Masteruppsats

Master's Programme in Applied Environmental Science

Impact of different catchments on the Brownification of Lake Bolmen

Environmental Science

Halmstad 2020-06-16
Kaela Chileshe

HÖGSKOLAN
I HALMSTAD

Preface

This thesis has been conducted as a research project to fulfill the graduation requirements for the master program of Applied Environmental Science at Halmstad University Sweden. This project work was conducted during the spring period of the year 2020. And it comprises of 15 hp.

I would like to thank my supervisor Antonia Liess for the excellent guidance and support during the project ‘course. During the project, my supervisor was always available and quick to respond to my queries. My sincere appreciation goes to Juha Rankinen from Sydyatten AB who not only showed me the maps of the sites to work with but also drove me to the sites and helped me with the sampling in the field. In the laboratory, Per-Magnus Ehde was extremely helpful and tutoring on analyzing the samples, thank you so much. I would also like to say thank you to Anna Borgström and Clemens Klante from Lund University who at the start of the project gave me some relevant articles on brownification. I also want to say thank you to my family, your support and wise counsel always gave me strength to keep on. And finally, to Jehovah God who has given me life, divine wisdom, and strength to finish this project.

Halmstad University, June 2020.

Kaela B Chileshe.

Supervisor:

Antonia Liess.

Partner company:

Sydvatten AB.

Abstract

Increased DOC and Fe concentrations from terrestrial landscapes has led to the browning of boreal surface waters. The negative societal and ecological impacts of brownification are increased cost of water purification, increased presences of algae and cyanobacteria, loss of ecosystem services and reduced recreational value. Impacts of climate change, changes in land use and reduced sulfur deposition have been identified as drivers of brownification. While it has been recognized that DOC and Fe from terrestrial landscapes is increasing, little has been done to understand the impact of different land use practices on brownification.

This research aims at evaluating the DOC and Fe runoff from spruce plantations, clear-cuts and wetland landscapes and determining the export of DOC from these landscapes into humic lakes. To do that, streams running through these three different land use types were sampled for water colour, pH, temperature, conductivity, DOC and Fe both at upstream and downstream of each land use type. Further, water discharge was calculated with the help of flow speed measurements and stream profiling (width, depth and channel shape). DOC (but not Fe) concentrations changed significantly depending on land use type. Wetlands lead to reduced DOC concentrations, whereas especially spruce plantations lead to increased stream water DOC concentrations.

Keywords: Brownification, dissolved organic carbon (DOC), Iron (Fe), water colour, landscapes, climate change.

Table of Contents

Abbreviations

DOC	Dissolved organic carbon
Fe	Iron
DOM	Dissolved organic matter
EPA	Environmental protection agency
Δ	Change in

1.0 Introduction

Increasing colour of surface waters has been observed and confirmed by various studies across the northern hemisphere (Evans et al, 2005; Ekström, 2013). This development is known as brownification (Kazanjian et al. 2019) and has been attributed to the increasing concentrations of dissolved organic carbon (DOC) (Ekström 2013) and iron (Fe) in aquatic systems (Kritzberg & Ekström 2012). This change in water colour has negative ecological and societal impacts (Kritzberg et al. 2020). Brownification affects society through its impacts on aquatic ecosystems (Evans, Monteith & Cooper, 2005), human health (Ekström 2013) and provision of ecosystem services (Leech *et al.*, 2018: Kritzberg *et al.*, 2020). The impact on aquatic ecosystems affects the quality of drinking water resources hence increasing the cost of purification (Kritzberg & Ekström, 2012; Weyhenmeyer *et al.*, 2016) . The increased water colour associated with increased DOC levels impacts on the drinking water purification processing by increasing the amount of chemicals used (Kritzberg et al. 2020). Brownification also increases the possibility of drinking water containing high levels of pharmaceutical residues (Kritzberg et al. 2020) and byproducts of chlorination which may be carcinogenic (Ekström, 2013; Leech *et al.*, 2018; Kritzberg *et al.*, 2020). Furthermore high levels of dissolved organic carbon in lakes and rivers have a tendency to mobilize pollutants and heavy metals (Tuvendal & Elmqvist, 2011) such as mercury (Hall *et al.*, 2008; Sørensen *et al.*, 2009). These pollutants and heavy metals have toxic effects on human health. The increased presence of algae and cyanobacteria in browner water is known to cause skin allergic reactions hence reducing the recreational value (Trigal *et al.*, 2013; Kritzberg *et al.*, 2020) of lakes for swimming. Brownification also affects the ability of the lakes and rivers to provide ecosystem services and reduces their tourism potential (Kritzberg et al. 2020).

Ecologically increase in water colour impacts on the aquatic food webs as the reduced amount of light penetrating into aquatic ecosystems greatly affects photosynthesis (Karlsson *et al.*, 2009; Kritzberg, 2017). This further affects the primary and secondary production of aquatic organisms (Karlsson *et al.*, 2009; Bragée, 2013) and benthic productivity (Bartels et al. 2016). The reduced light availability inhibits benthic primary production which cascades through the food web leading to lower secondary production (Bartels et al. 2016). Reduced light into the browner water leads to less nutrients in the ecosystem hence affecting phytoplankton communities (Karlsson et al. 2009) and encourages the growth of species and toxins such as cyanobacteria that adjusts to low light conditions (Lebret et al. 2018). Consequently, increased water colour leads to lower dissolved oxygen concentration in the water which impacts negatively on aquatic life (Evans, Monteith & Cooper, 2005; Leech *et al.*, 2018). In small lakes brownification leads to a steady thermal stratification (Piccolroaz, Toffolon & Majone,2015) which results in high productivity of algae (Kazanjian et al. 2019).

Several mechanisms have been suggested as the reasons for increased Fe (Kritzberg & Ekström, 2012), and DOC concentrations (Evans et al, 2005;Tuvendal & Elmqvist, 2011; Kritzberg *et al.*, 2020) and these include climate change (Sarkkola et al. 2013) , changes in land cover and reduced acid deposition (Evans et al 2005; Kritzberg & Ekström, 2012; Köhler *et al.*, 2013)

Climate change impacts such as increased temperatures , precipitation and atmospheric carbon dioxide (CO_2) (Weyhenmeyer et al. 2012) have contributed to the increased water colour. These factors have increased terrestrial productivity and amounts of DOC and Fe exports from both terrestrial habitats and ground water (Weyhenmeyer *et al.*, 2016; Kritzberg, 2017; Kritzberg *et al.*, 2020). DOC contains high levels of humus matter and high molecular weight compounds which reduces light penetration into aquatic systems (Karlsson *et al.*, 2009; Bartels *et al.*, 2016; Madsen-Østerbye *et al.*, 2018). Warmer climate has changed the pattern of precipitation globally and the Northern Hemisphere has experienced a rise in the distribution and period of precipitation (Ukonmaanaho *et al.*, 2014; Mzobe *et al.*, 2018) leading to increased storm water flow which has heightened the leaching of DOC (Tuvendal & Elmqvist, 2011). Sepp *et al.*,(2018) argues that as the climate becomes warmer lakes, streams and rivers will become browner as more DOC will be exported from terrestrial ecosystems. Higher temperatures and carbon dioxide concentration are likely to increase the productivity of terrestrial habitats and consequently increase the DOC export into rivers and lakes (Boisvenue & Running, 2006; Ekström, 2013). Seasonal variations due to climate change will reduce the snow cover period hence allowing the export of organic matter to aquatic ecosystems for a longer period during the year (Weyhenmeyer *et al.*, 2012; Ekström, 2013). This will not only increase the amount of dissolved organic matter imported from the terrestrial habitats but will reduce the removal of dissolved organic matter within the aquatic ecosystems (Ekström 2013). This imbalanced nutrient cycle where the organic matter inflow is greater than decomposition will increase DOC concentrations in lakes (Bragée 2013) resulting in an increase in water colour (Corman et al. 2018). This will also be influenced by the processes within aquatic systems that transform DOM considering that they are subject to the water residence time and the quality of DOM such as molecular weight (Ekström 2013).

Furthermore the increase in organic matter solubility and consequently increased export of DOC from terrestrial to aquatic systems has been attributed to the declining atmospheric sulfur (S) deposition (Evans, Monteith & Cooper, 2005; Škerlep *et al.*, 2019). The decrease in atmospheric sulfate deposition has led to an increase in soil pH and subsequent reduced soil ionic strength that has increased solubility of OM hence increasing DOC exports (Škerlep et al. 2019). This hypothesis was verified by field experiments that showed a higher solubility of organic matter in soil water with low acid added than the one with a higher acid addition (Evans *et al.*, 2012; Ekström, 2013). However, a study of historical data of water color from 50 lakes in southern Sweden indicated that water colour was increasing even before the atmospheric sulfur started decreasing (Kritzberg 2017), whereas no reduction in water colour was detected in the period when acid deposition increased (Ekström, 2013; Kritzberg, 2017). Therefore, declining acid deposition is not enough to explain the increase in water colour.

However, brownification cannot be exclusively explained by an increase in DOC. Sarkkola *et al.*, (2013) and Škerlep *et al.*, (2019) argue that as the concentrations of DOC increases the Iron (Fe) concentrations have also been increasing. Hence Fe has also been associated with brownification but its availability in aquatic systems is dependent on its interaction with DOM (Ekström, 2013; Xiao *et al.*, 2015; Ekström *et al.*, 2016). The change in Fe concentrations has been attributed to the increase in storm water rich in Fe(II) from anoxic soils into aquatic systems leading to the oxidation of Fe(II) to Fe(III) which increases water colour (Kritzberg &

Ekström 2012). It has been argued that landscapes associated with accelerated rates of redox reactions such as wetlands and peatlands might also be source of increasing Fe (Kritzberg & Ekström 2012).

Changes in land cover mainly from agriculture to forestry has also been identified as a driver of brownification (Kritzberg, 2017; Corman *et al.*, 2018). The increase in DOC concentrations due to change in land use (Kritzberg et al. 2020) alongside the increase in water colour of lakes and rivers has been observed in northern Europe (Sarkkola *et al.*, 2013; Bragée, 2013; Schelker *et al.*, 2014; Arvola, Äijälä & Leppäranta, 2016). Most research has established that DOC in lakes and rivers is usually from the terrestrial humus matter coming from the different landscapes in the catchment area (Tuvendal & Elmqvist, 2011) and the concentrations are known to vary with changes in land use (Arvola, Äijälä & Leppäranta, 2016; Bartels *et al.*, 2016; Kritzberg *et al.*, 2020). For example increased DOC concentrations and water colour has been observed where forestry and clear cutting are predominant (Schelker et al. 2014). In fact Bragée, (2013) and Kritzberg *et al.* (2020) have argued that clear cut landscapes contribute more to brownification because of high organic matter and consequently high DOC export into the catchment area. However, Schelker *et al.*,(2014) argues that for clear cutting to show a significant increase in DOC concentrations downstream a critical area of the catchment needed to be harvested. Therefore, it is important to understand how each land use type contributes to brownification.

To understand how different land use types, contribute to the increase in water colour, my study will analyze the upstream and downstream concentrations of DOC and Fe from wetlands, spruce plantations, and clear-cut land use types around the Lake Bolmen and lake Jälluden catchment. Lake Bolmen is the tenth largest lake in Sweden and the major sources of drinking water in southern Sweden (SWWA, 2020). This research will be in line with the sustainable development goal number six (6) which advocates for clean water and sanitation for all and sustainable water use to conserve life in aquatic ecosystems (UNDP, 2015). Further the Swedish environmental protections agency state that lakes and rivers must be ecologically sustainable in order to preserve the biodiversity as well as the cultural and recreational assets (Swedish EPA, 2020). This is important because it ensures a sustainable clean water supply from both surface and ground water. This study will contribute to the research on the brownification of water ecosystems in Sweden and will most importantly highlight the impacts of land use type on brownification and pave a way for land use type management to reduce brownification.

Aim

The aim of this research is to evaluate how the export or uptake of DOC (ΔDOC) and Fe (Δ Fe) through different land use types contribute to brownification of lakes like Lake Bolmen.

Study Questions

This research aims at answering the following questions

1. Is there a difference in the change of concentration of DOC and Fe and change in water colour between wetlands, clear-cut and spruce plantation streams?
2. Is there a difference in change of DOC concentration (ΔDOC) between the three land use types (wetlands, clear-cut and spruce plantations) per km of stream lengths?

3. Is there a correlation between the change in water colour of the three land use types and the change in concentration of DOC and Fe?

2.0 Materials and Methods

2.1 Research design

In this field survey, water samples were collected from three different land use types i.e. clear-cut areas, spruce plantations, and wetlands draining into Lake Bolmen and Lake Jällunden. I collected samples upstream as well as downstream of each land use type. For the spruce plantations samples were collected from spruce forests which were between 10 to 20 years and samples from clear cut areas where collected from areas that had recently been clear cut. At the time of sampling it was sunny and calm and hence the samples where not compromised by rains nor was the water velocity affected by the wind. Temperature, conductivity, and PH of the water were measured on site while the DOC, Fe and water colour where analyzed in the university chemistry laboratory.

2.2 Study catchments and sampling

This study was conducted around the Lake Bolmen and Lake Jällunden catchment in south-west Sweden in the municipality of Hyltebruk. The vegetation in the study areas was mainly spruce but mixed with pine in some forests while the ground vegetation consisted of grasses and lingonberry and blueberry shrubs. Many natural wetlands exist in this area, while forestry is the dominant form of land use. Water samples were collected from the upstream and downstream of streams flowing through the three-land use types clear-cut areas, spruce plantation, and wetlands. We sampled from 4 wetlands, 4 spruce plantations and 4 clear-cut areas. A long-handled sampling dipper was used to access further parts of the streams. The water samples where kept in 50mls bottles and transported back to the laboratory in a cooler box. A total of twenty-four (24) water samples were collected from the streams of the three land use types. Eight (8) water samples were collected from the wetlands that is 4 from the upstream and 4 from the downstream. Eight (8) water samples were collected from the spruce plantations that is 4 from the upstream and 4 from the downstream. Lastly eight (8) samples were collected from the clear-cuts areas that is 4 from the upstream and 4 from the downstream.

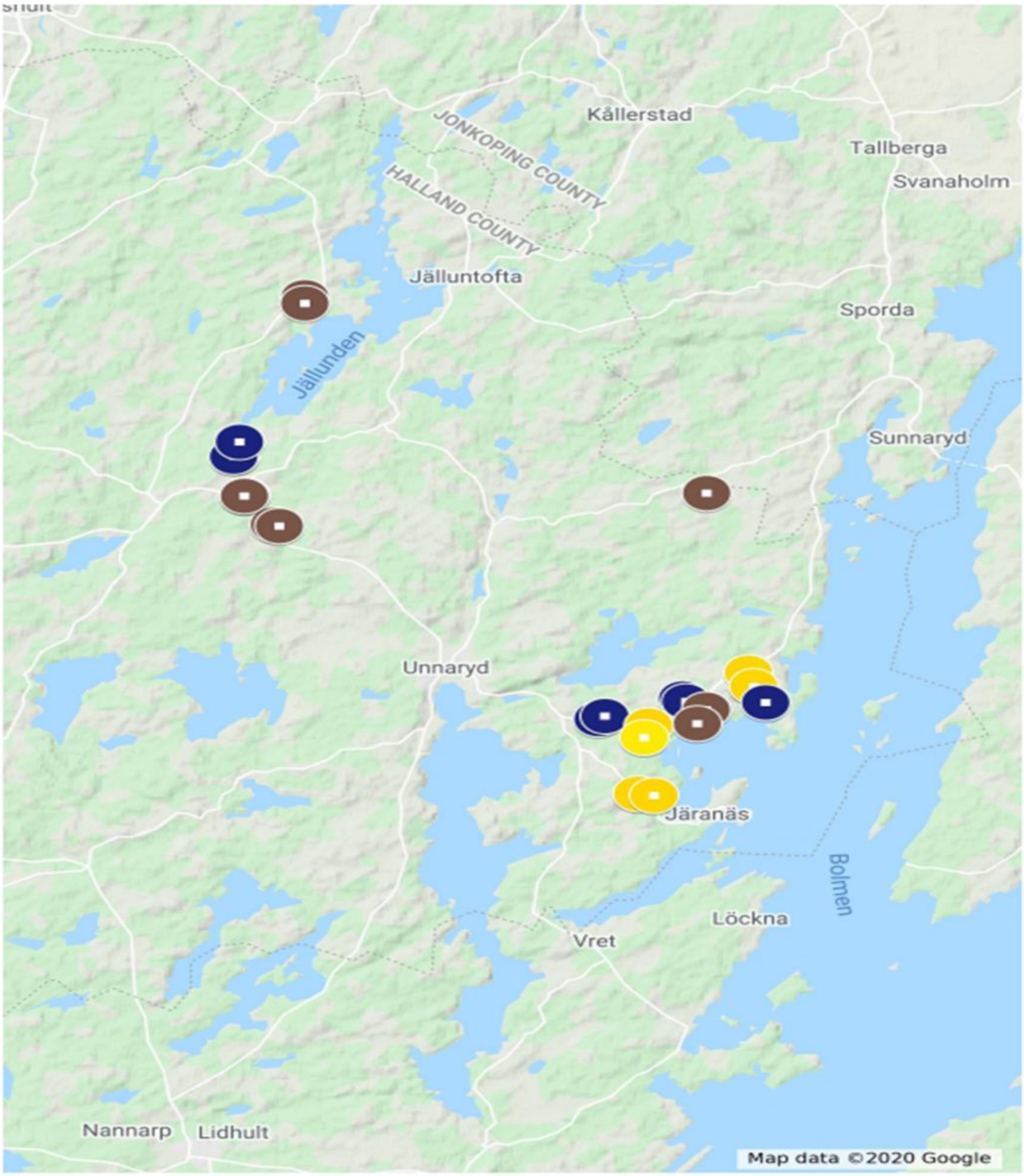

Figure 1: shows the location of the sampling points. The yellow colour indicates the upstream and downstream sampling points for spruce plantations, while brown shows the upstream and downstream sampling points for clear-cut areas and dark blue shows the upstream and downstream sampling points for wetlands.

The field sampling was conducted in spring in the month of April 2020 for a period of three days. The pH, temperature and conductivity were measured with a HANNA (HI-9811) multimeter at the upstream and downstream sampling points of the three different land use types. The depth of the stream was measured 20cm from both edges of the stream and the middle part of the stream by using a carpenter's ruler and the width was measured by using a measuring tape. Both the depth and the width were measured at the upstream and downstream of the land use type. This was used to calculate the area of flow of the water. To determine the water flow rate, a tennis ball was thrown in the water and allowed to float through a known distance while monitoring the time it took with a stopwatch. This flow speed of water at the upstream and downstream sampling points was multiplied by the area at the upstream and downstream sampling points to determine the discharge of water. To determine the change in discharge the upstream discharge was subtracted from the downstream discharge. The laboratory analyses were done to determine the concentrations of DOC and Fe from each land use type. And lastly, I determined the water colour for all the samples from each land use type.

2.3 Laboratory analysis

To determine water colour the colour absorbance was analyzed at 420nm with the UV-1800 Spectrophotometer. To determine the concentration of DOC, the samples were filtered and a HACH LANGE TOC-X5 was used to purge out all inorganic carbon. Then 1ml of each sample was put into a cuvette that is screwed to an indicator cuvette. The screw holding the two cuvettes together has a barcode that enables the spectrophotometer to analyze the sample. This cuvette combination was put in a reactor for 2 hours at 100 ^{o}C after which it was cooled to room temperature. DOC concentration was then analyzed by putting the combined cuvette one at a time into the analyzing cell of the HACH Lange DR 2800 spectrophotometer. This procedure was followed for all the samples. To determine the concentration of Fe in the water samples the Atomic Absorption Spectrometry - Varian SpectraAA-100 was used.

2.4 Data Analysis

Data was tabulated according to the land use type and the different parameters that were sampled. The changes in concentration of DOC and Fe, changes in absorbance, temperature, pH and conductivity between the upstream and downstream sites for each land use type was calculated. This was done to determine the impact of the land use type on the measured parameter

2.5 Statistics Analysis

All the Statistics analysis were done using SPSS version 24. Variables which were not normally distributed were log_{10}-transfomed. One-way ANOVAs were performed to test if the changes in concentration of the response variables (ΔDOC, ΔFe as well as Δwater colour) depended on land use type.

One-way Anova was also used to test if the Δ DOC concentration along the stream lengths was different for each land use.

Pearson's correlation was used to describe the association between the variables water colour, DOC and Fe.

2.6 Ethics

This study involved the collection of water samples and all the sites where we sampled from had public access and did not require us to get specific permission. Since this study did not involve endangered or protected species there were no ethical considerations or clearance taken into consideration before or during the research. Nevertheless, if the results of this research indicate any possibility of environmental or health threat, stipulated procedure will be followed.

3.0 Results

The Δ DOC, Δ Fe, Δ water colour and other parameters between upstream and downstream sampling points were calculated as shown in Table 1.

Table 1. The Mean and standard deviation (±SD) of Δ DOC and Δ Fe and Δ temperature, Δ conductivity, Δ pH and Δ water colour between the upstream and downstream sampling points of the streams in different land use types.

Parameter	Wetlands	Clear-cuts	Spruce plantations
Δ DOC (g/m^3)	-9.23 ± 9.49	-0.75 ± 1.92	3.90 ± 3.46
Δ Fe concentration (g/m^3)	-0.27 ± 0.34	0.13 ±0.36	0.11 ± 0.16
Δ Water colour	-0.23 ± 0.32	0.06 ± 0.09	0.13 ± 0.15
Δ pH	0.07 ± 0.09	-0.18 ± 0.87	0.22 ± 0.79
ΔTemperature ^oC	0.33 ± 0.09	0.50 ± 0.61	-1.23 ± 1.26
ΔConductivity	-0.01 ± 0.10	-0.01 ± 0.03	0.01 ± 0.01
Δ Discharge m^3/s	0.04±0.02	0.002±0.007	0.004±0.006
Reach Length km	0.34±0.21	0.27±0.22	0.32±0.18

3.1 Results for question 1

Q 1: Is there a difference in the change of concentration of DOC and Fe and change in water colour between wetlands, clear-cut and spruce plantation streams?

There is a significant difference in the change of concentration of DOC between the wetlands, clear- cuts and spruce plantations ($F = 5.210$, $df = 2,11$ and $p = 0.031$). From the post Hoc test the difference is between the wetlands and the spruce plantations $p = 0.030$. On the contrary there is no significant difference between the clear-cut areas and the spruce plantations $p = 0.694$ and between the wetlands and the clear-cut areas $p = 0.109$. Similarly, there was no significant difference in the Δ temperature, Δ conductivity, and Δ pH ($P > 0.05$) between the three land use types. There was also no significant difference in the Δ Fe concentrations $p = 0.165$. and Δ water colour $p = 0.078$ between the three land use types.

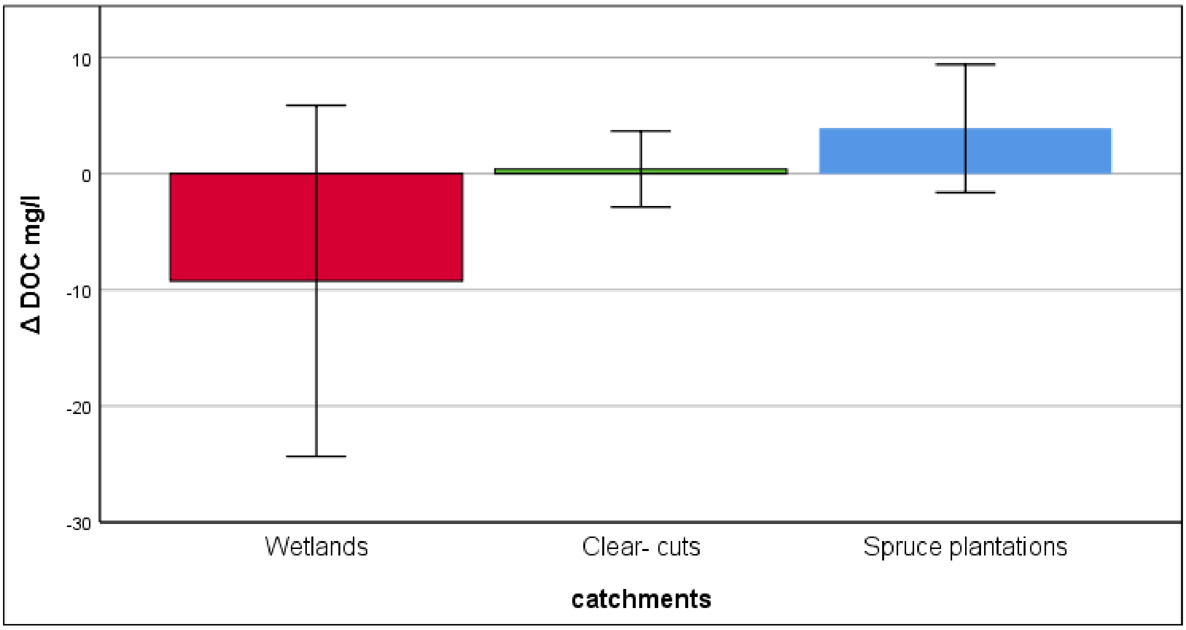

Figure 2: shows the differences in **Δ** DOC concentrations between the three land use types.

3.2 Results for question 2

Q 2: Is there a difference in change of DOC concentration (ΔDOC) between the three -land use type (wetlands, clear-cut and spruce plantations) per km of stream lengths?

There is a significant difference in the ΔDOC concentration along the stream length of the three-land use type p = 0.006, df =2, 11 and f =9.574. From the post Hoc test the difference is between the wetlands and the spruce plantation p=0.005. There is no significant difference between the wetlands and the clear-cuts p = 0.069 and similarly there was no significant difference between clear-cuts and spruce plantations p = 0.236.

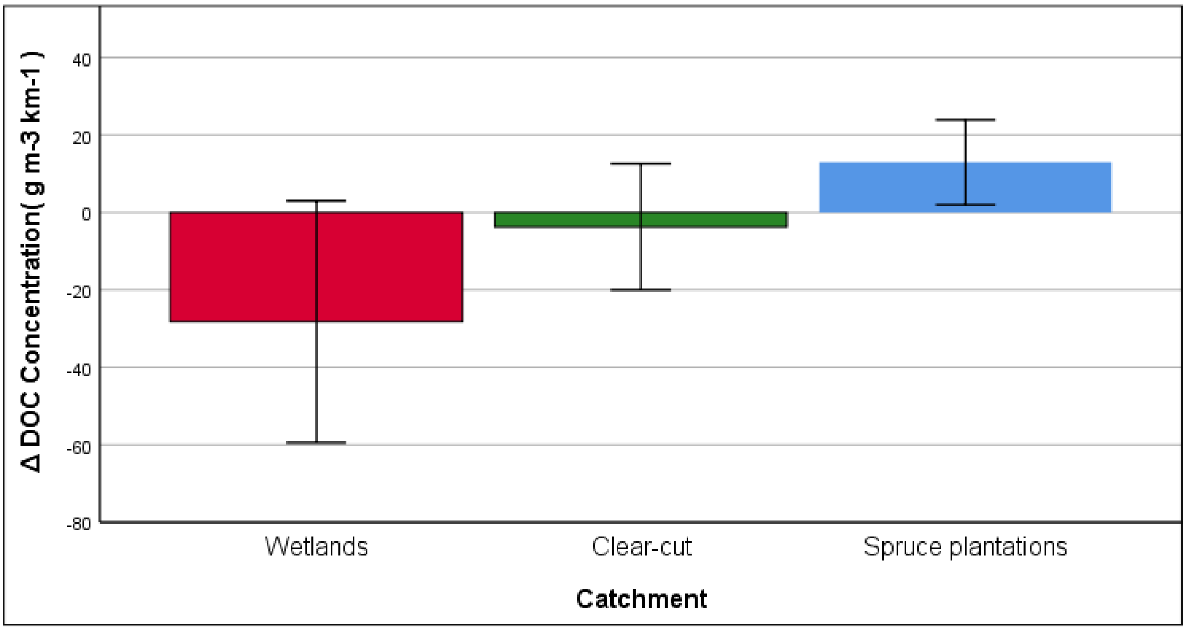

Figure 3: shows the differences in ΔDOC concentration g m^{-3} km^{-1} along the stream length.

3.4 Results for question 3

Q 3: Is there a correlation between the change in water colour of the three land use types and the change in concentration of DOC and Fe?

The strongest correlation with regards to Δ water colour was with ΔDOC $r = 0.929$ and $p = 0.000012$ but Δ Fe also showed a strong correlation with water colour $r = 0.840$ and $p = 0.001$. However, water colour did not show any significant correlation with Δ pH ($P > 0.05$). Figure 2 and 3 shows the scatter charts for the correlation between Δ water colour, ΔDOC and Δ Fe.

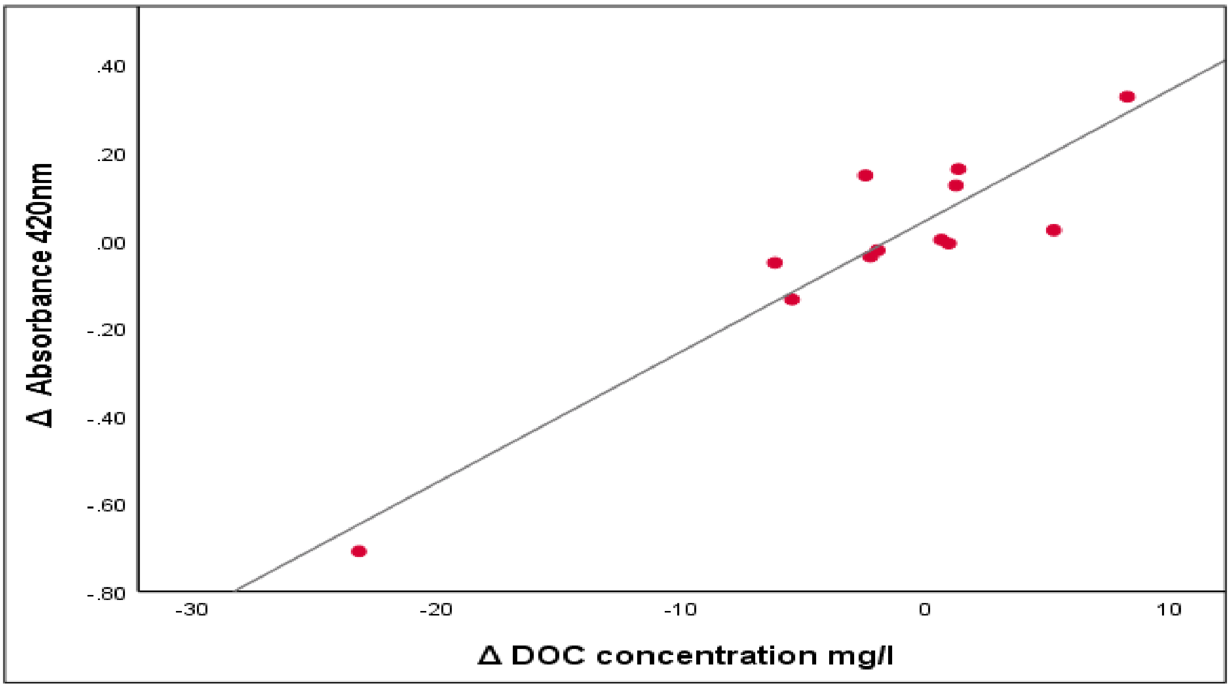

Figure 4: The relationship between Δ DOC concentrations and Δ water colour (Δ absorbance 420nm).

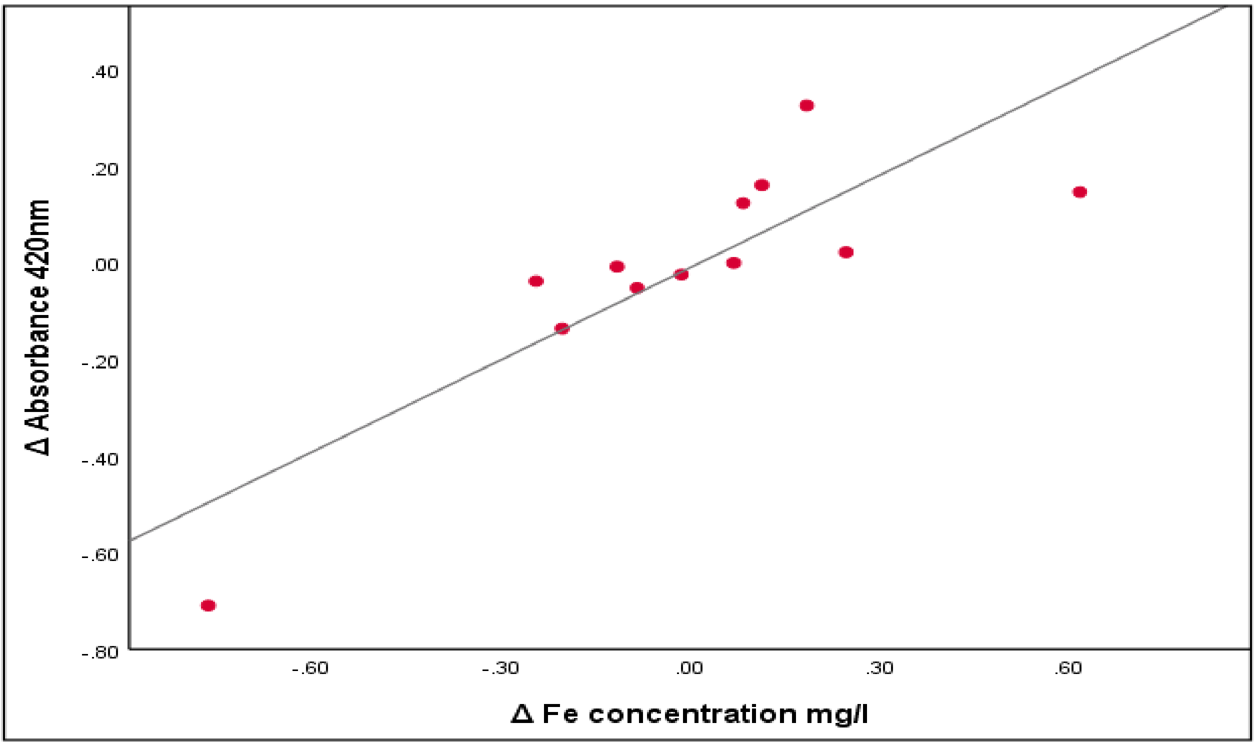

Figure 5: The relationship between Δ Fe concentration and Δ water colour (Δ absorbance 420nm).

4.0 Discussion

This study shows that there is a significant difference in the change of concentrations of DOC between the streams of the three land use types (figure 2) on the contrary, there was no significant difference in the change of Fe concentrations and change in water colour between the streams of the three land use type (answering question 1). Many studies have observed a parallel increase in the concentrations of DOC and iron (Ekström, 2013: Björnerås *et al.*, 2017: Kritzberg, 2017) but have also stated that DOC and Fe don't have similar mobilization process as their concentrations vary with land use type (Kritzberg & Ekström 2012) . Ekström *et al.*, (2016) argues that variations in iron concentrations are strongly influenced by redox conditions in the catchment and for these land use types it can be argued that the variations of Fe concentrations are not directly influenced by the variations in DOC concentrations (Ekström, 2013; Ekström *et al.*, 2016). From the post hoc tests the differences were between the wetlands and the spruce plantations. The change in DOC concentration from the spruce plantations was increasing and this indicated that the spruce plantations were discharging DOC into the streams while the change in DOC concentration from the wetlands was reducing indicating that the wetlands were removing DOC. The decreasing DOC concentrations from wetlands is because of microbial activities within the wetland and dilution by water low in DOC entering the streams (Ågren et al. 2007) between the upstream and downstream sampling points. These results show that changes in land use to spruce plantations has increased the DOC concentrations into streams from forest habitats (Wilson & Xenopoulos, 2008). In northern Europe agricultural land has been converted to mainly spruce plantations (Meyer-Jacob et al. 2015) and this has led to an increase in soil carbon sinks (Diodato *et al.*, 2016; Škerlep *et al.*, 2019) through high litter production and mineralization (Evans, Monteith & Cooper, 2005). Similarly wetlands have been drained and natural forests clear-cut in order to increase land for spruce plantations (Tuvendal & Elmqvist, 2011) and this has caused increased run off which transport organic carbon into lakes and rivers (Tuvendal & Elmqvist, 2011; Diodato *et al.*, 2016). It has also been observed in many boreal regions where catchment land areas mainly consist of spruce plantations that aquatic ecosystems receive high amounts of DOM causing brownification (Palviainen et al. 2016). Therefore, spruce plantations are exporting DOC into lakes and hence contributing to increasing water colour of the aquatic systems.

This study reveals that there was a significant difference in the change of DOC concentration per km of stream length between the three land use types. My findings show that this difference was between the wetlands and the spruce plantations. Stream length in catchment areas significantly contribute to the processing of DOC (Kritzberg et al. 2020) and the results of this study show a decrease in DOC concentration with increasing stream length in the wetlands streams (figure 3). From table 1 the wetlands had the longest mean stream length therefore we can conclude that that the streams run longer through them. The DOC loss per stream length in the wetlands can be attributed to dilution and microbial processing in the streams (Schiff *et al.*, 1998). Other studies e.g. Ågren *et al.*,(2007) have reported that transit time for humic matter in longer streams is increased hence allowing for more decomposition and oxidation of organic carbon. Another factor influencing the loss of DOC concentrations along the stream length was the discharge from the land use type. From table 1 the change in discharge was higher in the wetland streams. This is an indicator that additional water was coming into the wetland streams between the upstream and downstream sampling points and hence diluting the DOC concentration. Though the source of this water was not investigated in this study, other studies have attributed it to groundwater (Ågren et al. 2007) and increased rainfall (De Wit et al. 2016). Increased precipitation links segregated wetland pools and this flushes out the accumulated DOC for the surface (Schiff *et al.,* 1998) and increased flow from precipitation and groundwater tend to dilute the DOC concentration (Schiff *et al.*, 1998:Dawson et al. 2008). Hence, we can conclude that increased precipitation due to climate change and hydrological processes within the land use type (Kristensen *et al.*, 2018; Tiwari, Sponseller & Laudon, 2019) influences the change in concentration of DOC along the stream length.

This study shows a stronger correlation for ∆ water colour and ∆ DOC concentrations (figure 4) as well as that of ∆ water colour and ∆ Fe concentrations (figure 5) in the three land use types (answering question 3). This is supported by previous studies that have found a strong correlation between DOC and water colour (Škerlep et al. 2019) and also between water colour and iron (Knorr, 2013; Björnerås *et al.*, 2017). This study shows that both DOC and Fe from the different land use types are contributing to brownification of lake Bolmen and lake Jälluden. Many other studies have argued that they is a strong relationship between dissolve organic carbon and Fe (Kritzberg & Ekström, 2012; Sarkkola *et al.*, 2013),however it is important to note that Fe does not contribute to the browning effect of dissolved organic carbon but it has a coloring effect on its own. Therefore, a combination of DOC and Fe can have a greater effect on brownification of lakes and rivers.

Therefore, this study shows that Fe and DOC from different land use types in the lake Bolmen and lake Jälluden catchments are contributing to brownification. However the increase in DOC concentrations has been attributed to change in land use from agriculture to spruce plantation (Björnerås et al. 2017). Changes in precipitations patterns driven by climate change are also enhancing the export of DOC from land use types hence increasing water colour. It is sufficient to say that climate change as well as change in land use has accelerated brownification by exposing more soil organic carbon surfaces as a result of soil erosion (Sarkkola *et al.*, 2013:Arvola, Äijälä & Leppäranta, 2016). This organic soil layer increases with the age of a forest and it becomes the source of organic carbon export to aquatic systems (Laudon *et al.*, 2011; Kritzberg *et al.*, 2020). It can be argued that the changes in water colour and increased DOC concentration observed over the past years are because of the land cover changes that have increased the soil organic carbon (Kritzberg et al. 2020).

5.0 Conclusion

This study concludes that spruce plantations are discharging DOC into catchment streams as compared to wetlands and clear-cuts. This shows that change in land use from agriculture to spruce plantations has strongly influenced the increasing DOC concentrations from terrestrial landscapes (Škerlep et al. 2019)**.** This study also shows that increased precipitation driven by climate change and hydrological factors within a land use type influences the change of DOC concentration along the stream length. DOC and Fe concentrations were strongly correlated with water colour thus showing that both DOC and Fe from the land use types contribute to the brownification of water**.** This study highlights that change in land use to spruce plantations is increasing the DOC concentration from terrestrial landscapes and increased precipitation as an impact of climate change is a major factor in the export of DOC from different land use types into the lake Bolmen and lake Jälluden.

5.1 Health aspects and Environmental goals

Although DOC is known to increase solubility and facilitates the transport of chemicals (Kritzberg et al. 2020) such as mercury (Hall et al. 2008) in water, it should be noted that surface water that is meant for drinking water is purified in a water treating plant to remove bacteria, heavy metals and organic matter before it is safe to drink (SWWA, 2020). This implies that there are no negative health impacts from drinking the treated water nevertheless the cost of treating surface water that has high concentrations of DOC and Fe is exorbitant. On the other hand, the presences of algal blooms and cyanobacterial in surface water may pose a health risks to swimmers and reduce recreation value such as fishing (Trigal *et al.*, 2013; Kritzberg *et al.*, 2020). This study has shown that spruce plantations are discharging DOC into lakes and impacting on water colour therefore land use types surrounding aquatic ecosystems which are sources of drinking water should be considered as a factor when treating water.

The importance of providing clean drinking water through sustainable surface and ground water management and the conservation of aquatic life has been emphasized in the united nations sustainability goals and the Swedish environmental goals (UNDP, 2015;Swedish EPA, 2020) Nevertheless, the present situation in boreal lakes as presented in this study and previous studies create a lot of uncertainties on whether these goals will be attained.

5.2 Further studies

More studies should be done to understand the seasonal variations in DOC export from different land use types taking into consideration the effects of climate change. Oni *et al.*,(2015) argues that there is a gap of knowledge on the combined effects of both forest management and climate change on DOC in surface water. The impact of DOC from clear-cut land use type on the downstream catchment still needs to be further investigated taking into consideration factors such as catchment area and area harvested for clear-cut areas. As this was an experiment over a limited time, I would propose that it be done for a longer period and increasing the number of sites investigated. It is only through long term monitoring data sets that the impacts of land use type on brownification coupled with climate change will be ascertained. Once more knowledge about the factors and mechanisms that influence brownification from different land use types are understood, land use management plans can be implemented that will help reduce on brownification.

6.0 References

Ågren, A, Buffam, I, Jansson, M, & Laudon, H 2007, 'Importance of seasonality and small streams for the landscape regulation of dissolved organic carbon export', *Journal of Geophysical Research: Biogeosciences*, vol. 112, no. 3, pp. 1–11.

Arvola, L, Äijälä, C, & Leppäranta, M 2016, 'CDOM concentrations of large Finnish lakes relative to their landscape properties', *Hydrobiologia*, vol. 780, no. 1, pp. 37–46.

Bartels, P, Hirsch, PE, Svanbäck, R, & Eklöv, P 2016, 'Dissolved Organic Carbon Reduces Habitat Coupling by Top Predators in Lake Ecosystems', *Ecosystems*, vol. 19, no. 6, pp. 955–967.

Björnerås, C, Weyhenmeyer, GA, Evans, CD, Gessner, MO, Grossart, HP, Kangur, K, Kokorite, I, Kortelainen, P, Laudon, H, Lehtoranta, J, Lottig, N, Monteith, DT, Nõges, P, Nõges, T, Oulehle, F, Riise, G, Rusak, JA, Räike, A, Sire, J, Sterling, S, & Kritzberg, ES 2017, 'Widespread Increases in Iron Concentration in European and North American Freshwaters', *Global Biogeochemical Cycles*, vol. 31, no. 10, pp. 1488–1500.

Boisvenue, C & Running, SW 2006, 'Impacts of climate change on natural forest productivity - Evidence since the middle of the 20th century', *Global Change Biology*, vol. 12, no. 5, pp. 862–882.

Bragée, P 2013, A palaeolimnological study of the anthropogenic impact on dissolved organic carbon in South Swedish lakes.

Corman, JR, Bertolet, BL, Casson, NJ, Sebestyen, SD, Kolka, RK, & Stanley, EH 2018, 'Nitrogen and Phosphorus Loads to Temperate Seepage Lakes Associated With Allochthonous Dissolved Organic Carbon Loads', *Geophysical Research Letters*, vol. 45, no. 11, pp. 5481–5490.

Dawson, JJC, Soulsby, C, Tetzlaff, D, Hrachowitz, M, Dunn, SM, & Malcolm, IA 2008, 'Influence of hydrology and seasonality on DOC exports from three contrasting upland catchments', *Biogeochemistry*, vol. 90, no. 1, pp. 93–113.

Diodato, N, Higgins, S, Bellocchi, G, Fiorillo, F, Romano, N, & Guadagno, FM 2016, 'Hydro-climatic forcing of dissolved organic carbon in two boreal lakes of Canada', *Science of the Total Environment*, vol. 571, pp. 50–58. Available from: http://dx.doi.org/10.1016/j.scitotenv.2016.07.112.

Ekström, S 2013, Brownification of freshwaters - The role of dissolved organic matter and iron. Department of Biology, Lund UNniversity.

Ekström, SM, Regnell, O, Reader, HE, Nilsson, PA, Löfgren, S, & Kritzberg, ES 2016, 'Increasing concentrations of iron in surface waters as a consequence of reducing conditions in the catchment area', *Journal of Geophysical Research: Biogeosciences*, vol. 121, no. 2, pp. 479–493.

EPA 2020, 'Swedish environmental protection agency'.Available on: http://www.swedishepa.se/Environmental-objectives-and-cooperation/Swedens-environmental-objectives/The-national-environmental-objectives/Good-Quality-Groundwater/

Evans, CD, Jones, TG, Burden, A, Ostle, N, Zieliński, P, Cooper, MDA, Peacock, M, Clark, JM, Oulehle, F, Cooper, D, & Freeman, C 2012, 'Acidity controls on dissolved organic carbon mobility in organic soils', *Global Change Biology*, vol. 18, no. 11, pp. 3317–3331.

Evans, CD, Monteith, DT, & Cooper, DM 2005, ‘Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts’, *Environmental Pollution*, vol. 137, no. 1, pp. 55–71.

Hall, BD, Aiken, GR, Krabbenhoft, DP, Marvin-DiPasquale, M, & Swarzenski, CM 2008, ‘Wetlands as principal zones of methylmercury production in southern Louisiana and the Gulf of Mexico region’, *Environmental Pollution*, vol. 154, no. 1, pp. 124–134.

Karlsson, J, Byström, P, Ask, J, Ask, P, Persson, L, & Jansson, M 2009, ‘Light limitation of nutrient-poor lake ecosystems’, *Nature*, vol. 460, no. 7254, pp. 506–509.

Kazanjian, G, Brothers, S, Köhler, J, & Hilt, S 2019, ‘Incomplete resilience of a shallow lake to a brownification event’, , pp. 1–17.

Knorr, KH 2013, ‘DOC-dynamics in a small headwater catchment as driven by redox fluctuations and hydrological flow paths - Are DOC exports mediated by iron reduction/oxidation cycles?’, *Biogeosciences*, vol. 10, no. 2, pp. 891–904.

Köhler, SJ, Kothawala, D, Futter, MN, Liungman, O, & Tranvik, L 2013, ‘In-Lake Processes Offset Increased Terrestrial Inputs of Dissolved Organic Carbon and Color to Lakes’, *PLoS ONE*, vol. 8, no. 8, pp. 1–12.

Kristensen, E, Madsen-ØSterbye, M, Massicotte, P, Pedersen, O, Markager, S, & Kragh, T 2018, ‘Catchment tracers reveal discharge, recharge and sources of groundwater-borne pollutants in a novel lake modelling approach’, *Biogeosciences*, vol. 15, no. 4, pp. 1203–1216.

Kritzberg, ES 2017, ‘Centennial-long trends of lake browning show major effect of afforestation’, *Limnology and Oceanography Letters*, vol. 2, no. 4, pp. 105–112.

Kritzberg, ES & Ekström, SM 2012, ‘Increasing iron concentrations in surface waters - A factor behind brownification?’, *Biogeosciences*, vol. 9, no. 4, pp. 1465–1478.

Kritzberg, ES, Hasselquist, EM, Škerlep, M, Löfgren, S, Olsson, O, Stadmark, J, Valinia, S, Hansson, LA, & Laudon, H 2020, ‘Browning of freshwaters: Consequences to ecosystem services, underlying drivers, and potential mitigation measures’, *Ambio*, vol. 49, no. 2, pp. 375–390.

Laudon, H, Berggren, M, Ågren, A, Buffam, I, Bishop, K, Grabs, T, Jansson, M, & Köhler, S 2011, ‘Patterns and Dynamics of Dissolved Organic Carbon (DOC) in Boreal Streams: The Role of Processes, Connectivity, and Scaling’, *Ecosystems*, vol. 14, no. 6, pp. 880–893.

Lebret, K, Langenheder, S, Colinas, N, Östman, Ö, & Lindström, ES 2018, ‘Increased water colour affects freshwater plankton communities in a mesocosm study’, *Aquatic Microbial Ecology*, vol. 81, no. 1, pp. 1–17.

Leech, DM, Pollard, AI, Labou, SG, & Hampton, SE 2018, ‘Fewer blue lakes and more murky lakes across the continental U.S.: Implications for planktonic food webs’, *Limnology and Oceanography*, vol. 63, no. 6, pp. 2661–2680.

Madsen-Østerbye, M, Kragh, T, Pedersen, O, & Sand-Jensen, K 2018, ‘Coupled UV-exposure and microbial decomposition improves measures of organic matter degradation and light models in humic lake’, *Ecological Engineering*, vol. 118, no. December 2017, pp. 191–200. Available from: https://doi.org/10.1016/j.ecoleng.2018.04.018.

Meyer-Jacob, C, Tolu, J, Bigler, C, Yang, H, & Bindler, R 2015, ‘Early land use and centennial scale changes in lake-water organic carbon prior to contemporary monitoring', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 112, no. 21, pp. 6579–6584.

Mzobe, P, Berggren, M, Pilesjö, P, Lundin, E, Olefeldt, D, Roulet, NT, & Persson, A 2018, 'Dissolved organic carbon in streams within a subarctic catchment analysed using a GIS/ remote sensing approach', *PLoS ONE*, vol. 13, no. 7, pp. 1–20.

Oni, SK, Tiwari, T, Ledesma, JLJ, Ågren, AM, Teutschbein, C, Schelker, J, Laudon, H, & Futter, MN 2015, 'Local- and landscape-scale impacts of clear-cuts and climate change on surface water dissolved organic carbon in boreal forests', *Journal of Geophysical Research G: Biogeosciences*, vol. 120, no. 11, pp. 2402–2426.

Palviainen, M, Laurén, A, Launiainen, S, & Piirainen, S 2016, 'Predicting the export and concentrations of organic carbon, nitrogen and phosphorus in boreal lakes by catchment characteristics and land use: A practical approach', *Ambio*, vol. 45, no. 8, pp. 933–945.

Sarkkola, S, Nieminen, M, Koivusalo, H, Laurén, A, Kortelainen, P, Mattsson, T, Palviainen, M, Piirainen, S, Starr, M, & Finér, L 2013, 'Iron concentrations are increasing in surface waters from forested headwater catchments in eastern Finland', *Science of the Total Environment*, vol. 463–464, pp. 683–689. Available from: http://dx.doi.org/10.1016/j.scitotenv.2013.06.072.

Schelker, J, Öhman, K, Löfgren, S, & Laudon, H 2014, 'Scaling of increased dissolved organic carbon inputs by forest clear-cutting - What arrives downstream?', *Journal of Hydrology*, vol. 508, pp. 299–306. Available from: http://dx.doi.org/10.1016/j.jhydrol.2013.09.056.

Sepp, M, Kõiv, T, Nõges, P, & Nõges, T 2018, 'Do organic matter metrics included in lake surveillance monitoring in Europe provide a broad picture of brownification and enrichment with oxygen consuming substances?', *Science of the Total Environment*, vol. 610–611, pp. 1288–1297. Available from: https://doi.org/10.1016/j.scitotenv.2017.08.179.

Sherry Schiff, Ramon Aravena, Eric Mewhinney, Richard Elgood, Barry Warner, Peter Dillon, ST 1998, 'Precambrian Shield Wetlands: Hydrologic control of the sources and export of dissolved organic matter'.

Škerlep, M, Steiner, E, Axelsson, AL, & Kritzberg, ES 2019, 'Afforestation driving long-term surface water browning', *Global Change Biology*, , no. July 2019, pp. 1390–1399.

Sørensen, R, Meili, M, Lambertsson, L, & Brömssen, C Von 2009, 'The Effects of Forest Harvest Operations on Mercury and Methylmercury in Two ...', *Library*.

Swedish water and wastewater Association 2020, 'Produktion av dricksvatten'. Available from: http://www.svensktvatten.se/fakta-om-vatten/dricksvattenfakta/produktion-av-dricksvatten.

Tiwari, T, Sponseller, RA, & Laudon, H 2019, 'Contrasting responses in dissolved organic carbon to extreme climate events from adjacent boreal landscapes in Northern Sweden', *Environmental Research Letters*, vol. 14, no. 8.

Trigal, C, Hallstan, S, Johansson, KSL, & Johnson, RK 2013, 'Factors affecting occurrence and bloom formation of the nuisance flagellate Gonyostomum semen in boreal lakes', *Harmful Algae*, vol. 27, pp. 60–67. Available from: http://dx.doi.org/10.1016/j.hal.2013.04.008.

Tuvendal, M & Elmqvist, T 2011, ‘Ecosystem services linking social and ecological systems: River brownification and the response of downstream stakeholders’, *Ecology and Society*, vol. 16, no. 4.

Ukonmaanaho, L, Starr, M, Lindroos, AJ, & Nieminen, TM 2014, ‘Long-term changes in acidity and DOC in throughfall and soil water in Finnish forests’, *Environmental Monitoring and Assessment*, vol. 186, no. 11, pp. 7733–7752.

UNDP 2015, *Sustainable development goals*. Available from: https://www.undp.org/content/undp/en/home/sustainable-development-goals.html.

Weyhenmeyer, GA, Fröberg, M, Karltun, E, Khalili, M, Kothawala, D, Temnerud, J, & Tranvik, LJ 2012, ‘Selective decay of terrestrial organic carbon during transport from land to sea’, *Global Change Biology*, vol. 18, no. 1, pp. 349–355.

Weyhenmeyer, GA, Müller, RA, Norman, M, & Tranvik, LJ 2016, ‘Sensitivity of freshwaters to browning in response to future climate change’, *Climatic Change*, vol. 134, no. 1–2, pp. 225–239.

De Wit, HA, Valinia, S, Weyhenmeyer, GA, Futter, MN, Kortelainen, P, Austnes, K, Hessen, DO, Räike, A, Laudon, H, & Vuorenmaa, J 2016, ‘Current Browning of Surface Waters Will Be Further Promoted by Wetter Climate’, *Environmental Science and Technology Letters*, vol. 3, no. 12, pp. 430–435.

Xiao, YH, Räike, A, Hartikainen, H, & Vähätalo, A V. 2015, ‘Iron as a source of color in river waters’, *Science of the Total Environment*, vol. 536, pp. 914–923. Available from: http://dx.doi.org/10.1016/j.scitotenv.2015.06.092.

Kaela Chileshe

HÖGSKOLAN
I HALMSTAD

Besöksadress: Kristian IV:s väg 3
Postadress: Box 823, 301 18 Halmstad
Telefon: 035-16 71 00
E-mail: registrator@hh.se
www.hh.se