Examensarbeten 2018:3

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

Forest Drainage Effects on Tree Growth in Northern Sweden

- Developing Guidelines for Ditch Network Maintenance

Foto: Hanna Glöd

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- Developing Guidelines for Ditch Network Maintenance

Skogsdikningens inverkan på trädtillväxt i norra Sverige – utveckling av riktlinjer för dikesunderhåll

Hanna Glöd

Keywords / *Nyckelord:*

Ditch cleaning; Ditch network maintenance; Drainage effect; Forest drainage; Indicators / *Dikningseffekt; Dikesrensning; Dikesunderhåll; Indikatorer; Skogsdikning*

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Abstract

At present, there are no clear guidelines for when and where ditch network maintenance (DNM) should be performed in Sweden. Recently there have been attempts to create tools that indicate the need for DNM, one of these tools is the Ditch Flow Tracker (DFT). The DFT determines the catchment area (CA) and soil type to predict if a ditch segment does *not* need DNM. The tool is based on the hypothesis that ditches with small CA's do not need maintenance because they do not function to drain enough water to improve tree growth. The overall goal of this study was to ground truth the DFT by testing how well the CA, soil type and water flow divided into category can predict ditch function in terms of tree growth. Since the decision of DNM should take into account the ecological impacts the ability of the DFT to predict biodiversity of plants was also tested.

A field study was conducted in the Krycklan Catchment Study at 18 drained sites with different CA's and soil types. At each site, different ditch characteristics were measured as well as forest variables at different distances from the ditch. The analyses indicated that soil type had an effect on the increase in tree growth caused by ditches. Ditch segments in till soils had a higher volume in plots closest to the ditch as well as a higher volume overall compared to peat soils. Contrary to my hypothesis, CA did not affect the effectiveness of a ditch segment. Instead, water flow divided into categories seemed to effect the growth effect from drainage. Ditch segments with a high water flow had the highest standing volume as well as had a gradient of decreasing volume away from the ditch. CA did however indicate the biodiversity of plants within a ditch segment. The analysis showed that ditches with larger CA (1-2 ha) had a significantly higher plant diversity than the ditches with smaller CA's. Neither soil type nor CA showed any influence on the long term growth effect of ditching when tree rings were examined. However this was calculated from only 10 of the 18 sites due to too few trees having been established when the ditches were first dug, which brings into question how strong this result was. The findings as a whole indicate that soil type and water flow category can be used to predict the effectiveness of a ditch segment in terms of affecting tree volume, while CA can be used to predict the biodiversity of plants of a ditch.

Keywords: Ditch cleaning; Ditch network maintenance; Drainage effect; Forest drainage; Indicators

Sammanfattning

Det finns idag inga riktlinjer för när och var underhåll av diken bör utföras i det svenska skogslandskapet. För att underlätta beslutet om dikesunderhåll har flera verktyg utvecklats. Ett av dessa verktyg är ”Ditch Flow Tracker” (DFT) som kan indikera om ett dikessegment är i behov av underhåll genom att avgöra dikets avrinningsområde och jordart. Verktyget DFT baseras på teorin att ett mindre avrinningsområde inte behöver underhållas då det inte dränerar tillräckligt med vatten för att förbättra trädens tillväxt. Målet med denna studie var att utvärdera verktyget DFT genom att testa hur avrinningsområde, jordart och vattenflöde indelat i kategorier kan förutse ett dikessegments funktion. Eftersom beslut att utföra dikesunderhåll även bör baseras på hur åtgärden påverkar de ekologiska förutsättningarna, testades även DFT’s möjlighet att indikera ett dikessegments biodiversitet.

En fältstudie utfördes inom Krycklans avrinningsområde på 18 områden med olika storlek på avrinningsområde och jordarter. Inom varje område mättes dikets egenskaper samt skogliga variabler på olika avstånd från diket. Analyser av fältdata indikerade att jordarten påverkade dikenas effekt på trädens tillväxt. Dikessegment i morän påvisade en högre volym, både nära diket och generellt, jämfört med torvmark. I motsats till hypotesen hade avrinningsområdets storlek ingen påverkan på ett dikessegments effektivitet. På grund av detta ersattes avrinningsområdets storlek med variabeln vattenflöde indelat i tre kategorier. Dikessegment med högst vattenflöde hade den högsta stående volymen och en avtagande stående volym med ökande avstånd till diket. Däremot kunde avrinningsområdets storlek ge en indikation om ett dikessegments biodiversitet. Diken med större avrinningsområde (1-2 ha) hade signifikant större artdiversitet bland de undersökta växterna. Varken avrinningsområde eller jordart påverkade dikenas långsiktiga tillväxteffekt. Detta resultat var dock baserat på endast 10 av de totalt 18 områdena eftersom för få träd var etablerade då dikena grävdes på 8 av de studerade områdena, vilket gör underlaget till detta resultat mer osäkert. Fynden som helhet indikerar att jordart och vattenflödet (indelat i kategorier) kan användas för att förutsäga effektiviteten av ett dikessegment när det gäller trädtillväxt, medan avrinningsområdets storlek kan användas för att förutsäga den biologiska mångfalden av växter i ett dike.

Nyckelord: Dikningseffekt; Dikesrensning; Dikesunderhåll; Indikatorer; Skogsdikning

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Abbreviations

AIC	Akaike information criterion
BA	Basal area
CA	Catchment area
DBH	Diameter at breast height
DFT	A combination of GIS and flow accumulation modelling used to determine the catchment area of ditches called the “DitchFlowTracker”
DNM	Ditch network maintenance
dplR	The dendrochronology program library in R
ha	Hectare
KCS	Krycklan Catchment Study
LMM	Linear mixed effects model
l/s	Liter per second
m^3sk/ha	Cubic meter standing volume per hectare/ forest cubic meter per hectare
REML	Restricted maximum likelihood
RWI	Ring-width indices
s/cm	Seconds per centimeter
SE	Standard error
SGS	Swedish Geological Survey
SNFI	The Swedish National Forest Inventories
TRADER	Tree Ring Analysis of Disturbance Events in R
VWC	Volumetric water content
%GC	Percentage growth change

1 Introduction

1.1 Background

Sweden and Finland are the most peatland rich countries in Europe, containing almost a third of the European peatlands, with about ten million hectares (ha) each (Hånell 1990; Montanarella et al. 2006; Päivänen & Hånell 2012). Out of Sweden's total peatland area only half, approximately five million hectares, is considered productive with an annual forest production of at least one cubic meter standing volume per hectare (m3sk/ha) (Hånell 2004). These five million hectares make up about 21 % of Sweden's total productive forest land (Riksskogstaxeringen 2017). The amount of peatland that has been drained for forestry in Sweden is difficult to calculate since most of the ditches are old and not registered properly (Hånell 1990). Estimates have been done using data of the length of ditches dug every year from 1873 to 1982 as well as registered ditches in the Swedish National Forest Inventories (SNFI). These calculations indicated that the drained forest areas make up around 1.5 to 2 million hectares (Päivänen & Hånell 2012). Meaning that roughly a third of the productive peatlands in Sweden have been drained at some point (Drott 2016). Since most of the ditches we see today were dug a long time ago without any real plan for how they may function, their placement in the landscape may not always be ideal (Hånell 1990). Previously, ditches were dug under the assumption that all peatland could be made into productive forest land no matter what the initial conditions were (Päivänen & Hånell 2012). It is estimated that about 250 000 hectares of drained forest land remains non-productive even after drainage (Hånell 2004), making further efforts such as ditch network maintenance (DNM) unnecessary in these areas.

The drainage of Swedish peatlands started in the late 1700s or early 1800s with the purpose to improve growth and yield, though it did not start at a larger scale until the 1900s (Lundberg 1914), with peaks around 1930s and 1980s (Hånell 1990). The first peak in the 1930s was due to government funding for forest drainage that was introduced in an attempt to mitigate the Great Depression. The second peak occurred in 1980s when remedial ditching, which is the digging of shallow ditches with a depth less than 0.5 m, became a popular method to prevent waterlogging during the reforestation phase (Hånell 1990). Starting with an increased awareness of the negative environmental consequences of ditching and a change in legislation during the 1990s, the use of drainage has gradually decreased. However, in recent years the Swedish Forest Agency has seen an increased interest in peatland forestry which raises the questions of how, when and if ditches should be managed and maintained (Drott 2016). Today there are three different types of forest drainage activities: traditional forest drainage, remedial drainage, and DNM.

1.1.1 Traditional forest drainage

Traditional forest drainage involves the creation of new ditches, deepening of existing ditches or other measures aimed to improve drainage in an area. This is done with the intention of permanently lowering the ground water table to increase forest growth (The Swedish Forest Agency 2017). However, traditional forest drainage always requires permission from the County Administrative Board according to chapter 11. 9b§ in the Swedish Environmental Code (SFS 1998:808). Because drainage is prohibited in Southern and Central Sweden, the permit could be difficult to get and often requires special circumstances to be approved (The Swedish Forest Agency 2017).

1.1.2 Remedial drainage

Remedial drainage is made up of temporary ditches dug with the intention of avoiding waterlogged conditions during the regeneration phase. These ditches are shallow, with a depth less than 0.5 m, and are not allowed to be cleaned in the future (The Swedish Forest Agency 2017). Remedial drainage always needs to be announced to the Swedish Forest Agency at least six weeks before the work is about to start according to 14§ in the Forestry Act (SFS 1979:429).

1.1.3 DNM

DNM is the cleaning of old ditches down to the original ditch depth. Studies have shown that DNM can have a positive effect on tree growth as long as the site is not lacking in nutrients or that the peat soil has compacted and decomposed to such an extent that the site is permanently changed (Ahti & Päivänen 1997; Ahtikoski et al. 2008). The main reason for DNM is that ditches deteriorate over time, for example when the ditch bottom fills up with sediment or vegetation, which leads to a decreased drainage effect and in turn a negative effect on tree growth (Paavilainen & Päivänen 1995; Sikström & Hökkä 2016; Drott 2016). Another reason for the decrease in ditch depth is the subsiding of the peat layer (Heikurainen 1957; Leifeld et al. 2011). In many cases a consultation with the Swedish Forest Agency is required before DNM can commence according to the Swedish Forest Agency regulations (SKSFS 2013:3) and chapter 12. 6§ in the Swedish Environmental Code (SFS 1998:808). This applies, for example, if the cleaning can have a negative effect on lakes and waterways or if the ditch is located close to areas with high environmental values. The role of these consultations are to ensure that the cleaning does not affect downstream aquatic environments or that the ditches are so old that the effect of cleaning them will be the same as the original, traditional forest drainage. Before DNM, the work needs to be carefully planned and the economic gain needs to be weighed against the environmental consequences to make sure no unnecessary DNM will be performed (The Swedish Forest Agency 2017).

1.2 Function of ditches

The main purpose of forest drainage is to increase tree growth by increasing root respiration. This is done by lowering the ground water table and thereby making the soil more air-filled (Glinski & Stepniewski 1985; Koivusalo et al. 2008; Sikström & Hökkä 2016). This aeration of the soil can in turn result in an increased tree height and diameter, as long as no other factors are limiting. This positive effect on tree growth has been confirmed by a number of studies and is generally agreed upon (Payandeh 1973; Hånell 1988; Freléchoux et al. 2000; Choi et al. 2007: Socha 2012). Drainage of forest land can also lead to an increase in the number of trees per hectare due to more favorable conditions for plants (Päivänen & Hånell 2012). Furthermore, drainage can enable afforestation on certain types of wetlands as well as facilitate reforestation on sites that suffer from paludification after harvesting of the previous stands (Lõhmus et al. 2015). The effect of drainage is also greatly affected by the site type (Hånell 1988), stands with thick peat soil are more likely to lack sufficient amount of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) which may restrict tree growth despite drainage (Päivänen & Hånell 2012; Moilanen et al. 2015). Even though drainage can have positive effects on tree growth, it can have negative environmental impacts on both the ecology and hydrology of forest landscapes. Drainage, both traditional forest ditching and DNM, leads to an increase in dissolved elements such as Mn, Ca, Mg as well as other nutrients, pH and suspended solids in downstream waterways (Joensuu et al. 1999; Åström et al. 2001; Nieminen et. al 2010; Hynninen et al. 2011; Nieminen et al. 2017). This increase is primarily caused by erosion and soil deposition (Stenberg et al. 2015a) and is greatest during the first year after DNM and during the first spring flood after DNM (Stenberg et al. 2015b). These changes, caused by drainage, are damaging for downstream watercourses and the organisms that live there (Manninen 1998; Ecke 2009; Stenberg et al. 2015b).

The hydrology in forest landscapes is also greatly altered by drainage, and can stay altered for decades (Lõhmus et al. 2015). The biggest alteration is the lowering of the ground water table, caused by both drainage and the increased evapotranspiration and interception from the additional forest growth and afforestation on the site (Kopp et al. 2013). The lowering of the ground water table, in turn, alters the whole ecosystem of the forest. Some species may be favored by this, while others may disappear from the area. The overall number of species is not necessarily affected by drainage but the species composition can be altered where the mire species are at disadvantage (Korpela 1999). However, there are studies indicating that species richness of plants can be higher in ditches than in the surrounding forest. This is mainly due to the altered condition in light and moisture that ditches create, making it possible for several different species to live together (Zielinska et al. 2013). These specific conditions in ditches may allow mire species to survive in the ditches while they disappear from the rest of the forest (Korpela 1999). Studies have also shown that the plant species richness increase with the stream size. The reason for this have been theorized to be the increase riparian area that an increased stream size causes which in turn allows for more species. Another possible explanation is that larger stream have a larger CA which in turn increase the possible area to collect seeds from (Kuglerová et al. 2015). This correlation between stream size and plant species richness are very likely to also exist for ditches of different sizes.

1.3 Forest drainage today

Due to the extensive history of drainage in the Swedish forest landscape there is now approximately 360 000 km of ditches across Sweden (Hånell 1990), many with unknown location or function. Most of these ditches were made without a thought of where they would be most suited in the landscape, making it difficult to determine which ditches should be maintained (Hasselquist et al. 2017).

Most of the ditches in the Swedish forest are more than 80 years old and may be in need of DNM to retain or regain their drainage capabilities. Ditches can deteriorate over time and gradually lose their drainage effect, resulting in a loss of the positive growth response of trees (Paavilainen & Päivänen 1995; Sikström & Hökkä 2016; Drott 2016). According to Hånell (2004), there are approximately 120 000 hectares of drained forest land in Sweden with non-functioning ditches. Studies have shown that ditches may be in need of DNM 20-30 years after the initial drainage to maintain a growth effect (Ahti et al. 2008; Ahtikoski et al. 2008) due to the subsistence of the peat layer (Heikurainen 1957; Leifeld et al. 2011) or blockage caused by collapsing walls or vegetation (Timonen 1983; Silver & Joensuu 2005). This deterioration of ditches is mainly affected by time and peat thickness (Sikström & Hökkä 2016). However, it has been indicated that the age, quality and depth of ditches are insufficient indicators of whether a site is in need of DNM (Sikström & Hökkä 2016). This leads to the issue of DNM in today's forestry, because even though there is widely reported that DNM can have positive effects on tree growth (Ahti & Päivänen 1997; Ahtikoski et al. 2008), clear guidelines for when and where DNM should be performed are still lacking. In 2016, the Swedish Forest Agency pointed out the lack of clear and simple recommendations for when DNM should be performed in specific stands (Drott 2016), drawing attention to the need of more studies on the subject.

There are recommendations that DNM may be beneficial after clear-cutting to counter the elevation of the ground water table (Lundin 1979; Dubé et al. 1995) that otherwise may hinder the regeneration phase (Lieffers & Rothwell 1986; Lewty 1990; Lieffers & Macdonald 1990). Clearing out older ditches may increase drainage and make up for the loss of evapotranspiration that the harvest of the tree layer causes (Roy et al. 2000). However this recommendation is general, and does not take into account different site factors that can affect the functionality of the ditches. There have been attempts to find a way to determine the need of mid-rotation DNM in different sites. One of the most recent being the creation of the DitchFlowTracker (DFT), a semi-automatic tool that determines the catchment area (CA) for ditch segments which in turn can help to determine if the ditches are likely to have enough CA to drain the surrounding area. Ditch segments with a CA smaller than 0.4 hectares are unlikely to have an effect on tree growth in the surrounding forest (Ågren et al. 2015; Hasselquist et al. 2017). In addition to the CA, the soil type could also be an important factor in determining the drainage function of ditches. Soil characteristics such as pore space, organic matter content and particle size are what determine the retention and movement of water (Fisher & Binkley 2000). Till soils can drain faster and deeper than peat since they have a higher hydraulic conduciveness (Fisher & Binkley 2000). Because of this, peat sites are more likely to benefit from drainage than till sites. Peat and till soil types will be the main focus in this study, since those are the most commonly occurring and the sites in peat and till soil (mostly likely represents wet mineral soil) are the most likely to be in need of DNM (Hasselquist et al. 2017).

The ability of the DFT to prioritize DNM will be evaluated in this Master's thesis. Older ditch segments with different CA's and in different soil types will be evaluated to see if they initially increased, and continue to increase, tree growth. Water flow in ditches will also be investigated because the condition of the ditch, indicated by the water flow, could also predict the influence of ditch segments on tree growth. Creating better recommendations for DNM will not only benefit profitability by increasing tree growth and reducing unnecessary work and costs, it might also help to minimize the ecological problems that ditching and DNM can cause for downstream waterways (Sikström & Hökkä 2016).

1.4 Primary questions

The overall objective of this Master's thesis was to ground truth the DFT as a way to identify ditches that does *not* need DNM. This was done by testing the explaining variables that affect the tree growth such as CA, soil type and water flow. DNM operations should be decided by weighing the economic benefits against the negative ecological impacts of the DNM (Sikström & Höökä 2015). The DFT might help this prioritization by, in addition to the growth effect, predicting the biodiversity of a ditch segment. To test this, the effect of CA and soil type has on plant diversity in ditches will also be explored. Hopefully this study will be a step towards developing guidelines for when and where DNM is needed on the ditch segment level. The primary questions of this thesis were:

(i) Does the drainage effect on tree growth vary with CA or soil type?

(ii) Have ditches at sites with different CA and soil type had similar effects on tree growth over time?

(iii) Can water flow, soil moisture and humus depth be used as indicators of a ditch segments effectiveness?

(iv) Does CA affect the plant diversity in and close to the ditch?

1.5 Hypotheses

(i) The drainage effect on tree growth will decrease with distance from the ditch (Miina et al. 1991; Päivänen & Hånell 2012). Ditches with smaller catchments areas (< 1 ha) will not show any relationship between increased tree growth and distance from ditch while the largest CA (1-2 ha) will. Peat sites are more likely to benefit from drainage than till soils and will therefore show an increase in growth nearer the ditch (Hasselquist et al. 2017).

(ii) Tree growth will initially increase after drainage and then the effect will level off with time as the ditch deteriorates or other factors become limiting (for example nutrients) (Paavilainen & Päivänen 1995; Ahti & Päivänen 1997; Ahtikoski et al. 2008; Sikström & Höökä 2015). Small CA's is not likely to carry any flowing water and will therefore have no influence on a ditch effect on tree growth. Larger CA's between one and two hectares is likely to initiate flow and therefore influence the drainage effect on tree growth. Sites in till soils have a better drainage capacity than peat soils and will therefore not benefit as much from drainage as peat (Hasselquist et al. 2017).

(iii) Previous studies has shown that ditch segments needs to be cleaned because of ditch deterioration caused by vegetation and collapsing walls (Timonen 1983; Paavilainen & Päivänen 1995; Silver & Joensuu 2005). The deterioration of ditches could possibly be explained by the flow of water in the ditch. Where deteriorated ditches with low flow, high soil moisture and thick humus depth have low or no effect of tree growth.

(iv) Diversity in ditches has been shown to originate from differences in flow permanence, depth, amount of water flow and altitude (Williams et al. 2004). Since the flow should be higher in larger CA's the biodiversity of ditches should also rise with the size of the CA (Ågren 2015).

2 Method

2.1 Study area

The sites included in this study were located in the Krycklan Catchment Study (KCS), a research catchment in northern Sweden situated 60 km north-west of Umeå (Laudon et al. 2013). KCS is approximately 6 780 hectares of boreal landscape with forests, mires, streams and lakes. There is estimated to be about 150 km of ditches within the KCS (Figure 1) (Hasselquist et al. 2017).

The sites in this study were spread throughout the KCS in mixed forested stands taller than seven meters (older thinning stands) with mainly Scots pine (*Pinus sylvestris L.*), Norway spruce (*Picea abies L.*) and birch (*Betula L.*). Stand delineation was done by the Department of Forest Resource Management using their standard forest classification system. For inclusion in the study, sites needed to contain a ditch situated at least 150 m from any other type of drainage in one direction so that the plots farthest away from the ditch were not affected by ditches or streams other than the focus ditch. Half of the sites were located on peat soils and the other half on till soils based on Swedish Geological Survey (SGS) maps. In Sweden, the definition of peatland and mire is divided into two categories: peatlands, where the peat is thicker than 30 cm, and wet mineral soils, where the peat thickness is less than 30 cm and the bottom layer of the vegetation is dominated by species adapted to wet conditions (Päivänen & Hånell 2012). The thickness of the peat layer may compact and decompose (subside) after drainage, meaning that some of the areas that are today counted as "wet mineral soils" might once have been peatland (Päivänen & Hånell 2012). Henceforth in this thesis the mention of peatland will mean both areas peatland and wet mineral soils. Sites with steep slopes were avoided (<5 m elevation change over 75 m). The size of the CA's used in this study was determined by the DFT (Hasselquist et al. 2017). The ditching history for most of the sites was unknown but they were probably dug in the 1930s when the digging of ditches were extensive in the area. Only one of the sites, number 61, were drained sometime between year 1963 and 1968 according to old aerial photos.

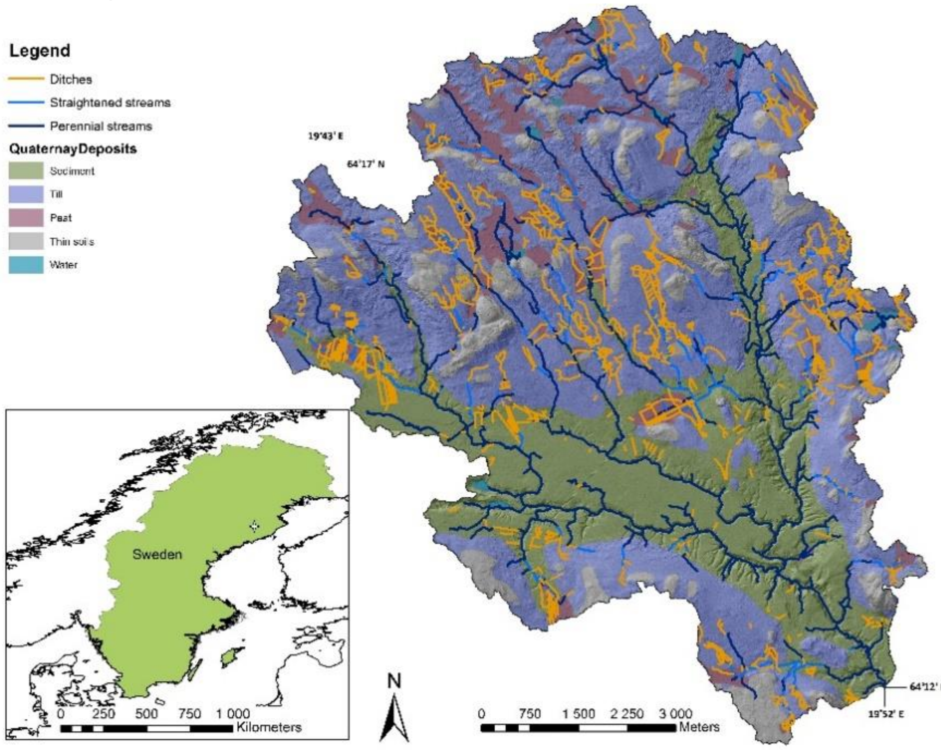

Figure 1. Krycklan Catchment Study area with waterways and soil type delineated (Figure by Eliza Maher Hasselquist).

2.2 Field data collection

Three different CA sizes were included in the study: i) >0,4 ha, ii) 0,4 - 1 ha and iii) 1 - 2 ha. These CA sizes were used in the development in the DFT and therefore is the most interesting to evaluate. About 80 % of the ditches within the KCS are located on till and peat soils (Hasselquist et al. 2017) and because they are likely to have different drainage functions (Eriksson et al. 2005), sample sites from these two different soil types were included (Figure 2) (Hasselquist et al. 2017). With three replicates of these six different combination of sites, a total of 18 sites were studied (3 catchment areas x 2 soil types x 3 replicates = 18).

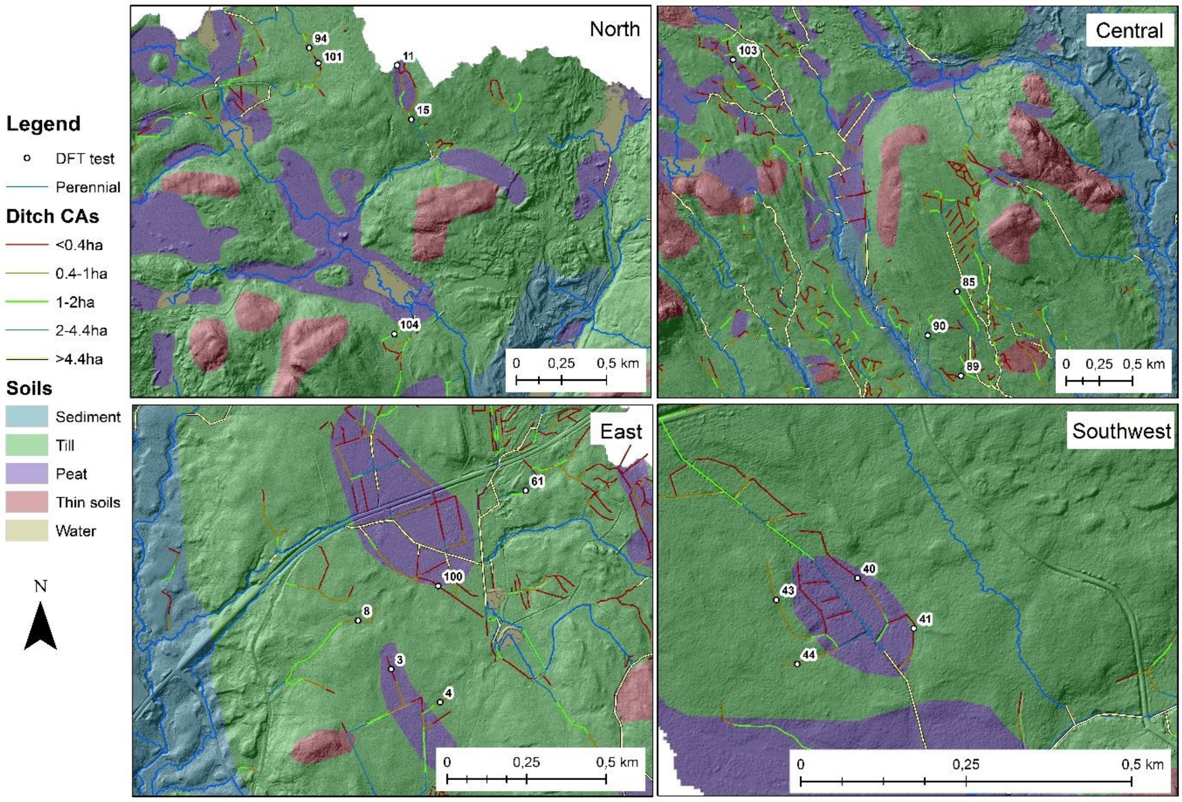

Figure 2. Location of the sites within the KCS included in the study with CA size and soil type (Figure by Eliza Maher Hasselquist).

At each of the 18 sites included in the study, three transects were placed perpendicular to the study ditch. Each transect was made up of four sample plots distanced 5.65, 17, 40 and 75 m from the middle of the ditch. The sample plot located 75 m from the ditch was used as a control since no effect from the ditch should be acquired from this distance (Sikström & Hökkä 2015). Each sample plot had a radius of 5.64 m and was named with an individual ID (Figure 3). This radius was chosen since it makes it easier to scale up the result, the observations within each plot only needs to be multiplied by 100 to get number of observations per hectare. This is because the area of the plots is approximately 100 m^2 which multiplied with 100 is 1 hectare (10 000 m^2). In each sample plot the following site data were collected: site type, soil type, soil texture, soil moisture class, field layer type, moss layer type, humus layer thickness and volumetric water content (VWC) (Appendix 1). The VWC was measured three times in each sample plot using a soil volumetric water content probe called a HydroSense II (Cambell Scientific) fitted with twelve cm long probes. In the first sample plot on each transect a plant species list was compiled as well as several measurements of the ditch, including width, depth, water depth and water flow velocity (if water was present). The water flow were calculated by measuring how long it took for a few drops of colored dye (Fluorescein sodium salt, Sigma-Aldrich) to travel ten cm (s/10cm).

All trees within each sample plot were numbered and their diameter was calipered at breast height (DBH); trees smaller than five cm in DBH were not included in the study. The heights of four trees within each plot were measured; the two largest diameter trees, the smallest diameter tree and a tree from the middle of the range in diameters for the plot. These measurements were used to create a height model to predict the height of the rest of the measured trees. In addition, an increment core sample (5 mm in diameter) was collected from the tree with largest DBH in each sample plot with an increment corer, resulting in twelve increment cores per site and a total of 216 cores from all sites. The cores were stored in paper straw and dried in a drying oven at 60°C for at least 24 hours before storage (Speer 2010).

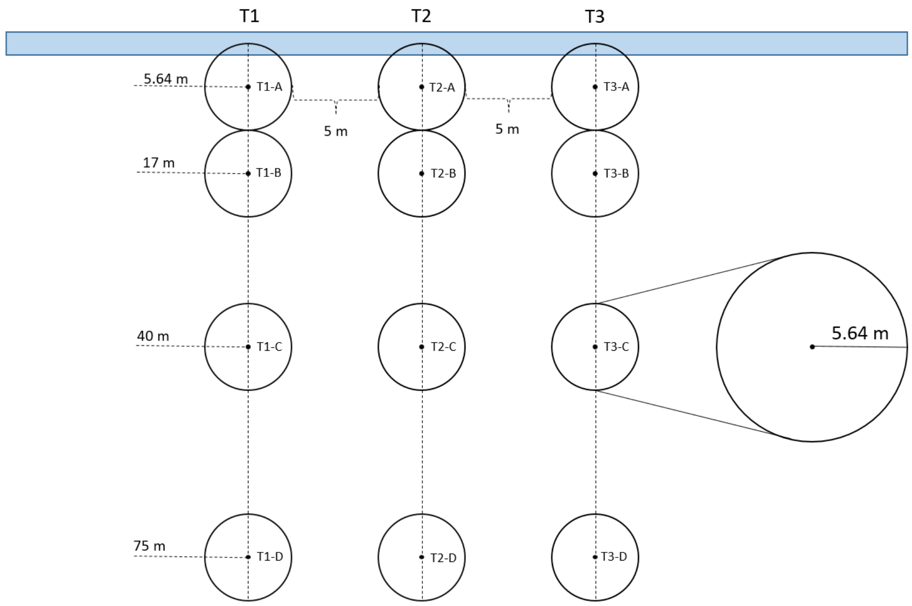

Figure 3. Location of sample plots divided into three transects perpendicular to the ditch with distance from ditch and id number for each plot.

2.3 Analysis of field data

At each site, the tree heights taken from the four measured trees within each plot were regressed against their DBHs to find a function that best could explain their relationship, in this case a logarithmic function. This function was then used to estimate the height of the remaining trees measured in the plot:

$$h_i = c_0 + c_1 \times \ln(d_i)$$

Where h_i is the estimated height for tree number i, c_0 and c_1 are coefficients determined by the logarithmic function and d_i is the diameter for tree number i. The estimated tree heights were then used to calculate the individual tree volume:

$$v_i = BA_i \times h_i \times 0{,}47$$

Where v_i is the volume for tree number i, BA_i is the basal area for tree number i, h_i is the height for tree number i and 0,47 is a coefficient that takes into account the trees conical shape. All individual tree volumes where then averaged for each sample plot. Basal area (BA) were estimated from DBH, in meter, for each tree from which an average was calculated. This average for each plot where then scaled up to basal area per hectare to make it easier to compare between the sample plots. The following formula was used:

$$BA/ha = ((\sum (DBH/2)2 \times \pi)/n) \times 100$$

Stems per hectare were estimated by taking the total number of stems with a diameter at breast height over five cm and multiplying with 100.

The flow rate by volume in liter per second (l/s) for each ditch was calculated by first converting the field measured flow rate from s/10 cm to m/s. This flow rate was then multiplied by the water depth and width within the ditches to calculate m3/s and then converted to l/s. The water flow data where log transformed to meet assumptions of normality for statistical tests, but because of many zeros in the data we could not meet these assumptions. To continue to use the flow data in analyses, they were divided into three categories. Those that had No flow (~ 0 l/s) were one category and the other two categories were the based on the shape of the normal distribution of the non-zero log-transformed flow data: the lower half of the bell curve was designated as 'Low flow' (~ 0.006-0.8 l/s) and the upper half of the bell curve as 'High flow' (~ 0.8-77 l/s).

All statistical analyses were performed in R, a language and software environment for statistical analyses and graphics (R Development Core Team 2017). To assess the impact of CA, soil type and distance from the ditch on the different forest productivity variables, linear mixed effects models (LMM) with restricted maximum likelihood (REML) was used. This model, called 'lmer' in R, tested the fixed effects of soil, CA, distance from ditch and their interactions while taking into account the random effect of the transect or site. These analyses where carried out on the three forest productivity variables that had the best correlation to the rest of the forest variable; volume (m^3sk) which correlated with basal area, mean diameter which correlated with height, and stems per hectare which did not have a high correlation with any other forest productivity variables and therefore had to be added. The strong correlation made the other forest variables redundant to analyze which resulted in a total of three models (volume, mean diameter and density (stems per hectare)). The models were started with all fixed effects and their 2-way interactions and were then simplified when certain effects were shown as insignificant. The different models for each forest variable were evaluated against each other using Akaike information criterion (AIC). The AIC estimates the relative quality of the models, where the lowest AIC-value indicates the best model. The models were completed when they consisted of only significant fixed effects and the AIC- values were lower than for the previous model. When the linear mixed effect models were reduced to only significant factors for each forest variable, a pair wise comparison were performed to determine how the significant fixed effects affected the forest variables. The initial models indicated that CA had no effect on tree growth. Instead of Ca the water flow divided into categories, which had a high correlation to Ca, was added in the models. LMMs were also performed for the factors of soil moisture, humus depth and water flow to assess how these factors were affected by CA, soil type and distance from ditch. This was done to evaluate if any of these factors could explain why CA, soil type and distance from the ditch effected the forest productivity.

2.4 Reconstruction of stand growth over time

Before the tree ring analysis the dried tree cores were soaked in water overnight. This gave the cores the right degree of humidity to be planed on one side in a sliding microtome. The planed tree cores were then scanned and analyzed using WinDENDRO, an image processing an analysis tool that measure tree rings automatically (Guay et al. 1992). The tree ring width was measured for each year with an accuracy of 0,001 mm. The age range of the increment cored trees varied greatly, between 45 to 185 years, which is an unnecessary large range of data to work with. Since the most of the ditches were dug before 1990's according to the oldest aerial photos and the fact that a vast majority of forest drainage were done after the 1900's (Lundberg 1914; Hånell 1990; Drott 2016) only ring width data from year 1897 to 1990 were used. Ring width data were analyzed in TRADER (Tree Ring Analysis of Disturbance Events in R) an open source software package in R. TRADER uses a number of steps to analyze tree growth history and disturbance events (Altman et al. 2014). The first step was to detrend and convert the tree width data into ring-widths indices (RWI) using a negative linear model in CRUST (Melvin & Briffa 2014). The CRUST method was chosen since it is one of the most commonly used methods for detrending (Sullivan et al. 2016). The RWI data were then averaged for each year using the arithmetic mean to create a standard chronology. This was done with the 'chron' function in the dendrochronology program library in R (dplR) (Bunn 2008).

The RWI data contains information of increases and decreases in tree growth during the time period the tree was alive. An increase that exceeds a set threshold are called releases and are used to identify events that have had a positive effect on tree growth, in this case drainage. To calculate releases, the TRADER function 'growthAveraginALL' was used which implements the method: radial-growth averaging criteria (Nowacki & Abrams 1997). This method calculates percentage growth change (%GC) using the average radial growth for the preceding ten year period (M1) and the average radial growth for the subsequent 10 year period (M2) (Altman et al. 2014):

$$\% \text{ GC} = [(M^2 - M^1)/M^1] \times 100$$

To be able to differentiate minor and substantial disturbances, the releases were divided into two classes: moderate and major magnitude releases (Altman et al. 2014). The release thresholds were 25 % GC for moderate releases and 50 % GC for major releases (Nowacki & Abrams 1997). The moderate and major releases for trees within the same site and with the same distance from the ditch were averaged to create two release values for each distance (5.6, 17, 40 and 75 m). The releases were then plotted in a table together with the information of how many sample trees that existed during that time period. The total number of releases and their magnitude (minor or major) where averaged for each distance within a site and plotted into an area graph in Minitab 17. These area graphs together with the table of moderate and major releases were used to calculate the most likely year of ditching and how long the release lasted (Appendix 2; Appendix 3). The length of the releases only shows how long the growth increased from previous years (the peak of growth) and not how long the higher level of growth were sustained. To find the total years of increased growth the yearly basal area growth was calculated from the ring width data. The yearly basal area growth for each tree was then averaged into ten year periods to reduce the impact of other disturbances that could affect growth. Finally, the trees from the same site that existed during the time of the ditching and that showed a major or moderate release were averaged to get the growth history for each site. From this data the length of each drainage induced growth increase for each site could be calculated (Appendix 3). However, not all stands were old enough to have trees from the time of the initial drainage, making these calculations only possible for ten out of the 18 sites. The length of the releases and the total growth effect where analyzed with a linear mixed effects model (LMM) with restricted maximum likelihood (REML). This model tested how the fixed effects of soil type, CA and their interactions affected the long term effect of drainage while taking into account the random effect of the site.

2.5 Analysis of plant diversity

The final question included in this study was to examine how CA and soil type effect plant diversity. The number of species of vascular plants and bryophytes were combined to determine species richness. The Shannon index (Spellerberg & Fedor 2003) was used to analyze the plant diversity because it takes into account both abundance and evenness of the occurring species and is widely used by researchers all over the world (Hughes 1977). Only CA and soil type were used as fixed factors, and not distance from the ditch, in the analysis because plant species data were only taken at the plots nearest the ditch. In addition to Shannon's diversity index, a LMM were created with the number of plants, CA and soil type.

3 Result

3.1 Drainage effect on forest volume, density and diameter

The hypothesis that ditches with smaller catchments areas (< 1 ha) would not show any relationship between forest productivity and distance from ditch while ditches with the largest CA (1-2 ha) would, was rejected. CA did not significantly explain any variation of the measured forest productivity variables. Instead, soil type in combination with distance from ditch, were significant in the models (Appendix 4). Density (stems per hectare) and mean diameter were also significantly affected by distance from the ditch independent from soil type (Appendix 4). When CA was replaced by flow category, some of the variance in the forest variables could be explained by the models (Table 1).

Table 1. Statistical analysis of variance on the effect of soil type, flow category and distance on different forest variables.

Model	Factor	df	F	P
Volume	Soil	1	12,07	0,003**
	Flow Category	2	3,24	0,043*
	Distance	3	3,66	0,013*
	Flow category*Soil	2	0,38	0,683
	Soil* Distance	3	3,58	0,014*
	Flow category* Distance	6	2,33	0,034*
Density	Soil	1	0,07	0,792
	Flow Category	2	4,62	0,012*
	Distance	3	10,63	<0,0001***
	Flow category*Soil	2	7,38	0,001**
	Soil* Distance	3	14,44	<0,0001***
	Flow category* Distance	6	1,13	0,347
Mean diameter	Soil	1	4,71	0,043*
	Flow Category	2	0,1	0,907
	Distance	3	2,90	0,036*
	Flow category*Soil	2	0,71	0,494
	Soil* Distance	3	9,25	<0,0001***
	Flow category* Distance	6	2,53	0,022*
Soil moisture	Soil	1	0,02	0,88
	CA	2	0,71	0,51
	Distance	3	32,07	<0,0001***
	Soil*CA	2	0,48	0,63
	Soil* Distance	3	12,1	<0,0001***
	CA* Distance	6	1,3	0,26
Average humus depth	Soil	1	0,33	0,576
	CA	2	1,09	0,366
	Distance	3	20,93	<0,0001***
	Soil*CA	2	1,11	0,360
	Soil* Distance	3	1,66	0,178
	CA* Distance	6	3,06	0,007**
Plant diversity	Soil	1	0,02	0,878
	CA	1	5,14	0,038*
	Soil*CA	1	0,15	0,702

The forest volume was explained by flow category where the volume was higher closer to the ditch in ditches with low- and high flow (Table 1; Figure 4). Volume in stands with a ditch segment with high flow had higher stand volume than stands with no flow and low flow (Table 1; Figure 4).

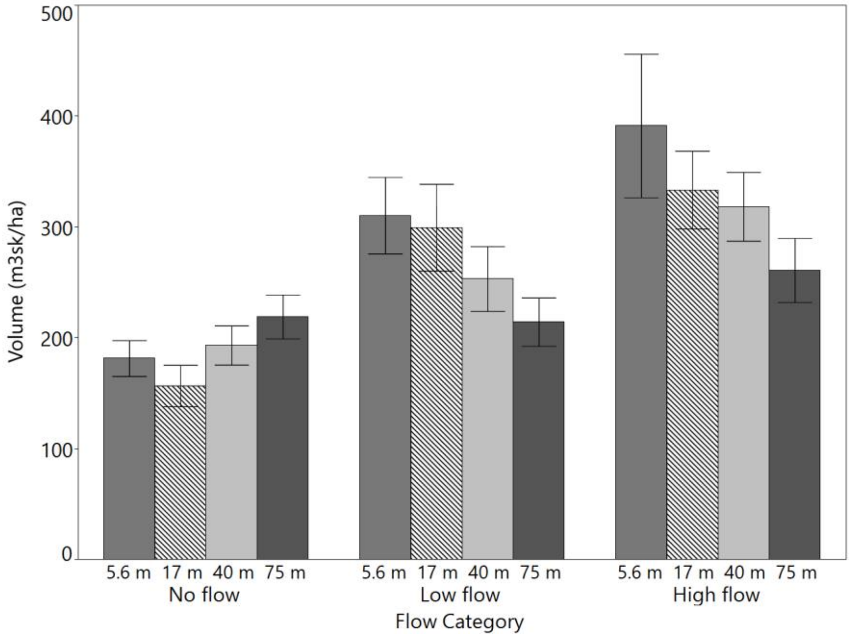

Figure 4. Forest volume with ± 1 SE (Standard error) by flow category and distance from the ditch, 5.6 m, 17m, 40m and the control distance, 75 m.

The forest volume was higher closer to ditches in till soil. There was no significant difference in volume 5.6 m and 17 m from the ditch. However the volume at both these distances was significantly higher than the volume 40 m from the ditch and the control plot. There were no significant differences in volume between the control plot and the different distances from the ditch in peat soils (Figure 5).

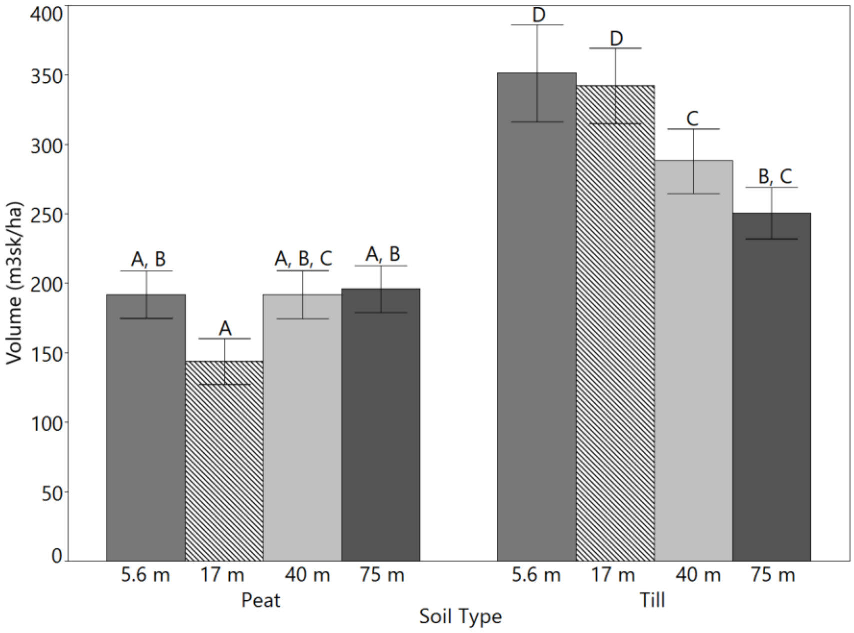

Figure 5. Mean tree volume with ± 1 SE divided by soil type and distance from the ditch, 5.6 m, 17 m, 40 m and the control plot, distanced 75 m from the ditch. The letters above the bars indicate statistically significant differences among the volumes at different distances (P<0.05).

The tree density (stems per hectare) had the opposite relationship than volume where the density was higher close to the ditch in peat soil, but not in till soil. The density in peat was significantly higher 5.6 m from the ditch than any other distance, including the control plot. The density 17 m from the ditch was also higher than the control plot. The density in till soil did not change significantly with distance from the ditch (Figure 6).

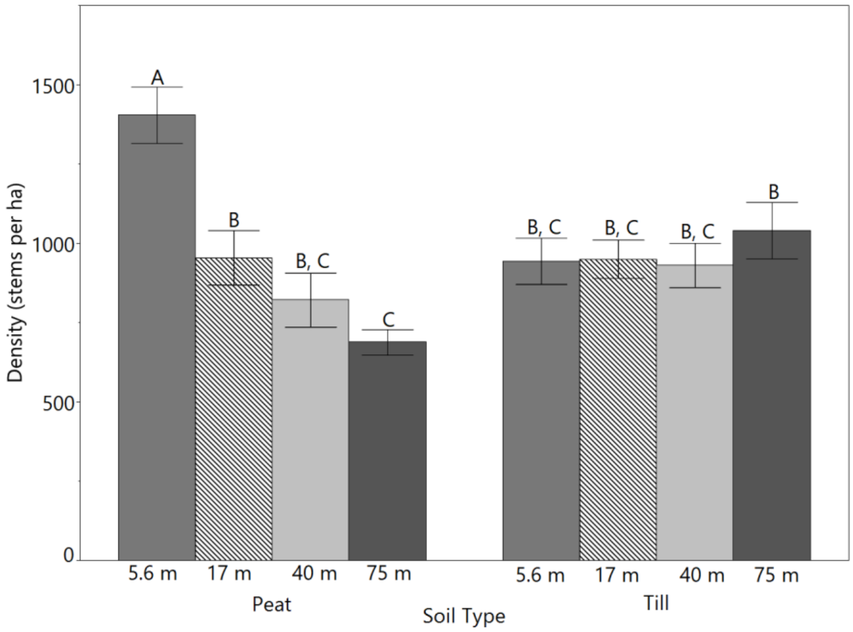

Figure 6. Tree density with ± 1 SE by soil type and distance from the ditch, 5.6 m, 17m, 40m and the control distance, 75 m. The letters above the bars indicate statistically significant differences between the density at different distances (P<0.05).

The mean diameter was lower closer to the ditch in peat, but not till. The lower mean diameter could be seen at distance 5.6 m and 17 m from the ditch in peat soils. There was no significant difference in mean diameter from the distance 40 m from the ditch and the control plot. In till soil, the mean diameter was higher closer (5.6 m and 17 m) to the ditch than in the control plot, while there were no differences between the mean diameter of trees at 40 m away from the ditch and the control plot (Figure 7).

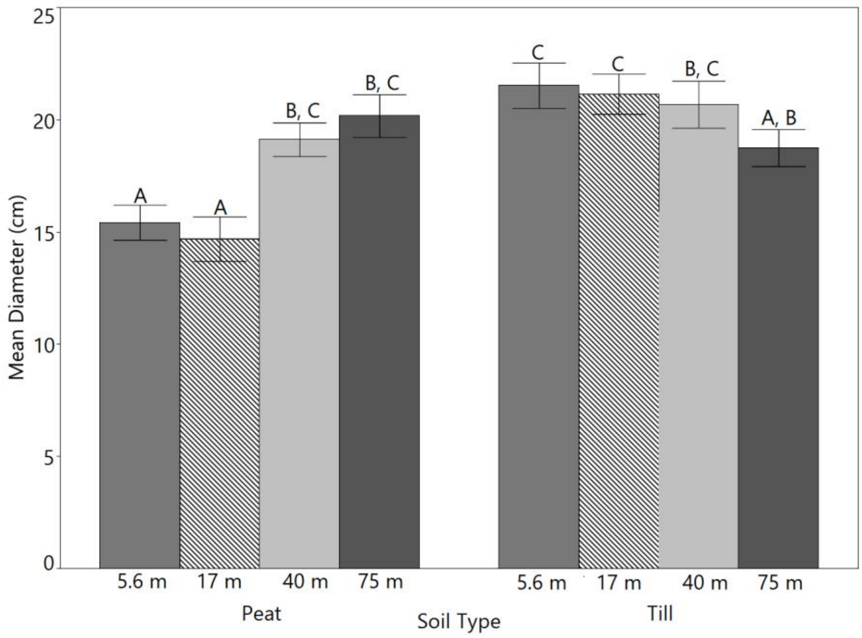

Figure 7. Mean diameter of trees with ± 1 SE divided by soil type and distance from the ditch, 5.6 m, 17m, 40m and the control distance; 75 m. The letters above the bars indicate statistically significant differences among the mean diameter of trees at different distances from the ditch ($P<0.05$).

The soil moisture were highest closest to the ditch (5.6 m) and got significantly lower for each distance away from the ditch (17, 40 and 75 m) (Table 1). This clear gradient is only visible in peat while the soil moisture in till only were higher closest to the ditch compared to the distance 17 m and the control plot (Figure 8).

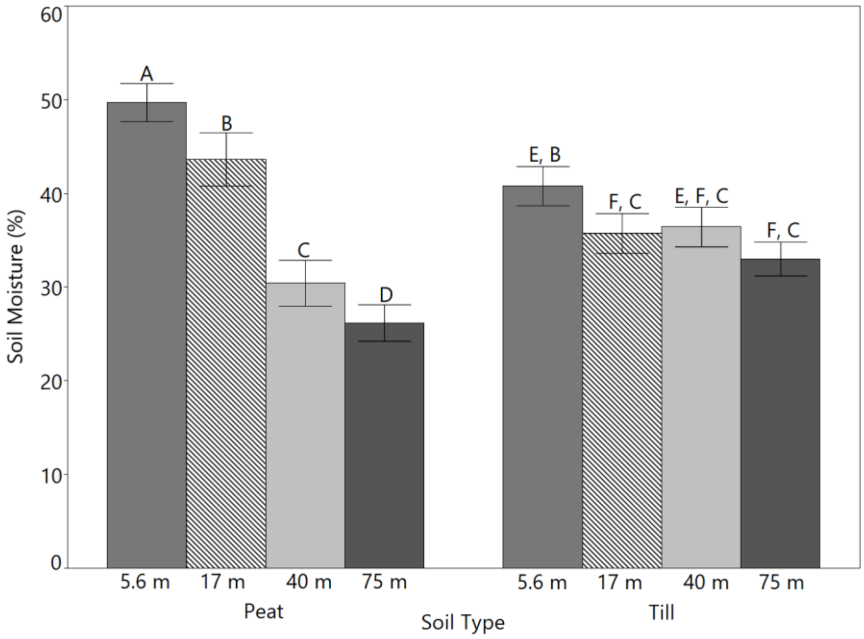

Figure 8. Soil moisture with ± 1 SE divided by soil type and distance from the ditch. The letters above the bars indicate statistically significant differences among the mean diameter of trees at different distances from the ditch (P<0.05).

The average humus depth were affected by CA and distance from ditch (Table 1). In the ditches with the smallest CA's (< 0.4 ha), and the largest (1-2 ha) the humus depth was thickest closest to the ditch (Table 1). The humus depth at 5.6 m and 17 m from the ditch were significantly higher than at 40 m from the ditch and the control plot. In the ditches with medium CAs (0.4 - 1 ha) there were no significant differences between humus depth and distance from ditch (Figure 9).

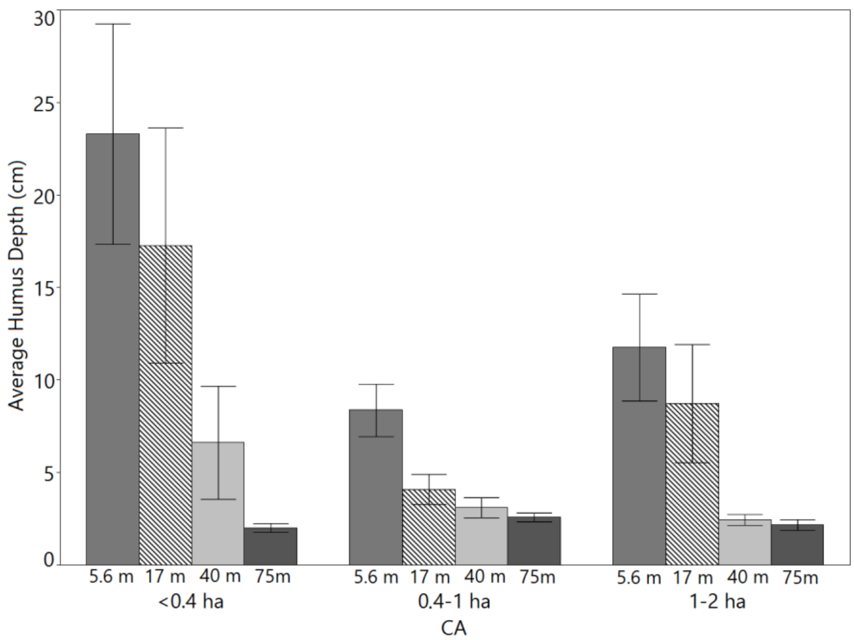

Figure 9. Average humus depth with ± 1 SE divided by CA and distance from the ditch.

3.2 Stand growth over time

From the 18 sites included in this study only ten (56 %) had trees old enough to have existed at the presumed time of the ditching. Out of these ten sites, 50 % were located in peat soil and 50 % in till soil. A majority of these sites were located in the smaller (<0.4 ha) and larger (1-2 ha) CA's with 40 % each while only 20 % of the sites were located in a CA of 0.4-1 hectare (Table 2). Of these ten sites, 70 % showed evidence of a release that could be linked to a likely year of drainage (Appendix 4). There were no significant difference between the length of a release or the growth effect between the sites with different soil types or CA size (Table 2). The mean length of a release for all sites was approximately 14 years and the mean length of the total growth effect was approximately 29 years.

Table 2. Mean length of releases and growth effects divided into soil type and CA with number of sites (N) and range.

	Peat **N=5**	**Till** **N=5**	**CA 0.4** **N=4**	**CA 0.4-1** **N=2**	**CA 1-2** **N=4**
Sites (N) with a release (%)	60	80	50	50	100
Mean length of release (years)	12	15	16	14	12
Range in release length (years)(max – min)	9	7	4	14	10
Mean length of growth effect (years)	47	20	45	20	28
Range in growth effect length (years) (max – min)	20	20	30	20	30

3.3 Plant diversity

Unlike tree growth, plant diversity in and close to the ditch was significantly (p =0.038) affected by CA size and not by soil type. The ditches with the largest CAs (1-2 ha) had the highest number of plant species (vascular and bryophytes combined) (Figure 10). This significance could only be seen with a linear mixed effects model and not with Shannon's diversity index, even though it was close to show a significance (Appendix 4).

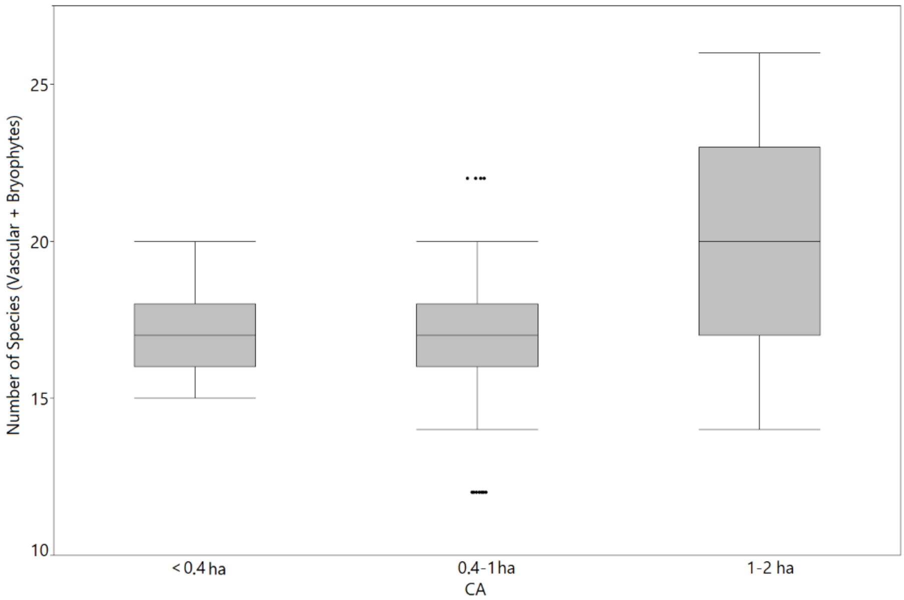

Figure 10. Number of plant species separated by the CA size.

4 Discussion

4.1 CA and soil types influence on the drainage effect

The results from this study suggest that a sites soil type affects the tree growth response to drainage while CA is less important. All the measured forest productivity variables were affected by both the soil type and the distance from the ditch, meaning that the ditch initiated the difference seen between the soil types. Together, this rejects the hypothesis that both soil type and CA would affect the response of tree growth.

The forest volume was higher closer to the ditch in till but not in peat (Figure 5). This indicates that the drainage only had an effect in till soils which rejects the hypothesis that peat sites would show an effect while till sites would not. One explanation for this could be that the potential growth effect in peatland is mitigated by a lack of nutrients that prevents tree growth despite the increased root respiration (Päivänen & Hånell 2012). The soil type was also connected to soil moisture where there was a clear gradient of higher soil moisture closer to the ditch in peat that decreased away from the ditch, but not in till soils (Figure 8). Previous studies has also shown that the groundwater table is lowered less in deep peat sites than sites with other soil types (Koivusalo et al. 2008). It might be that the ditches in peat soils are not effective enough to drain the site and therefore do not aerate the soil enough to show a growth effect on the trees. The fact that most of the ditches in the study are more than 80 years old makes it likely to assume that the drainage effect could have lessened and might even be non- existing today. This theory is supported by the fact that previous studies have suggested that ditches need to be cleaned approximately 20 to 30 years after the initial drainage to maintain their effect (Heikurainen 1957; Ahti et al. 2008; Ahtikoski at al. 2008).

The stem density was higher closer to the ditch in peat soil but not in till soils where there was no difference in the number of stems at any distance from the ditch (Figure 6). This difference in till and peat soil is more likely due to management practices than as an effect of forest drainage. In most peatland sites, a buffer zone seemed to have been placed around the ditch were they had not thinned or done any other management practices, resulting in a higher number of stems closer to the ditch. In till sites there were no apparent buffer zones since the sites had been thinned right up to the edge of the ditch. Many of the ditches in this study are old and have started to resemble streams, especially ditches in peat, which may explain why a buffer zone was placed there. The mean diameter was also lower closer to the ditch in peat than in till (Figure 7), likely because of the higher density of trees. A higher number of stems has been shown to give a low mean diameter because the crown is negatively affected by the lack of light, which in turn affects tree growth (Pettersson 1993; Ulvcrona et al. 2007). In till soil, the mean diameter was higher close to the ditch compared to the control plot (Figure 7). This is likely due to the density since there were fewer stems close to the ditch in till than at the control plot (Figure 6) even if it was not statistically significant (Table 1).

The soil type seemed to influence the effectiveness of a ditch segment to increase tree growth. The influence on density and mean diameter is likely more connected to management practices around wetlands instead of soil type. Forest volume, on the other hand, showed a more clear connection between soil type and drainage effect where stands in till soil had a higher growth (Figure 5). The strong effect the different soil types had on the drainage effect were somewhat unexpected since the mapping of the SGS did not match the soil types identified in the field. All of the till sites were correctly classified but only one of the nine presumed peat sites had humus layers over 30 cm and were, in fact, peat. This classification error could have been caused by the ditches since drainage can compact and decompose the peat layer which may turn them into wet mineral soils (Päivänen & Hånell 2012). However the difference that could be seen today in tree growth between the peat and till soils sites could still be valid. This is because the classified peat sites that today are till sites may have been peat soils at the time of the initial drainage and at the early stage of the trees growth. This means that the differences that can be seen today are legacies of the initial drainage conditions when the stands were established. It is also possible that the classification error stems from the SGS maps since they are made by using aerial photos and therefore not always accurate. The way the sample plots were placed in the field could also have affected the difference between the classified and the actual soil type. The control plot needed to be placed at least 75 m from other ditches which made it difficult to lay the sample plots towards peatlands which often are more densely ditched than other areas (Hasselquist et al. 2017). Before the soil type is used to identify the need of DNM the result from this study needs to be verified since it was an unexpected result that till soils showed an effect while peat soils did not, which contradicted the hypothesis and previous studies. Future studies should also test the available nutrients at each site to rule out if the lack of growth response is due to a lack of nutrients or any other factor.

It was surprising that the CA seems to have had no influence on the growth effect caused by drainage which contradicted the hypothesis. The reason that the CA of ditches does not seem to explain patterns of tree growth could be that the CA sizes included in this study were too similar in size to show an effect. According to Ågren (2015) the stream initiation threshold is approximately two hectare or one hectare if the site is drained by forest ditches during conditions of high flow, while the flow initiation threshold is 10 to 15 hectares during baseflow. It might be better to compare ditches with CA’s larger than two hectares against ditches with CA’s smaller than two hectares to determine if CA influences a the drainage effect of a ditch. Another possible explanation for this result could be that the CA’s calculated by the DFT is incorrect. The DFT assumes that all ditches have a depth of one meter when calculating CA while the real ditch depths varies greatly. A better result might be achieved if the DFT calculated CA with the actual depth of each ditch. Humus depth was significantly explained by CA (Figure 9), so if CA would have had an influence on the drainage effect these factors might be used as indicators to locate possible candidates for DNM.

Since CA had no effect on tree growth (Appendix 4) another variable with a strong correlation to CA, water flow category (Appendix 4), was used instead. The water flow, divided into three categories, seemed to explain the variation in tree volume where ditches with high water flow had higher tree volume than the sites with low flow or without any flow. Ditch segments with either low or high flow had higher volumes of trees closer to the ditch compared to the control plot (Figure 4). This difference in volume related to water flow is probably due to the drainage effect; a ditch with high flow is more likely to have a good drainage ability and therefore aerate the soil thus benefiting root respiration (Glinski & Stepniewski 1985; Sikström & Hökkä 2016). Ditches with no flow, on the other hand, indicate that the ditch does not drain the nearby area and therefore has no effect on tree growth.

This result indicates that water flow is a variable that could predict a ditch function and therefore determine the need for DNM which supports the hypothesis. Ditch flow was calculated using water depth, width and flow speed (s/cm) which, the hypothesis said can indicate how deteriorated a ditch is. These variables are also relatively simple to collect in the field which makes water flow easy to use as an indicator of ditch function. Since water flow is explained by CA (Appendix 4) the DFT might be able to identify ditch segments that are likely to have high water flow with the help of CA. These sites could then be measured in the field to measure the actual water flow. The obvious problem with this method is that it is difficult to interpret the result. For example, does a ditch segment with no flow indicate the need for DNM or that it is an “unnecessary” ditch that should not be cleaned at all. The same problem exists with ditches with low- and high flow. Even if these ditches show an effect on tree growth it is difficult to know if this means that the ditches work and are in no need of DNM or if the growth effect could be improved by DNM. One possible solution to this problem could be to look at the long term effect of ditches and find a variable that could be used together with water flow to predict the long term drainage effect. Water flow itself cannot be used to predict the long term effect of drainage since it is a highly changeable variable that are dependent on many variables that change with time. Water flow can be seen as a snapshot of the ditch function at a particular point in time and it is impossible to know how the water flow in the ditch was even two years ago, let alone 80 years ago. The high variation of this variable is also what makes it uncertain to predict the ditch function today. The water flow is dependent on the weather when the water flow was measured as well as which season the measurements were done.

A period with high rainfall could give a high water flow regardless of the ditch function over the whole year. Measurements during early spring could also give a high water flow due to the spring flood and not necessarily the ditch function. All the measurement of water flow in this study were taken in September which means that the seasonal changes are not taken into account. More accurate results might be achieved if measurements were taken for every season or even every month. This is also true for the variable soil moisture that was mentioned above.

Further studies should be done to evaluate the use of water flow to predict the need for DNM while taking into account how the weather and season affect the result. It would also be interesting to measure more sites and use more flow categories than three to better understand how water flow affect the ability of a ditch segments to drain water and increase tree growth. Another interesting development of this study would be to make a multivariable analysis of all the data used in this study, for example water flow category, CA, Soil, vegetation type etc. This could be a way to find a combinations of variables that can determine when a ditch segment is in need of DNM.

4.2 CA and soil types influence of the long term effect of drainage

The analysis of the long term drainage effect showed a growth effect that, on average, persisted 29 years. This is a longer growth effect than Ahti et al. (2008) and Heikuranen (1957) suggested but the growth responses in this study could vary as much as 30 years between sites. The wide range of the growth effect response could not be linked with either soil type or CA, indicating that neither soil type nor CA can be used to specify the effectiveness of drainage on the long term stand growth. There is however some issues with the calculation of the long time drainage effect in this study that needs to be mentioned. The main concern was that only about 20 % of the total number of sample trees were established during the time of the ditching. Since the cored sample trees had the highest diameter and therefore presumed to be the oldest at each sample plot it could be assumed that most stands are younger that the presumed drainage year. This made it only possible to use 55 % of the sites for the analysis and these site did not have a full set of trees resulting in a very small dataset. Studies of the long term effect on drainage needs be done on older stands that were established during the time of the drainage. However, stands like that is difficult to find and taking into account the other necessary requirement for the study sites, such as distance between ditches, makes it near impossible. There were also no separation between tree species in this study which may affect the result since spruce and pine have different growth patterns. Studies has shown that pine have a more fluctuating ring growth while the ring growth for spruce is more level and stay closer to the mean. The tree ring growth of pine is also more likely to be affected by the weather during the growth season than pine (Eklund 1954). This means that the tree growth response from drainage could be easier to detect in pine than spruce. A better result might be achieved if the tree ring data from spruce and pine were separated and analyzed independently.

4.3 Biodiversity in drained sites

The diversity patterns between ditches with different CA's is difficult to evaluate since there are few studies to compare the results to. Most studies, for example Williams et al. (2004) and Verdonschot (1990), compare diversity in ditches with other waterways such as streams. However in the comparison between these two studies there were one noticeable difference. Williams et al. (2004) showed that ditches had lower diversity than other waterways while Verdonschot (1990) showed that ditches had similar species diversity to other waterways. Williams et al. (2004) theorized that the difference in the result is due to location. The ditches in the Verdonschot (1990) study were located in low-lying areas and mostly had permanent flow, while the ditches in William et al. (2004) study were small and had highly seasonal flow. This suggests that the diversity is affected by water flow which in turn is affected by CA size. The higher flow in ditches with a CA size of 1-2 hectares could explain why the species diversity in this study was higher there than in ditches with a smaller CAs. Another possible explanation could be that the larger CA increases the possible collection of seeds from the surrounding landscape and thus resulting in higher diversity (Kuglerová et al. 2015). The result from this study indicate that the DFT could be helpful in predicting the plant diversity of a ditch segment based on their CA. Which in turn could be an important part of evaluating if DNM should be performed from the ecological point of view. Future studies should continue to explore the possibility to use CA to predict plant diversity to see if this correlation exist with CA larger than two hectares.

4.4 Conclusion

In today's forestry there is a need of clear guidelines for where and when DNM should be performed. In a response to this need the DFT was created, a semi-automatic tool that uses CA and soil type to predict the need for DNM. The purpose of this study was to evaluate how CA and soil type of ditches affects forest productivity, this was done by collecting and analyzing data from 18 sites in the Krycklan Catchment Study. The results indicated that a sites soil type had a significant effect on tree growth while the ditch's CA had no effect. The long term growth effect, determined with tree rings, showed no correlation with either CA or soil type. However the data set used in this analysis were quite limited since many sites were not old enough to have been established at the time of the initial ditching, which brings the result into question. There needs to be more studies done with older sites that were established at the time of the ditching and with a known drainage and maintenance history.

Water flow seems to be a promising tool to indicate the effectiveness of a ditch segment which confirms the hypothesis that ditch depth, width and water flow velocity could be used as an explanatory factors for a ditch segments function. Ditch segments with high water flow had higher mean tree volumes than those with no or low flow. Since water flow is strongly correlated to CA it might be possible to use the DFT to identify ditch segments in need of DNM with CA combined with water flow. Soil type also influenced the effectiveness of a ditch segment, where drainage in till soil gave a clear growth response on volume close to the ditch while sites in peat did not. Because this trend cannot be seen in the long-term growth effect as determined by tree ring analysis, there needs to be more studies done with better data to verify this result. Future studies should only include older stands that were established during the initial drainage. Future studies also needs to explore the possibility to use water flow as an indicator of a ditch's function which has been suggested in this study. Especially how predictability of water flow is affected by precipitation and season needs be explored. Ditches with larger CAs had a higher plant species richness and diversity. This is likely because the water flow was higher in ditches with larger CA's and the fact that larger CA's has a more area to collect seeds from. If future studies show that CA's size does influence the tree growth response of ditches the higher diversity of larger CA's needs to be involved in the discussion if these ditches should be cleaned.

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Appendices

6.4 *Appendix 1. Field form*

Fätblankett									
Datum:									
Område:	Beståndstyp:								
Objektsnr:	X:	Y:							
Dikesålder:	H.ö.h:								
Transekt:									
Dikesbredd:	Avst. Trädkant:								
Dikesdjup:	Vattendjup:								
Dikesfunktion:	Synligt vatten:								
		Provyta nr							
		a		b		c		d	
Markslag	1. Fastmark								
	2. Torvmark								
Jordart	1. Sediment m. hög sorteringsgrad								
	2. Sediment med låg sorteringsgrad								
	3. Morän								
	4. Häll								
	5. Torv								
Texturklass	1 Block								
	2 Sten								
	3. Grus								
	4. Sand								
	5. Mo (Can barely be roled)								
	6. Mjäla (Role 4-6 m								
	7. Ler (Role 1- 3 m)								
Markfuktighetsklass	1. Torr								
	2. frisk								
	3. Frisk- fuktig								
	4. Fuktig								
	5. Blöt								
Fältskikt:									
Fastmark	1. Högört utan ris								
	2. Högört m. blåbärsris								
	3. Högört m. ris								
	4 Lågört utan ris								
	5. Lågört m. blåbärsris								
	6. Lågört m. ris								
	7. Utan fältskikt								
	8. bred bladig grästyp								
	9. Smalbladig grästyp								
	10. Starr-fräkentyp								
	11. Blåbärstyp								
	12. Lingontyp								
	13. Kråkbär- ljungtyp								
	14. fattigristyp								
Torvmark	1. Högörtstyp								
	2. Lågörtstyp								
	3. Blåbär- fräkentyp								
	4. Högstarrtyp								
	5. Lingon- odon- skvattramtyp								
	6. Klotstarrtyp								
	7. Lågstartyp								
	8. Rosling- tranbärstyp								
Bottenskikt	1. Lavtyp								
	2. Lavrik vitmosstyp								
	3. Lavrik typ								
	4. Vitmosstyp (Sphagnum)								
	5. Sumpmosstyp (Björnmossor, Polytrichum)								
	Brunmossor (Drepanocladus, Scorpidium,								
	paludella, Calliergon, Tomentypnum, Campylium								
	6. Friskmosstyp (Vägg- hus och kvastmossa)								
Humustjocklek									
Torvdjup									
Moisture									
Diameter	1		T- G- B		T- G- B		T- G- B		T- G- B
	2		T- G- B		T- G- B		T- G- B		T- G- B
	3		T- G- B		T- G- B		T- G- B		T- G- B
	4		T- G- B		T- G- B		T- G- B		T- G- B
	5		T- G- B		T- G- B		T- G- B		T- G- B
	6		T- G- B		T- G- B		T- G- B		T- G- B
	7		T- G- B		T- G- B		T- G- B		T- G- B
	8		T- G- B		T- G- B		T- G- B		T- G- B
	9		T- G- B		T- G- B		T- G- B		T- G- B
	10		T- G- B		T- G- B		T- G- B		T- G- B
	11		T- G- B		T- G- B		T- G- B		T- G- B
	12		T- G- B		T- G- B		T- G- B		T- G- B
	13		T- G- B		T- G- B		T- G- B		T- G- B
	14		T- G- B		T- G- B		T- G- B		T- G- B
	15		T- G- B		T- G- B		T- G- B		T- G- B
	16		T- G- B		T- G- B		T- G- B		T- G- B
	17		T- G- B		T- G- B		T- G- B		T- G- B
	18		T- G- B		T- G- B		T- G- B		T- G- B
	19		T- G- B		T- G- B		T- G- B		T- G- B
	20		T- G- B		T- G- B		T- G- B		T- G- B
Höjd:									
Trädkärna:									

6.5 *Appendix 2. Table for number of releases*

Appendix 2. Number of trees showing major and moderate (*) release for each site and five year period. Values in parenthesis are the total number of sample trees existed during that five year period.

Site	1905	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985
6		2(3)					2(8)	3 (9)		1(9)						2(9)	3(9)
11																	
40						1(3)	2(3)	1 (3)				2 (5)	1(7)	1(9)			
89											2(9)				2(9)		
100																2(9)	
101		1(2)		1(2)	1(2)		1(3)		2(8)					4(9)			1(9)
4													1(8)	1(9)			
41				1(2)						1(7)		1(8)	2(8), 1(8)*	3(8), 1(8)*	1(8)		
44																	1(9)
8													2(9)				
43						1(1)					3(8)		1(9)	1(9)			
94						3(5)	1(7)						2(9)			1(9)	
15					1(1)								1(9)				
103					1(1)												
61							1(4)		1(7)				6(9)	1(9)			
85	1 (9)	3(9)		3(9)	4(9)	3(9)	1(9)										
104									1(6)			1(7)	2(8)				
90																	

6.6 Appendix 3. Table for length of releases and growth effect

Appendix 3. Probable drainage year and length of release and growth effect in years for each site.

Soil Type	Peat								Till									
CA	<0,4			0,4-1			1-2		<0,4			0,4-1			1-2			
Site	6	11	40	4	41	44	15	103	89	100	101	8	43	94	61	85	104	90
Year of drainage	0	*	1930	*	0	*	1925	1925	*	0	1965	*	*	1925	1960	1920	*	*
Length of release	0	*	18	*	0	*	9	9	*	0	14	*	*	14	12	19	*	*
Years of growth effect	0	*	60	*	0	*	40	40	*	0	30	*	*	20	10	20	*	*

*Sites where the sample trees were not old enough exist during the drainage.

6.7 Appendix 4. Table of statistical analysis using CA

Appendix 4 Statistical analysis of variance on the effect of soil type, CA and distance on different forest variables.

Model	Factor	df	F	P
Volume	Soil	1	7,65	0,017*
	CA	2	1,62	0,24
	Distance	3	2,52	0,06
	Soil*CA	2	0,07	0,93
	Soil* Distance	3	6,32	0,00046***
	CA* Distance	6	0,66	0,68
Density	Soil	1	0,06	0,81
	CA	2	2,48	0,13
	Distance	3	10,79	<0,0001***
	Soil*CA	2	0,19	0,83
	Soil* Distance	3	14,37	<0,0001***
	CA* Distance	6	0,51	0,80
Mean diameter	Soil	1	0,06	0,82
	CA	2	2,48	0,13
	Distance	3	10,79	<0,0001***
	Soil*CA	2	0,19	0,83
	Soil* Distance	3	14,37	<0,0001***
	CA* Distance	6	0,51	0,80
Soil moisture	Soil	1	0,02	0,88
	CA	2	0,71	0,51
	Distance	3	32,07	<0,0001***
	Soil*CA	2	0,48	0,63
	Soil* Distance	3	12,1	<0,0001***
	CA* Distance	6	1,3	0,26
Average humus depth	Soil	1	0,33	0,58
	CA	2	1,09	0,37
	Distance	3	20,93	<0,0001***
	Soil*CA	2	1,11	0,36
	Soil* Distance	3	1,66	0,18
	CA* Distance	6	3,06	0,0071**
Water flow	Soil	1	0,23	0,64
	CA	2	9,73	0,0031**
	Distance	3	1,23	0,30
	Soil*CA	2	2,16	0,16
	Soil* Distance	3	1,04	0,38
	CA* Distance	6	0,89	0,50
Plant diversity (Shannons index)	Soil	1	0,09	0,76
	CA	1	0,058	0,058
	Soil*CA	1	0,84	0,84

SENASTE UTGIVNA NUMMER

2016:2	Författare: Julia Mellåker Degradation and restoration method interact to affect the performance of planted seedlings in tropical rainforest restoration – evidence from plant functional traits
2016:3	Författare: Pia Sundvall Kväverikt spillvatten från sprängämnesproduktion – potentiell råvara i gödsel?
2016:4	Författare: Marcus Larsson Betydelsen av krukstorlek, odlingstäthet och planteringspunkt vid etablering och tillväxt hos täckrotsplantor – Analys av Jackpot & Powerpot
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