Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

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Using Tea Bag index to examine the effects of ditching in boreal peatlands

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Supervisor: Kristian Hassel
Co-supervisor: Marte Fandrem
June 2021

Høstadmyra, Trondheim

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Abstract

Peatlands suffer due to human interactions, often because of ditching. We studied how ditching impacts decomposition rate in the surrounding area through a transect study in a raised ombrotrophic bog in Trondheim municipality. The decomposition rate was studied using the Tea Bag index (TBI), a simple standardized litter bag study using manufactured tea bags. We also measured water table and determined the microstructures within the study site to understand the processes between ditching and decomposition rate. The subsidence was measured using LIDAR (Light Detection And Ranging) data. The distance effect of the ditch was analysed using a piecewise regression model to determine at what distances there was an effect of the ditch.
As expected, the water table was affected by the distance with a fast increasing water table mean within the first 15.99 m from the ditch. The subsidence had similar trends with steep slopes of the surface close to the ditch, then gentler slopes further away. However, the decomposition rate did not follow the same pattern as the water table and subsidence. The decomposition rate was decreasing with a gentle slope from the ditch, but it was not detected any breakpoints. At last, we found a correlation between the distance and the microstructures withing the bog, showing a greater occurrence of drier structures near the ditch, while wetter structures were found more frequent further away.
We found that the decomposition rate is affected by the ditch, though we could not find any clear correlations between the water table and the decomposition rate. The decomposition rate was increasing closer to the ditch. We conclude that the decomposition rate is changed by the ditch, but it might be altered through other factors than the water table. The water table might have a greater impact on the microstructures withing the peatland, which showed more similarities to the trends of the water table. For the TBI our results were different from what was reported earlier. We could not calculate the decomposition rate using the methods for the Tea Bag index, and the decomposition was higher than in other studies of TBI in peatlands.

Sammendrag

Menneskelige inngrep har ofte dårlige konsekvenser for myrer, som oftest grunnet grøfting. Vi har studert hvordan grøfting påvirker nedbrytningsraten i det nærliggende området gjennom et transekt studie i en ombrotrof høgmyr i Trondheim kommune. Tea Bag indeks, en standardisert metode for å måle nedbrytning gjennom ferdigproduserte te poser, ble benyttet for å bestemme nedbrytningsraten. Det ble gjort målinger av vannivået og mikrostrukturer ble bestemt i området for å forstå prosessene som styrer endringene i nedbrytningsraten grunnet grøfting. Nedsynkningen av myra ble målt gjennom LIDAR data. For å analysere effekten av grøften, ble det utført en piecewise regresjons modell for å tydeliggjøre hvor det var en effekt av grøfta.

Som forventet så var vannivået påvirket av avstanden til grøfta, og det var et raskt stigende vannivå de første 15.99 m fra grøfta. Nedsynkningen hadde en tilsvarende form, hvor det var rask stigning nærme grøfta, for så å flate ut lengre unna. Derimot fulgte ikke nedbrytningen det samme mønsteret som vannivået og nedsynkningen. Nedbrytningsraten sank desto lengre unna grøfta det ble målt, men det ble ikke målt noen bruddpunkt og endringer tilsvarende vannivået og nedsynkningen. Vi fant allikevel en sammenheng mellom mikrostrukturene og avstanden, da de tørrere strukturene var ofte nærme grøfta, mens de bløtere strukturene var ofte lengre unna.

Vi fant at nedbrytningen er påvirket av grøftingen, men vi fant ingen tydelig sammenheng mellom vannivået og nedbrytningen. Nedbrytningen blir høyere som følge av grøftingen, og effekten er sterkere nærmere grøfta. Vår konklusjon er at grøfta har en påvirkning på nedbrytning, muligens gjennom andre faktorer enn endringer i vannivået. Vi fant allikevel at vannivået har innvirkning på mikrostrukturer i myrene, som begge virket påvirket i samme grad av grøftingen. TBI resultatene våre hadde avvik fra hva som er funnet tidligere. Vi fikk ikke til å regne ut nedbrytningsraten ut ifra metodene for Tea Bag indeks, og vår nedbrytning var høyere enn det som var målt i andre myr studier med Tea Bag indeks.

Preface

The project started in June 2020 and lasted until June 2021. Since I am studying a teacher's degree, the project had to be worked on along other courses. The project has been very educational, and I am looking forward to use what I have learned when I am teaching my own students.

I am very thankful for the help, support and guidance provided by my supervisors Kristian Hassel and Marte Fandrem. I also want to thank Marte for letting me join her in the field on her own projects. At last, a thanks to the department of natural history at NTNU for lending me equipment and a workplace during the study.

Trondheim, June 1st, 2021

Torgeir Heldal

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List of Abbreviations

TBI	Tea Bag index
LIDAR	Light detection and ranging

Introduction

Low decomposition rates are among what defines mires and peatlands, as the accumulation of plant litter is higher than the decay, it is a production of peat substrate (Moen et al. 1999). Decomposition is the degeneration of plant litter that feed carbon back into the cycle as gasses or solutes (Laiho 2006). In peatlands these processes are haltered by high water table (Wiedermann et al. 2017), low pH (Rydin et al. 1999), and high refractory content of peatland litter (Moore and Basiliko 2006). The decomposition rate is also affected by conditions as the temperature, substrate, and moisture, which often is quite constant in peatlands (Clymo 1965). Human disturbance alters these conditions. Ditching and peat excavation lowers the water table, and the increased oxygen accelerates the degeneration of plant litter and thus the release of carbon from the ecosystem back into the carbon cycle (Lucchese et al. 2010; Turetsky and Louis 2006). Decomposition rate can be measured with litter bags (Moore and Basiliko 2006; Clymo 1965). The method involves buried bags of plant litter, for which subsets are often retrieved on a yearly basis after burial. The aim is to get the decomposition rate (k) for the exponential decay pattern ae^{kt} (where a is the start weight, and t represents time).This method inhibits larger detrivores from entering the mesh bags and the rate will only reflect the microbial decomposition (Vitt and Wieder 2006). The bags must be buried over a long period, at least two years, to get a decomposition plot where the curve is stable (Moore and Basiliko 2006). Litter bag studies can also be hard to compare between projects because of the use of local litter which may have different plants, microorganisms, or other soil conditions. In peatland *Sphagnum* is mostly used in these studies, but due to the acidic composition of *Sphagnum* the decomposition rate is low compared to other kinds of litter (Verhoeven and Toth 1995). Keuskamp et al. (2013) developed a new and quicker method called the Tea Bag index (TBI) which uses two kinds of Lipton tea (green- and rooibos tea) and calculates the decomposition rate after 90 days of being buried (Keuskamp et al. 2013). The use of similar litter, here commercially produced tea bags, could give a more comparable result across studies. The Tea Bag index gives a higher value of k than the traditional litter bag method, still they are correlated and can be used to describe the same processes (Didion et al. 2016; MacDonald et al. 2018). In peatlands the loss of plant litter is less than for example deciduous forests (Moore and Basiliko 2006), though as seen in Macdonald et al. (2018) the TBI can still be used to describe different decay patterns in peatland.

Ditching and lowering of the water table have been used to desiccate peatlands for: forestry, agriculture, and peat excavation (Rivedal 2020; Taylor et al. 2018). The most rapid change in water table happens within 10-20 meters from the ditch (Prevost et al. 1997), though it is expected a change in water table over 60 meters from the ditch (Landry and Rochefort 2012). However, ditching has been observed to affect the environment through altered water table in the peat up to 320 meters from the ditch (Paal et al. 2016). The drainage can have an impact on the topography of the surrounding peatland. The ditch gets wider by the compression and consolidation of nearby peat through the loss of water to the ditch (Lindsay et al. 2014). The compression and shrinkage of the peat have a large effect in the mire, and the peatland will subside at high rates after ditching (Eggelsmann 1984; Wösten et al. 1997). The subsidence rate is high in the first decades, which the peat can subside several meters, but different case studies show that after some time the subsidence stabilises at 3-20 mm/year (Wösten et al. 1997; Zanello et al. 2011). Even though the subsidence gets more stable, it will only stop by restoration of the acrotelm (Lucchese et al. 2010). The process of ditching changes the carbon balance of the peatland, which shifts the peatland from a carbon-sink to a carbon-source (Lindsay et al. 2014; Thom et al. 2014).

Few studies have examined the effect of lowering the water table on the decomposition rate in peatland (Laiho 2006). The drainage increases aeration which modifies the microbial content of the peat for a higher decomposition rate (Landry and Rochefort 2012; Minkkinen et al. 1999; Holden et al. 2003). At the same time decreased temperature and lowered pH retards the decay process in the peat (Minkkinen et al. 1999; Harris et al. 2020). The impact of drainage on decomposition rate is more protruding deeper in the peat, while the effect is lower below the surface in the acrotelm (Prevost et al. 1997; Wiedermann et al. 2017). Freeman et al. (1996) found that drought increased the mineralisation in peatland, while a more recent study by Harris et al. (2020) found no clear effect of drainage on the decomposition rate. The drainage also has an impact on the species distribution, which may further affect the decomposition rate (Strakova et al. 2012; Harris et al. 2020). *Sphagnum* needs a high water table to maintain growth (Kozlov et al. 2016), while sedges and shrubs thrive in the peatland when the water table is lowered (Gatis et al. 2016; Artz et al. 2014). A descending water table can be expected to give a shift in species composition from a *Sphagnum* dominated mire to a shrubland or even forest (Colomer et al. 2019).

The peatland often consists of different microstructures and elements (Rydin et al. 1999). The microstructures have different conditions in terms of water table and species distribution. The hummocks have low water table and consist of recalcitrant species like *S. fuscum* and *Calluna vulgaris*. Dry hummocks can be dominated by trees and shrubs and are shifting toward forest like environments (Gatis et al. 2016; Grygoruk et al. 2014). The hollows are low lying spots with high water table and at times even flooded. They have more easy decomposable species like *S. cuspidatum* and *S. tenellum.* Hollows can further be divided into lawns, carpets, and mud-bottoms (Rydin et al. 1999). Lawns are harder flat structures, with more sedges and more compact *Sphagnum* species. Carpets are less dense, and the feet sinks when walking there. Mud-bottom often have bare peat, and the vegetation are scattered in these structures, both carpets and mud-bottoms are often inundated. The hollows have fast growing, though more decomposable species. Opposed to the hollows, the hummock species degrade slower, but allocate less of the available resources to growth (Rydin et al. 1999; Turetsky et al. 2008). A lowering of the water table can result in an encroachment of vascular species, especially for the hummocks, where the water table is already low (Grygoruk et al. 2014). Grygoruk et al. (2014) presented a theory that a mean water table 30 cm below surface enables good conditions for shrubs, while Holmgren et al. (2015) presented a mean of 40 cm to be enough for *Pinus sylvestris* seedlings. *Ericaceae* thrive in conditions with water table between 30-45 cm, which supports the theory (Potvin et al. 2015). A high evapotranspiration among the vascular species contributes to further lowering the water table, and contributes to a shift in the peatland environment (Grygoruk et al. 2014).

Aims

The aim for this study is to better understand the impact of creating a ditch in peatlands. The theory state that the ditch dries the peat by removing the water, by lowering the water table of the surrounding peat (Lindsay et al. 2014). The lowering of water table will lead to an increased decomposition rate (Moore et al. 2007). It is hypothesized that the proximity to the ditch will affect the decomposition rate in a *Sphagnum* dominated peatlands. We explore how the ditch impact the decomposition rate at increasing distances from the ditch, as well as the correlation between the water table and decomposition rate. The microstructures might be affected by the distance from the ditch, thus following the same pattern as the water table and decomposition rate. By comparing two ditches of different age, we further investigate how the age of the ditch affects the decomposition rate and water table.

Methods

Study site

The study was conducted at Høstadmyra [63.403,10.107], South East in Trondheim municipality, Norway (Figure 1). The peatland is 1.5 km^2 and can mainly be classified as a raised bog, though parts of it can be classified as plateau bog (Lyngstad et al. 2017). The peat layer was deeper than 3 meters where the measurements where conducted. However, the deepest parts in the middle of the bog had nearly 5 meter deep peat, but the bog is shallower with only 1 meter deep peat in the west and other parts of the lagg zone (Lyngstad et al. 2017). The peatland has been impacted by human disturbances like peat harvest, artificial drainage, and parts of it drained for farming fields, but much of the peatland remains. It is two large ditches in the bog. The old ditch (OD) lies in the middle of the mire, it is 900 meters long and is expected to have been there at least 140 years. The new ditch (ND) leads into the old ditch. It is 500 meters long and was dug around 1970 and is 50 years old. It can be observed that the ND is narrower than OD. The study was conducted in the southern end of the mire, including both the old and the new ditch (Figure 2).

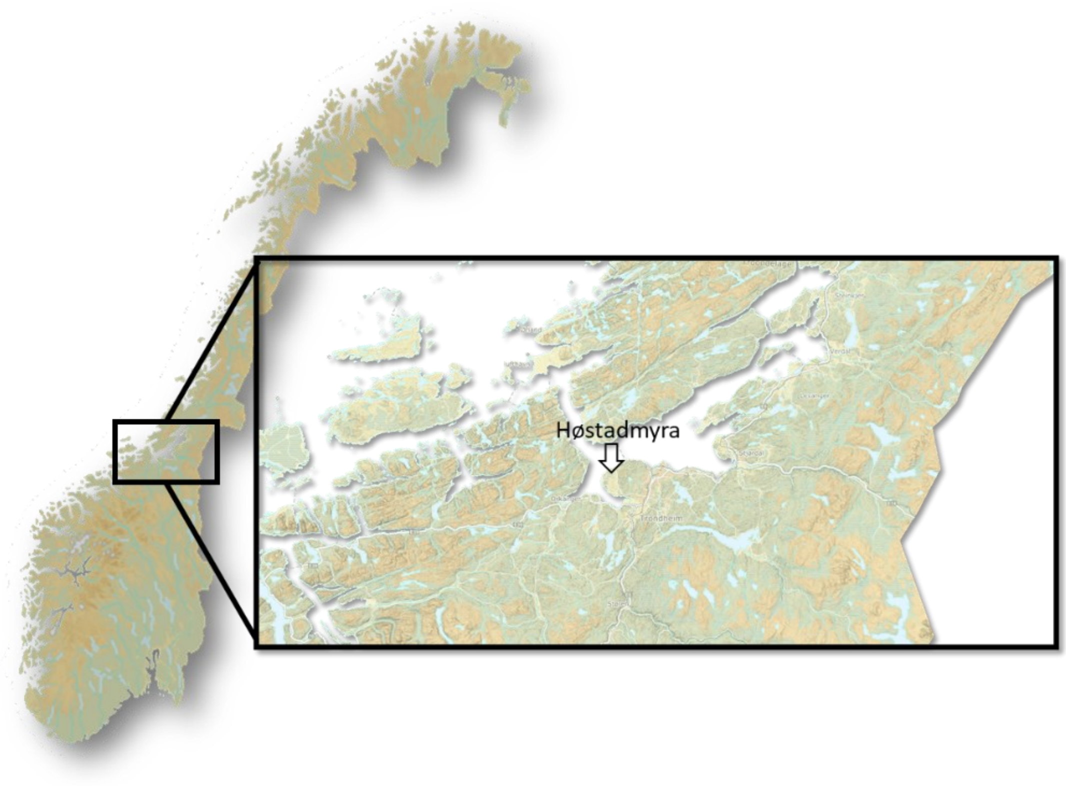

Figure 1: The study site located at Høstadmyra [63.403,10.107] east of Trondheim. See Figure 2 for an aerial photo of the study site.

Decomposition transects

The decomposition rate was determined using the Tea Bag Index, and we followed the protocol of Keuskamp et al. (2013). The bags were buried along transects perpendicular to the two ditches (Figure 2). The bags were placed 8 cm below active surface layer with approximately 50 cm between the green tea- and rooibos tea bag, and at the distances 0, 2.5, 5, 7.5, 10, 12.5, 15, 20, 30, 40 and 50 m away from the ditch. Five transects were used at each ditch, which allowed for 50 meters between the transects at ND, and 75 meters between the transects at OD. This gave 110 bags of each type of tea. The bags were buried July 1st and 2nd, and retrieved 89-90 days later, on September 30th and October 1st.

The species and microstructure were registered at each plot. The microstructures on the site were studied and classified according to the structures described in the introduction. Another microstructure was found in the drier parts of the mire, being drier than the hummocks and less protruding from the environment. We classify this as forest floor vegetation, since it consists of woody shrubs and heather (e.g., *Calluna vulgaris, Myrica gale, Empetrum nigrum),* and the ground was harder and different from the microstructures in the rest of the bog. The categories for microstructures resulted in high hummock, low hummock, lawn, carpet, mud-bottoms, and forest floor. The mud-bottoms consisted of areas with bare peat, though some loose bog species could be found there (e.g., *Sphagnum cuspidatum*). To determine the water table, a small hole was made using a long pole, the hole was left to fill up with water for at least 10 minutes before measuring. The distance from the surface to the water table was measured using a 60 cm long gardening stick, and a tape measure. The water tables were measured at each burial site and taken three times (July, September, and October). With the equipment, the maximum measurable depth was 60 cm, but only 8 of the 330 measurements was deeper.

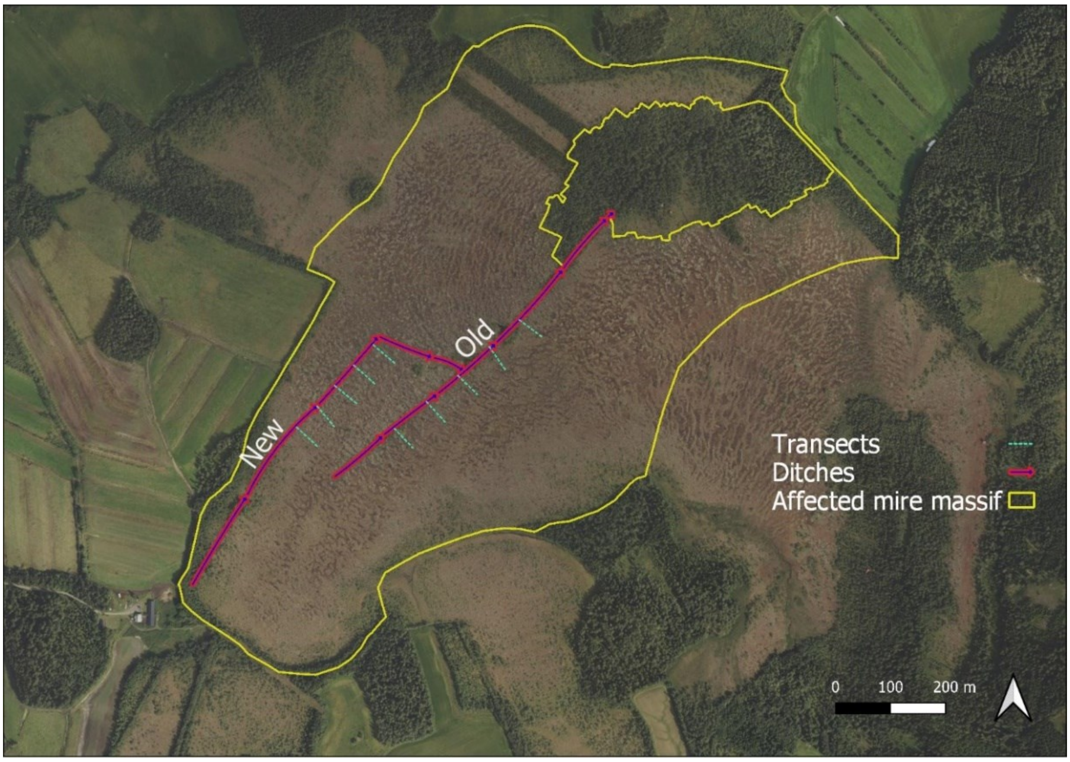

Figure 2: The transects (blue dashed lines) were placed perpendicular from the ditches (pink line). The experiment was conducted along these lines.

Weighing

The tea bag was marked, and then weighed before the experiment at 3 decimals (0.000 g) accuracy. Prior to the experiment each whole tea bag was weighed. The weight of the string, label and bag was later subtracted to get the weight of the content. After 90 days of burial the bags where dried [60°C, 72 hours] and the content weighed. The bags were brushed lightly to avoid excess debris from the peat.

LIDAR height data

The subsidence of the bog was analysed by examining the height of the bog in comparison to the ditch, assuming the surface had been level across the peatland in the affected area before drainage (Lindsay et al. 2014). Within the same area as the field transects, 20 transects of 90 meters length (10 new, and 10 old) was created with height analysing LIDAR tools at hoydedata.no.

Data analysis

The data analysis was done on two different data sets, one for the field experiment and one for the LIDAR data. Both data sets were organized into tidy format, where the columns represent variable, rows are an observed plot, and the cells are single values (Wickham 2014). The calculations provided by Keuskamp et al. (2013) was conducted directly in the given data sheet in excel. Analysis was completed in r v2.11 (R Development Core Team, 2010). All the models presented in this paper was made in the ggplot2 package (Wickham et al. 2016). To determine the correlation between different data the corrplot package was used (Wei et al. 2017).

Height data and subsidence

The height of the bog, retrieved from hoydedata.no, was normalized against the deepest part of the ditch. The height was analysed using a regression model in the glmmTMB package in r (Magnusson et al. 2017). The models depicted normalized height as a function of distance, blocking for the age of the ditch. The mean of the different distances was analysed using a breakpoint analysis with the segmented package (Muggeo and Muggeo 2017).

Water table

A correlation analysis was conducted between the fluctuations and the mean of the water table, which showed a high correlation between those. The mean of the three measurements of water table was then chosen as a representation of the water table. The water table was analysed using different regression models in glmmTMB (Magnusson et al. 2017). The most unfitting models were excluded using AIC (Akaike 1974), which suggested a second-degree regression model without the random effect of the transects and blocking for the age of the ditch. This made sense since the effect of the age proved insignificant ($p=0.85$). As the second-degree regression line seemed unfit due to the data looking more asymptotic, a linear segmented model was analysed using AIC again. The segmented model gave lower values for the AIC and was further used in the analysis (Muggeo and Muggeo 2017). A breakpoint analysis, similar as for the height data, was conducted for the model of water table.

Tea Bag index and decomposition rate

The decomposition rate could not be calculated for 69 of the 110 plots. Therefore, as a measurement of the decomposition rate, the percentile weight loss of the tea bags was used in the data analysis. The decomposition rates relation to the distance was also analysed in a linear regression model and a segmented analysis. The age of the ditch was also not significant enough and removed from the final model ($p=0.09$ for green tea, and $p=0.16$ for rooibos tea). The breakpoint analysis did not provide any clear breakpoints, but the segmented linear model was still used, since it has been applied on the other measurements.

Microstructures

The microstructures were analysed against the distance and mean water table using a linear regression model in glmmTMB (Magnusson et al. 2017), where the most likely model was retrieved using AIC (Muggeo and Muggeo 2017).

Results

Subsidence

The impact on the subsidence of the bog (Figure 3) shows that the old ditch has a longer range and have dug deeper than the new ditch. While the highest point of the surface near the new ditch is 0.80 m higher than the lowest level of the ditch, the old ditch is 1.62 m above the lowest level of the ditch at the same point (41.5 m from the ditch) and still increasing. The new ditch has a steep slope (0.178 m/m) the first 3.3 meter, while the slope is gentler (0.006 m/m) until it reaches 41.5 meter. After the second breakpoint, the slope is decreasing (-0.004 m/m). This might be an interference by the old ditch, since the transects are in the area between the two ditches. The old ditch follows the same pattern, with a steep slope (0.166 m/m) the first 6.1 meters. The slope is gentler (0.024 m/m) until the next breakpoint at 27.0 meters. The slope is then slightly increasing (0.006 m/m) further into the terrain and not fully levelling out within the measured distance from the ditch.

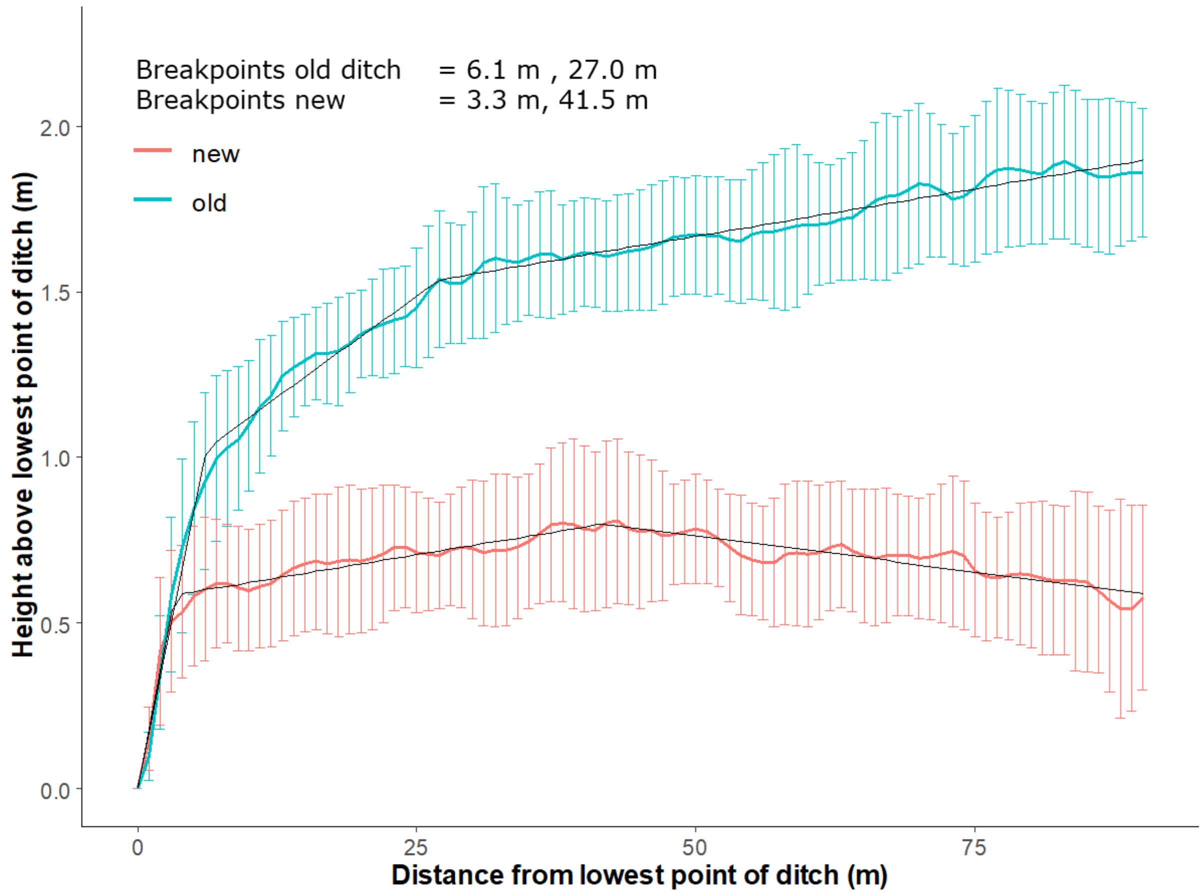

Figure 3: The normalized height above the lowest point of the ditch. The blue is the old ditch, and the red is the new ditch. The regression lines are added by a breakpoint analysis, and the breakpoints are at 3.7 m and 42.5 m from the new ditch, and at 6.2 m and 24.4 m from the old ditch. The data is gathered from LIDAR data available at hoydedata.no

Water table

The breakpoint analysis of the water table shows a clear shift after 15.99 m (SE 4.22 m). The first 16 meters have a clear slope of 0.95 cm/m, though the spread of the datapoints is higher at this part of the figure (Figure 4). After this the water table seems to stabilize with a slope of 0 cm/m. From 15 m from the ditch the measurements have a higher distance between them since it was expected a less impact from the ditch at these distances. The mean distance to the water table is 20.0 cm before the breakpoint, and it is 12.1 cm after the breakpoint.

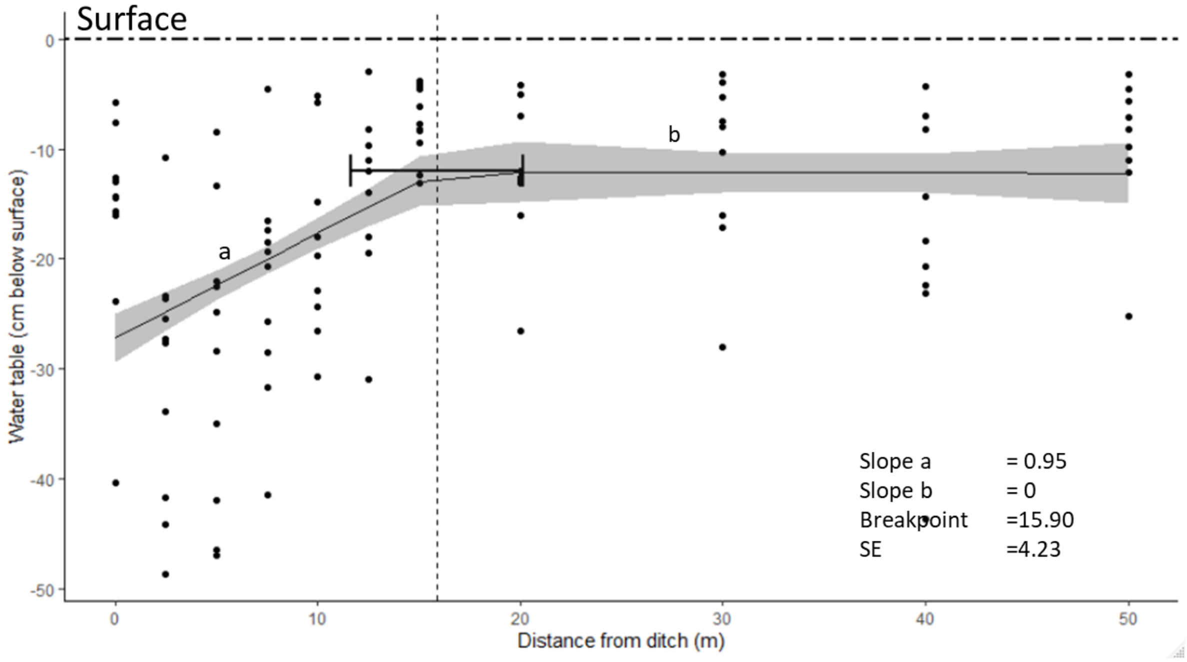

Figure 4: The water table in relation to the distance from the ditch. The water table is shown as cm below the surface (thick dashed line). A breakpoint was determined at 15.90 meter. The first slope had an increasing slope of 0.95 cm/m, while after the breakpoint the slope was determined as 0 cm/m.

Microstructures

The different microstructures showed a clear relation with distance from the ditches. The hummocks could be found at all the distances from the ditches and did not correlate with distance. The same result was found for the lawns, though the carpets were only observed further away from the ditch with a mean value of 28.2 m from the ditch. The mud-bottoms had a similar trend with the mean distance at 25.9 m from the ditch. The forest floor microstructure was only found closer to the ditch, with a mean of 2.5 m. The distribution of the microstructures can be seen in the boxplot (Figure 5). The relation between distance and microstructure is significant for the forest floor (p=0.0326), carpet (p=0.0412) and mud-bottom (p=0.0240). The age of the ditch did not interact with the distance effect on the microstructure (p=0.48). Still, there were some observable differences, as it was not detected any forest floor microstructures along the new ditch transects. The water table had significant correlations with all the microstructures.

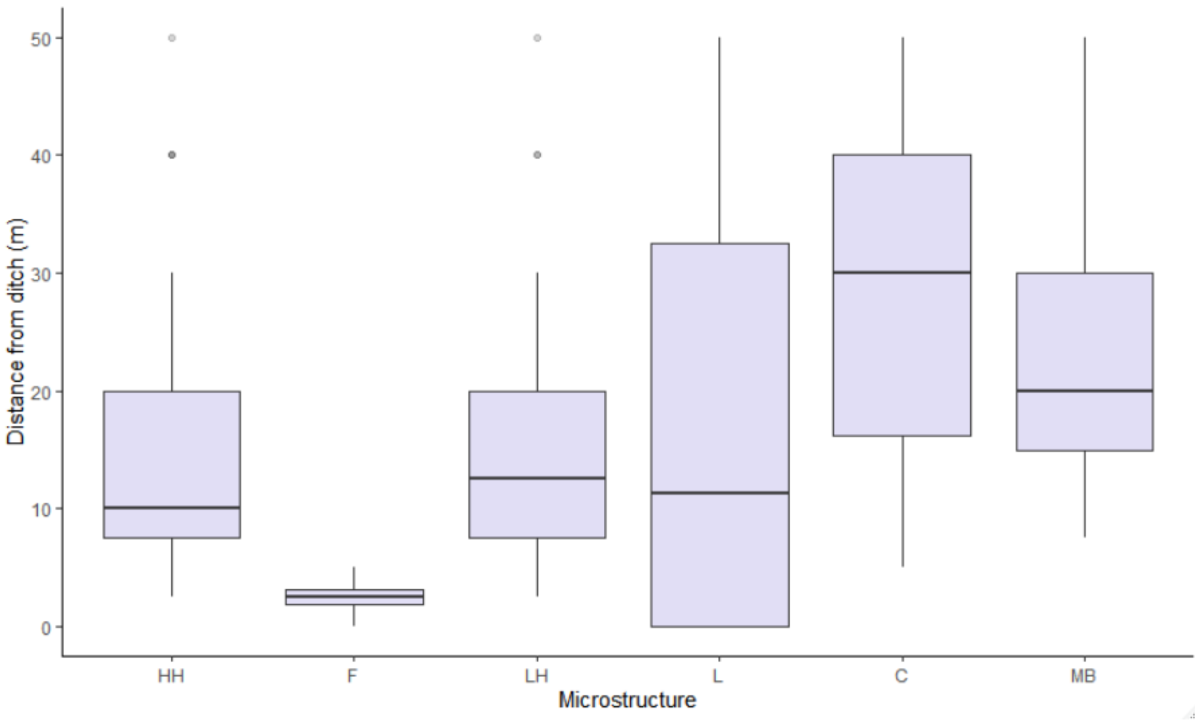

Figure 5: The microstructure at different distances from the ditches. (HH – High hummock, F- forest floor, LH – low hummock, L – Lawn, C – Carpet, MB – Mud-Bottom)

Decomposition

The green tea bags had lost from 48.0-85.4% of its original weight after the experiment, with a mean of 62.0% (SE=0.7). This was higher than the rooibos tea bags, which had only lost 18.1-44.1% of its original weight, with a mean of 38.6% (SE=0.3). This difference in weight loss was expected, but rooibos tea had greater weight loss than reported in MacDonald et al. (2018) with respectively 69.1% and 29.5% for the green- and rooibos tea. Because of the high weight loss of rooibos tea, it was not possible to calculate the decomposition rate by the formulas provided by Keuskamp et al. (2013). The model for the decomposition showed no difference between the new and the old ditch, neither for the rooibos tea nor the green tea. The age of the ditch was therefore excluded from the final model (Figure 6, Figure 7). Neither the green nor the rooibos tea showed any breakpoints in the analysis. The decomposition had a slightly decreasing slope for both tea types. The graph shows a steady weight loss at all the distances from the ditch for the green tea (Figure 6), and the effect of distance on the weight loss is unsignificant. (p=0.594). For the rooibos tea the graph (Figure 7) shows a decreasing weight loss further away from the ditch (0.065%/m) with a significant effect of distance on the weight loss (p=0.001).

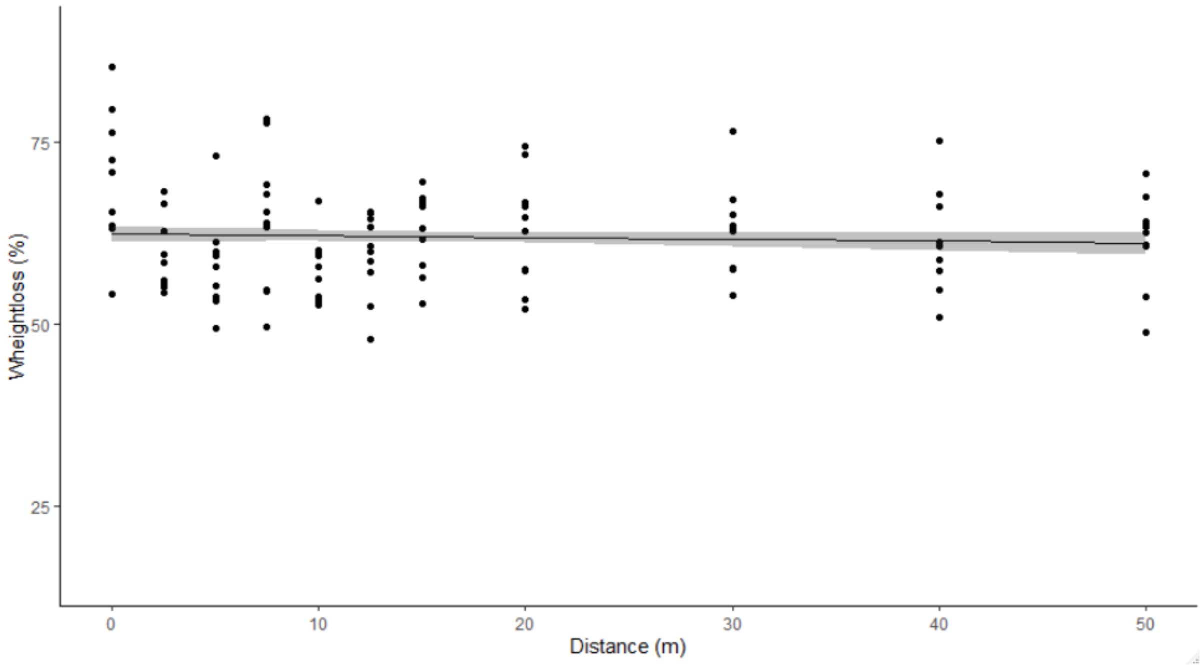

Figure 6: The effect of distance from the ditches on the weight loss of green tea.

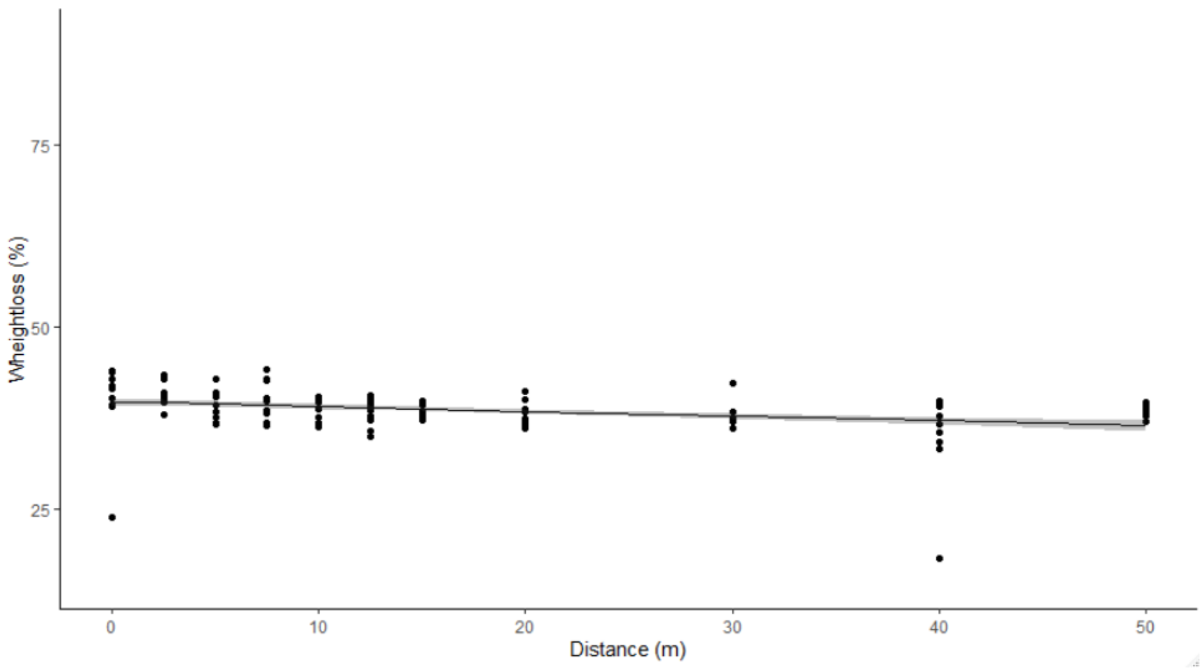

Figure 7: The effect of distance from the ditches on the weight loss of rooibos tea.

Discussion

In this study we wanted to find the impact of ditching on the decomposition rate of peat. We hypothesised that the decomposition rate would be closely correlated with the water table, and that the trends of subsidence would follow from the water table and decomposition rate. We could not calculate the decomposition rate using the calculations provided by Keuskamp et al. (2013). This could be explained by that the tea bags had decomposed too much. Weight loss values found earlier in another peatland study was lower for the rooibos tea (29.5%) (MacDonald et al. 2018), which implies that our tea bags have been in the soil too long. We therefore used percentile weight loss of the tea bag content as measurement for decomposition rate instead (e.g., Prevost et al. (1997); Cornelissen and Thompson (1997)). The distance from the ditch showed no significant effect on the decomposition of green tea, but a significant decrease in decomposition was seen in the rooibos tea. This suggests that the decomposition rate is increasing because of the ditching, and with a higher impact closer to the ditch. The impact of the ditches on subsidence of the peat surface could be divided into clear breakpoints at several distances from the ditches: first at a short distance from the ditches, 3.3 m from the new ditch, and 6.1 m from the old, then again further away from the ditches, 41.5 m, and 27.0 m for the new and old ditch, respectively. A breakpoint could also be found for the effect of the ditches on the water table, where the breakpoint is at 15.9 m from the ditch. After approximately 16 m distance from the ditches, we found no effect on the water table. Even though the water table seemed fixed at this distance, the relative height of the peat surface was increasing, suggesting a subsidence effect even further away from the ditch. We observed a 0.82 m difference of the two ditches at 41.5 m from the ditch. This could indicate that water table is affected by the ditch further than the break point suggests. Also, the microstructures had a correlation with the distance to the ditch. The structures dependent on a high water table like carpets and mud-bottoms were only found at long distances from the ditch. The opposite was true for the forest floor vegetation, that was found at close distance from the ditch. Structures less dependent on a high water table like the hummocks and lawns were found at all distances. This supports earlier encroachment studies, where a lowering of the water table leads to establishment of herbaceous species (Grygoruk et al. 2014).

Effect of ditching on the decomposition rate

The effect of ditching on the decomposition of green tea was not significant. This suggests that the ditch have no clear effect on the decomposition rate even if the water table is lowered because of the ditch. We expected an effect on the decomposition rate with a lowering of water table, as other studies have found this earlier (Freeman et al. 1996; Holden et al. 2003), and that increased aeration should increase aerobe respiration. Keuskamp et al. (2013) presents the need for a more labile and a recalcitrant litter bag to be used in the same experiment, in that study the green tea reached a stable weight after approximately 60 days of being buried. It is expected a lower decomposition rate in *Sphagnum* peatland than in deciduous forests. Even though, in our experiment the green and rooibos tea had higher decomposition than MacDonald et al. (2018). Therefore, the green tea should have reached its limit weight within the 90 days we conducted the experiment. Since the labile content of the green tea should be completely degraded, it is not unexpected that the decomposition of green tea is unaffected by the distance from the ditch. Therefore, we think that the decomposition of rooibos tea is better at determine the effect of the ditch on the decomposition rate.

The rooibos tea showed a slight increase in decomposition with proximity to the ditch. As hypothesized the ditch affect the decomposition rate, and the distant areas from the ditch have lower decomposition rate. Since the green tea is expected to have reached its limit value, and the effect of ditching on green tea is inconclusive, the green tea cannot describe the effect of ditching on decomposition rate. The rooibos tea could still be used as a measurement of the decomposition rate, and the result of the decomposition rate is more reliable since the rooibos tea should not be completely decomposed in the timeframe of this experiment. Even though the weight loss is higher than reported in MacDonald et al. (2018), the effect of the ditch on decomposition of rooibos tea was significant, which it should not be if the decomposition of rooibos tea had reached the limit value. We conclude that the ditch affects the decomposition rate negatively with increasing distance from the ditch.

Even though the slope of the decomposition of rooibos decreases further away from the ditch, it does not follow the trends of the subsidence and water table closely. Holden et al. (2003) presents theories that pH and temperature within the soil might prevent sufficient microbial activity in the soil. This would explain why the lowered water table do not affect the decomposition rate. The pH in a *Sphagnum* dominated bog is low, and unfavourable for many microbes, and Høstadmyra is mostly dominated by *Sphagnum.* The pH was not measured in this experiment, but it might be a factor which also is affected by the ditching. Minkkinen et al. (1999) found that ditching lead to a decrease of the pH in the upper layer of the peat. Still in our experiment the rooibos tea showed higher decomposition within the period of 90 days than expected. A low pH would promote low decomposition of the rooibos tea, and therefore does not support the pH to be the leading factor for the trends in decomposition rate.

The water table mean was at 12.1 cm below the surface after the breakpoint which is lower than the buried tea bags at 8 cm. This suggests that the observed effect of the drainage might be deeper in the soil than we have measured. The effect of water table on decomposition rate have earlier been reported to be stronger deeper in the peat, approximately 30 cm (Prevost et al. 1997). If the effect of the drainage is more prominent deeper in the soil, it could explain why the decomposition of the tea is quite stable when the experiment was conducted only 8 cm below the surface and does not have clear breakpoints like the subsidence and the water table. Since the water table does not have an impact on the decomposition rate in the top layer of the soil, it is unknown how the effect of distance on the decomposition rate is mediated.

The transects from the new ditch leads toward the old ditch, it is expected that the old ditch may have some confounding impact on the effect of the new ditch. The second breakpoint in the subsidence data of the new ditch might be a result of this, as the slope decreases after the breakpoint. This also suggests that it is only one breakpoint in the new ditch data related to the subsidence. The ditches might be too old to get a clear effect of aging of the ditch on the decomposition rate. Wösten et al. (1997) concludes that the subsidence rate stabilises at a low rate after a few decades, though this depends a lot on the water table, and the rate might be higher in drier areas (Zanello et al. 2011). This could explain why there is no difference between the ages of the ditch, except for the subsidence of the peatland. The results from our study does not suggest an effect of microstructures on the decomposition rate. The water table within hollow structures are higher, which should give more anoxic conditions. The hummocks have lower water table, and it could be expected more decomposition there. The tea bags could be affected by the local species within the bog. Verhoeven and Toth (1995) found that the *Sphagnum* species not only is reluctant to decompose, but it prevents other litter from decomposing. This is an unlikely explanation since the decomposition of the tea bags was higher than expected. Therefore, the decomposition of tea bags showed little evidence of being suppressed by the adjacent *Sphagnum*, and the effect of microstructures are unlikely.

Ditching lowers the water table

The water table showed similar trends as the subsidence of the mire. We expected a high influence on the water table in the proximity of the ditch. The water table had a breakpoint at 15.90 m, which is 10-12 m after the first breakpoints found for the effect on subsidence. Paal et al. (2016) and Prevost et al. (1997) refers to similar distances, and a rapid change in water table the first 15-20 m. This suggests a primary impact of the ditch, where the water table is drawn into the ditch with horizontal flow. Further away the water table does not change, and therefore the bog is seemingly unaffected by the ditch at these distances. Still, we observe an effect of subsidence further away from the ditch. The old ditch has subsided more than the newer ditch, and the effect can be observed at least at the distance of 41.5 m, which is the highest parts of the new ditch. This suggests an effect of subsidence further away from the ditch. The peat subsides due to consolidation, compression, and mineralization (Eggelsmann 1984). Since we did not find any effect of the water table further than 15.99 m, the subsidence might be more affected by mineralization through decomposition at these distances. The decomposition rate is slowly decreasing from the ditch, and the peat surface is also slowly increasing away from the ditch, though the slope of the decomposition is lower than the slope of the subsidence. We did fewer measurements after 15 m from the ditch, which gives less certainty for the effect of the ditch. It might be possible that the water table mean is slightly increasing further away from the ditch, but it wasn't detected in our study, which can explain why the further distances from the ditch have subsided as well.

The ditch had significant effect on some of the microstructures. In Figure 5 the microstructures show a shift around the water table breakpoint. The drier structures, hummocks and lawns are found closer to the ditch. Further away than the breakpoint at 15.9 m mud-bottoms and carpets are more dominant. Other studies show similar results, as the lowering of water table results in a shift to more drier species (Gatis et al. 2016). This effect is especially strong close to the ditch, where the microstructures is classified as forest floor vegetation. Since the forest floor only was observed on the old ditch site the new ditch might be too young for the forest floor vegetation to establish yet. The forest floor is close to the first breakpoint of the old ditch, where the subsidence has the highest slope. This suggest that the edge of the ditch have changed to a forest structure. Grygoruk et al. (2014) and Holmgren et al. (2015) presented numbers of water tables 30 and 40 cm below the surface to be sufficient for shrubs and trees to establish. We would then expect a change in the environment closely to the ditch. The microstructure changed significantly with the water table. This suggests that microstructure could be altered by the water table, and then is prone to water table changes due to ditching.

Conclusion

We found a negative interaction between decomposition rate and increasing distance from the ditch in Høstadmyra. The decomposition rate is higher closer to the ditch, though we could not determine what factors caused this interaction as the water table seemed to not influence the decomposition rate. The water table and subsidence of peat showed clear effects of the distance from the ditch. The first 15.99 meters from the ditch had greatest effect on the water table. We did not find an effect of the age of the ditch, though this might be because both ditches are too old to find a clear difference between them. We also found an effect of the distance from the ditch on the occurrence of different microstructures.

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Appendices

Appendix 1: Model outputs from data analysis in r.

<table>
<tr><th>Model:</th><th>Summary output:</th></tr>
<tr><td>Normalized height ~ Distance from ditch + Age + (1| Transect)</td><td>Family: gaussian (identity)
Formula:
heightdata$Height_normalized ~ heightdata$Distance + heightdata$Ditch_id +
(1 | heightdata$Transect_id)
AIC BIC logLik deviance df.resid
77.8 105.3 -33.9 67.8 1815
Random effects:
Conditional model:
Groups Name Variance Std.Dev.
heightdata$Transect_id (Intercept) 0.02743 0.1656
Residual 0.05830 0.2415
Number of obs: 1820, groups: heightdata$Transect_id, 20
Dispersion estimate for gaussian family (sigma^2): 0.0583
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) 0.3840417 0.0538649 7.13 1.01e-12 ***
heightdata$Distance 0.0064458 0.0002155 29.92 < 2e-16 ***
heightdata$Ditch_idold 0.8520246 0.0749323 11.37 < 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1</td></tr>
<tr><td>Segmented model old ditch:

Mean height ~ Distance</td><td>***Regression Model with Segmented Relationship(s)***
Call:
segmented.glm(obj = mymod, seg.Z = ~subdistance, psi = list(subdistance = c(10, 40)))
Estimated Break-Point(s):
Est. St.Err
psi1.subdistance 6.124 0.176
psi2.subdistance 27.040 0.795
Meaningful coefficients of the linear terms:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.005933 0.020493 0.289 0.773
subdistance 0.166471 0.005684 29.288 <2e-16 ***
U1.subdistance -0.142092 0.005786 -24.557 NA
U2.subdistance -0.018664 0.001104 -16.910 NA

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for gaussian family taken to be 0.0009045718)
Null deviance: 12.770252 on 90 degrees of freedom
Residual deviance: 0.076889 on 85 degrees of freedom
AIC: -371.69
Convergence attained in 7 iter. (rel. change 1.9614e-15)</td></tr>
<tr><td>Segmented model new ditch:

Mean height ~ Distance</td><td>***Regression Model with Segmented Relationship(s)***
Call:
segmented.lm(obj = mymod, seg.Z = ~subdistance, psi = list(subdistance = c(10, 40)))
Estimated Break-Point(s):
Est. St.Err
psi1.subdistance 3.276 0.141</td></tr>
</table>

	psi2.subdistance 41.493 1.074 Meaningful coefficients of the linear terms: Estimate Std. Error t value Pr(>|t|) (Intercept) 0.0007940 0.0205073 0.039 0.969 subdistance 0.1782990 0.0109616 16.266 <2e-16 *** U1.subdistance -0.1727190 0.0109676 -15.748 NA U2.subdistance -0.0098671 0.0004391 -22.473 NA --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Residual standard error: 0.02451 on 85 degrees of freedom Multiple R-Squared: 0.9582, Adjusted R-squared: 0.9557 Convergence attained in 3 iter. (rel. change 5.4201e-15)
Decomposition Weightloss (%, GT) ~ Distance + Age + (1|Transect)	Family: gaussian (identity) Formula: WeightLossPercentageGT ~ Distance + Ditch_id + (1 | Transect_id) Data: Decompdata AIC BIC logLik deviance df.resid 760.5 774.0 -375.2 750.5 108 Random effects: Conditional model: Groups Name Variance Std.Dev. Transect_id (Intercept) 1.364e-07 0.0003693 Residual 5.494e+01 7.4121000 Number of obs: 110, groups: Transect_id, 10 Dispersion estimate for gaussian family (sigma^2): 54.9 Conditional model: Estimate Std. Error z value Pr(>|z|) (Intercept) 61.25562 1.28297 47.75 <2e-16 *** Distance -0.02480 0.04597 -0.54 0.590 Ditch_idold 2.41887 1.41343 1.71 0.087 . --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Decomposition Weightloss (%, GT) ~ Distance + Age	Call: glm(formula = WeightLossPercentageGT ~ Distance + Ditch_id, data = Decompdata) Deviance Residuals: Min 1Q Median 3Q Max -14.0419 -5.5608 -0.3429 4.1447 24.1684 Coefficients: Estimate Std. Error t value Pr(>|t|) (Intercept) 61.25562 1.28297 47.745 <2e-16 *** Distance -0.02480 0.04597 -0.540 0.5907 Ditch_idold 2.41887 1.41343 1.711 0.0899 . --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 (Dispersion parameter for gaussian family taken to be 54.93919) Null deviance: 6055.4 on 109 degrees of freedom Residual deviance: 5878.5 on 107 degrees of freedom AIC: 757.81 Number of Fisher Scoring iterations: 2
Water table Mean WT ~ Distance + Distance^2 + Age + (1|Transect)	Family: gaussian (identity) Formula: WT_mean ~ Distance + Distance2 + Ditch_id + (1 | Transect_id) Data: Decompdata AIC BIC logLik deviance df.resid 838.2 854.4 -413.1 826.2 104 Random effects: Conditional model: Groups Name Variance Std.Dev. Transect_id (Intercept) 3.494e-07 5.911e-04 Residual 1.070e+02 1.034e+01

<table>
<tr><td></td><td>Number of obs: 110, groups: Transect_id, 10
Dispersion estimate for gaussian family (sigma^2): 107
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) 25.745574 2.306247 11.163 < 2e-16 ***
Distance -0.837502 0.238033 -3.518 0.000434 ***
Distance2 0.011552 0.004714 2.451 0.014257 *
Ditch_idold -0.386364 1.972419 -0.196 0.844702

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1</td></tr>
<tr><td>Water table

Mean WT ~ Distance + Distance^2 + (1|Transect)</td><td>Family: gaussian (identity)
Formula: WT_mean ~ Distance + Distance2 + (1 | Transect_id)
Data: Decompdata
AIC BIC logLik deviance df.resid
836.2 849.7 -413.1 826.2 105
Random effects:
Conditional model:
Groups Name Variance Std.Dev.
Transect_id (Intercept) 2.507e-07 5.007e-04
Residual 1.070e+02 1.035e+01
Number of obs: 110, groups: Transect_id, 10
Dispersion estimate for gaussian family (sigma^2): 107
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) 25.552391 2.085109 12.255 < 2e-16 ***
Distance -0.837502 0.238075 -3.518 0.000435 ***
Distance2 0.011552 0.004715 2.450 0.014273 *

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1</td></tr>
<tr><td>Segmented Water table

Mean WT ~ Distance + Age</td><td>***Regression Model with Segmented Relationship(s)***
Call:
segmented.lm(obj = m3, seg.Z = ~subdistance, psi = list(subdistance = c(15)))
Estimated Break-Point(s):
Est. St.Err
psi1.subdistance 15.899 4.246
Meaningful coefficients of the linear terms:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -27.3378 2.4366 -11.220 < 2e-16 ***
subdistance 0.9479 0.2472 3.834 0.000215 ***
Ditch_idold 0.3864 1.9720 0.196 0.845045
U1.subdistance -0.9513 0.2872 -3.312 NA

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 10.34 on 105 degrees of freedom
Multiple R-Squared: 0.2198, Adjusted R-squared: 0.1901
Convergence attained in 2 iter. (rel. change 0)
AIC = 832.9963</td></tr>
<tr><td>Segmented water table

Mean WT ~ distance</td><td>***Regression Model with Segmented Relationship(s)***
Call:
segmented.lm(obj = m4, seg.Z = ~subdistance, psi = list(subdistance = c(15)))
Estimated Break-Point(s):
Est. St.Err
psi1.subdistance 15.899 4.227
Meaningful coefficients of the linear terms:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -27.1446 2.2181 -12.238 < 2e-16 ***
subdistance 0.9479 0.2461 3.852 0.000201 ***
U1.subdistance -0.9513 0.2859 -3.327 NA</td></tr>
</table>

<table>
<tr><td></td><td>---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 10.29 on 106 degrees of freedom
Multiple R-Squared: 0.2195, Adjusted R-squared: 0.1974
Convergence attained in 2 iter. (rel. change 0)
> AIC(myseg)
[1] 831.0365</td></tr>
<tr><td>Decomposition rooibos tea

Weight loss RT ~ Distance + (1|transect)</td><td>Family: gaussian (identity)
Formula: wr ~ subdistance + (1 | t)
     AIC   BIC   logLik deviance df.resid
   564.7   575.5   -278.3   556.7   106
Random effects:
Conditional model:
 Groups   Name   Variance Std.Dev.
 t   (Intercept) 0.5768   0.7595
 Residual   8.7871   2.9643
Number of obs: 110, groups: t, 10
Dispersion estimate for gaussian family (sigma^2): 8.79
Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) 39.75152   0.49099   80.96   <2e-16 ***
subdistance -0.06509   0.01838   -3.54   4e-04 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1</td></tr>
<tr><td>Decomposition rooibos tea

Weight loss RT ~ Distance + Age</td><td>Call:
glm(formula = wr ~ subdistance + ag)
Deviance Residuals:
     Min   1Q   Median   3Q   Max
-18.6027   -1.0578   0.1372   1.4410   4.4662
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 39.34128   0.53220 73.923 < 2e-16 ***
subdistance -0.06509   0.01907 -3.413 0.000907 ***
agold   0.82047   0.58631   1.399 0.164591

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Dispersion parameter for gaussian family taken to be 9.453448)
    Null deviance: 1140.2 on 109 degrees of freedom
Residual deviance: 1011.5 on 107 degrees of freedom
AIC: 564.23
Number of Fisher Scoring iterations: 2</td></tr>
<tr><td>Segmented decomposition rooibos tea

Weight loss RT ~ Distance + Age</td><td>***Regression Model with Segmented Relationship(s)***
Call:
segmented.glm(obj = rm1, seg.Z = ~subdistance, psi = list(subdistance = c(15)))
Estimated Break-Point(s):
                   Est. St.Err
psi1.subdistance 43.721 2.275
Meaningful coefficients of the linear terms:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)   39.84358   0.58665 67.917 < 2e-16 ***
subdistance   -0.11420   0.03561 -3.207 0.00178 **
agold   0.82047   0.56871   1.443 0.15208
U1.subdistance 0.62572   0.21984   2.846   NA

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Dispersion parameter for gaussian family taken to be 8.894219)
Null   deviance: 1140.17 on 109 degrees of freedom
Residual deviance: 933.89 on 105 degrees of freedom</td></tr>
</table>

<table>
<tr><td></td><td>AIC: 559.44
Convergence attained in 0 iter. (rel. change 0.016074)</td></tr>
<tr><td>Decomposition green tea

Weight loss GT ~ Distance + Age + (1|transect)</td><td>Family: gaussian (identity)
Formula: wgt ~ subdistance + ag + (1 | t)
AIC BIC logLik deviance df.resid
759.8 773.3 -374.9 749.8 105
Random effects:
Conditional model:
Groups Name Variance Std.Dev.
t (Intercept) 8.857e-08 0.0002976
Residual 5.344e+01 7.3103251
Number of obs: 110, groups: t, 10
Dispersion estimate for gaussian family (sigma^2): 53.4
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) 61.25562 1.26536 48.41 <2e-16 ***
subdistance -0.02480 0.04534 -0.55 0.5844
agold 2.41887 1.39402 1.74 0.0827 .

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1</td></tr>
<tr><td>Segmented decomposition green tea

Weight loss GT ~ Distance + age</td><td>Call:
lm(formula = wgt ~ subdistance + ag)
Residuals:
Min 1Q Median 3Q Max
-14.0419 -5.5608 -0.3429 4.1447 24.1684
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 61.25562 1.28297 47.745 <2e-16 ***
subdistance -0.02480 0.04597 -0.540 0.5907
agold 2.41887 1.41343 1.711 0.0899 .

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 7.412 on 107 degrees of freedom
Multiple R-squared: 0.02921, Adjusted R-squared: 0.01107
F-statistic: 1.61 on 2 and 107 DF, p-value: 0.2047</td></tr>
<tr><td>Segmented decomposition green tea

Weight loss GT ~ Distance</td><td>Call:
glm(formula = wgt ~ subdistance)
Deviance Residuals:
Min 1Q Median 3Q Max
-14.1126 -5.4738 -0.2804 4.1453 22.9590
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 62.46505 1.08030 57.822 <2e-16 ***
subdistance -0.02480 0.04638 -0.535 0.594

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for gaussian family taken to be 55.92031)
Null deviance: 6055.4 on 109 degrees of freedom
Residual deviance: 6039.4 on 108 degrees of freedom
AIC: 758.78
Number of Fisher Scoring iterations: 2</td></tr>
<tr><td>Microstructure

-Mean WT ~ Microstructures + (1|Age/Transect)</td><td>Family: gaussian (identity)
Formula: -WT_mean ~ Microstructure_condensed + (1 | Ditch_id/Transect_id)
Data: decomp_t_bag
AIC BIC logLik deviance df.resid
745.5 772.5 -362.8 725.5 107
Random effects:
Conditional model:
Groups Name Variance Std.Dev.</td></tr>
</table>

<table>
<tr>
<td></td>
<td>Transect_id:Ditch_id (Intercept) 3.018e+00 1.737339
Ditch_id (Intercept) 4.212e-07 0.000649
Residual 5.493e+01 7.411369
Number of obs: 110, groups: Transect_id:Ditch_id, 10; Ditch_id, 2
Dispersion estimate for gaussian family (sigma^2): 54.9
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) -13.882 1.523 -9.118 < 2e-16 ***
Microstructure_condensedh 9.126 2.326 3.924 8.71e-05 ***
Microstructure_condensedht -13.683 2.075 -6.595 4.24e-11 ***
Microstructure_condensedlt -2.482 2.127 -1.167 0.2431
Microstructure_condensedm 6.377 3.163 2.016 0.0438 *
Microstructure_condensedNA 9.779 7.678 1.274 0.2028
Microstructure_condensedsb -19.725 3.122 -6.318 2.64e-10 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1</td>
</tr>
<tr>
<td>Microstructure

Distance ~ Microstructures + age</td>
<td>Family: gaussian (identity)
Formula: Distance ~ Microstructure_condensed + Ditch_id
Data: decomp_t_bag
AIC BIC logLik deviance df.resid
875.0 899.3 -428.5 857.0 109
Dispersion estimate for gaussian family (sigma^2): 215
Conditional model:
Estimate Std. Error z value Pr(>|z|)
(Intercept) 15.7542 3.1924 4.935 8.02e-07 ***
Microstructure_condensedh 9.0205 4.5082 2.001 0.0454 *
Microstructure_condensedht -0.3089 4.0182 -0.077 0.9387
Microstructure_condensedlt -1.2468 4.1482 -0.301 0.7638
Microstructure_condensedm 11.5635 6.2040 1.864 0.0623 .
Microstructure_condensedNA 2.1536 14.9849 0.144 0.8857
Microstructure_condensedsb -15.3464 6.0364 -2.542 0.0110 *
Ditch_idold 2.0922 2.9594 0.707 0.4796

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1</td>
</tr>
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