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The effects on DOC export to boreal streams, caused by forestry

(Photo: Erik Holm)

Foto: Björn Olofsson

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I denna rapport redovisas ett examensarbete utfört vid Institutionen för skogens ekologi och skötsel, Skogsvetenskapliga fakulteten, SLU. Arbetet har handletts och granskats av handledaren, och godkänts av examinator. För rapportens slutliga innehåll är dock författaren ensam ansvarig.

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

Preface

This study is a thesis in soil and environmental science comprising 30 hp and is performed at the department of forest ecology and management, Swedish university of agricultural sciences (SLU), Umeå. The thesis is a part of the 277 Balsjö research experiments, which in its turn is a part of the EU-Life-Forest for Water project, a project with the purpose to adapt modern forestry to the European water frame directive.

I would like to thank everyone that has been involved and helped me in my work! My supervisor Hjamlar Laudon for great support and introducing me to the Balsjö projects, which was the kind of work I was searching for. Then my examiner Tord Magnusson for the viewpoints he gave me.

I also would like to thank Jakob Schelker, Peder Blomquist, Mahsa Haei and Anneli Ågren that really have helped me a lot when working with the data, and Kevin Bishop for a short but valuable dialogue. Finally I would thank Ida Taberman and Viktor Sjöblom for introducing me in the field and laboratory work.

Erik Holm
Umeå, February 2010

Abstract

The thesis is about forestry and its effects on the export of Dissolved Organic Carbon (DOC) to stream water. Forestry is of large importance for the Swedish society and important for our economy. But there are also some ecological drawbacks with the industry. This thesis is set out to test how we can manage forestry in a more sustainable way. A well known consequence of clear cutting is a groundwater table rise because of decreased evapotranspiration and a higher snow accumulation in the clear cut area when the trees are felled. With a higher groundwater table there will be an increased runoff of water to the streams, and superficial DOC rich soil layers will be connected to the soil water and export more DOC to the stream. With a higher DOC concentration the streams and lakes can turn into CO_2 sources and the physical environments run the risk to be changed. An increased DOC transport can also affect the pH and the transport of metals and organic pollutants.

The sampling area is located in Balsjö 70 km west of Umeå. The area consists of two treated areas, one totally clear cut and one with a buffer zone along the stream. There are also two untreated control areas. To examine the effects of forestry the DOC concentration, estimated from absorbance measurements at 254 nm, is compared between the treated sites and the controls. Automatic water sampling devices (ISCOs) was used in all four sites to collect stream water samples that later was analyzed in the lab. The results show that there are higher concentrations of DOC from the treated sites than the controls. In other words an effect caused by the forestry. But there is also a difference between the controls in DOC export. This difference could derive from different riparian wetlands, which is established as an important DOC source.

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Introduction

Forestry in Sweden

Approximately 70 % of the Swedish land area is covered with boreal forests. Of this share around 80 % is productive with a tree volume growth of > 1 m^3/ha/year. This area constitutes about 23 million ha (Löfgren et al 2009). The forestry and its refining industries are of very large importance for the Swedish economy and occupation. Both the sawmills wood products and pulp is exported to large extent. Nearly 15 % of Sweden's goods exports consist of these kinds of products. The forest is also important for extraction of fuels like chips, pellets and ethanol .

Before industrialization the conifer forests did not have as high value as today. Wood where used in a small scale for house building and as a fuel source. The conifer forests was more seen as an obstruction for agriculture, and farmers was encouraged to burn forests in benefit for agriculture land. Leaf forest on the other hand, special the oak was used for ship building .

It was when sawmills were established in the 19th century that the large Swedish conifer forest became threaten. Later in the same century the pulp industry started. The forest was fast cut down and floated along river-ways to the industries at the coast. The forestry in Sweden has from that time been very exploiting. But since the turn of the century reforestation has been required. At present we have 65 % more forest than in the 1920s, despite much higher rate of forestry

Today the Swedish forests are more than a source of primary products. The demand on environmental consideration is now more important than ever. The forests also give recreation possibilities to many people in the shape of hunting, fishing, hiking, picking berries and fungi's.

In other words modern Swedish forestry now days has to live up to demands on production as well as environmental consideration and recreation.
(www.wikipedia.org).

Hydrology effects by forestry

According to Andréassian (2004) the influence of forestry on forest hydrology is well known. However less is known about the effects on the stream water quality. Forestry is the most important landscape based industry in the boreal region, and the influence of water quality could be substantial. Because of the limited availability of empirical evidence and varying results more data are needed to ensure the expected role of forestry in degrading stream water quality (Laudon et al 2009).

However, according to Sun et al (2001) the effects of forestry on forest hydrology are in the most cases caused by increase in water table level. The reason for this is the sharp decrease in evapotranspiration, because of the removal of trees. The compaction of soils made by heavy machines also leads to a water table rise because of its contribution to the degradation of the drainage capacity. The soil compaction becomes greater with higher soil wetness, clay content and driving intensity of logging vehicles. The increased accumulation of snow in open clear cuts is a further contributing factor to the increased water table (Sørensen et al 2009). The increased water table then leads to an increased runoff (Löfgren et al 2009). Generally, the hydrological effects after harvesting last a few decades, until new forest has been established enough to lower the water table (Andréassian 2004).

Earlier studies from Balsjö have demonstrated an average runoff increase of 35 % on the harvested sites compared with the control sites (Sørensen 2009). According to Seibert et al (2003) is there a clear correlation between the groundwater level and the stream flow. When the groundwater table raises superficial highly conductive soil layers becomes saturated and more groundwater can be horizontally transported to the stream and the flow increases (Seibert et al 2003, Vikberg 2009). This correlation decreases with the distance from the stream, but it is noticeable up to 35 – 60 meters from the stream.

A high water table or flow peak associated with careless driving with forest machines can easily degrade water quality by elevating concentration of suspended particles (Sun et al 2001). The effect is biggest close to streams, and particularly problematic at stream crossings. The machine tracks acts as channels which can lead degraded water with suspended material to the streams (SkogsEko 2007). If the stream water quality is degraded it could cause harm to many stream living organisms (Rivinoja & Larsson 2001).

There is an exception concerning the water table level observed by Sun et al (2001) in some very dark colored soils. The removal of the forest has lead to a drop of the water table because of a higher amount of solar radiation reaching the ground and thereby a bigger absorbance of sunlight which leads to a higher evaporation. Also the increased advection can lead to a higher evaporation (Sun et al 2001).

Depending on the evapotranspiration properties some plant species keep the water table lower than others. The water table rise also depends on the soil texture. After clear cutting on fine mineral soils the water table tends to rise. But after forest harvesting on coarse sandy soils no significant water table rise normally occur (Dubé et al 1995). Dubé et al (1995) also found that during rainy periods the water tables are close to the surface in both clear cut and untreated areas and that the differences between seasonal maximum and minimum in water table depth are usually smaller after clear cutting. The fluctuations in water table depth after clear cutting are also greater the deeper the water table was before clear cutting (Dubé et al 1995). A rise in water table leads to a delay in the establishment of plants and the wood production potential is decreased. The watering up effect can be reduced by drainage ditching, but is still a considerable problem (Dubé et al 1995).

Boreal forest land is a contributor on aquatic ecosystems of nutrients (N and P), organic matter, suspended solids and metals, including base cat ions ($Ca^{2+,}$ $Mg^{2+,}$ Na^{+} and K^{+}), aluminum (Al) and mercury (Hg). Because of the increased runoff caused by the harvest leaching of these elements in dissolved form to stream water will also increase (Löfgren et al 2009). Another effect of the harvest is the increased solar radiation that reaches the ground, which supports the mineralization of organic material and the nitrification in the soil. These processes together will affect the nutrient and acidity dynamics for years after the harvest (Löfgren et al 2009).

Dissolved organic carbon

The organic carbon that occurs in the nature is divided into two groups, Particular Organic Carbon (POC) and Dissolved Organic Carbon (DOC). Together they constitute Total Organic Carbon (TOC). The difference between POC and DOC is that DOC pass through a 0,45 µm filter and POC do not (Ågren 2007). In northern Sweden POC seldom exceeds 5 % of TOC (Ågren 2007). Consequently the value of TOC gives a decent good value on DOC in the boreal part of Sweden. The organic material can also be divided into two other groups based on its origin. The allochthonous material is derived from terrestrial systems and is transported to the stream, while the autochthonous material originates from biological production in the stream. In Boreal regions and especially in streams most of the DOC is of allochthonous origin (Ågren 2007).

Effects caused by DOC

Because the most of the organic material occur in the upper part of the soil profile, in the O horizon (Bishop[1]), especially in the near stream zone more DOC will be washed out to streams and lakes with an increased water table (Löfgren et al 2009). Allochthonous DOC is an important energy source for heterotrophic bacteria in humic lakes and streams. When the DOC concentrations exceed ca 5 mg/l the lake or stream shift from an autotrophy to a net heterotrophy system (Ågren 2007). The net heterotrophy will make the lakes and streams act as net CO_2 sources. Studies indicate on a relationship between higher DOC concentration in lake and stream water and increased CO_2 emissions (Ågren 2007). The DOC transport has because of that been an actual theme in the global warming debate (Ågren 2007). An increased DOC concentration can also change the physical environment in the water. The particles absorbance properties decrease the inflow of light to the water which provides a difficult environment for the phototropic organisms. The increased light absorption also heats up the water which degrades the conditions for several aquatic species (Ågren 2007).

When the organic material in the soil is decomposed hydroxyl (-OH) and carboxyl groups (-COOH) are created. These groups easily release their hydrogen ions (H^+) and they are accordingly acids. The acids has a big variance in size and structure, from humus acids with thousands of carbon atoms to citric, malic and butyric acids with just four to six carbon atoms. The small acids are easily solved in the soil solution and follow the infiltrating water, while the bigger acids are harder solved and to a greater extent stay in the soil (Grip & Rodhe 2003). An increased leach of DOC (citric, malic and butyric acids), and the hydrogen ions from the humus acids has therefore a decreasing pH effect in the reception streams. Especially during the spring runoff, when the flow is higher than normal (Grip & Rodhe 2003, Laudon et al 2004). When the hydrogen ions are released from the hydroxyl and carboxyl groups, metal ions from the soil solution are adsorbed on the negatively charged sites instead and the humus particles act as an ion exchange (Grip & Rodhe 2003). Among the ions in the soil solution even base cat ions occur. These ions are also adsorbed to the hydroxyl and carboxyl groups and transported with the DOC out of the system. This will reduce the acid neutralizing capacity (ANC) in the soil. The base cat ions are stronger attracted to the humus particles than the hydrogen ions and out compete the hydrogen ions from the system. When more basecations are leached from the soil more hydrogen ions are attracted to the humus particles and the soil solution gets furthermore acidic (Grip & Rodhe 2003).

[1]Kevin Bishop Professor SLU, personal communications 2008

The loss of metals even includes pollutants as heavy metals. These pollutants are also transported with the DOC to the recipient (Laudon et al 2004). Also the transport of organic pollutants is affected. This affect on pH, heavy metals and organic pollutants caused by increased transport of DOC will of course affect the biota in the stream or lake (Ågren 2007). Metals like Al and Hg is directly toxic to fish and other water living organisms. Al^{3+} is toxic because it damages the gill tissues on fish. Microorganisms transform Hg to MeHg (methyl mercury) which is more soluble and available for plants and animals. It accumulates in fatty tissues and the concentration increases in the food chain. Furthermore, Al has a strong tendency to hydrolyze (react with water and release protons). Because of that, high Al^{3+} concentrations act as a buffer that strongly counteracts any alkalinizing mechanism, and if such acid stream water high in ionic Al ends up in less acid lake water, it will acidify the lake water (Brady & Weil 2002).

Material and methods

Principal project

The project 277 Balsjö has been ongoing since 2004. The project is about the effects on the leaching of nitrogen (N), phosphorus (P), organic material, basecations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and aluminum (Al) to stream water caused by forestry. In the project the effect of a nutrient catching buffer zone along one of the streams is investigated. Finally the aim is how to manage Swedish forestry in the best ecological way in the future (Ring et al 2007).

The main reason for the project 277 Balsjö is that there are a limited amount of scientific studies of this topic. Also other available data are performed in the Southern Sweden in the 1970s and 1980s, when the environmental consideration was generally less than today. No previous study has been performed north of the river Ljungan and it is uncertain if the results from previous studies are representative for northern Sweden today (Ring et al 2007).

The project 277 Balsjö is included in the EU-Life-project “Forest for Water” (FFW) that aims at testing how to adapt European forestry to the objectives of the Water Framework Directive (Ring et al 2007). The project involves several European countries and is commanded by the Swedish forest agency. All the way from local actors to EU are engaged in the project. The project was in progress between 2003 and 2007 (Swedish Forest Agency 2010).

My thesis refers to the period April 17 to October 31, 2008 of the 277 Balsjö project. I will concentrate on the DOC leach from forested areas and its effects on the stream water quality over time. According to the earlier mentioned effects off increased DOC discharge, DOC seems to be a key factor to understand the efforts needed to minimize the hydrology effects caused by forestry (Hedtjärn 2008). I will also investigate if the buffer zone has a reducing effect on the DOC discharge.

Site description

The sampling area is located in Balsjö, 70 km west of Umeå, Västerbotten northern Sweden (Laudon et al 2009). The area belongs to the mid boreal forest region, a region that consist of fairly hilly terrain with valleys and mountains (Forslund et al 1993). The whole area is a typical

Scandinavian taiga, dominated with spruce (*Picea abies*) and pine (*Pinus sylvestris*). Spruce is mostly growing in the lower and wetter parts, and pine mainly at higher and dryer areas. Even some birch (*Betula*) grows close to the streams. The ground vegetation is dominated by herbs and shrubs as wood sorrel (Oxalis acetosella) cow-wheat (Melampyrum pratense), bilberry (Vaccinum myrtillus), cowberry (Vaccinum vitis-idaea) and closer to the stream cloudberry (Rubus chamaemorus) is found. In the open harvested areas grass such as wavy hair-grass (Deschampsia flexuosa) has become abundant, but also heather (Calluna vulgaris) are widespread (Laudon et al 2009). The annual mean temperature in the region is 0,6˚C, and the annual mean precipitation is 554 mm. The bedrock in the area belongs to the Svekofennian geological province (Loberg 1999). The species of rocks is dominated by granite and granodiorite, except in the northwest were sedimentary rocks such as sandstone, greywacke and clay slate dominates (Geological survey of Sweden 2009). The soil texture is dominated by moraine, but the riparian zones mostly consist of peat soil. Also some bare bedrock occurs, or covered with a thin soil layer (Geological survey of Sweden 2010, Laudon et al 2009).

Figure 1. The location of Balsjö, Västerbotten (Pettersson 2010).

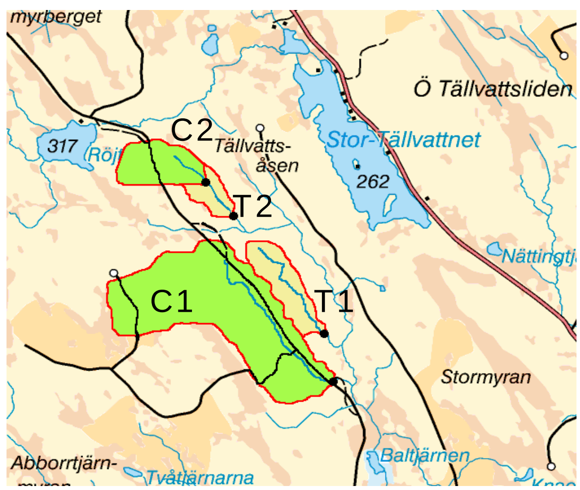

Figure 2. The sampling sites in the project area, Balsjö (Hedtjärn 2007).

Stream water samples are taken from four different sites. Each site represents an area as can be seen in figure 2. Two of the areas are treated by forestry (T_1 and T_2), and the other two are untreated control areas (C_1 and C_2). The size of C_1, C_2, T_1 and T_2 are 320, 25, 37 and 11 ha, respectively. Wetlands is a common feature in this landscape and represents 19%, 13%, 2% and 8% respectively for C_2, C_1, H_2 and H_1 (Laudon et al 2009). The elevation is 297, 292, 275 and 265 meters above sea level at the gauging station for C_2, T_2, C_1 and T_1 respectively (Löfgren et al 2009). The two treated areas are managed in two different ways. T_1 is completely clear cut while T_2 has the earlier mentioned buffer zone along its stream. The buffer zone is approximately 5-10 m wide on each side of the stream (Löfgren et al 2009). The area C_1 and T_1 represents one catchment area each. While the areas C_2 and T_2 make up the same catchment area. The treated area T_2 lays downstream the control area C_2 and the values in C_2 must be involved in the calculations for T_2 to exclude the influence from C_2.

According to Laudon et al. (2009) the DOC export from the four investigated areas, before clear cutting of T1 and T2, was very similar. In March 2006 T_1 and T_2 was treated (clear-felled). On T_1 and T_2 approximately 5400 m^3 and 2200 m^3 of wood where felled respectively (Löfgren et al 2009). 36 % of the total catchment area T_2 and C_2 constitute together was felled and 73 % of T_1. On an average 200 m^3/ha (including bark) were harvested (Sørensen et al 2009). In June 2008 the treated sites were scarified with a disc trencher and at the same time tree seedlings where planted (Löfgren et al 2009).

Picture 1. The buffer zone in T_2 (Photo: Erik Holm).

Picture 2. The stream in T_1 (Photo: Erik Holm).

Sampling

The stream water samples were taken automatically in all four sites using an ISCO sampler at 00:00 and 12:00 every day. All samples were stored in one separate 1 l bottle inside the ISCO. Once a week all the ISCOs and their bottles were emptied. Water from each sample was transferred to one 250 ml bottle. The 250 ml bottle was first rinsed three times with the actual stream water before it was filled. Under base flow only the samples from 12:00 were transferred to 250 ml bottles, but under rain periods and high flows all samples were taken. If the sample from 12:00 for some reason should not have been taken by the ISCO the sample from 00:00 the same day could be taken instead.

The discharge data were collected hourly at 90˚ V-notch weirs by TruTrack (WT-HR 64K) loggers and pressure transducers connected to Campbell (CR10) loggers. These are located at sites C_2, T_2 and T_1. The weirs were calibrated by taking the time it took to fill a bucket with known volume with water. The precipitation measurements for the 277 Balsjö experimental areas were performed by Swedish meteorological service (SMHI). Surrounding SMHI stations were used to give interpolated precipitation data for the area (Schelker[2]).

Lab analysis

The 250 ml bottles were then placed in complete darkness in a refrigerator at 4°C over night. The next day the absorbance was measured at the wavelength 254 nm on the water from the 250 ml bottles. It was done with a Hewlett Packard 8452A diode array spectrophotometer (Laudon et al 2009). The absorbance was used to appreciate a proxy for the DOC concentration under the study period.

Calculations

The absorbance measured by the spectrophotometer is dimensionless and has no unit. To convert these values to get a proxy for the DOC concentration (mg/l) every value is multiplied with 23,5 following, which is the empirical convert factor. Laudon et al (2004) estimated that there is nearly a linear relationship between the DOC concentration and the absorbance at 254 nm, and the factor 23,5 is the mean direction coefficient.

The DOC concentration and the discharge in site T_2 must be recalculated because of influences from C_2. The discharge is recalculated by subtracting the total discharge in T_2 with the discharge in C_2 every hour to get the addition of stream water from the area of T_2 alone. Then the average value for every day is used.
To correct the values on the DOC concentration in T_2 this formula was used:

$$DOC_{T_2} = \frac{DOC_{(C_2+T_2)} * Q_{(C_2+T_2)} - DOC_{C_2} * Q_{C_2}}{Q_{T_2}}$$

Where $DOC_{(C2+T2)}$ and $Q_{(C2+T2)}$ is the total DOC concentration and runoff in site T_2, while DOC_{C2} and Q_{C2} are the DOC concentration and runoff in C_2. DOC_{T2} and Q_{T2} are the DOC concentration and runoff derived for the harvested area alone (Laudon et al 2009).

[2]Jakob Schelker Doctoral candidate SLU, personal communications 2010

As can be seen in the formula both the total DOC concentration from T_2 and the DOC concentration from C_2 is needed for every specific occasion to calculate the DOC concentration for T_2 alone. But this is not always the case. All occasions that just have the sample from one of the sites has been deleted. The curve for site T_2 therefore contains some fewer points.

The logger gives the discharge in l/s every hour. For every 24 hour period a mean value is calculated. The discharge is then recalculated to specific discharge (mm/day). That is done with this formula:

$$Q_{Spec} = \frac{Q * 86400}{A}$$

Where Q_{Spec} is the specific discharge in mm/day, Q is the discharge in l/s, 86400 is seconds per day and A is the catchment area in m^2.

Hypotheses

The hypotheses for this study were:

1. That the raised groundwater level following the harvest has lead to an increased DOC export to the adjacent stream because more superficial DOC rich pathways are activated.

2. The buffer zone in T_2 will reduce the DOC export to the stream.

Results

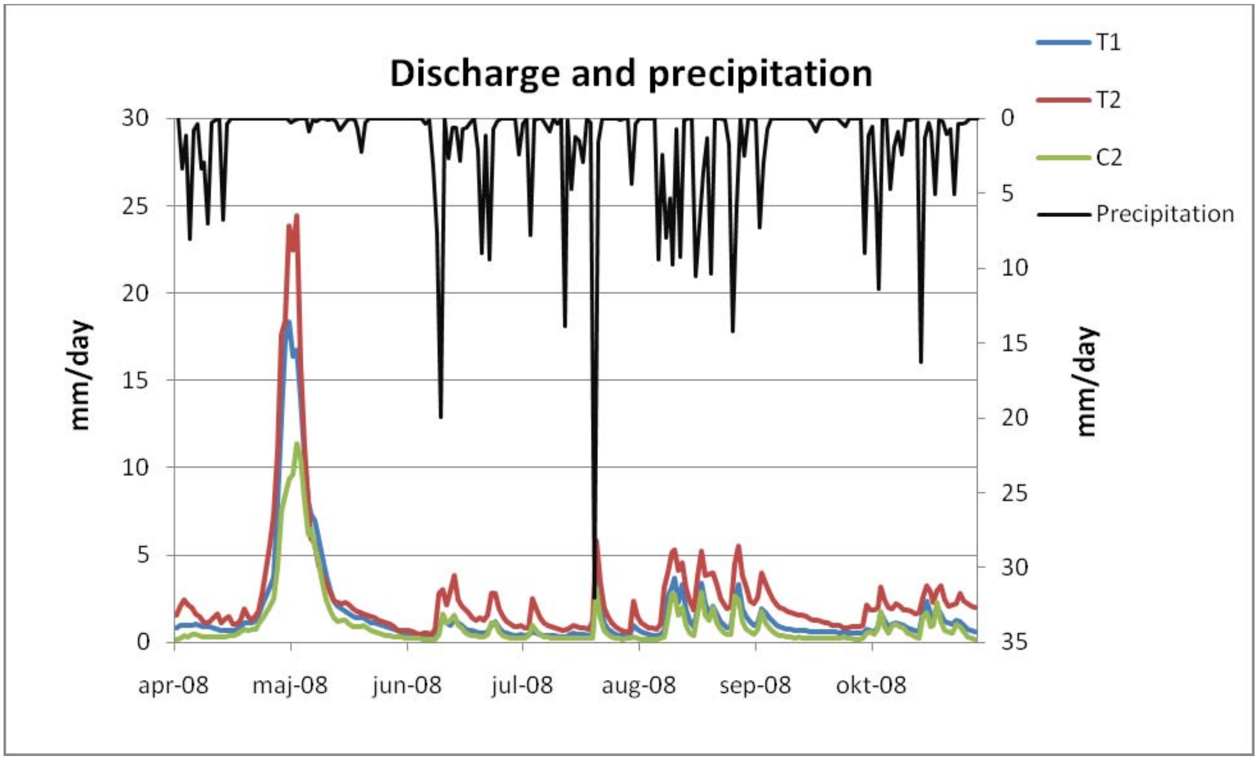

Figure 3. The specific discharge in site T_1, T_2 and C_2 and the precipitation in C_2 from April to October 2008.

The total precipitation throughout the study period from April to October reached 590 mm. There is some precipitation in the first half of April then there is an intermission under the spring flood period. During the whole summer from June to early September there is a lot of precipitation, and then it is a break again until October when there was more rainfall. The four largest precipitation episodes occur between 6th to 26th June, 1st to 22 July, 6th August to 5th September and 1st to 31st October with totally 62, 70, 113 and 70 mm respectively. The difference in specific discharge between the different sites is largest under the spring flow. Site T_2 nearly reaches 25 mm/day at its peak and site T_1 approximately 18 mm/day. C_2 has its peak around 12 mm/day. From June and further there are just smaller peaks in the late July, August and October. T_2 has the highest flow throughout the whole period. The flow in T_1 and C_2 is very close to each other from June to late July, but from August and further T_1 dominates somewhat over C_2.

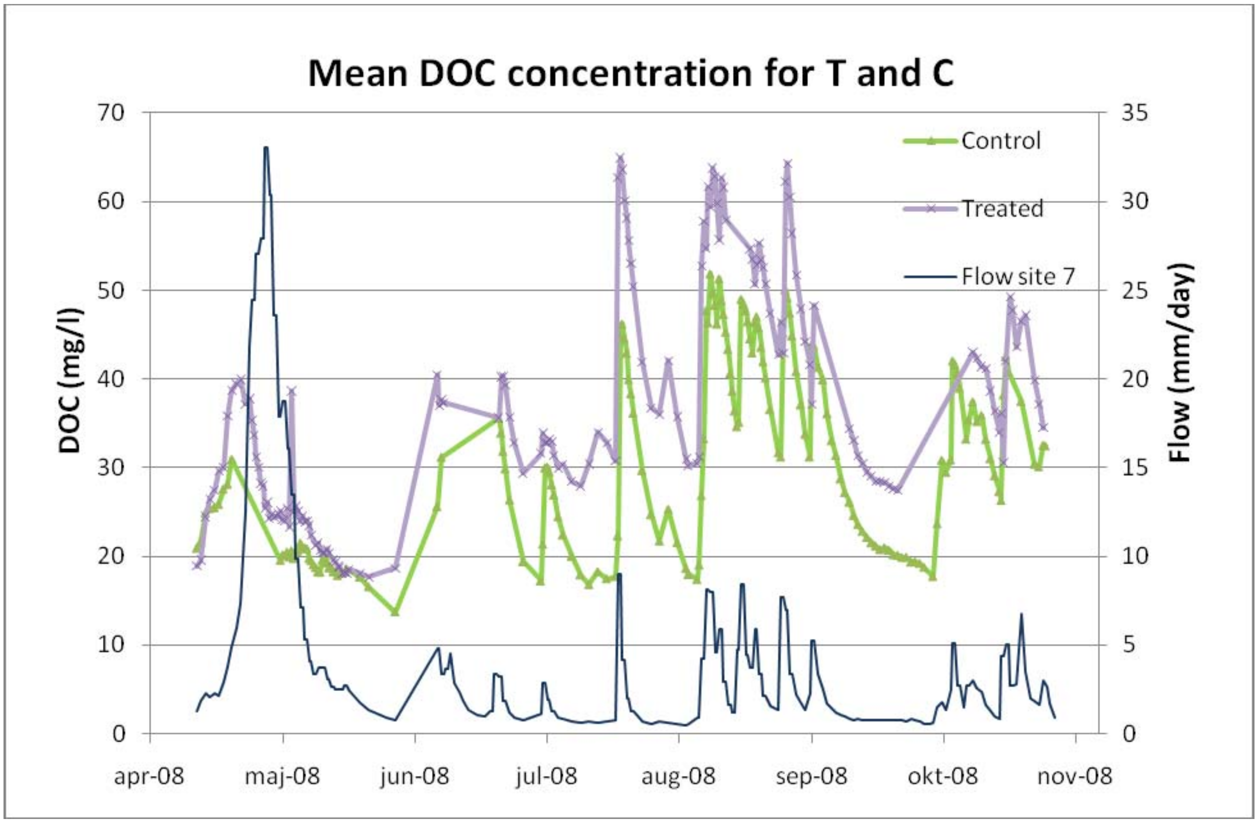

Figure 4. The mean DOC concentration, estimated from absorbance measurements at 254 nm, in C_1 and C_2, T_1 and T_2 and the flow in C_2 from April to October 2008.

When studying figure 4 it's clear that the harvesting has an effect on the DOC concentration in the stream. The mean value for the treated sites is higher than the mean value for the control sites throughout the whole period. The difference between controls and treatments is largest under low flow.

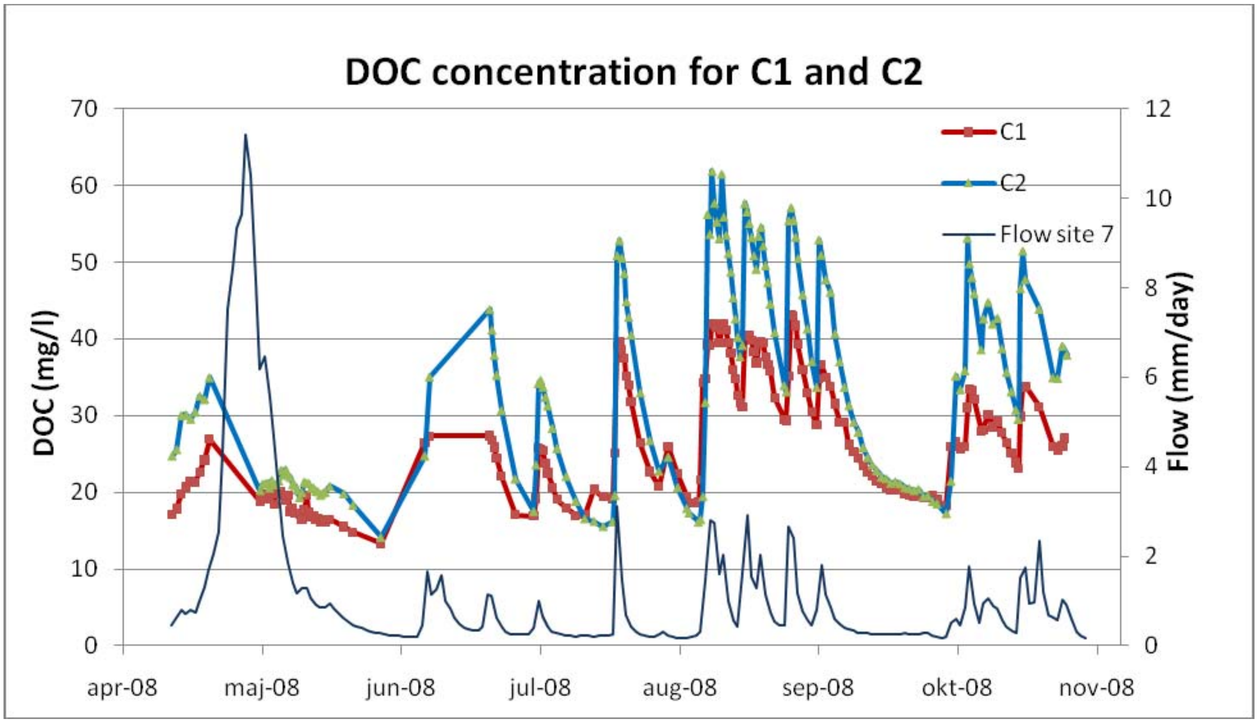

Figure 5. The DOC concentration, estimated from absorbance measurements at 254 nm, in C_1 and C_2 and the flow in C_2 from April to October 2008.

In figure 5 we see that there is a considerable difference in DOC concentration between C_1 and C_2. It's higher in C_2 nearly throughout the whole study period. The difference is biggest under the flow peaks.

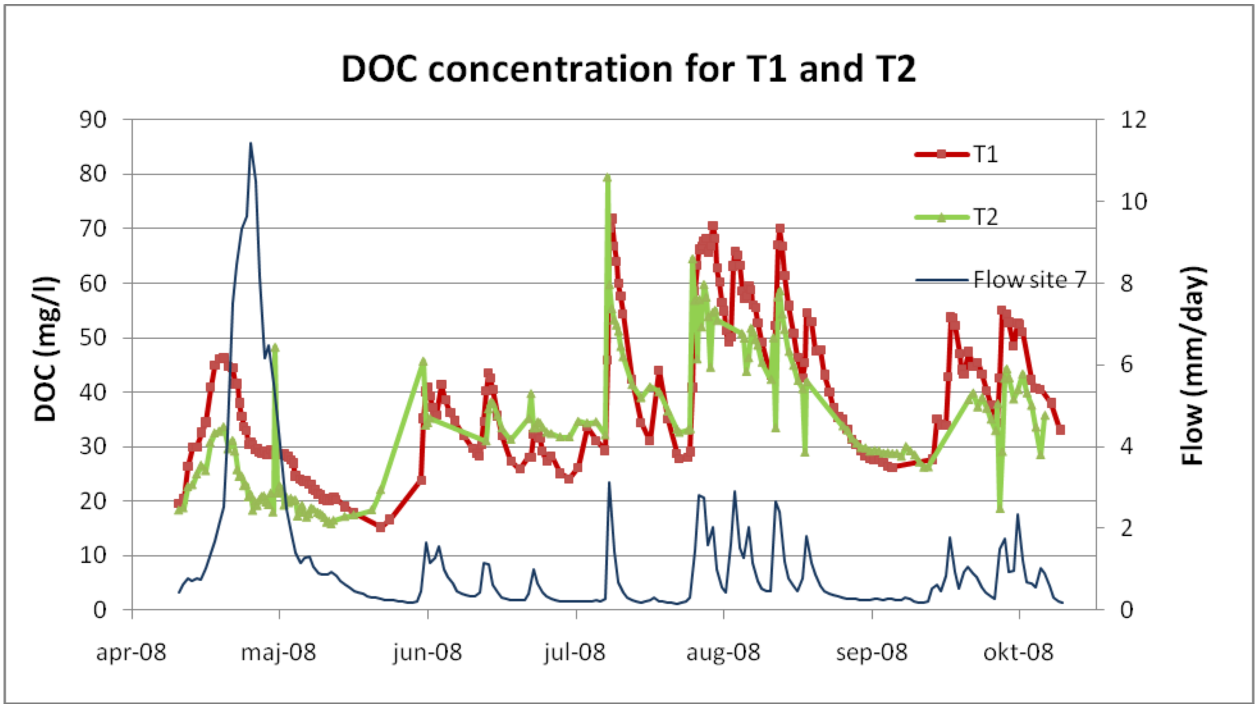

Figure 6. The DOC concentration, estimated from absorbance measurements at 254 nm, in T_1 and T_2 and the flow in C_2 from April to October 2008.

When comparing the DOC concentration for the two treated sites with and without the buffer zone it's totally somewhat higher in T_1, especially during high flows. But the difference is not that big. The mean DOC concentration over the period for T_1 and T_2 is 40 and 33 mg/l respectively. T_2 even exceeds T_1 in the late May, early June, July and mid September.

Discussion

What is then the reason for the observed difference in DOC export between the harvested sites and the controls? The amount of wetlands could be a guess (don't mix up with riparian wetland). But Laudon et al (2009) reject that suggestion. The share of wetlands is much smaller on the treated sites, which export more DOC than the controls. The share of wetland is 8 and 2 % for T_1 and T_2 respectively. While its 13% and 19 % for C_1 and C_2 respectively. Laudon et al (2009) also states that the DOC export was nearly similar from the four sites before harvest, and as we have established the clear cuts export a lot more DOC after harvest. In other words there should be another DOC source in the relatively wetland poor catchments. The wetlands are also nearly treeless and the hydrology should not be that affected when harvested (Laudon et al 2009).

In this study the DOC concentration in C_2 is higher than in C_1 nearly throughout the whole study period, as can be seen in figure 5. The difference in DOC concentration between the controls can probably be explained by the suggestion of Inamdar and Mitchell (2006) who points out the riparian zones in the stream valley bottoms as the main DOC source. According to this we can probably suppose that C_2 has a higher share of riparian wetland than C_1. The correspondence between increasing DOC concentrations in adjacent stream and water table rise indicates a DOC export from these riparian areas. The riparian wetlands are even suggested to be the most important DOC source in boreal catchments (Laudon et al 2004). Under the summer months when there is a balance of moist, heat and access to organic matter the decomposing organisms will thrive in the riparian wetland and a lot of DOC will be produced. When the flow peaks appear and nearly saturates the riparian zone a lot of this DOC is washed out to the stream (Schelker[3]). Under the high flow episodes previously unleashed uphill areas are conducted to the leaching water and a larger area will contribute to the runoff. This will of course activate new unleashed DOC sources, and the quantity of DOC leached to the stream will increase (Inamdar et al 2004).

The discharge is higher in T_2 than T_1 throughout the whole period which may seems strange because T_2 has the buffer zone which should decrease the discharge. At the same time the DOC concentration totally seems to be somewhat higher in T_1 than in T_2, which also is counterintuitive. Shouldn't the highest flow be caused by elevated groundwater levels that cause an increased discharge through superficial, DOC rich soil layers and export the highest DOC concentration as Seibert et al (2003) states? According to Schelker[4] it could be explained by deep ground water movements several meters down in the soil. These deep layers are DOC poor and very low amounts of DOC are leached with the water when it reaches the stream in T_2 from below.

The observed difference in DOC concentration between treated and control sites can partially be described by changes in the microclimate. The trees in the uncut forest act as a shelter for temperature fluctuations. When the forest is cut down the soil is more exposed to solar radiation. This leads to a heat up in the soil during day time (Kubin & Kemppainen 1991). The combinations of the heat up in the soil and wetter conditions tend to increase the biological activity, which also increase the DOC production (Christ & David 1996). After clear cutting residues are normally left on the ground, which can be expected additional DOC sources.

[3]Jakob Schelker Doctoral candidate SLU, personal communications 2009
[4]Jakob Schelker Doctoral candidate SLU, personal communications 2010

Another explanation for elevated DOC concentrations in stream water is that when the trees are cut down much more precipitation reaches the ground. When the forest covers the ground much of the precipitation are assembled on the trees and then evaporated, so called interception evaporation. When the ground receives more precipitation, more water percolates trough the ground and more DOC are washed out to the streams (Hedtjärn 2007). According to Piirainen et al (2002) the increased DOC concentrations after clear cutting could be a result of both leached soluble organic material from the O horizon as well as decomposed logging residuals.

On the other hand Palviainen et al (2004) found that the decomposition was slower for a clear cut area than a forest area. The reason for this should be that a greater amount of solar radiation reaches the ground when the trees are felled and leads to an increased evaporation. This makes the soil surface conditions dryer, especially at higher elevations and the decomposing organisms will be exposed to water stress. Even the frequency of frosty nights increases and is also unfair to the decomposing organisms (Palviainen et al 2004). According to this decomposed logging residuals may not be the answer to the increased DOC export in the treated sites. The theory of a higher amount of precipitation reaching the ground and percolating trough the soil leading to more DOC being washed out with the water sounds more probable (Hedtjärn 2007, Piirainen et al 2002).
The buffer zone in T_2 has not had the expected reducing effect in DOC leaching demonstrated by the marginal difference in DOC concentration between T_1 and T_2. The buffer zone is either too thin to keep the water table low enough, or is not affecting the factors determining the DOC export.

Conclusions

The purpose of the study was to examine the effect on DOC concentration caused by forestry. It is clear that the treated sites have higher concentrations of DOC, and that the harvesting has an effect. The absence of trees both elevates the groundwater level because of decreased evapotranspiration, and more precipitation infiltrates the ground because of decreased shelter from the tree canopy. As a consequence more DOC are washed out to the streams. Not only forestry affects the DOC transport. A high amount of riparian wetland also increases the DOC production. That’s the reason for high DOC concentration also in C_2. A high discharge doesn’t necessarily mean a high DOC export. Discharge can come from below the stream through DOC poor soil layers. The expected effect of the buffer zone was marginal, it’s probably too thin to decrease the ground water table and reduce the DOC transport.

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