranged from 9, 18% to 67, 5% (Fig. 14). The three aspens that had been growing on the clear-cut had a considerably higher SO value than the trees that had been growing in the mature stand. Some examples of the photos taken on some of the sites can be seen in fig. 15.

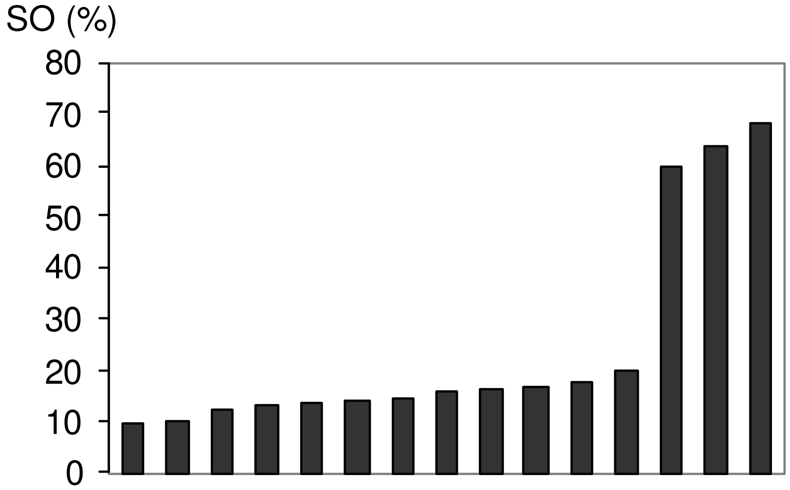

Fig. 14. Distribution of the site openness values, sorted by individual SO values.

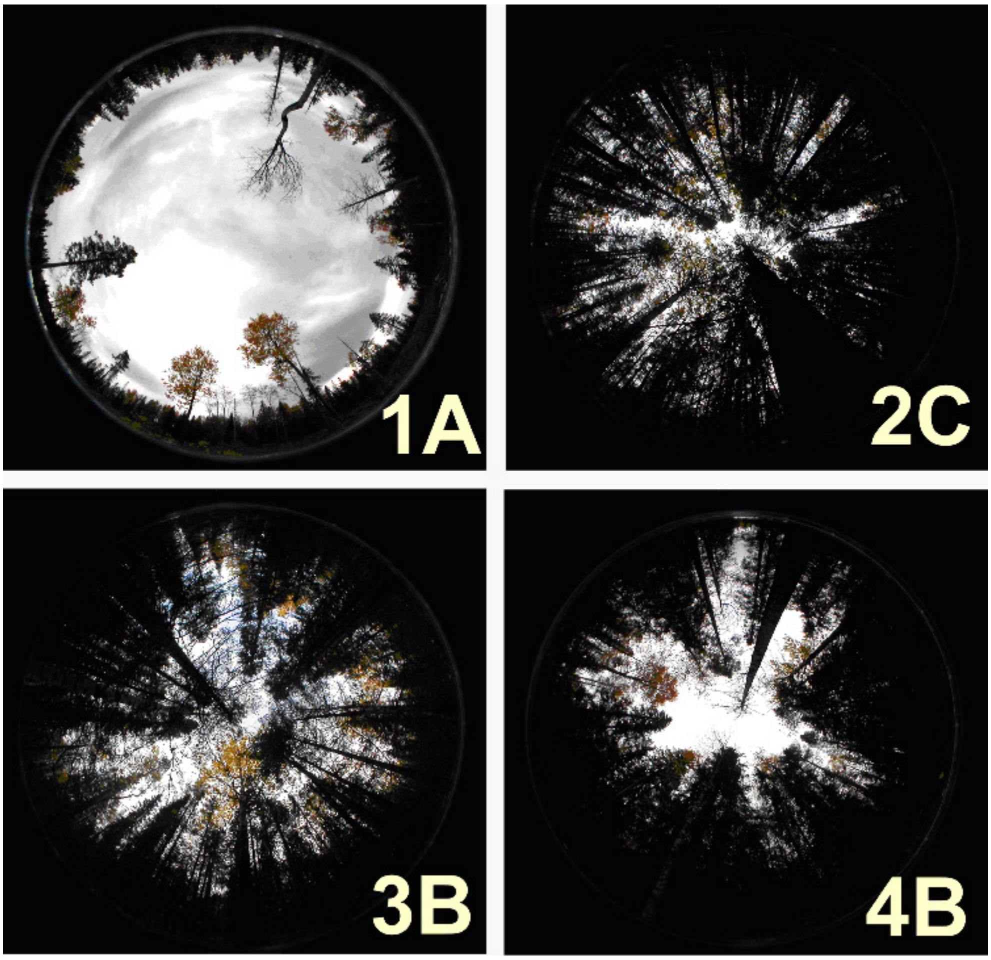

Fig. 15. Examples of fisheye photos from 4 of the aspen stumps, labelled with the number and letter of the tree they represent. Tree 1A had the highest SO value (67, 5%), while 2C had the lowest (9, 18%). The values of 3B and 4B were rather intermediate; 15, 96% and 17, 43%, respectively.

The statistical analyses showed that site openness (SO) and basal area surrounding the aspen were closely related (p=0,001, calculated with 3 basal area classes). This was the most evident of the correlations for the SO variable. The relation between SO and basal area can be seen in fig. 16.

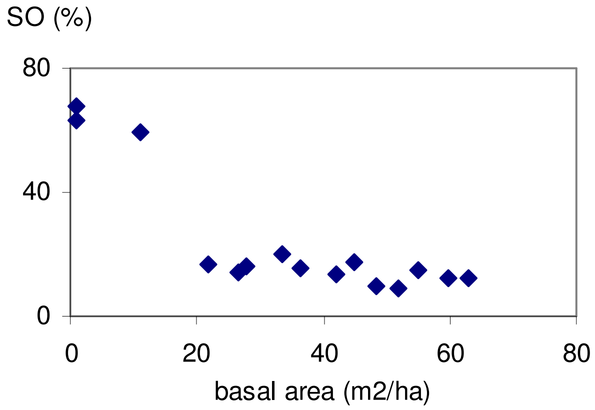

Fig. 16. Basal area vs. % site open.

3.6 W20

In the statistical analyses, the W20 data from 1, 3 m. was divided into 3 different classes (Table 3).

Table 3. Classification of the W20 data, and the number of values in each class

W20 class	W20 (1,3 m) interval	Number of values
1	0,1969-0,2844	3
2	0,2845-0,4895	10
3	0,4896-0,7711	2

A significant correlation was found between W20 and age. Older trees had generally a lower W20 value. This correlation was statistically significant for the W20 data from 1, 3 m. (p=0, 04) and 50% of the tree height (p=0, 03) when 3 age classes were used. The results from 1, 3 m. can be seen in fig. 17, and fig. 18 shows the results from 50% of tree height. For the W20 data from 75 % of the tree height the correlation was no longer significant, (p=0, 071), but the overall trend was the same as it was on the other levels (Fig. 19).

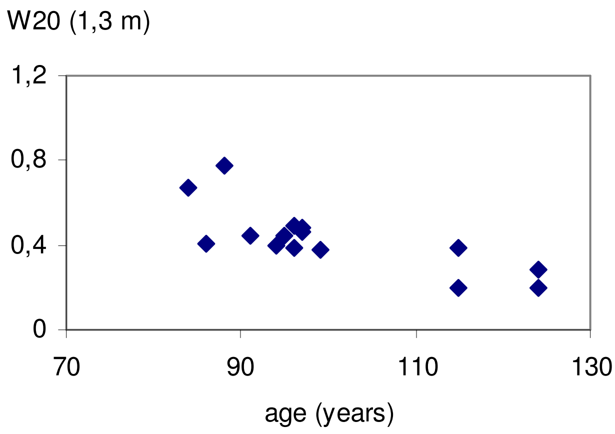

Fig. 17. Age vs. W20 at 1, 3 m height.

Fig. 18. Age vs. W20 at 50% of tree height.

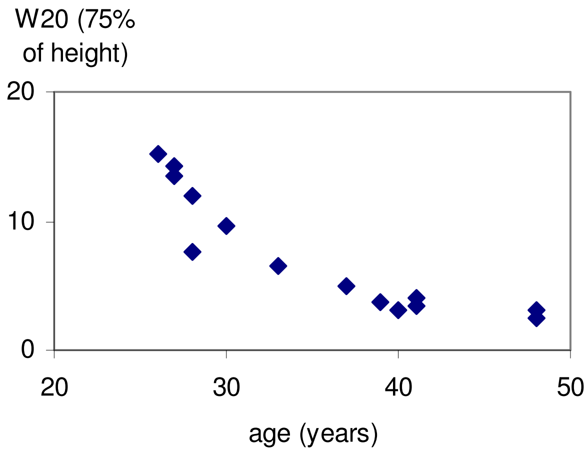

Fig. 19. Age vs. W20 at 75% of tree height.

W20 was furthermore tested against SO, but no significant correlation could be found between these two variables at 1,3 m. ($p= 0.494$). The trend was similar for the other studied height levels. On 1, 3 m, one tree from the clear-cut showed the highest growth for the latest 20 years, while trees from site 2 and 3 showed the highest growth on 50% and 75% of the tree height. The relation between W20 and SO at 1, 3 m. can be seen in fig. 20, and at 50% of tree height in fig. 21.

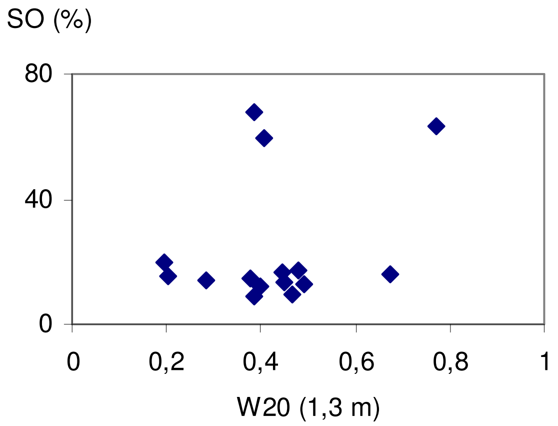

Fig. 20. W20 at 1, 3 m vs. % site open.

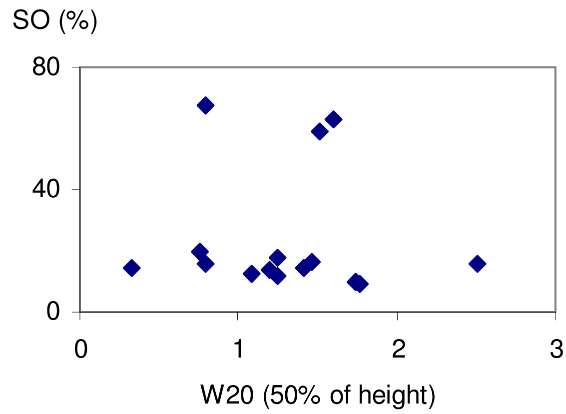

Fig. 21. W20 at 50% of tree height vs. % site open.

No significant correlation could be found between W20 and the basal area surrounding the aspen clones. The p-values were 0.498, 0, 644 and 0, 181 for 1,3 m; 50% of tree height and 75% of tree height, respectively. The relation at 1, 3 m. can be seen in fig. 22.

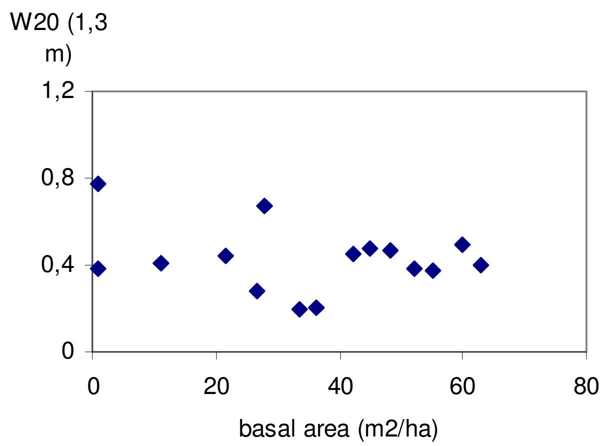

Fig. 22. W20 vs. basal area at 1,3 m. tree height.

One noteworthy observation concerns the results from the clear-cut (site 1). On the wood discs cut out at 1, 3 m. from this site, a growth increase had occurred during the last 7 years (see fig. 23). The highest increase was found in tree 1B. For this tree, the total width of the 7 latest annual rings on the wood disc from 1, 3 m. was 39 mm in the radial direction that showed the highest increase. This can be compared to the width of the 7 previous annual rings, which was 19 mm. In tree 1A and 1C the effect was less obvious, but still evident. In the trees from the sites in the mature stand, no significant growth increase had taken place during the last 20 years. However, on 50% and 75% of the tree height, the highest W20 values could be found in trees that had been growing in the mature stand (site 2 and 3). In other words, the growth increase on the clear-cut was seemingly limited only to the 1, 3 m.

height level.

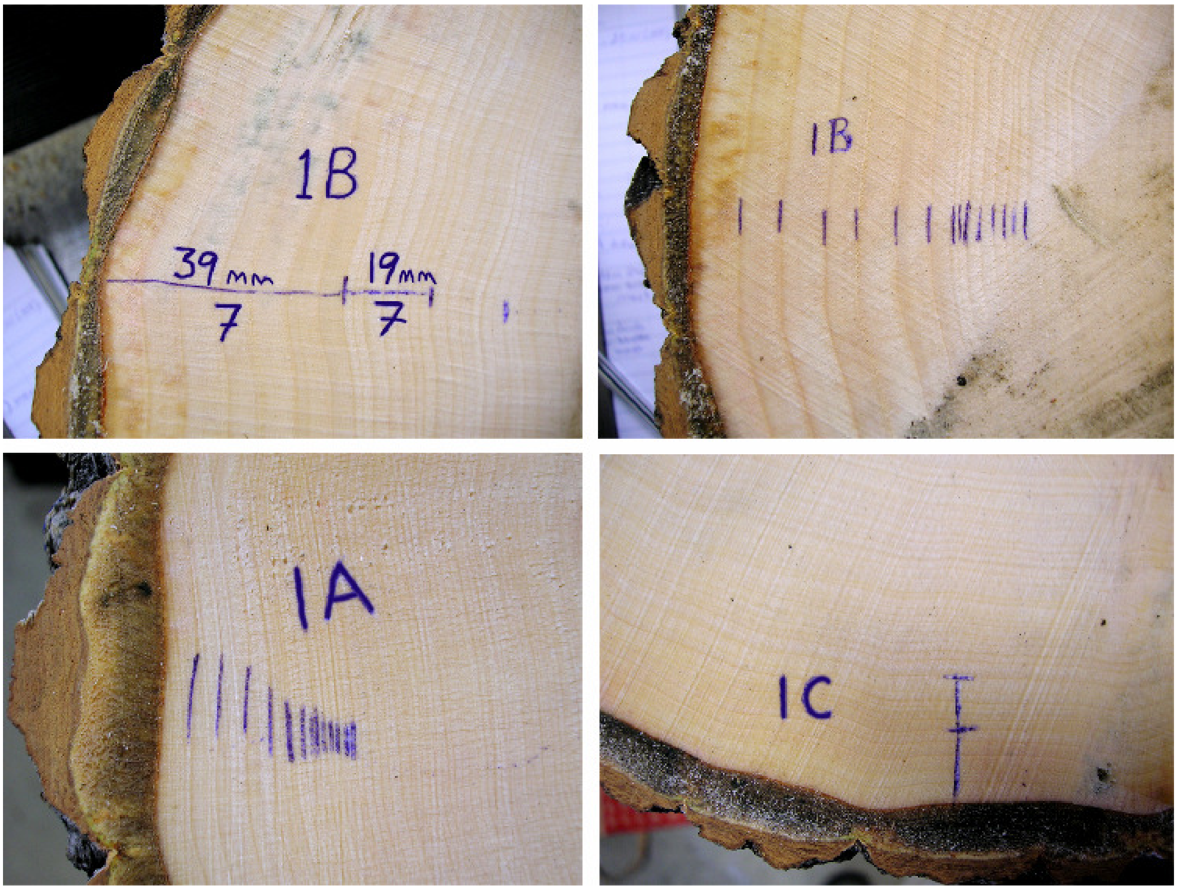

Fig. 23. 4 photos showing the growth increase on the clear-cut. The two upper pictures are from the wood disc taken from 1, 3 m height in tree 1B. This tree had the largest growth increase. The lower photos are from tree 1A and 1C. The growth increase is less obvious in these trees, but still evidential.

3.7 Health Index

Of the wood discs that were cut out at the 1, 3 m. level in the 15 studied trees, 7 were partially rotten. Furthermore, 6 aspens showed discolourations that most likely was a preliminary state of rot. On the second height level (50% of total tree height), rot was found in one disc, while 3 discs showed discolouration. On 75% of tree height, no rot could be seen, but discolouration was found in one disc. The appearance and extent of the rotten or discoloured wood varied considerably, as can be seen in fig. 24.

Fig. 24. Photos showing 4 of the studied trees in which rot or discolouration could be found. In the upper left picture (tree 1B), the wood is discoloured - a preliminary state of rot. In the other 3 photos, trunks with various extents of rotten wood can be seen.

The distribution of the HI values and the parameters that were used for determining them are displayed in table 4. Two trees, 2C and 3B, had no indications of fungus infection at all. These trees were given a HI value of 10. Tree 1A was the only tree where rotten wood could be found in the transverse cut at 50% of the height, and it also had fungi conks growing on the trunk. This tree was given the lowest HI value of all the trees (4). The HI of the remaining trees ranged between 5 and 8.

Table 4. The data used for determining the health index of each studied tree

Site	Tree	Diameter of rotten wood area/area with discolouration in the transverse cut >50 % of the total diameter at 1,3 m height	Diameter of rotten wood area/area with discolouration in the transverse cut <50 % of the total diameter at 1,3 m height	Rot or discolour-ation found at 50 % of tree height	Rot or discolour-ation found at 75 % of tree height	Fungi conks found on the trunk	Health index
1	A	x*		x*		x	**4**
	B		(x)				**8**
	C		(x)				**8**
2	A	(x)					**7**
	B	(x)					**7**
	C				no data		**10**
3	A		x*			x	**7**
	B						**10**
	C	x*		(x)	(x)		**5**
4	A	(x)					**7**
	B		x*			x	**7**
	C		(x)				**8**
5	A		x*	(x)		x	**6**
	B		x*	(x)			**6**
	C		x*			x	**7**

x* = rot occurrence
(x) = discolouration occurrence (no rot)

No obvious trend could be found between HI and tree height (Fig. 25), and no statistically significant correlation (p=0.554) could be found between basal area and HI (Fig. 26).

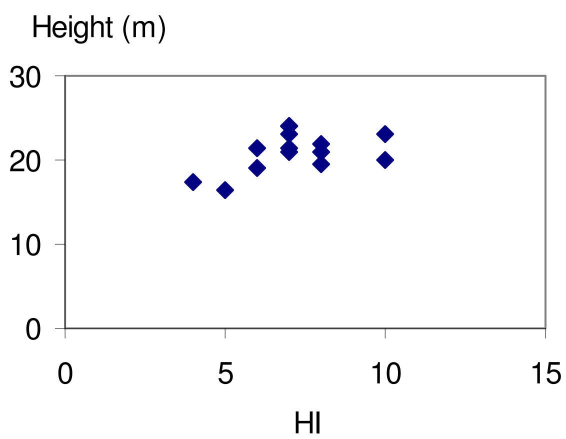

Fig. 25. Height vs. health index.

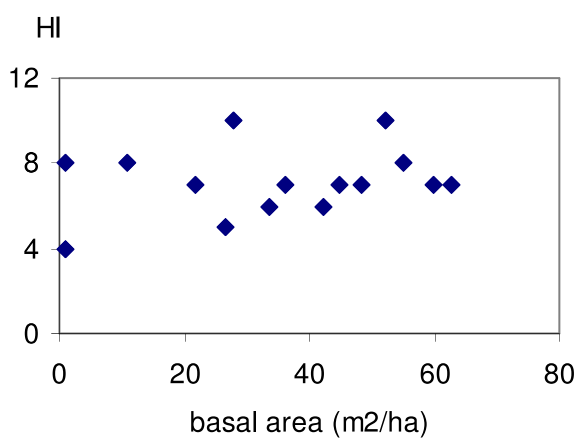

Fig. 26. Basal area vs. health index.

No correlation could be found between HI and SO (Fig. 27). The lowest HI value was found in one of the trees on the clear-cut, but the other two trees from that site had a HI value of 8, which was above the average value of 7, 1. The highest HI values could be found in the trees 2C and 3B. 2C had the lowest SO value of all the aspens (9, 18%), while 3B had a SO value of 15, 96%, which is slightly higher than the average value in the mature stand (14, 3%). Overall, no general trend could be found.

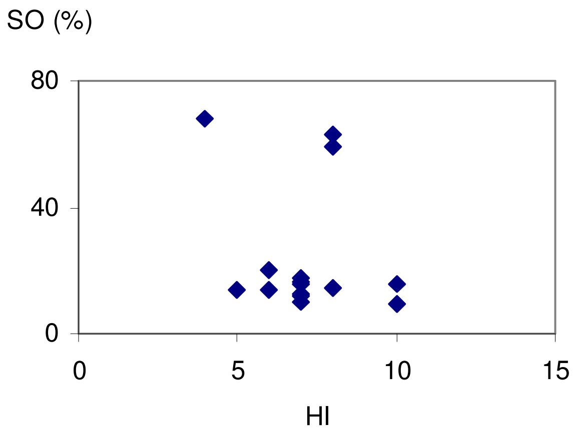

Fig. 27. Health index vs. % site open.

A statistically significant (p=0,038, with 3 age classes) correlation could be found between HI and age at the 1, 3 m. height level (Fig. 28). Older trees generally had a lower HI. The trend was the same for the two other height levels (Fig. 29 and fig. 30).

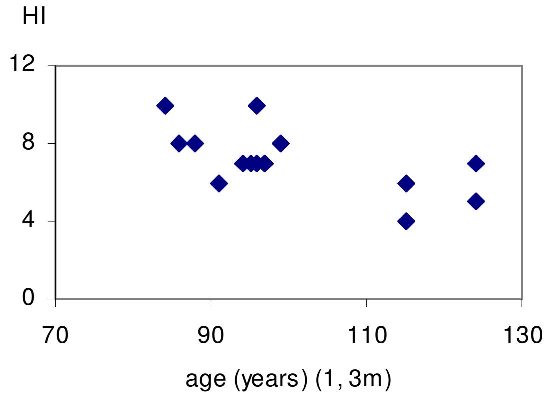

Fig. 28. Health index vs. age at 1,3 m.

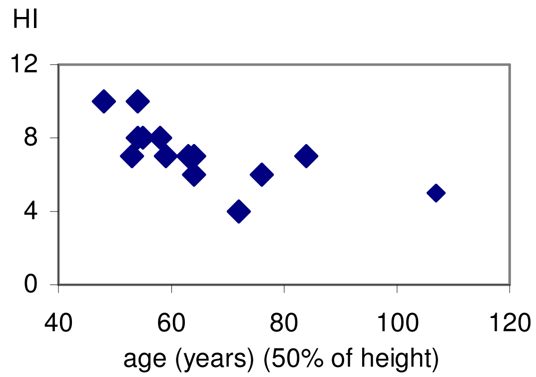

Fig. 29. Health index vs. age at 50% of tree height.

Fig. 30. Health index vs. age at 75% of tree height.

W20 and HI were the variables that were used as indicators for the vitality of the trees. The results show that the relationship between these two variables is rather strong, and that higher health index generally means that the growth during the last 20 years have been higher. The correlation was not statistically significant according to a one-way ANOVA test where 3 W20 classes (from the 1, 3 m. height level) were used (p=0,114), but regression analyses showed that the R^2 value for HI versus W20 at 1, 3 m. of the height was 20, 1% and that the R^2 for 50% of the tree height was 68, 8, which indicates a correlation. The plot diagrams also indicate a trend between the variables. The relation between W20 and HI at 1, 3 m. can be seen in fig. 31; at 50% of tree height in fig. 32; and at 75% of tree height in fig. 33.

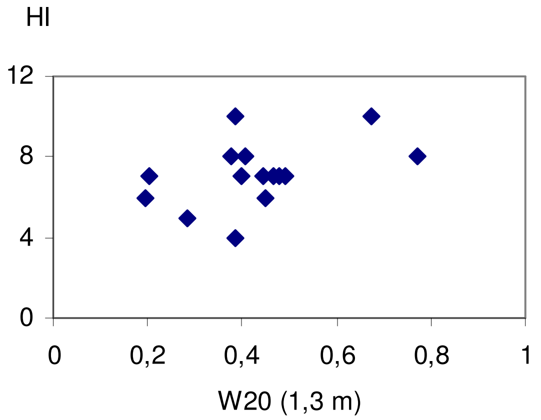

Fig. 31. W20 at 1,3 m. vs. health index.

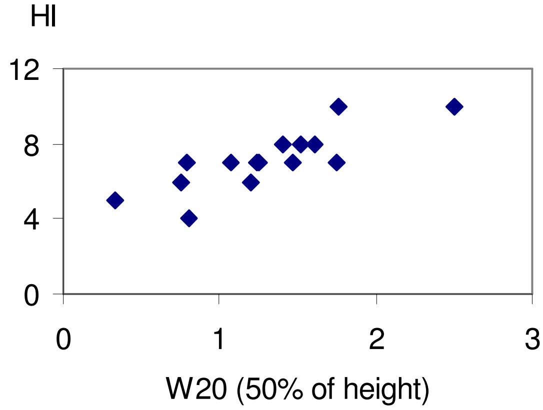

Fig. 32. W20 at 50% of tree height vs. health index.

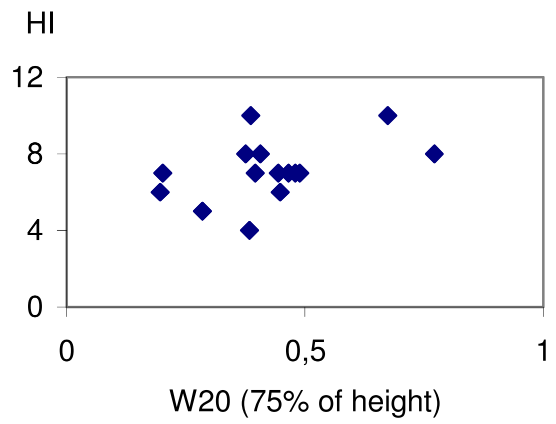

Fig. 33. W20 at 75% of tree height vs. health index.

4. Discussion

The purpose of this study was to investigate how light competition affects vitality in old aspen trees. The results suggest that age affects the vitality of the aspens more than light competition does, and that basal area and amount of incoming light have a rather weak influence on the health state and growth of the trees. However, it is also shown that a reduction of stand density, such as a final harvest, can result in a significant growth increase in the remaining aspens.

The height data from the aspens used in this study showed no correlation with the basal area data. Similar results were shown in a previous study, where no evidential difference in height development could be found between aspen stands where precommercial thinning had been applied and unthinned aspen stands (Rytter & Werner 2007). However, 2 of the 3 tallest trees used in this study could be found on the darkest site, and the possibility of stronger light competition leading to increased focus on height development (rather than diameter expansion) should not be entirely dismissed.

Age was the variable that seemed to have the most influence on vitality. There was a significant difference in growth during the 20 most recent years between the youngest and the oldest aspens included in this study, despite the relatively high age of all the trees. Aspens do not usually become very old (Almgren 1990), and it is possible that the oldest trees used in this study had entered a stage in which height and diamater growth had a low priority, regardless of light conditions. Furthermore, tree rot probably had a substantial influence on the overall state of these trees. It is known that rot is a serious threat to aspens, and even though a tree may live for many years with the rot infection inside, it sooner or later reaches a point where its health is negatively affected by the fungi. In older aspens, rot fungi have had more time to spread, and more damage has been done in the trunk. This might limit the growth possibilities of the tree, since more of its resources then must be used for defense and protection and also since it becomes more vulnerable to other threats. In other words, even though this study uses health index (based mainly on rot occurence) and growth as two different indicators of vitality, these variables are rather strongly connected, and age has a heavy influence on them both.

The age data from the aspens and the spruces suggest an age distribution where aspens generally are 10-20 years older than the spruces. This indicates that the aspen, as it accordning to the literature typically does, established first in the stand and that the spruce entered later. It can also mean that some kind of disturbance occurred in the area, since aspen was able to establish first and probably dominated the stand during its initial state. It is possible that this was the result of a forest fire. On the other hand, there are some facts that contradict this hypothesis. For instance, even if the aspens generally are older than the spruces, their ages range from 84 to 124 years, *i.e.* they did not all establish at the same time. Moreover, no traces of fire could be found in the stand, and a few coniferous trees that were older than the aspen clones were found. Hence, it is also possible that the aspen stand established after some other kind of disturbance, for instance partial cuttings. It is known that industrial exploitation of the boreal forest started ca 100-150 years ago in the northern parts of Sweden, and that it initially was based mainly on high-grading and selective logging (Hellberg 2004). Clear-cut harvesting systems, where larger forest areas were exploited, were generally not introduced until the 1950s. However, the cuttings made in the beginning of the 19th century could be rather extensive at times, leaving only trees that were considered to have a low economic value (Bosaeus 1938) and creating areas well suited for aspen establishment. Thus, another hypothesis could be that the forest used in this study is a result of human disturbance, even if more information and a larger data material would be needed in order to make any certain conclusions about the stand history.

The results from the fisheye photos showed that basal area and site openness were realatively closely correlated. The earlier presented deviations in the relationship between basal area and site openness can have several explanations. For instance, even though two trees might have exactly the same surrounding basal area, the site openness can differ quite a lot between them since the trees growing on one of the sites may be few and large, while they may be small and numerous on the other. Although the sites included in this study were rather similar, there was a variation in stand composition and size distribution. It is also worth mentioning that for a few aspens, some surrounding small trees, mostly spruces and birches, had to be removed before the aspens tree itself could be taken down. However, this should not have affected basal area or site openness to any significant extent, since these trees were generally too small to be included in the diameter registrations. In addition, they were also too short to have any noteworthy influence on the incoming light values.

It should also be mentioned that the fisheye photos were taken in September, when the aspen leaves already had started to fall off. This might have affected the calculated site openness to some minor degree, but it should not have had any significant influence on the value relations between the trees since the percentage of fallen leaves were approximately the same on all the sites.

In this study, vitality was represented by W20 and HI. While the W20 variable, although it was transformed via calculations, was measured directly on the wood discs; the model for determining HI was created by subjectively constructing a model based on certain criteria. There is very little information about vitality in aspen trees to be found in scientific literature, but since rot is such a serious and common factor affecting the health state of aspens, it was chosen to become the main component in this index. Moreover, rot was by far the most frequent health influencer found in the aspens used in this study. It is known that fungi such as White heartwood rot may live inside an aspen tree for a long time without killing it. Thus, it was difficult to estimate how seriously a fungus infection in a tree should be viewed upon. In addition to this, it was not easy to decide what scale to use in the index, and what weights the included factors should be given in relation to each other. Nevertheless, since a trend could be found in the connection between HI and W20 (*i.e.* these two variables do not contradict each other too much), it should be possible to use it as an indicator of vitality as long as it is kept in mind that the index model is quite subjectively constructed.

One of the aims of this study was to find out whether creating more open space around old aspens is a useful method for prolonging the trees' lives or not. The results do not provide any obvious answer to this question. However, both the W20 and the health index data suggest that old aspens tend to lose vitality regardless of stand density and amount of incoming light. This indicates that reducing the light competition in a stand has little effect on the life span of the trees. On the other hand, this conclusion is to some extent opposed by the growth increase that could be found in the trees on the clear-cut. There is no doubt that the harvesting that took place there gave the remaining aspens the chance to increase their stem diameters. If growth during the last 7 years had been used as an indicator of vitality, the aspens that grew on the clear-cut would have been considered far more vital than the rest of the studied trees. It should also be pointed out that even though one of the aspens on the clear-cut had the lowest HI value of all the trees, an obvious growth increase could be found in this tree. This indicates that a reduction of stand density can induce increased growth even if the vitality of the affected tree is low.

It is also interesting to note that the growth increase on the clear-cut only could be detected in the wood discs cut out at 1, 3 m. It is possible that reduced stand density results in the trees allocating more of their growth to the trunk instead of the crown, since light competition decreases and the trees become more exposed to wind and thus need to increase their stability. Similar reactions are usually found after thinnings in coniferous stands (Karlsson 2005; Liu *et al.* 2003).

It is, however, important to keep in mind that the growth of a tree depends a lot on factors such as water and nutrient supply, and that light merely is one of the many variables influencing the development of a stand. Furthermore, the cutting on site 1 was a rather extreme disturbance that most likely changed the growth potential for the remaining trees radically. The trees in the mature stand have been growing under the same conditions for very long, and many important ecological processes have probably been kept on the same level for several years. It is, for instance, possible that nutrient availability affects the W20 variable more than stand density does, and that the cutting on site 1 resulted in a large amount of nutrients being released to the soil, thus changing the growth conditions considerably. Furthermore, since it is unknown what the former stand on this site looked like stand up until 7 years ago, no general conclusions about long-scale tree development can be based upon the data from that site. Apart from the growth increase that took place after the harvesting, most variables from these trees, such as height and diameter, mainly developed while the aspens were growing in the former stand. It is, however, interesting to use them as a reference of what happens to trees that have been left after a cutting.

The data material used this study is rather small, and no large-scale conclusions should be based on the results. 15 aspens were used in the analyses, and all of them were located in the same area. The trees were chosen on a number of criteria; for instance that they should be old, have a relatively large diameter, and also that they should be located rather close (<40 m) to each other on each site, but the selections were not based on any statistically objective method, and there is a possibility that there is a certain bias in the collected data. Furthermore, the applicability of the results is geographically limited. The study was made in Norrbotten, where the summers are short and the winters are cold and snow-rich. The species that reside here are fewer than in the south of Sweden, where, for instance, a large number of additional wood fungi and insects that may affect the vitality of aspens can be found. Lower temperatures also usually prevent the spreading of wood fungi (Rönnberg *et al.* 2006), and the growth period in Norrbotten is shorter than in the southern parts of the country. Moreover, nutrient conditions are very different. It is also worth mentioning that the W20 data from the wood discs taken out at 75% of tree height are the least reliable. At 75% of the tree height, the aspens' crown shapes vary a lot, and the diameters are usually very small, which makes it difficult to compare them to each other.

Overall, the results from this study indicate that creating more space around old trees in dense stands that have stagnated in growth can induce larger stem diameters, even if these trees are in a relatively bad health state. Since large aspens have a high value for biodiversity, this method should be regarded as a useful one. However, it should be remembered that a final harvest is a radical disturbance that changes many stand factors. Other variables than increased light amount, such as altered nutrient conditions and water supply, may have affected the growth on the clear-cut. Furthermore, a final harvesting is much more extensive than the kind of cuttings usually made when the purpose of the treatment is to create more space around specific trees. This study does not provide an answer to how strong the cutting/thinning needs to be if a growth increase is to be obtained, it merely shows that a large-scale cutting most likely will induce larger stem diameters in the left over trees.

Seen from a management perspective, liberation of old aspens can be considered a practicable method for increasing the proportion of large broadleaved trees in forest stands. There are, however, other methods that can be used as well, and each activity should be adjusted to fit the local and site-specific conditions and objectives. The method of creating more space around trees that are well suited for developing a large diameter should probably be primarily applied in stands where other tree species or younger trees are suppressing the old aspens, and where the goal is to increase the percentage of deciduous trees in a mixed forest. Furthermore, the importance of continuity should be emphasized. A treatment such as creating more space around specific trees usually needs to be repeated after a few decades, since spruce and other species eventually will take over the site otherwise.

5. Conclusions

The results from this study indicate age influences the vitality of old aspen trees more than basal area and light competition does. No significant correlation could be found between basal area and vitality (represented by health index and growth during the last 20 years), or between site openness and vitality.

A significant correlation could be found between age and the overall subjectively created variable health index (HI), and also between age and the more objectively measured variable representing relative growth during the last 20 years (W20). Older trees generally had a lower HI and a lower W20 value.

A noteworthy growth increase could be found in the aspens that had been growing on the site that was harvested 7 years ago. This indicates that creating more space around aspens can induce larger stem diameters, even if the trees are rather old. Consequently, even though it is doubtful whether reducing the light competition around an aspen tree will prolong its life span, it seems to be a useful method for making the tree develop larger dimensions. This is important since old, large aspens have a high value for biodiversity.

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