What makes birches grow?

Relating environmental factors to the growth of birch in raised bogs




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Abstract

The invasion of birch (*Betula spp.*) in raised bogs in the Netherlands threatens the recovery of *Sphagnum* mosses due to evapotranspiration and shading. Nature conservation organizations put many efforts in the removal of birch. This research focuses on the environmental factors that are important for the radial growth of birch (B*etula spp.*) on a raised bog, the Haaksbergerveen. By defining factors that favour birch growth management tools can be suggested that limit birch invasion and hence enable the conservation of raised bogs. Stem disks have been taken from trees growing on experimental plots with different densities of birch, as it was thought that a higher tree density will increase evapotranspiration rate creating better micro-site conditions. The annual radial growth has been measured and related to tree density, water table level, the availability of ammonium, nitrate and phosphorus, as well as pH and climate conditions.
The factors mainly explaining radial growth of birch in the Haaksbergerveen were found to be water table level in summer and phosphorus availability, which are interacting, as a lower water table level results in a higher decomposition and mineralisation rate. Furthermore, the temperature in May and the precipitation between March and July also had a positive effect on birch growth. From literature it was found that a low cutting height decreases the re-sprouting success of birch. Therefore it can be concluded that birch management in raised bogs must focus on cutting birches as low as possible, simultaneously increasing the water table level periodically, while carefully observing the effects on *Sphagnum* mosses.

Keywords: *raised bogs, Betula spp., tree-ring analysis, hydrology, evapotranspiration, nutrient availability, climate*

Foreword

Already in my second year studying Forest- and Nature Conservation I told Juul Limpens, during an excursion in the Haaksbergerveen, “I would like to do my Master-thesis about raised bogs and birch”. And see: 3 years later the research and report are finished, lying in front of you!

With lots of fun and interest I have been working on this study. During the previous six months I have been assisted by several persons. I would like to thank my two supervisors: Juul Limpens and Ute Sass-Klaassen, for their knowledge about raised bogs and dendrochronolgy and their help and comments during the whole period of this thesis.
Futhermore, I want to thank Roy Dear of State Forest Service, for the permission for doing research in the Haaksbergerveen and for the information about the area and the applied management practices.

I received help in the field by Frans Möller, with whom I survived the swampy field conditions and dangerous vipers. Jan van Walsem helped me with the nutrient analysis in the chemical lab, where we performed the bubbling “pre-historical” Olsen’s Method. I am very grateful for that.

Last but not least, I would like to thank the people that supported me while working on this research and I hope you will read this report with pleasure and interest!

A viper in the Haaksbergerveen

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Summary

Since the last ice age (12.000 years ago) extensive raised bogs developed in permanently wet depressions in the European landscape, forming large organic soil layers, called peat. The organic peat layers in bogs are mainly built up of *Sphagnum* species (peat mosses). Bogs are ombrotrophic and the *Sphagnum* mosses depend on water and nutrients from the air. In the Netherlands few raised bogs are left as a result of the intensive peat extractions since the Middle Ages. Since the last century nature conservation organisations are working hard to restore these valuable ecosystems. However, the invasion of trees (mainly birch), delays the restoration of the raised bogs. This invasion has been ascribed to changes in hydrology and nutrient availability. Due to peat extractions the hydrological balance has been disturbed and nowadays drainage in surrounding agricultural areas made that bogs have become desiccated. The change is nutrient availability is caused by the increased atmospheric deposition. In a normal situation the litter of *Sphagnum* mosses can bind nutrients such as N and P from the rhizosphere, preserving the nutrient poor situation and making it difficult for vascular plants to survive. However, in the Netherlands the deposition has exceeded the empirical critical load of nutrient-poor raised bogs. Nutrients are leached to the rhizosphere were it becomes available for vascular plants, such as *Molinia caerulea* and *Betula spp*. These species negatively affect the growth of *Sphagnum* by dessication due to evapotranspiration, and shading. Nature conservation organisations apply two kind of management interventions, namely, water management; building dams and increasing the water table level. And birch management; the regular cutting of birch trees.

This study aims at revealing the environmental factors that mainly influence the growth of birch on raised bogs. By defining factors that favour birch growth management tools can be suggested that limit birch invasion and hence enable the conservation of raised bogs. The experiment has been carried out in the Haaksbergerveen, the Netherlands. Plots were chosen based on tree density and tree samples of different diameter classes were selected. Measurements included the water table depth, availability of ammonium, nitrate and phosphorus. Furthermore, growth has been related to climate factors (temperature and precipitation) and birch management, as a part of the plots has been managed in the past. Performance of trees was measured as radial growth dynamics. Data was statistically analysed using SPSS.

It was found that either tree density (basal area) and the difference in water table level between winter and summer, nor basal area and radial growth were correlated with each other. On the other hand water table level seemed to have the strongest effect on radial growth of birch. And of the three nutrients measured phosphorus was found to be most important. Furthermore, diameter and age were correlated with each other, despite the big distribution of measurements. We also found a lot of variation in growth patterns, with an unusual trend break around 1995. Trees that germinated before 1995 grew significantly lower after 1995, whereas trees which germinated after 1995 showed a normal growth pattern. Birch management resulted in an enormous growth peak after re-sprouting, but average growth did not differ compared to normal germinated trees that grew up in the same period. Relating radial growth patterns of birch with climate conditions resulted in the temperature from March till May and the precipitation from March till July as the explaining factors.

In literature it is written that trees have a stimulating effect on the evapotranspiration rate, creating better micro-site conditions. But the effect of birch on water table level depth is still not proven, as comparative studies show mixed results. In our study we did not find a relation between basal area and water table level or average growth. However, we did find some indirect evidence. Namely, the trend break in growth around 1995 might be the result of intensive birch management in that period. As many trees evapotranspirate more, the removal of birches will decrease the evapotranspiration making the site conditions wetter, decreasing the growth of birches that are still standing. Trees that germinated after the event in 1995 adapted their root system to the new situation (possibly by keeping it more shallow) and therefore seem to have no growth problems. That water table level is important for growth show our results. The finding that phosphorus is important for birch growth was also argued by an experiment in a desiccated bog in Ireland. The study shows that P indeed is an important nutrient for the growth of *Betula*, since above ground biomass did not increase under N-enriched conditions as P was limiting. In the Netherlands both N and P are deposited sufficiently, so *Betula* has no problem to grow. Furthermore, the variation in diameter-age relations and growth patterns can be explained by the characteristics of raised bogs. They are not homogeneous in site conditions. Due to local differences in water table, vegetation or nutrient availability. Concerning climate conditions, in this study it was found that a high amount of precipitation between March and July increased the growth of birch. This result might be explained by the desiccation of the upper peat layer in the summer negatively affecting the shallow root system of birch. A little more precipitation compared to other years might then increase the water availability in the peat layer preventing roots to dry out. Finally, trees that have been cut down re-sprout again and show a growth peak in their first year. This is likely related to the fact that the root system is still present. It may enable them to start growing new shoots rapidly. However, the growth peak has a limited duration, as we did not find an increased growth of trees in managed plots compared to trees that were not managed.

Based on our findings and literature the management of State Forest Service could try firstly to periodically increase the water table level, decreasing the growth of standing trees. Secondly, they could cut the stem of the birch as low as possible during birch management, as that seems to negatively affect the success of re-sprouting.

Samenvatting

Sinds de laatste ijstijd (12.000 jaar geleden) hebben zich in permanente natte depressies in Europa uitgestrekte hoogvenen ontwikkeld. Deze hoogvenen bestaan uit dikke organische lagen, veen, welke voornamelijk opgebouwd zijn uit *Sphagnum* soorten (veenmossen). Hoogvenen zijn ombrogeen, de veenmossen zijn afhankelijk van regenwater en nutriënten uit de lucht. Als gevolg van het steken van turf sinds de Middeleeuwen zijn er nog maar weinig hoogvenen in Nederland. De laatste decennia steken natuurbeherende instanties veel energie in het behoud van deze waardevolle ecosystemen. Echter, de invasie van bomen (voornamelijk berk), vertraagt het herstel. De invasie van berk wordt geweten aan veranderingen in hydrologie en nutriëntenbeschikbaarheid. Het turfsteken heeft de hydrologische balans verstoort en hedendaagse drainage in omliggende agrarische gebieden hebben er voor gezorgd dat venen zijn uitgedroogd. De nutriëntenbeschikbaarheid is veranderd door een hogere atmosferische depositie. In een normale situatie kan het plantafval van *Sphagnum* nutriënten zoals stikstof (N) en fosfor (P) aan zich binden, waardoor de voedselarme situatie in stand wordt gehouden en andere planten geen kans krijgen. De N-depositie is in Nederland echter zo hoog dat de kritische waarde is overschreden en *Sphagnum* niet meer in het voordeel is. Planten als *Molinia caerulea* en *Betula spp*. ontkiemen en hebben een negatieve invloed op de veenmossen doordat evapotanspiratie wordt versterkt en de bovenste veenlaag uitdroogt. De natuurbeherende instanties gebruiken twee beheersingrepen, namelijk waterbeheer; het bouwen van dammen en het verhogen van de waterstand. En het beheer van de berken waarbij ze regelmatig om worden gezaagd.

Dit onderzoek bekijkt de omgevingsfactoren en hun effect op de groei van berk. Als we eenmaal weten welke factoren de groei van berk stimuleren kunnen we beheersmaatregelen verzinnen die de invasie van berken juist afremmen om zo de hoogvenen te behouden. Het experiment heeft plaatsgevonden in het Haaksbergerveen. De plots zijn uitgekozen op basis van dichtheid en berkjes van verschillende diameter zijn gebruikt. Waterstand, pH en de beschikbaarheid van ammonium, nitraat en fosfor zijn gemeten. Daarnaast is de groei gerelateerd aan klimaatfactoren (temperatuur en neerslag) en het beheer van berken. De groei van berken is gemeten in de vorm van dynamiek in radiale groei. De gegevens zijn statistisch geanalyseerd met behulp van SPSS.

De resultaten laten zien dat er geen relatie bestaat tussen de dichtheid van berk (grondvlak) en het verschil in waterstand tussen winter en zomer, maar ook niet tussen de dichtheid van berk en gemiddelde radiale groei. Echter, waterstand had wel het sterkste effect op groei en van de nutriënten was fosfor het belangrijkste. Daarnaast waren diameter en leeftijd met elkaar gecorreleerd, ondanks de hoge spreiding in metingen. Ook in de groeipatronen zat veel variatie, met zelfs een merkwaardige groeitrend rond 1995. Berken die voor 1995 gekiemd waren groeiden na 1995 significant minder, terwijl bomen die na 1995 kiemden een normaal groeipatroon lieten zien. Het omzagen van berk leidde tot een enorme groeipiek bij de herspruiten, maar de gemiddelde groei verschilde niet vergeleken met bomen die in dezelfde periode opgegroeid ware. Van de klimaatfactoren waren de temperatuur in mei en de neerslag tussen maart en juli het belangrijkst voor de groei van berk.

Uit literatuur is op te maken dat bomen de evapotranspiratie stimuleren en zo hun eigen groeicondities verbeteren. Dat berken ook echt een effect op de waterstand is echter nog niet bewezen, omdat vergelijkbare onderzoeken verschillende resultaten laten zien. In ons onderzoek hebben we geen relatie gevonden tussen grondvlak en waterstand of radiale groei, maar wel indirect bewijs. De trendbreuk in groei rond 1995 zou namelijk een resultaat kunnen zijn van intensief berkenbeheer in diezelfde periode. Veel bomen evapotranspireren namelijk veel en het verwijderen van veel berken vermindert de evapotranspiratie waardoor de waterstand iets hoger wordt. Dit heeft een negatief effect op de berken die achtergebleven zijn. Bomen die na de ingreep gekiemd zijn hebben hun wortelsysteem aangepast aan de nieuwe situatie (door het oppervlakkiger te houden) en vertonen daarom geen groeiproblemen. Waterstand is erg belangrijk voor de groei, net zoals fosfor. Dit laatste is ook geobserveerd in een verdroogd veen in Ierland. De studie laat zien dat de bovengrondse biomassa van berk niet toeneemt bij een verhoogde stikstofbeschikbaarheid, waarschijnlijk doordat fosfor ontbreekt. In Nederland zijn stikstof en fosfor genoeg voorhanden, dus hier heeft de berk geen groeibeperkingen. Verder is de variatie in diameter-leeftijd relaties en groeipatronen te verklaren door de heterogene groeicondities van hoogvenen. Er bestaan grote lokale verschillen in waterstand, vegetatie en nutriënten-beschikbaarheid. Beheer van berken heeft ook een effect op groei (een groeipiek in het eerste jaar) wat verklaart kan worden door het wortelsysteem, dat nog steeds aanwezig is. Het zorgt ervoor dat nieuwe scheuten snel kunnen groeien. De groeispurt is echter van korte duur. Wat betreft klimaatfactoren is het belang van veel neerslag tussen maart en juli misschien wat vreemd. Echter, als de bovenste veenlaag in de zomer uitdroogt ondervinden de wortels van berken droogte stress. Een beetje meer regen dan normaal voorkomt dit.

Gebaseerd op de resultaten van dit onderzoek en literatuur zou Staatsbosbeheer in eerste instantie kunnen proberen the waterstand periodiek te verhogen, zodat de groei van aanwezige berken wordt bemoeilijkt. Daarnaast zouden ze gedurende het zagen van berken de stam zo laag mogelijk om kunnen zagen, aangezien dat het aantal herspruiten zou verminderen en op den duur de stobbe zou uitputten.

Birches in the Haaksbergerveen

1 Introduction

Raised bogs in the Netherlands
Since the last ice age (12.000 years ago) extensive raised bogs developed in permanently wet depressions in the European landscape, forming large organic soil layers, called peat. The organic peat layers in bogs are mainly built up of *Sphagnum* species (peat mosses), making these bryophytes a kind of ecosystem engineers (Van Breemen 1995). As these *Sphagnum* mosses mainly depend on water and nutrients from the air, raised bogs are often referred to as ombrotrophic (= rain water fed and poor in nutrients). The *Sphagnum* mosses are very efficient in using nutrients and they produce a decay-resistant litter which reduces the mineralisation rate and increases the peat accumulation rate (Malmer *et al*. 2003). Because of the low decomposition rate of *Sphagnum,* carbon accumulates in peat bogs (Clymo *et al*. 1998). Furthermore, the litter of *Sphagnum* mosses can bind nutrients such as N and P from the rhizosphere (Malmer *et al*. 2003, Lamers *et al*. 2000), preserving the nutrient poor situation and making it difficult for vascular plants to survive.

In the Netherlands few raised bogs have been left as a result of the intensive peat extractions since the Middle Ages. At the end of the last century, it was realised that these valuable ecosystems must be conserved. However, conservation is frustrated by massive establishment of trees, mainly birch, presumably as a result of changes in hydrology and the increase in nutrient availability.

Changing nutrient status and the invasion of birch
As a consequence of the intensifications in agriculture, traffic and industrial activities, the atmospheric nitrogen (N) deposition in the Netherlands has increased enormously to 40 kg N ha^{-1} yr^{-1} (Tomassen *et al*. 2004). This exceeds by far the empirical critical load of nutrient-poor raised bogs which has been set at 5-10 kg N ha^{-1} yr^{-1} (Bobbink and Roelofs 1995). Unsurprisingly, this increase in N availability has affected the composition of flora and fauna in raised bogs, leading to expansion of species not indigenous to raised bogs, such as *Molinia caerulea* (L.) Moench and *Betula spp*. (Tomassen *et al*. 2004). The most invasive tree species are *Betula pubescens* Ehrh and *Betula pendula* Roth, but also some *Pinus sylvestris* L. can be observed.
The complex interaction between birch growth and *Sphagnum* growth and the availability of nitrogen and phosphorus, respectively, is summarised in Figure 1.

Effects of the establishment of birch on raised bogs
The germination and establishment of birch in raised bogs in the Netherlands is experienced as a negative phenomenon, as the species strongly influences the performance of *Sphagnum* mosses and hence the existence and management of raised bogs. It has been suggested that the establishment of birch leads to increasing local evapotranspiration rates. Frankl and Schmeidl (2000) described the positive relationship between evapotranspiration and the establishment of heather and woodland species (*Betula, Pinus*) in a South German raised bog (Rottauer Filz). By enhancing evapotranspiration which causes local desiccation (lower water table) and an improved nutrient availability (increased decomposition), birch trees are able to create micro-site conditions that favour birch growth as well as germination and establishment of more birches (fig 1). A higher tree density will intensify

evapotranspiration and therefore might increase the growth conditions for trees in the raised bog.
Furthermore, it was found that shading by trees and other vascular plants may negatively affects *Sphagnum* growth (Heijmans *et al.* 2001). Contrary, well-growing *Sphagnum* makes germination and growth of birch seedlings difficult (Satyanti 2006) (fig 1).

Management interventions
Two management practices are currently applied in raised bogs to prevent birch establishment and growth: water management and birch management.
Water management includes the creation of dams to increase the water level and/or to keep it constantly high. A persistent high water level has a negative effect on the radial growth of birch (fig 1).
Birch management comprises the cutting of birch trees present in the area. However, as birch is able to re-sprout from the remaining stumps, regular cutting campaigns are necessary.

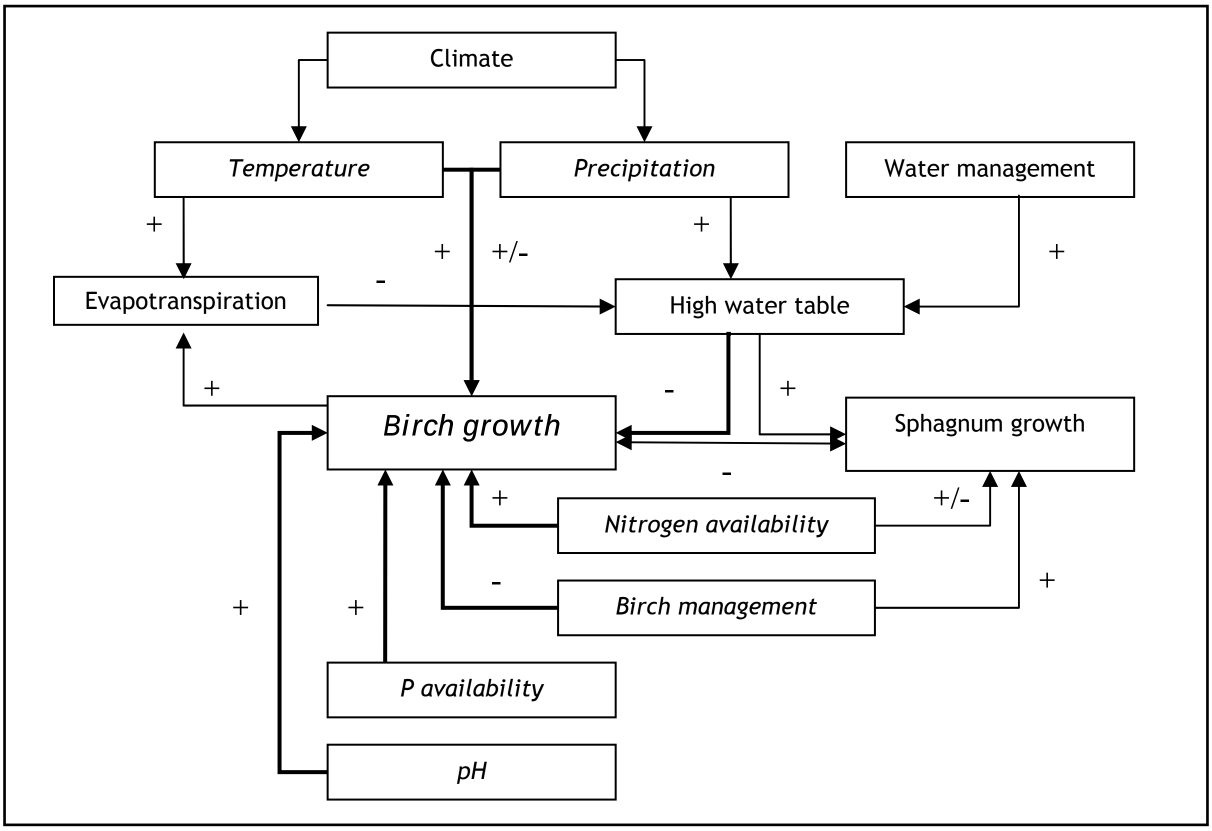


Fig 1 Conceptual model of the factors that potentially influence the growth of birch
Factors analysed in this study are indicated in italic; bold arrows mark the studied effects

Role of climate

Beside site-specific factors and natural and human disturbances, radial growth of trees is also influenced by changing weather conditions.

It is likely that temperature will have a positive effect on growth through stimulation of photosynthesis. And under high temperatures evapo(transpi)ration is increased drying out the upper peat layer creating better rooting opportunities for birch. Precipitation is likely to increase the water table in the raised bog and may therefore have a negative influence on birch growth. However, when summer temperatures are too high, the peat might become too dry that even the roots of birch experience drought stress. Therefore precipitation can also have a positive effect (fig 1).

Approach

In peat bogs birch is able to establish and to grow under highly variable micro site conditions; i.e. on relatively wet and on dry peaty substrate and on rich and on poor soil. Whereas earlier research has focused on the germination and establishment of birch on raised bogs (Satyanti 2006; Barendse 2007), this study aims on the assessment of those environmental factors that mainly influence the growth of birch on raised bogs. Moreover the interaction between *Sphagnum* growth and birch growth is discussed. By defining factors that favour birch growth management tools can be suggested that limit birch invasion and hence enable the conservation of raised bogs.

In this study we made use of an existing experiment that has been carried out in the Haaksbergerveen, the Netherlands, to define environmental factors that affect the growth of birch most. Plots were chosen based on tree density and tree samples of different diameter classes were selected. The main focus of this study was to assess the effect of density of birch trees, water level, nutrient availability, and climate (temperature and precipitation) on the performance of *Betula* on a raised bog. Performance of trees was measured as radial growth dynamics.

Research question

Based on the conceptual model (fig 1) and on the literature the following question has been raised:

How do tree density, water table level, nutrient availability, climate factors and birch management influence the radial growth of birch in a raised bog?

We expected that:

- a high basal area of birch leads – through local drainage as a consequence of a higher evapotranspiration rate – to an increase in radial growth;
- a low water table level in summer results in a higher radial growth of birch;
- radial growth of birch increases with the availability of N and P;
- temperature has a positive and precipitation has a negative effect on the radial growth of birch;
- birch management reduces the growth of birch by cutting trees, however, birch that establish from re-sprouts are growing faster than those established from seedlings.

2 Methods

2.1 Research site

The experiment was carried out in the Haaksbergerveen, the Netherlands (fig 2) (52°07’N, 6°46’O). The Haaksbergerveen is a Natura 2000 area of circa 600 hectares. The Haaksbergerveen is a relict of one of the raised bog areas on the border of the Netherlands and Germany and forms a reserve with the Ammeloër Venn in Germany. After previous degradation, the reserve is now in a restoration phase. During the last few decades a network of dams was constructed (Appendix I) in order to restore the necessary water tables to allow the fen-vegetation to recover. The recovery of *Sphagnum* mosses show promising results for the future.

Fig 2 The field location Haaksbergerveen

2.2 Experimental set-up

We made use of an existing experiment that is situated in the Haaksbergerveen. This experiment has been set up to investigate the effect of tree density on the growth of *Sphagnum*. Plots of 10x10 m are situated in pairs, whereby in one of the plots all trees were removed. Height (cm) and circumference (mm) of these removed birches have been measured. The 14 plots show a gradient in basal area (our indicator for tree density) which is normally seen in raised bogs (fig 3). Eleven of these plots have been used in this study, as from three plots the removed stems were not available anymore. Furthermore, one additional plot from the same area has been included. In total 12 plots have been sampled (see Appendix I).

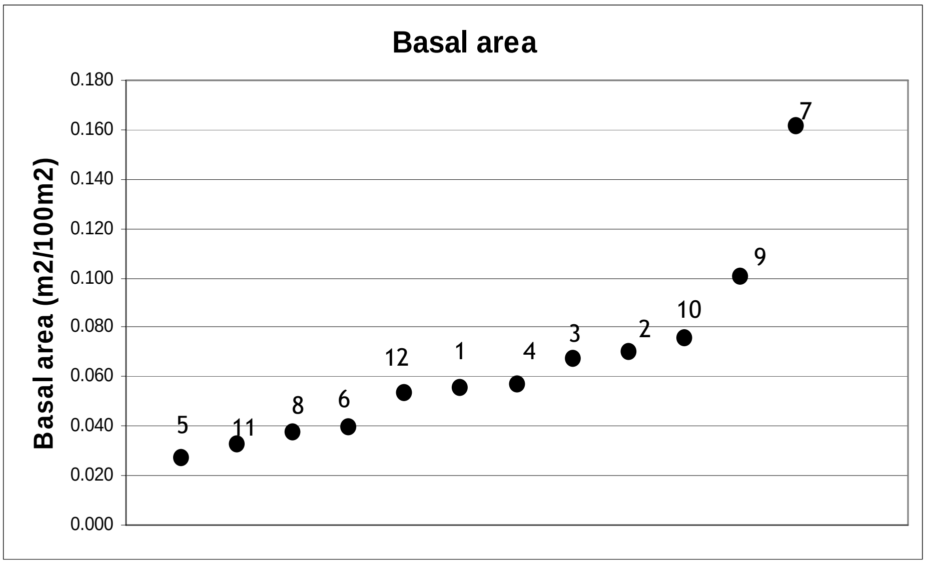


Fig 3 The gradient in basal area of the 12 experimental plots used in this research

Field work

From the removed birches in the 12 plots a representative sample of circa 20 trees has been taken per plot to avoid effects of germination year or accidentally favourable conditions. Selection of trees was based on histograms, showing the frequency of the circumference of the stem. The smallest group of trees

(circumference 0-20 mm) and groups of big trees (circumference >120 mm) that had few individuals were not taken into account.
To indicate the effect of site conditions on the growth of birch in raised bogs, we sampled a birch growing on sandy soil in the Haaksbergerveen. Differences in habitus between trees growing on sand and on peat have been observed and analysed.

2.3 Measurements of site factors

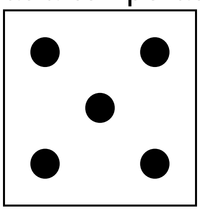
To collect information about the site conditions in the Haaksbergerveen, water table level and nutrient availability in the peat layer of the experimental plots were measured.

2.3.1 Water table level

Water level tubes have been installed in February 2008 (one tube per plot; on plots with and without trees). At the same time the water table level has been recorded. In May 2008 the water table level was measured a second time. Data from the plots with birch cover intact was used to calculate the difference between the water level in winter and (early) summer. A big difference between the winter and summer value means a big decrease in water table level. The data of the experimental plots where trees were still standing have been used.

2.3.2 Nutrient availability

As we would like to investigate the factors that increase or decrease the growth of birch and on the other hand want to exclude certain factors having no influence on the growth of the tree, we measured the nutrient availability for *Sphagnum* and birch.
The organic material for the analyses was collected in March at five locations in each experimental plot (fig 4) to create a mixed sample. The material has been prepared for analysis the day after the field work. In the mean time they were kept at a temperature of 4 degrees (refrigerator).



For *Sphagnum* total N and total P have been measured by a destruction analysis. For the analysis the tops of the *Sphagnum* plants have been taken.

Fig 4 Soil sampling protocol

For the measurement of the nutrient availability for birch soil samples were taken from the peat layer in which the tree rooted (20 cm below surface). The mixed peat samples were used for four measurements; ammonium ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) availability, phosphorus (P) availability and pH. Ammonium and nitrate availability have been analysed by adding 30 ml CaCl with 3 gram organic material, after 2 hours shaking the $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ have been measured with an auto analyzer (Skalar). For the phosphorus availability the Olsen Method has been applied (Houba *et al*. 1995); phosphorus has been measured with a spectrometer (Thermo). The Olsen method gives a good indication of phosphorus weakly bound to iron and organic material. The pH was measured with a pH meter after shaking the peat samples for 30 minutes in 30 ml H_2O.

2.3.3 Management practices

In five out of twelve plots birch management has been applied in the past (ca. 10 years ago). Afterwards the birches have re-sprouted again and therefore the sampled trees in these plots are mainly re-sprouts. We used these plots in our study to observe effects of management on birch growth.

2.4 Sample preparation

Approximately 1-cm thick stem disks were extracted from the stem base of each of the 234 sampled trees. The samples were taken as low as possible above the soil surface in order to include all tree rings. The cross sections were carefully prepared with a razor blade. Chalk was rubbed on the surface to fill the vessels and make the tree rings visible.

2.5 Statistical analysis

2.5.1 Site conditions

To see which environmental factors affect the average annual radial growth of birch trees most a multiple linear regression with Backward selection was carried out. The full regression model encompassed the average growth of birch per plot, the availability of NH_4, NO_3 and P, water table level in May (the difference with the water table level in February), basal area in 2007 (density), a proxy for the proportion of old trees in the plots and an indicator for management (0=no; 1=yes). The *proxy* used in the analysis gives the percentage of trees older than 17 years in each plot. It was used as a kind of correcting factor for the average growth. Namely, average radial growth is the dependent variable in most tests, this value could be underestimated for older trees, as they show a growth decrease after 1995 (fig 14). The proxy corrects for the possible effect of this underestimated growth on the test results.

Another multiple regression has analysed the effect of nutrient availability on the growth of *Betula*. Using Backward selection the growth of birch was related to the availability of NH_4, NO_3 and P, and a proxy for the proportion of old trees in the plots.

2.5.2 Dendrochronological analyses

2.5.2.1 Radial Growth

The number of tree rings was counted using a binocular microscope to determine the age, mean growth rate, and the year of germination for the trees in the different plots.

To assess the radial growth dynamic of the birch trees from the Haaksbergerveen, ring width was measured with a precision of 0.01 mm using the LINTAB system (RinnTech) and the Time Series Analysis and Presentation Software (TSAP). Two radii were measured per stem disk in order to account for intra-tree variability. The radial growth measurements of the tree-ring analysis have been averaged per tree, after which graphs have been created showing annual radial growth and cumulative growth, to be able to observe differences in growth patterns between trees and between plots.

Furthermore, a correlation with all data has been performed to find a relation between the diameter and the age of the tree. Differences in average growth in certain periods of time have been found applying (paired) t-tests.

2.5.2.2 Climate-growth relationship

To assess the climate growth relationship the longest tree-ring series with the highest intercorrelation were averaged into a mean site chronology (42 trees from 10 different plots). This site chronology reflects the mean growth pattern of the birches growing at the Haaksbergerveen. The growth pattern has been compared with climate data which is available from the Royal Netherlands Meteorological Institute (KNMI, www.knmi.nl). For the Haaksbergerveen the closest weather station is located in Twente. We used records of monthly mean temperature and monthly sum of precipitation from 1976 till 2007.

A multiple linear regression has been conducted to assess the relation between climate conditions and the annual radial growth of birch. The annual growth data was related to mean temperature T (˚C) and monthly precipitation Prec (mm), and to T and Prec in the periods September-August, September-February and March-August. In addition Pearson correlation coefficients were calculated in Excel.

2.5.3 Birch management

T-tests have been used to evaluate differences in average growth between even-aged managed and unmanaged trees.

Data analysis has been carried out using SPSS 15.0 for Windows.
For more detailed information about the tests that have been performed and the data sets that were used see Appendix II.

A wet part of the Haaksbergerveen

3 Results

The birches growing on wet peat had a different habitus than those growing nearby on a sandy ridge running through the raised bog. The birches on the raised bog look very inferior, with a dark, bended and irregular stem, while the birches growing on the sandy soil have a straight and white colored stem. In general the annual radial growth of birch on sandy soil is much higher. This difference is illustrated by the growth rings (fig 5, 6). The growth of birch on peat soil in the Haaksbergerveen was compared with stem disks collected in Denmark (Portland Mose) and Ireland (Cain Park). The average growth showed to be half as low (own measurements).

Fig 5 Tree-ring patterns of a 30-year old tree growing on the raised bog (d = 1.19 cm)

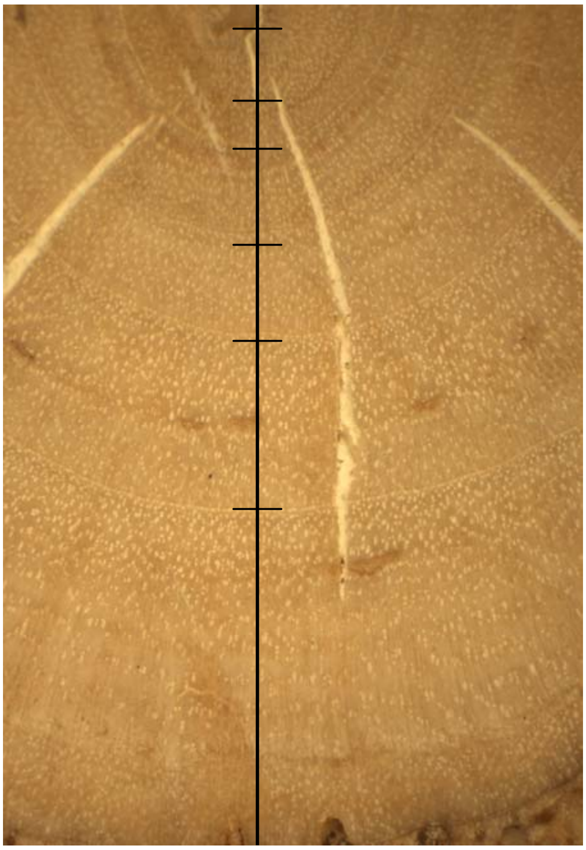


Fig 6 Tree-ring patterns of a 6-year old tree growing on sandy soil (d = 3.49 cm)

In total 92 trees in managed plots and 134 in unmanaged plots have been analysed.

The results have been split up in five chapters, namely *Growth, Site conditions, Growth patterns, Climate-growth relationship* and *Birch management*.

3.1 Growth

The age of the sampled trees varied considerably, both within and between plots. Taken all together age ranged from 2 to 32 years (table 1). Radial growth rate also showed high variability indicating heterogeneous growth conditions. Despite the high variability age-diameter (Spearman 0.533**; P < 0.001) (fig 7) and height-diameter (Spearman 0.714**, P < 0.001) (fig 8) relationships were highly significant.

Table 1 Average growth and age characteristics of sampled birches on the 12 experimental plots, and height characteristics of all birches in the 12 plots

Plot	Average growth (mm)	Minimim age	Maximum age	Hoogte (m) (mode)	Hoogte (m) (max)
1	0,99	4	19	2.30	3.62
2	0,76	6	30	1.20	4.10
3	0,92	3	17	0.92	4.03
4	0,52	4	31	1.22	2.25
5	0,78	3	11	0.52	2.10
6	0,80	3	17	1.72	2.61
7	1,12	8	11	2.10	4.10
8	0,82	2	16	0.35	4.45
9	0,64	4	32	-	-
10	0,93	3	11	0.98	4.50
11	0,80	5	9	0.95	3.08
12	0,72	4	8	0.95	2.26

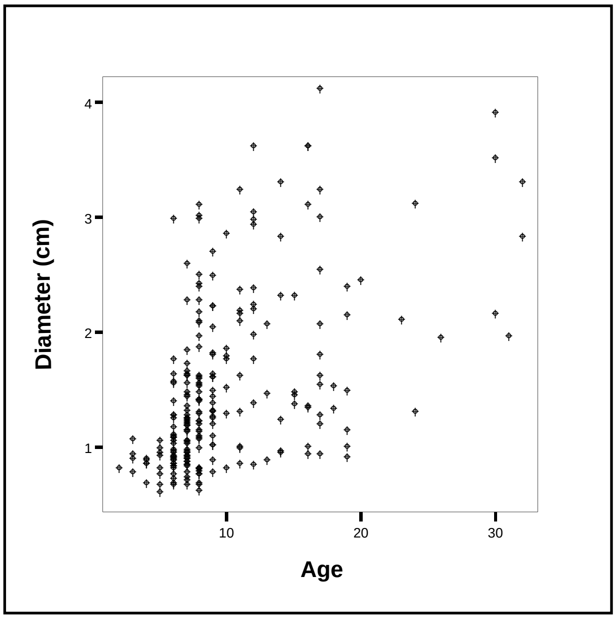


Fig 7 The age and diameter of the sampled birches

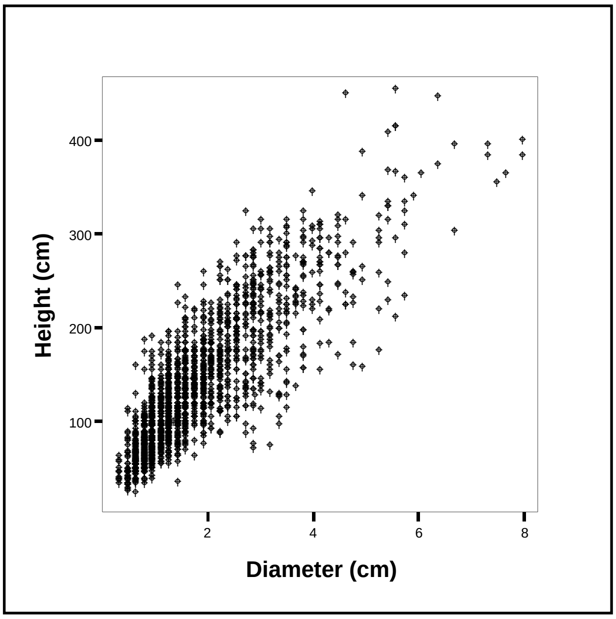


Fig 8 The height and diameter of all birches on the experimental plots

3.2 Effect of site conditions on radial growth

3.2.1 Water table and tree density

From the full regression model the difference (Δ) in water table level (fig 9) and the proportion of old trees in the plot explained the average radial growth in the Haaksbergerveen best (Adj. R^2 = 0.681, $P \leq 0.05$). The bigger Δ water table level, the higher the average radial growth in the plot, whereas an increased proportion of old trees per plot lowered the average growth.

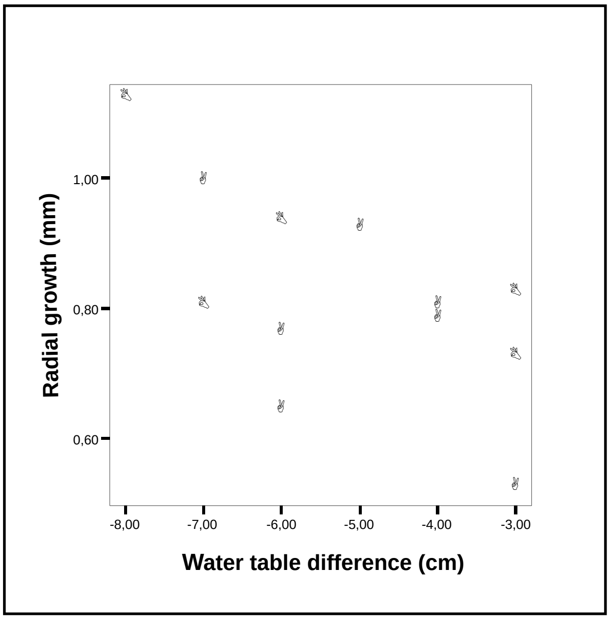


Fig 9 Δ Water table against radial growth for managed (Δ) and unmanaged (o) plots

Basal area and Δ water table level are highly variable in this study (Appendix III). Through evapotranspiration trees transfer water from the bog to the atmosphere thereby lowering the (local) water table. A higher density of trees will therefore lead to a higher evapotranspiration rate and this finally improves the growing conditions for birch. However, in our study we did not find a correlation between Δ water table and basal area (Pearson -0.532, $P \geq 0.05$) (fig 10). We also did not find a correlation between basal area and average growth (Pearson 0.362, $P \geq 0.05$) (fig 11).

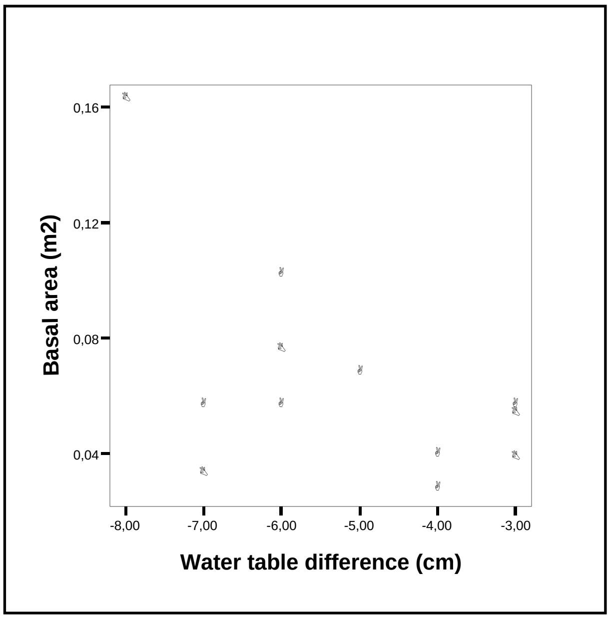


Fig 10 The relation between water table difference and basal area for the managed (Δ) unmanaged (o) plots

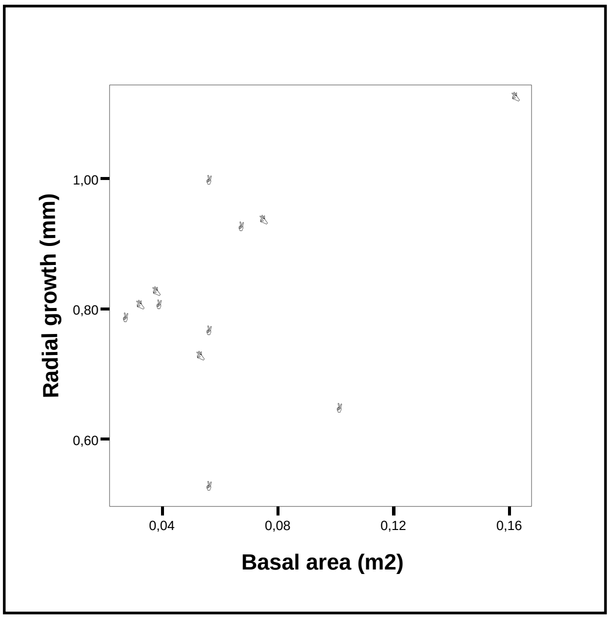


Fig 11 The relation between basal area and average growth for the managed (Δ) and unmanaged (o) plots

3.2.2 *Effect of nutrient availability*

When water table was omitted from the design the availability of phosphorus became the next explanatory factor for the radial growth of birch (Adj R^2 = 0.772, $P \leq 0.05$) (fig 12). Between basal area and phosphorus availability no correlation was found (Pearson 0.438, $P > 0.05$). The pH also did not show any effect either on radial growth nor on basal area of birch ($P > 0.05$).

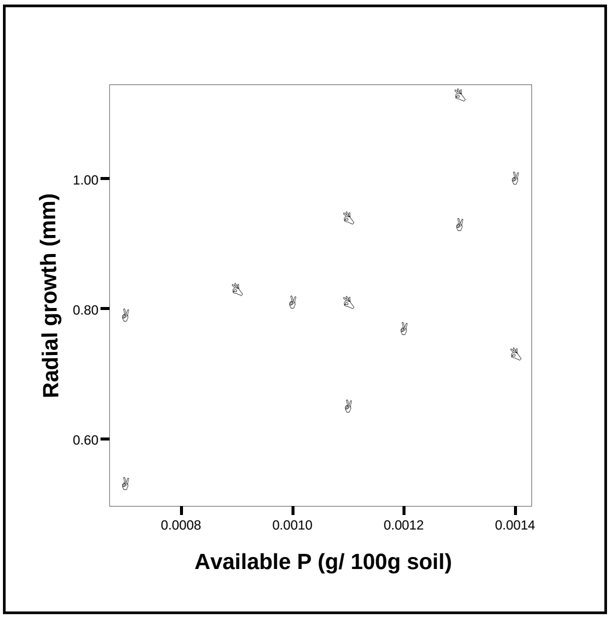


Fig 12 The availability of P against radial growth for managed (Δ) and unmanaged (o) plots

3.3 Growth patterns

3.3.1 *Growth fluctuations*

Growth patterns are useful to study variation in environmental conditions. The annual radial growth of birch fluctuated throughout the time period 1976 till 2007, as is shown for plot 2 as an example (figure 13). In certain years growth peaks can be observed for almost all trees. In paragraph 3.4 we tried to relate these peaks with climate conditions.

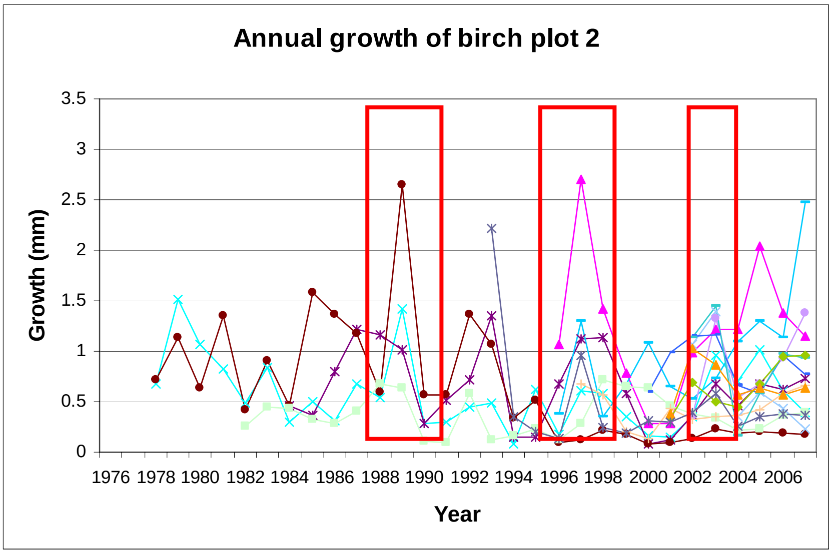


Fig 13
The annual radial growth of 14 birches in plot 2 showing three growth peaks

Furthermore, we found a lot of variation in growth patterns, as we tried to make groups of trees showing the same peaks and depressions in radial growth. Trees in managed plots showed a more common signal (fig 16).

3.3.2 Trend break

In 1995 older birches in plot 1, 2, 4 and 9 showed a trend break (in other plots most trees are younger than 1995). All trees which germinated before 1995 were depressed in their growth, whereas trees that germinated after 1995 displayed a normal growth pattern. The trend could be observed best for plot 9 (fig 14). We compared the annual growth before and after 1995 of trees that germinated before 1995. The growth of the trees was significantly lower after 1995 (paired t-test, $t = 6.044$, $df = 46$, $P < 0.001$). There was also a significant difference between the annual growth of older and younger trees after 1995 (t-test, $t = 7.632$, $df = 241$, $P < 0.001$). This difference led us introduce the proportion of old trees as an additional factor in our analysis.

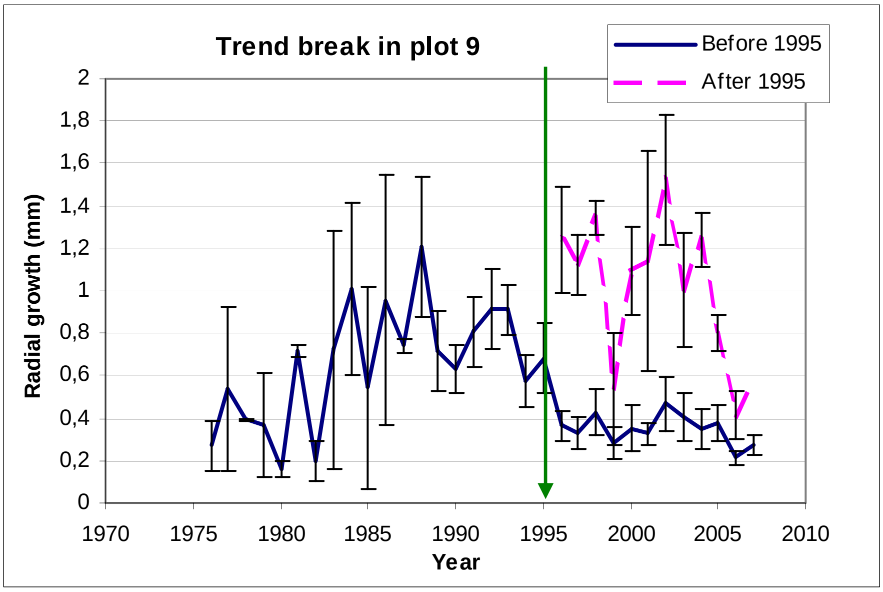


Fig 14 The growth pattern of older and younger trees in plot 9 - Error bars indicate standard error

3.3.3 Birch management

Figure 15 shows the average radial growth of trees who germinated in a certain year, in unmanaged and managed plots. We did not find a significant difference between average growth of trees in managed and unmanaged plots who germinated in the same year ($P > 0.05$).

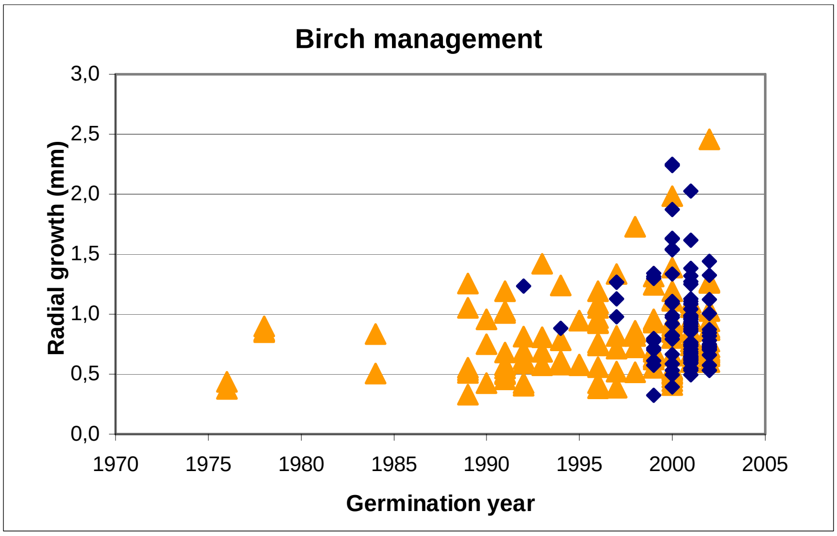


Fig 15 Average radial growth of trees in managed and unmanaged plots (Δ) per germination year

If studying radial growth in more detail it becomes obvious that striking changes in growth through time occur. Trees growing in managed plots show an enormous growth peak in their first year (fig 16), which is not observed among trees in unmanaged plots. This might be caused by re-sprouting of new trees on the stumps that are left after management. Re-sprouting also explains why the trees all germinate in the same year.

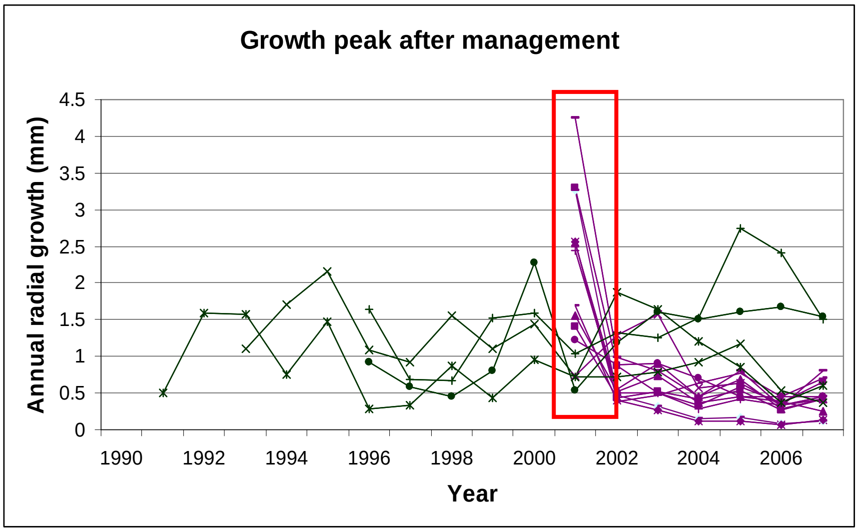


Fig 16
The growth pattern of re-sprouting birches after management (purple lines) compared to unmanaged birches

3.4 Effects of climate

3.4.1 Temperature and precipitation

To analyse the effect of temperature and precipitation on the radial growth of birches in the Haaksbergerveen, we calculated a mean ring-width chronology. This chronology shows the common growth signal of a selection of 42 older birches. The ring-width chronology was related to monthly and annual data of temperature and precipitation. Correlation analysis indicated that ring width was significantly positively influenced by a high temperature in May (Pearson 0.320)(fig 17) and above-average rainfall in March and July (Pearson 0.340 & 0.296 resp.) (figs 17 & 18). When we compared the annual growth with temperature and precipitation in three periods e.g. September-August (=end previous growing season to end of current growing season), September-February (=previous autumn and winter), and March-August (=growing season) we found a significant positive effect of temperature from March to May (Pearson 0.144) (fig 19); also the precipitation between March and July had a positive effect on the growth of birch (Pearson 0.172) (fig 20). We also tried to relate annual growth with climate conditions in the year before, with no significant result.

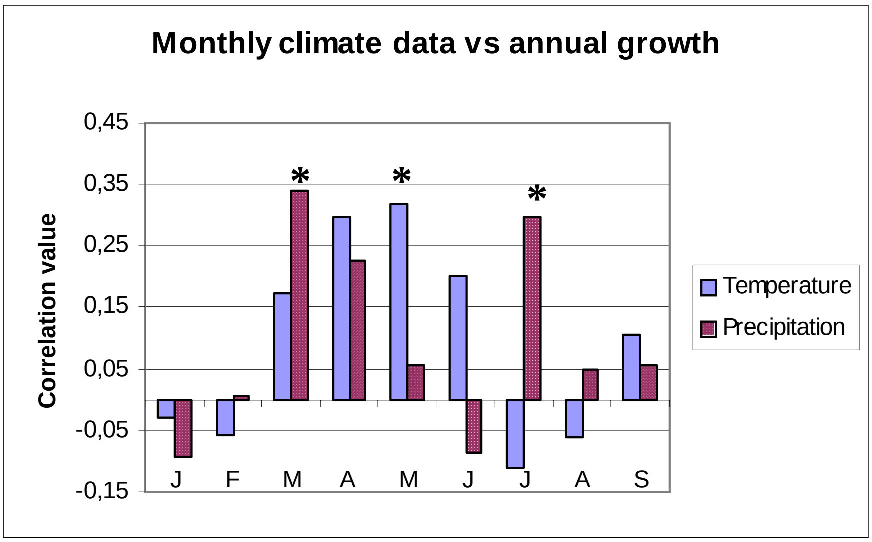


Fig 17 The correlation values of temperature and precipitation against radial growth and the significant months (*)

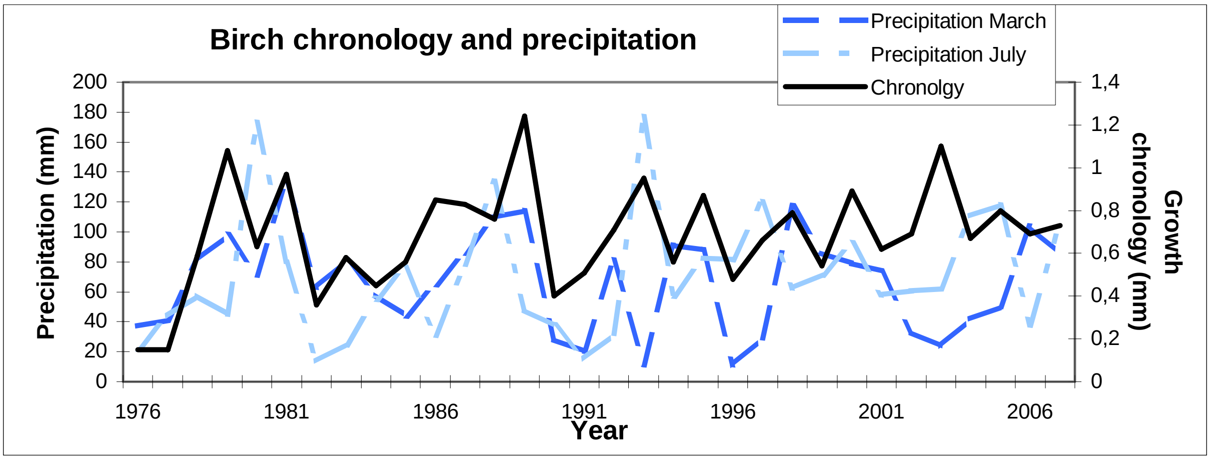


Fig 18 The birch chronology plotted against precipitation in March and July

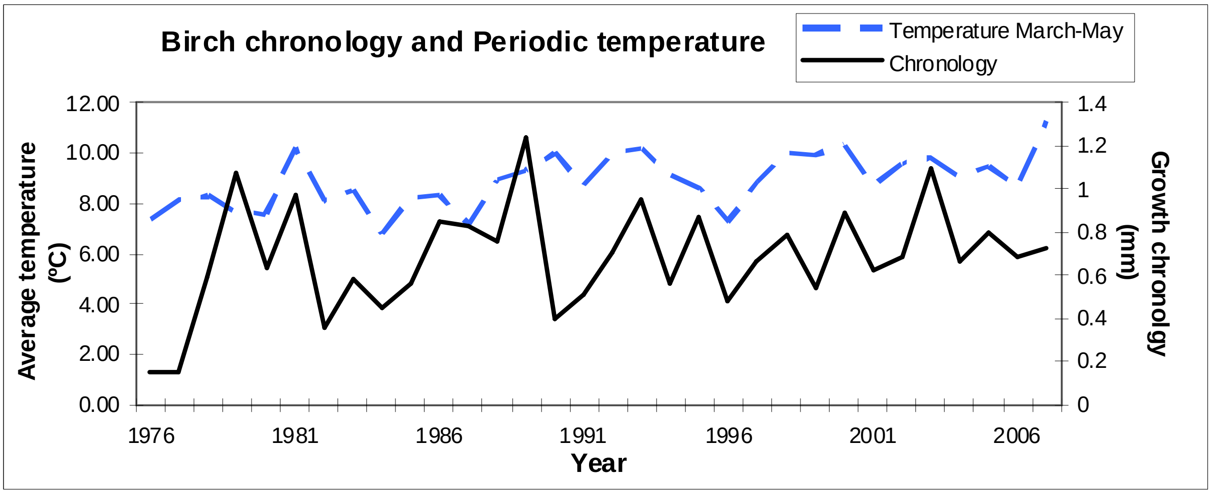


Fig 19 The birch chronology plotted against temperature in the period March till May

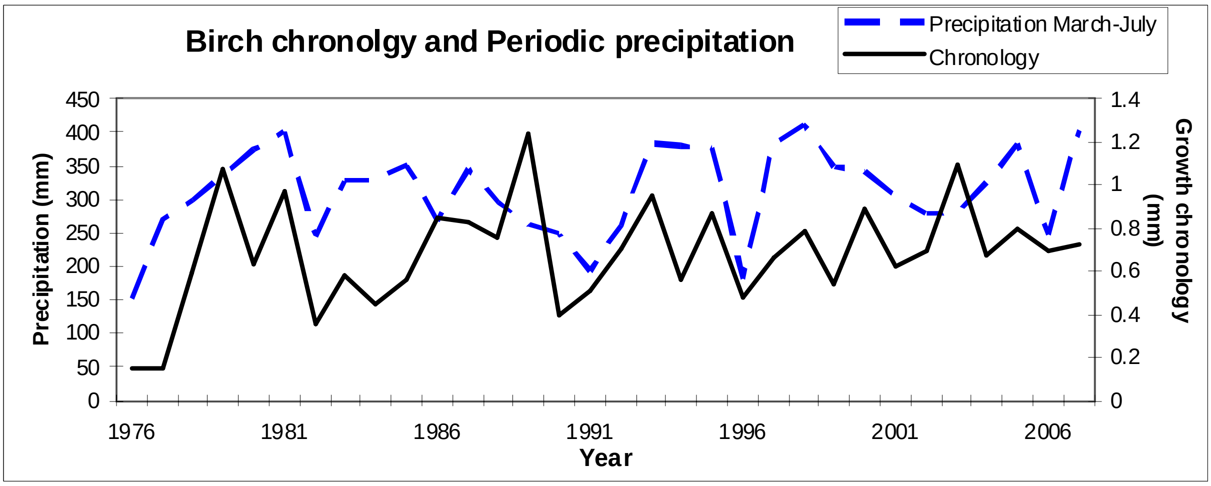
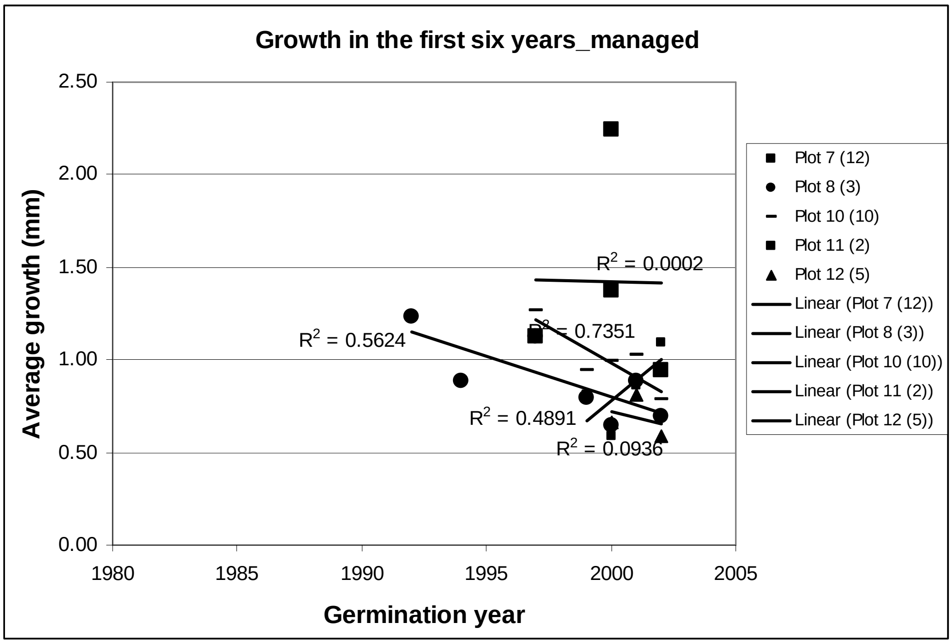


Fig 20 The birch chronology plotted against precipitation in the period March till July

3.4.2 *Juvenile growth of birches*

To see how growth changes per plot and through time, we calculated the average growth in the first six years of trees which germinated in the same year. This showed a more or less increasing line through time. However, when we did the same per plot, for managed and unmanaged plots separately, different trends were observed (fig 21).

The managed plots showed a negative trend, except for plot 11. The unmanaged plots showed an increasing trend, except for plot 2. Birch management might affect tree growth in a negative way, but maybe also tree density plays a role in this, as most of our managed plots also are in lowest density categories (see # behind plot in legend). Most unmanaged plot have quite a high density and might profit from better micro site conditions due to a higher evapotanpiration rate.



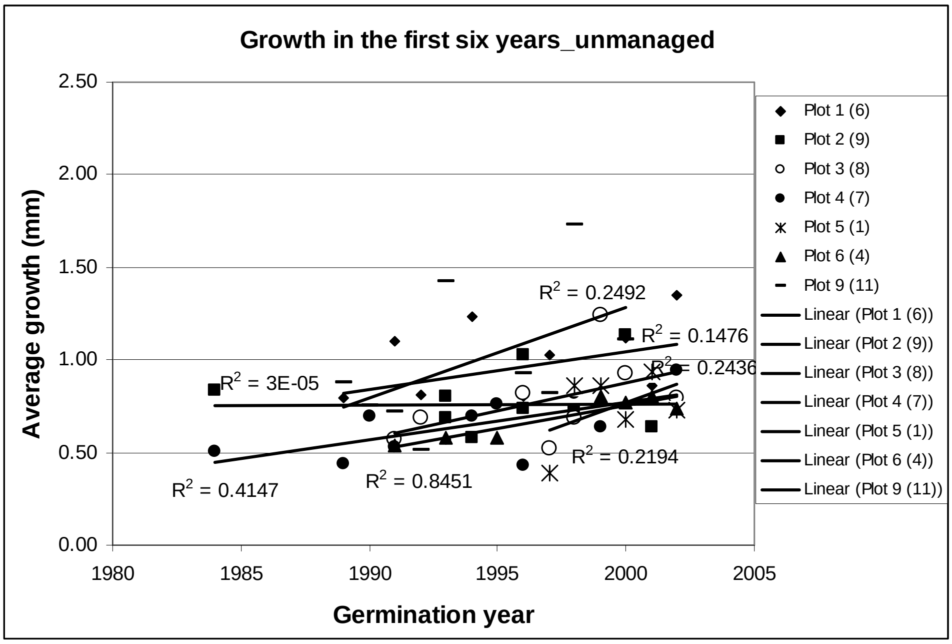


Fig 21 The average growth in the first six years per germination yearfor managed and unmanaged plots (the number between brackets gives the density ranking, 1 = low, 12 = high; Appendix III)

4 Discussion

This research provides clear results about those environmental factors that mainly trigger the growth level and annual growth dynamics of birch on raised bogs. However, during the work we also discovered some drawbacks of the experimental design we used. These will be discussed together with the explanation and interpretation of the results, and the implications for the restoration management of raised bogs.

Water table level and tree density

In our research the water table level we measured turns out to be the most important factor affecting tree growth in the Haaksbergerveen. A low water table in the growing season resulted in increased radial growth.

Against our expectations we failed to find a relation between basal area (tree density) and the water table depth in summer. We hypothesized that a high tree density would result in a higher evapotranspiration rate thereby lowering the local water table level. Despite the above we have some circumstantial evidence that suggests that birch may have an effect on the water table after all.

Around 1995 we observed a big difference in growth rate between birches before and after 1995 (fig 14). The reason for this difference seems tied to changes in water table as a result of management in the area. For plots 7 and 9 management includes the construction of a dam in 1994 (Appendix I) which might have caused an increase of the water table level, affecting the growth of standing trees. However, near the other plots no dam has been built in that period, but, State Forestry Service applied intensive birch management (Management Report State Forestry Service, Roy Dear pers. com.). In a raised bog in Southern Germany, Frankl and Schmeidl (2000) showed that a continuous decrease of the water level corresponded with the establishment of heather and woodland species, who transported the bog water into the atmosphere by (evapo)transpiration. The removal of many trees in the southern part of the Haaksbergerveen (where plot 1-6, 8, and 10-12 are located) might have reduced the total evapotranspiration rate in that area, leading to increased precipitation surplus and a higher water table level. As root systems of the standing trees had developed under conditions with a lower water table, the increase in water table presumably resulted in a growth decrease as a high water table inhibits oxygen uptake thereby lowering the assimilation of nutrients by tree roots (Penttilä 1991 and Trottier 1991 in: Linderholm and Leine 2004). For black spruce (*Picea mariana*) and tamarack (*Larix laricina*) it was reported that growth was reduced with a high water table (Lieffers and Rothwell 1987).

Tree species that grow on fens and bogs are forced to form a shallow root system, as the water level is normally between the surface and some tens of centimetres below the surface. This shallow root system makes the trees susceptible to windthrow. Some species, such as *Alnus glutinosa, Fraxinus nigra* and *Salix spp.* can cope with shorter or longer periods of flooding during the growing season (Crum 1988 in: Rydin and Jeglum 2006), but *Betula pubescens* can not. Therefore, *Betula* is likely to establish only as a consequence of (striking) changes in hydrology and nutrient availability due to peat extraction and nutrient deposition respectively. As water tables drop, decomposition and mineralisation rates of the peat increase creating favourable germination and growing conditions for *Betula*.

In contrast, after damming ditches, water level rises and the surface waters change back to bog-water characteristics again, i.e. with low pH and low mineral and nutrient contents (Rydin and Jeglum 2006). Therefore, trees that germinated after the event in 1995 might have adapted their root system to the new situation (possibly by keeping it more shallow) and therefore seem to have no growth problems (fig 14).
The effect of water table on the development of roots has been investigated for *Pinus contorta*. The root systems were found to be pre-dominantly lateral, only in the driest plot (water table in summer ± 0.40 cm under the surface) the trees had better developed root systems which in turn increased shoot-growth ratio. Furthermore, after establishment tree growth initiated a process whereby the peat was dried further (Boggie 1972).

On the whole the feedbacks between birch density and water table remain elusive. The latter is also reflected in the contrasting results in literature. Åberg (1992) studied tree colonisation by *Betula pubescens* in three mires in Southern Sweden. The trees started to grow from the marginal zone, where better drainage occurs. Once the trees are established they functioned as self drainers of the mire surface through their water uptake (Åberg 1992). Also Schouwenaars (1988) reported that evapotranspiration by bushes and trees can impact the water table of disturbed bogs in the Netherlands. But, comparative studies show mixed results when comparing evapotranspiration from open water to vegetated wetlands (Rydin and Jeglum 2006). For example, Diamond *et al.* (2003) conducted a field experiment to prove that evapotranspiration by *Betula pendula* can depress the water table in a bog, but they failed to do so. Also Cross (1987) observed no significant effects of a 20-hectare birch plot on the water table of the All Saints Bog in Ireland. According to Lafleur (1990) differences in results between the various studies are probably related to differences in vegetation characteristics as well as methods of measurement.

The effect of birch might be very local, improving its direct environment without affecting the total water level. But, removing many trees at once probably showed how important their presence is for the trees that are left.

Nutrient availability
It was found that of the three measured nutrients (NH_4, NO_3 and P) phosphorus explained the birch growth best (fig 12). This was also reported for an experiment in a desiccated bog in Ireland (Clara bog), with low atmospheric deposition. The study shows that P indeed is an important nutrient for the growth of *Betula*, since above ground biomass did not increase under N-enriched conditions as P was limiting (Tomassen *et al.* 2004). In the Netherlands both N and P are deposited sufficiently, so *Betula* has no problem to grow; the tree even has been observed on floating rafts, which are permanently wet (Tomassen *et al.*, 2003). According to Limpens *et al.* (2003) the successful establishment and growth of *Betula* in undrained bogs is probably due to a combination of a lower water table and the availability of other nutrients than N. As *Betula* seedlings have problems establishing at locations where the water table is permanently high (Limpens *et al.* 2003), currently standing birches must have been established under a different water regime.
The finding that water table level and phosphorus availability are the two most important factors for birch growth might be caused by an interaction between

these factors; the lower the water table, the higher the phosphorus availability, as decomposition and mineralisation rates of the peat increase (Tomassen *et al.* 2003).

Growth patterns

We found a lot of variation in diameter-age relations and in growth patterns, and big differences in average growth between trees and between plots (table 1).
Both the variation in diameter-age relations (fig 7) and growth patterns might be explained by the characteristics of raised bogs; they are not homogeneous in site conditions. Due to local differences in water table, vegetation or nutrient availability.
Locations close to each other may differ widely in suitability, leading to considerable differences in growth rate. Similar variability has been reported for undisturbed bogs displaying hummock-hollow patterns. Hummocks are vegetation ridges characterised by a thicker portion of well-aerated peat than hollows (Lindholm and Markkula 1984). As a consequence root development in hummocks is better than in hollows, leading to different expectations for survival. The latter was shown by Gunnarsson and Rydin (1998). The authors conducted a long-term (up to 15 years) experiment to the distribution of *Pinus sylvestris* on two raised bogs in eastern Sweden. The germination of pines did not differ significantly between hummocks and hollows, however, seedling mortality was much higher in hollows compared to hummocks. This was probably caused by desiccation in the upper peat layer of hollows in summer. Plants with superficial root-systems will be affected by this. Strange enough hummocks do not often dry out, which is caused by the species *Sphagnum fuscum* maintaining moisture by capillary water transport (Rydin 1985). Seedlings growing on hummocks will therefore not suffer from desiccation (Gunnarsson and Rydin 1998). In the Haaksbergerveen *Sphagnum fuscum* is not found and therefore the precipitation between March and July might be found to be very important for the growth of birch.

Birch management

We found is a difference in first years growth between trees in managed and unmanaged plots. Trees in managed plots showed an enormous peak after germination (fig 16). This is likely related to the re-sprout of shoots which develop on the stump after cutting. As the root system is still present this may enable them to start growing new shoots rapidly. However, as we did not find an increased growth of trees in managed plots compared to trees that were not managed, the growth peak has a limited duration.

Birches are able to re-sprout easily, which is one of the reasons to use them as coppice in the past. The height of cutting seems to be very important for the success of re-sprouting. When the stem is cut too high the stump will become too big in the next cuttings. In contrast, when cut too low the number of shoots will be small (Boer 1857). Possibly birch management in the Haaksbergerveen could try to cut the birches as low as possible to decrease the re-sprouting success.
A drawback of the experimental design that is related with management is the selection method we applied. The trees used for the tree-ring analysis were already cut in the field. Based on the diameter classes we took several trees per plot. However, as after management birches re-sprout, some samples might have been taken from the same tree. Better would have been to cut individual trees only, meaning one re-sprout from a managed tree.

Climate

In this study we found a relation between annual growth and the temperature between March and May (fig 19). At the same time, a high amount of precipitation between March and July was found to increase the growth of birch (fig 20). It might sound strange as birches do not like to grow in very wet conditions, but maybe the conditions are not that wet as expected. During the measurement of the water table level in summer the peat was quite dry compared to the situation in winter and spring. Perhaps the upper peat layer dries out to such extent each year negatively affecting the shallow root system of birch. A little more precipitation compared to other years might then increase the water availability in the peat layer preventing roots to dry out, as *Sphagnum fuscum* is not present to maintain the upper peat layer moist.

We observed weak correlations between climate data and birch growth on the raised bog. The same was found for Scots pine (*Pinus sylvestris*) by Linderholm *et al.* (2002). They measured tree-rings of Scots pine growing on peatlands and on neighbouring dry sites, from North to South Sweden. Pines at peatland sites showed lower among-tree correlation than trees at neighbouring dry sites. Furthermore, the variability in tree growth was slightly higher in the chronologies of pines growing on the peatlands. Thirdly, the variance in tree growth that could be explained by climate was in all cases lower at the peatland sites (Linderholm *et al.* 2002). In the Haaksbergerveen we also observed a big variation in growth between trees, which we already related to the heterogeneous site conditions present in a raised bog.

Synthesis

Analysing all the effects together gives us an overview of how the growth of birch and site factors are related in the Haaksbergerveen.

Some small changes have to be made to the flow-diagram (fig 1). Namely, we did not find an effect of pH on birch growth and nitrogen availability seemed to be less important for growth compared to phosphorus. A low water table definitely has a positive impact on radial growth of standing birch, as it gives birch the opportunity to extend its root system and simultaneously stimulates mineralisation. However, the amount of precipitation has to be above average to prevent drought stress for birch as the upper peat layer dries out too much.

The relation between water table level and phosphorus availability could make it relatively easy to define a management tool to control tree growth. However, an increase in water table level could have an affect on the standing trees, while the growth of newly germinated trees (germinating under new conditions) is unimpaired.

In the future climate is projected to change. Summers will become warmer and wetter. Combined with water management this could have major effects on the growth of birch. Temperature stimulates growth but a too high water level almost prevents growth as a result of oxygen deficit and reduced nutrient uptake. However, higher temperatures and higher precipitation rates might also result in the perfect growing conditions for birch. Furthermore, germination of birch will continue, but survival of seedlings might be impacted by a too dry upper peat layer or too wet conditions.

Additional research is necessary to be able to find a relation between basal area (density), the water table level, birch management and the radial growth of birch. Measuring the evapotranspiration rate is important for this. Examining different ways of cutting management, like the suggestion of a very low cutting-height by Boer (1857), could help to find the most effective method to decrease the invasion of birch.

Haaksbergerveen in winter time with on the background 'some' birches

5 Conclusion

The aim of this study was to relate the radial growth of birch with environmental factors to come up with tools to decrease or prevent birch growing on the raised bog.

The results of our study show that in the Haaksbergerveen water table level and phosphorus availability are the most important factors affecting radial growth of birch, having a negative and positive influence respectively. Furthermore, the temperature in May and a high amount of precipitation between March and July seem to have a positive effect on birch growth. Tree density, however, was not found having an effect on growth by decreasing the water table level due to evapotranspiration. But more research on this is needed.

The current management interventions seem to work only for a short period of time. Based on our findings and literature the management of State Forest Service could try firstly to periodically increase the water table level, decreasing the growth of standing trees. Secondly, they could try to cut the stem of the birch as low as possible during birch management, as this seems to negatively affect the success of re-sprouting.

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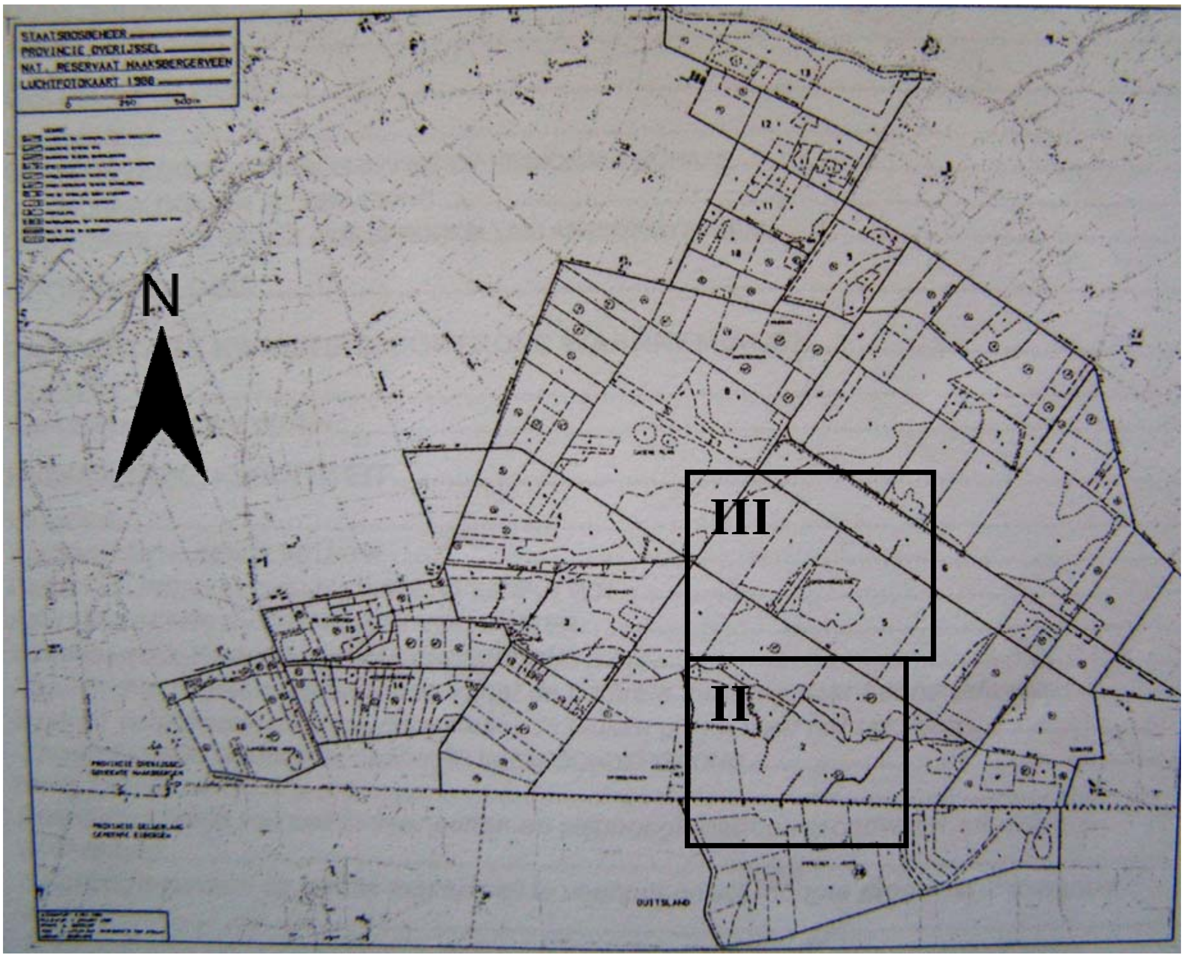
Appendices

Appendix I Location of the plots

Map I

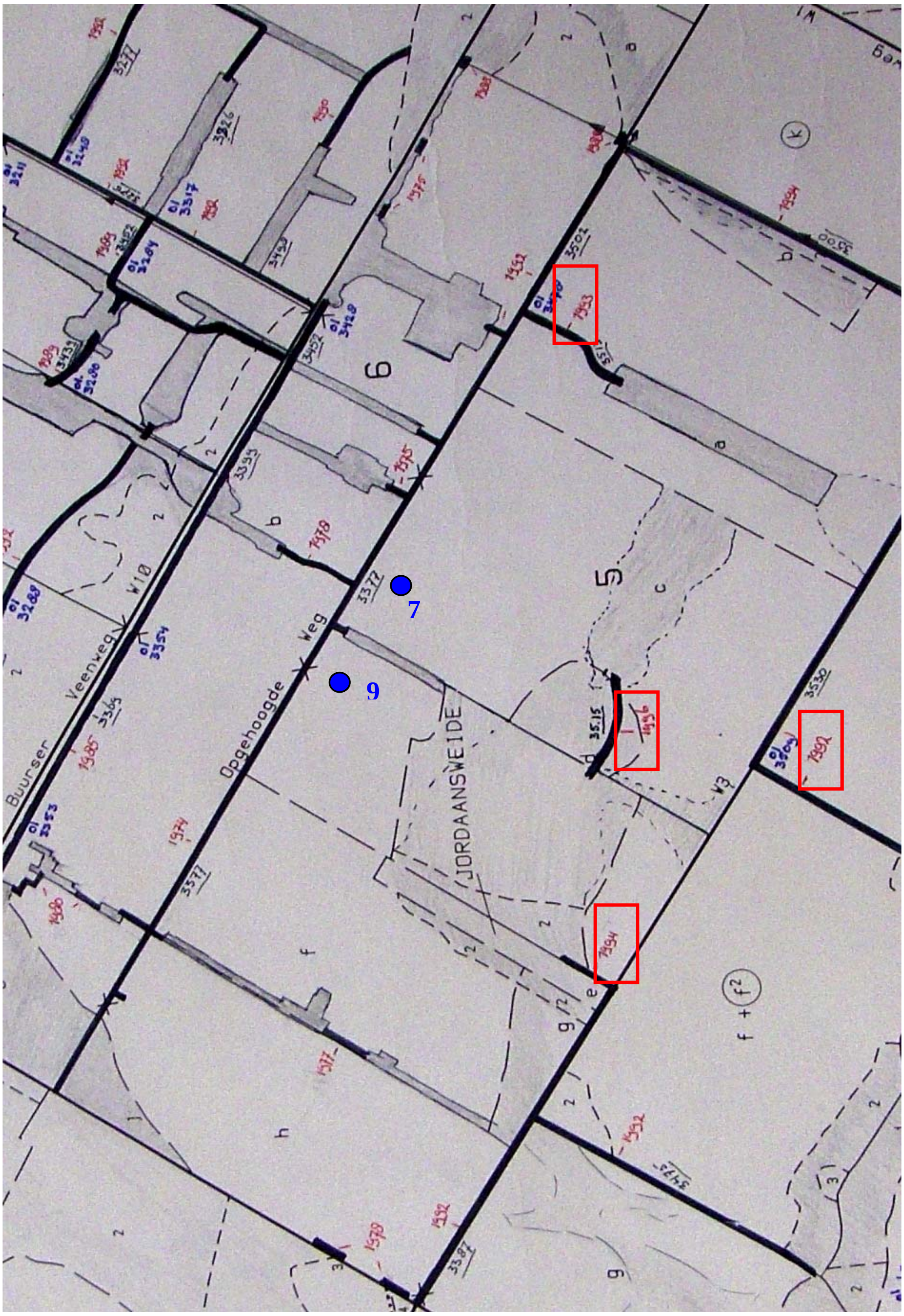
The area of the Haaksbergerveen with the boundaries of the subsequent maps (map II & III)



Map II

Plot 1-6, 8, 10-12; and the years in which certain dams have been built

Map III
Plot 7 & 9; and the years in which dams have been built



Appendix II Test overview

nr	Name	Test	Input variables	Significant variables	Test-value	P	Adj. R2
1	Diameter vs age	correlation	age, diameter		Spearman 0.533**	0.000	
2	Diameter vs height	correlation	height, diameter		Spearman 0.714**	0.000	
3	Environmental factors (all) vs growth	multiple regression	Avg-growth per plot, water table, basal area, management, NH4, NO3, P, proxy (all trees)	water table, proxy		≤ 0.05	0.681
4	Basal area vs growth and P availability	Correlation	Basal area, radial growth per plot Basal area, phosphorus availability		Pearson 0.362 Pearson 0.438	≥ 0.05 ≥ 0.05	
5	Water table level vs basal area	Correlation	Water table difference, basal area		Pearson -0.532	≥ 0.05	
6	Environmental factors (nutrients) vs growth	multiple regression	Avg-growth per plot, NH4, NO3, P, proxy (all trees)	phosphorus, proxy		≤ 0.05	0.772
7	Growth before-after 1995	paired t-test	avg-growth before and after 1995 (same trees) (all trees that germinated before 1995)		t = 6.044; df = 46	0.000	
8	Growth after 1995	t-test	avg-growth after 1995 of trees that germinated before and after 1995 (all trees)		t = 7.632, df = 241	0.000	
9	Management vs growth	t-test	avg-growth of managed and unmanaged trees (all trees)			>> 0.05	
10	Growth vs climate (months)	correlation in Excel	Avg-growth (chronolgy of 42 trees), monthly temperature and precipitation	Temperature in May; Precipitation in March and July	Pearson 0.320; 0.340 & 0.296		
11	Growth vs climate (periods)	correlation in Excel	Avg-growth (chronolgy of 42 trees), periodical temperature (Sep-Aug, Sep-Feb, Mar-Aug) and precipitation (Sep-Aug, Sep-Feb, Mar-Aug, Mar-April, May-June, July-Aug, Mar-July)	Temperature from March to May; Total precipitation March-July	Pearson 0.144 & 0.172		

Appendix III Plot information

Plot information on basal area, water table and birch management

Plot	Basal area (m2/100m2)	Density ranking	# trees	Water table difference (cm)	Birch management
1	0.056	6	83	7	no
2	0.070	9	103	6	no
3	0.067	8	132	5	no
4	0.056	7	151	3	no
5	0.027	1 (low)	166	4	no
6	0.039	4	124	4	no
7	0.162	12 (high)	245	8	yes
8	0.038	3	127	3.5	yes
9	0.100	11	167	6.5	no
10	0.075	10	226	6	yes
11	0.032	2	187	7	yes
12	0.053	5	350	3	yes