The impact of long-term agricultural drainage on concentration and composition of Dissolved Organic Carbon (DOC) in a boreal peatland in western Newfoundland

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Abstract

Although peatlands cover only 2.84% of the world's land area, they play a key role in the global C cycle and store one-third of the global soil carbon.

Dissolved Organic Carbon (DOC) is one of the available forms of carbon in peatlands, which is lost from the peatland together with other forms of carbon, including dissolved inorganic carbon (DIC) and as the gases carbon dioxide (CO_2) and methane (CH4). DOC contains both biologically available (labile) and recalcitrant components. In peatlands, the influence of DOC on the C cycle is more significant than in terrestrial and aquatic ecosystems, and thus understanding of any changes in DOC quality induced by peatland drainage is critical.

The quality and quantity of DOC determine the further role of DOC in biogeochemical cycles. Accordingly, this study investigated the effects of agricultural drainage on DOC in a boreal peatland in western Newfoundland, by quantifying (concentration) and qualifying (composition) of DOC in two drained and natural peatland sites. The effect of microforms in the natural site on quality and quantity of DOC, was also examined.

This study showed that long-term drainage increased DOC concentration both at the peat surface (10 cm) and at a depth of 40 cm by 32% and 47%, respectively. The quality of DOC was also affected by agricultural drainage and microforms (hummock or hollow). Agricultural drainage reduced the DOC aromaticity and transformed DOC from refractory to labile forms. In the natural sites, hummock had higher DOC concentration and showed more recalcitrant and humified DOC.

Although DOC in both the drained and the natural site was mainly plant-driven regardless of the different vegetation compositions and microforms, DOC at the drained site was of a plant-derived source over microbially processed DOC throughout the peat layers. Increasing DOC concentration

following agricultural drainage shifts the Dissolved Organic Matter (DOM) from the microbial-derived source to a plant-derived source. Similarly, agricultural drainage increased the degree of humification at both peat depths.

Comparing two different depths of sampling revealed that the shallower sampling depth had greatest differences in DOC quantity and quality across the drained and natural sites. It means that the variation in DOC caused by any management changes has an intensive effect on shallower peat layers. Furthermore, there is more humified microbially-sourced DOC found at the deeper peat layers. Results also demonstrated the different DOC concentration and composition associated with different plant communities in the drained site and different microforms in the natural site.

Our study showed that establishment of reed canary grass followed by drainage in the drained peatland pasture site could introduce labile carbon compounds with a high degree of humification into the belowground environment during the growing season.

Results of this study support the fact that land management activities (such as agricultural drainage) have effects on DOC quantity together with quality of peatlands and also have a profound effect in increasing labile DOC at the deeper layers, which can affect the carbon balance of boreal peatland ecosystems. This raises the possibility of managing the plant community to control DOC concentration to reduce carbon losses from peatlands.

The effect of land management, plant community, and its effects on peat properties should be given more weight in large-scale carbon modeling.

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Contribution Statement

For this work Dr. Jianghua Wu wrote the research grants, developed the layout of this research field trial (set up the experimental design). Dr. Tao Yuan guided using Cytation™ 3 Cell Imaging Multi-Mode Reader. Mr. Gyimah Asare, Mr. Riad Eissa, and Mr. Sepehr Khosravi helped in field data collection.

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1. Introduction

1.1 Background

Peatlands are an important terrestrial carbon store, which constitutes an essential component of the global carbon cycle (Page et al., 2011; Scharlemann et al., 2014). The rate of production and accumulation of organic material far exceeds the rate at which it is degraded and exported which results in pristine peatlands to function as long-term carbon reservoirs (Frolking et al., 2011) which can hold approximately 200-450 Pg C (Gorham, 1991).

The estimated global land surface covered by peatlands is 4.23 million km^2, approximately 2.84% of the world land area (Xu et al., 2018). Peatland area in North America accounts for 31.6% of the global peatlands, which is 5.42% of the land area of North America (Xu et al., 2018). Figure.1 shows the global peatland map, PEATMAP, developed by Xu et al., 2018.

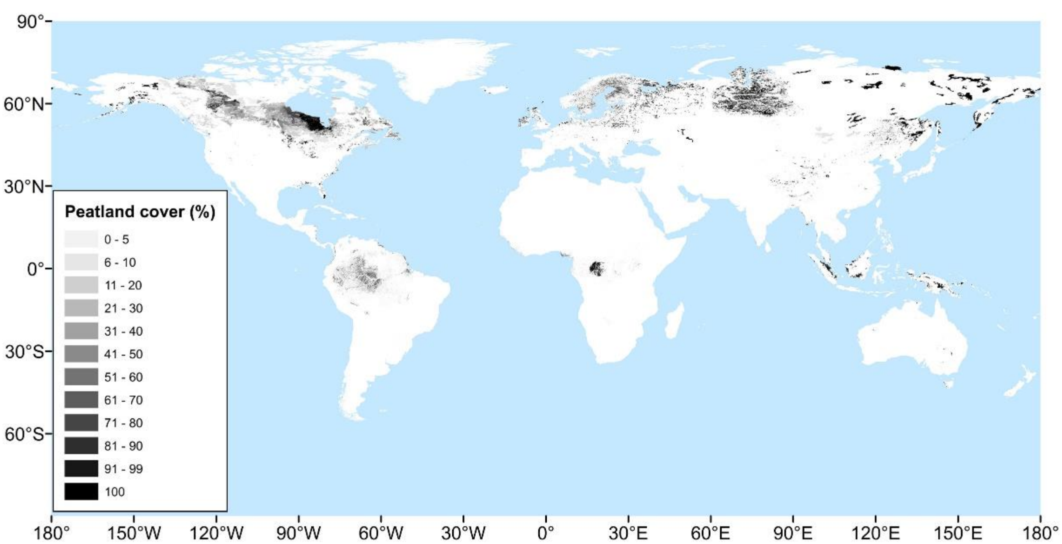

Fig. 1. Global peatland distribution derived from PEATMAP (Morris, 2018).

Northern peatlands, storing about one-third of the global soil carbon (C), between 473 and 621 Gt C, play a key role in the global C cycle, and represent a better long-term storage of C than do mineral soils, which have relatively high organic matter turnover and oxidation rates (Yu et al., 2001). Carbon in peatlands occurs in a variety of forms, with the majority of carbon found as soil organic matter (SOM), and other organic matter (OM), such as plant material. It is also present in a dissolved form, either organic (DOC) or inorganic (DIC), as microbial C, and as the gases carbon dioxide (CO2) and methane (CH4), which together are the primary forms of C that are lost from the peatland ecosystems.

Conventionally, DOC is defined as organic molecules that can pass through a 0.45 µm filter. DOC consists of a variety of molecules that range in size and structure from simple, aliphatic carbon chains (simple non-humic acids and sugars) to complex, aromatic ring structures (humic substances) and therefore contains both biologically available (labile; sometimes referred to high quality) and more recalcitrant components (sometimes referred to low quality) (Kalbitz et al., 2003; Thurman, 2012). The amount of these labile, as opposed to recalcitrant DOC compounds, is vital in the net carbon balance of northern peatland ecosystems under any changes, including climate change or drainage (Dieleman et al., 2016). Thus, concentration and composition of DOC can be varied in soil water according to changing conditions.

Peatlands with carbon-rich soils are a principal source of dissolved organic carbon (DOC) to the fluvial environment, as well. DOC transport could significantly alter the environmental conditions and ecosystem structure of receiving downstream aquatic ecosystems (Wallage, 2007). DOC concentration increase can seriously affect water quality in terms of color, taste, safety, as well as significantly altering the acid-base characteristics of the water, as it contains a large portion of colored humic acid (Freeman et al., 2004). All of these issues are the cause of more concern regarding DOC in the water treatment.

Although in other ecosystems, the influence of DOC pools and fluxes is small, DOC influence on the terrestrial and aquatic C cycles is significant in peatlands (Moore, 2003). While the production and release of DOC is a common natural process in peatlands, scientists have observed elevated DOC concentrations in many locations throughout the boreal zones (Wallage et al., 2006).

Investigation on any changes in DOC quality induced by, for instant, drainage is essential. The quality of DOC determined the further role of DOC in biogeochemical cycles as a terminal electron acceptor for biogeochemical reactions or as a source of energy to both in situ and ex-situ microbial metabolism (Marschner and Kalbitz, 2003; Tfaily et al., 2013). These roles can affect decomposition process pathways and rates and determining the available basal energy in an ecosystem (Dieleman et al., 2016).

1.1.1 Land management changes

For centuries, the artificial drainage of the peatlands has been carried out to satisfy the demands of the agricultural, forestry, and energy industries. The land management strategies of these industries have promoted the degradation of the peatlands (Holden et al., 2004) due to the lowered water table level and shifted the balance of carbon fluxes so that peatlands become net sources of carbon (Hooijer et al., 2012).

As excess moisture is critical to the maintenance of peatlands, they are therefore highly sensitive to changes in the water table (Clark et al., 2009), which can bring necessary transformation for agriculture and forestry (Landry and Rochefort, 2012). Unfortunately, artificial drainage has brought about several negative environmental impacts as well as adverse effects on all aspects of peatlands (Landry and Rochefort, 2012). For example, some studies have shown that the installation of drainage ditches has increased the release of DOC to the fluvial environment (e. g. Worrall et al. (2003); Holden et al. (2004); Wallage (2007); Strack et al. (2008)). The increasing drainage-induced of DOC concentration is not limited simply to the moment of installation, Strack et al. (2008) indicated the higher DOC concentration of pore water even 11 years after initial drainage.

So by increasing DOC flux along with increasing CO2 loss, the terrestrial ecosystem would experience losing valuable carbon stores and increasing levels of secondary environmental degradation. This degradation would happen, because DOC mobilizes metals and pollutants, reduces in-stream light penetration, and has the potential to produce the formation of potentially carcinogenic trihalomethanes (THM) compounds during chlorinated water treatment (Chow et al., 2003; Worrall et al., 2003) which have significant human health implications (Rook, 1977).

It has become increasingly apparent that the degradation of an important terrestrial carbon store following drainage and the associated ecosystem destruction observed is not desirable. Knowledge of how DOC composition and concentration are altered by drainage in peatlands is essential because changes to the character and speciation of DOC will ultimately alter the proportion of labile to recalcitrant compounds, which undoubtedly influences the way that DOC is transferred through the global carbon cycle. Furthermore, in many peatlands, the flux of DOC is of comparable magnitude to the rate of long-term carbon accumulation, and the size of waterborne carbon flux can, therefore, determine whether the site is a carbon sink or source.

Several studies including Strack et al. (2008), Blodau and Moore (2003) and Wallage et al. (2006) worked on effects on drainage along with persistent water table drawdown in surface water and pore water, as well as increased DOC export due to increased surface discharge in growing season from the peatland, although it could be different in a long-term drained peatlands with almost established water table position and different vegetation community which help to decrease surface discharge.

According to Strack et al. (2008), DOC production under lower water table conditions is likely related to an increase in vegetation biomass and more substantial fluctuations in the water table at the experimental and drained sites. Strack et al. (2006) reported that increase vegetation productivity following vegetation community changes in artificially drained peatland (Strack et al., 2006) enhances production and export of DOC (Freeman et al., 2004). Moreover, the initial cause of lowering water table is subsidence, which is owed to peat compression; this is responsible for decreased hydraulic conductivity and increased water table fluctuations (Strack et al., 2008).

Water table depth (WTD) lowering has a significant effect on indices of porewater DOC quality. As a resut of long-term drained site, DOC can be more aromatic, more humified, and also had less phenolic content (Hribljan et al., 2014).

Dieleman et al. (2016) concluded that a lowered water table increased decomposition rates and also have an impact on DOC composition. Furthermore, Hribljan et al. (2014) documented the effect of depth of sampling and WT lowering on $SUVA_{254}$ (Specific UV Absorbance as a measure of DOC aromaticity). Dieleman et al. (2016) also observed lower Fluorescence Index (FI) values (more aromatic carbon, terrestrially sourced) as opposed to higher Humification Index (HIX) values (more humified carbon) under the condition of the lowered water table.

Plant communities contribute not only to ecosystem carbon dynamics by taking up carbon via photosynthesis and carbon release through respiration, but also to peatland belowground carbon dynamics via varying carbon inputs including root excretion of soluble C (Dunn et al., 2016;

Dieleman et al., 2017). Vegetation composition should be taken more into account, as it has been suggested to be one of the determinants of DOC concentration and color of peatland stream water, because the physical and chemical properties of litter, which vary between plant communities, have a strong influence on the rate of decomposition and therefore DOC production (Parry et al., 2015). Also, it is implied that the production of DOC is regulated by the production and decomposition rates of the plants (Dorrepaal et al., 2005; Landry and Rochefort, 2012).

Land management activities have a substantial impact on peatland vegetation coverage, both the extent and the species composition (Munir et al., 2014). Some studies show that there are changes in DOC concentration in association with land management (Armstrong et al., 2010; Worrall et al., 2007; Yallop and Clutterbuck, 2009) which it may be attributable to the effect of vegetation. The effect of plant species on the carbon storage capabilities was also proposed by Dunn et al. (2016). There are changes in the vegetation community in boreal peatlands induced by drainage, which will affect how these ecosystems respond to lowered water table (Munir et al., 2014). Introducing aerobic conditions following lowering WT can generally promote vegetation growth, resulting in increased litter and root exudates that add to the DOC pool (Strack et al., 2008). Drainage-induced changes in vegetation growth led to increased biomass to counteract a portion of soil carbon losses (Munir et al., 2014). Gyimah (2018), also confirmed higher biomass production with a corresponding increase in peat decomposition due to peatland drainage.

Because of the role of the plant community as one of the primary drivers of C cycling in peatlands (Chapin III et al., 1996), an understanding of how the changes in vegetation composition affect DOC, as one of the critical contributors to C cycling, is essential. Moreover, not many studies investigated the relation between peatland vegetation type and DOC concentration (Armstrong et al., 2012a; Parry et al., 2015; Vestgarden et al., 2010) and DOC chemistry (Dieleman et al., 2017).

Besides, the effect of different vegetation composition on the production of DOC and water color from a range of ecosystem have been investigated only in the laboratory (Cleveland et al., 2004; Wickland et al., 2007).

It seems that further work is required at a plot scale to obtain a deeper level of understanding of DOC changes associated with different vegetation communities and individual species.

A reduction or loss of natural carbon sinks and the creation of CO_2 sources represent a significant problem from the standpoint of global climate change, and it is therefore imperative that we improve our understanding of how blanket peat and the fluvial carbon flux responds to water table modification. So, it is important to acknowledge that considering DOC characteristics in association with DOC concentration caused by the land use practice (drainage) based on different vegetation composition, and microforms, is critical to improve an understanding of factors which can have effects on DOC dynamics, and ultimately carbon cycling in peatlands.

1.2 Objectives

The main objectives were to ascertain if peatland drainage, as done for agriculture establishment, differences in vegetation composition and microtopography and have any significant impact on the quantity (concentration) and quality (composition) of DOC.

To achieve this, the main objectives of this study were:

- To assess the principal differences in DOC concentrations and composition, between natural and drained peatlands (site scale) at two different peat depths
- To identify whether changes in pore water DOC concentration and composition induced by drainage varied between peatland microforms and vegetation composition (plot scale)

2. Materials and methods

2.1 Site Description

The research sites are located in Robinson's pasture, western Newfoundland, 100 km southwest of Corner Brook, Newfoundland, and Labrador (48° 15.842'N, 58° 39.913' W). It is an oceanic temperate climate with an annual rainfall of 995 mm, with monthly lowest and highest average temperature of -11 and 21°C in February and August and yearly average temperatures of 5º C (Canadian climate normal data from 1981 to 2010 for the nearest weather station in Stephenville) (Environment Canada, 2011).

The research sites are situated in a peatland complex consisting of an abandoned peatland pasture with active drainage ditches and natural peatlands (Figure 2). The two sites were used to evaluate the effects of artificial agricultural drainage on concentration and composition of DOC: natural peatlands considered as the control; disturbed peatland, which was drained due to agricultural purpose and pasture usage and then converted to drained peatland 35 years ago, and was abandoned after 10 years of active pasture (Luan and Wu, 2014). It is composed of patches of different dominant species, including reed canary grass (*Phalaris arundinacea)* dominated patches, various herbaceous and graminoid species (*Carex* spp., *Ranunculus acris*, *Ranunculus repens*, *Hieracium* sp.) dominated patches, and clumps of low shrubs overtopped by the tall grass, including sweet gale (*Myrica gale*), labrador tea (*Rhododendron groenlandicum*), mountain fly honeysuckle (*Lonicera villosa*), Rhodora (*Rhododendron canadense*), and chokeberry (*Photinia* sp.).

The natural peatland includes some wet depressions and peatland pools. Microtopography, comprising of hummocks and hollows (where the surface is close to the water table and frequently inundated) which exists in the natural peatlands, disappeared in the disturbed peatland (pasture peatland). The hummocks and hollows develop from the peat and remain stable over long periods, even while climate and other environmental conditions change.

The substrate in the natural peatland is predominantly made up of *Sphagnum* species (e.g., *S. capillifolium, S. warnstorfii*), and covered partly with several species of lichens (*Cladina* spp.). Parcels of low ericaceous shrubs such as huckleberries (*Gaylussacia* spp.) are interspersed with a variety of other shrubs (*R. groenlandicum*) and herbs (*Trichophorum cespitosum*) typical of this type of peatland ecosystem on the island of Newfoundland (Luan and Wu, 2014). The hollows are dominated by sedges, while shrubs dominate the dry hummocks. Brown bog moss (*Sphagnum* sp.) occurs on the drier hummocks (namely hummocks where the peatland surface lies at least 20 cm above the maximum water table depth), and many of the same ericaceous shrubs and herbs occur on hummocks, but with lusher and more vigorous growth.

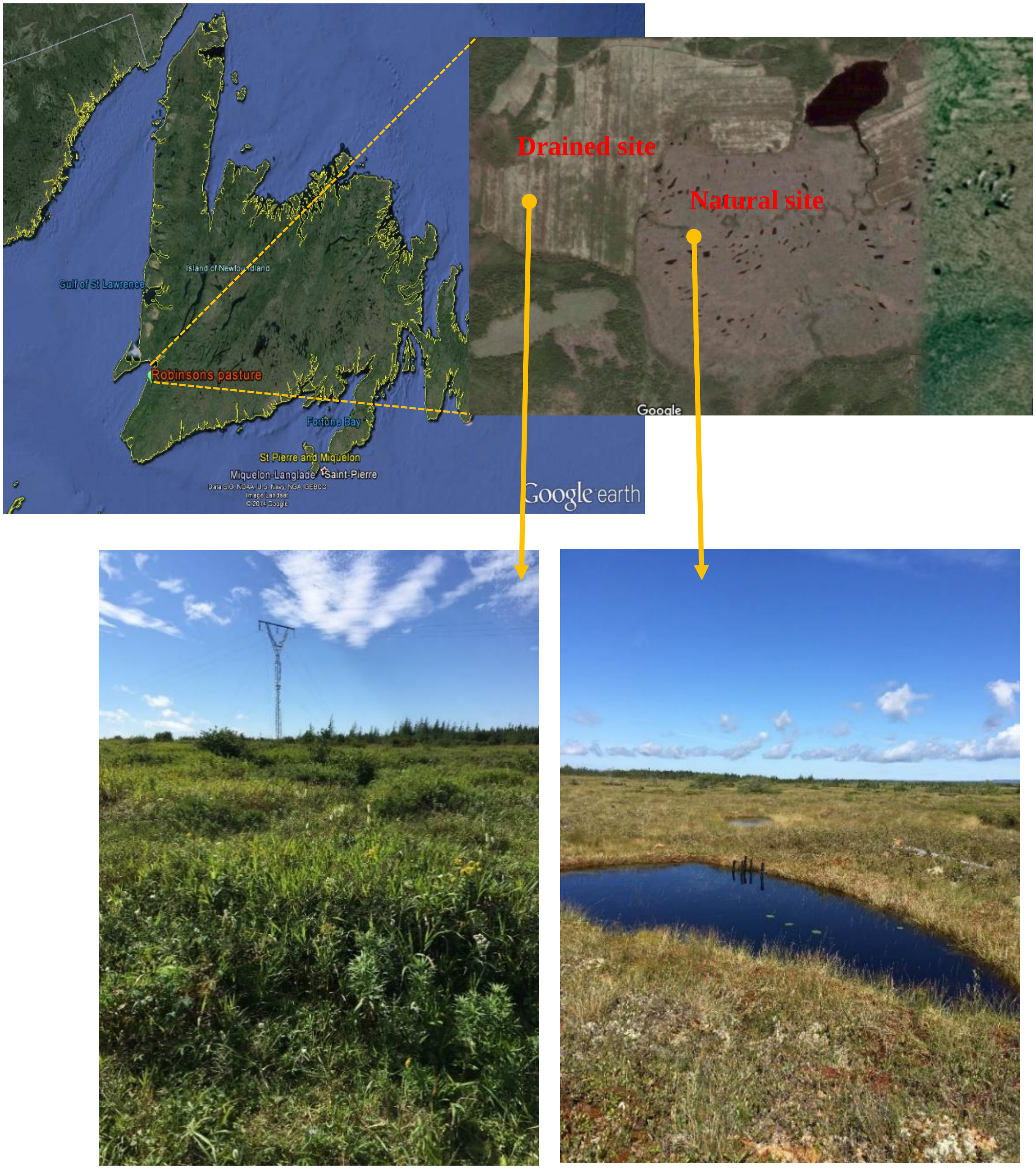

Fig. 2. Satellite image of the research sites (the drained and natural peatland) and pictures of these two research sites. (Photos by the author)

2.2 Experimental Design

The research site consisted of the natural and drained peatland. All measurements were done at these two sites during the growing season of 2016, which was from May to September in this region, on average. Length of growing season in the Atlantic Region including this research area, is measured in days starting from the estimated seeding date (10 days after average daily temperature is above 5°C) until fall frost (minimum daily temperature is 0°C) or until October 31st - whichever comes first (Agriculture and Agri-food Canada). As shown in Figure 3, the growing season number for the research sit is around 150-160 days for this study area based on the Climate change scenario: 2010-2039.

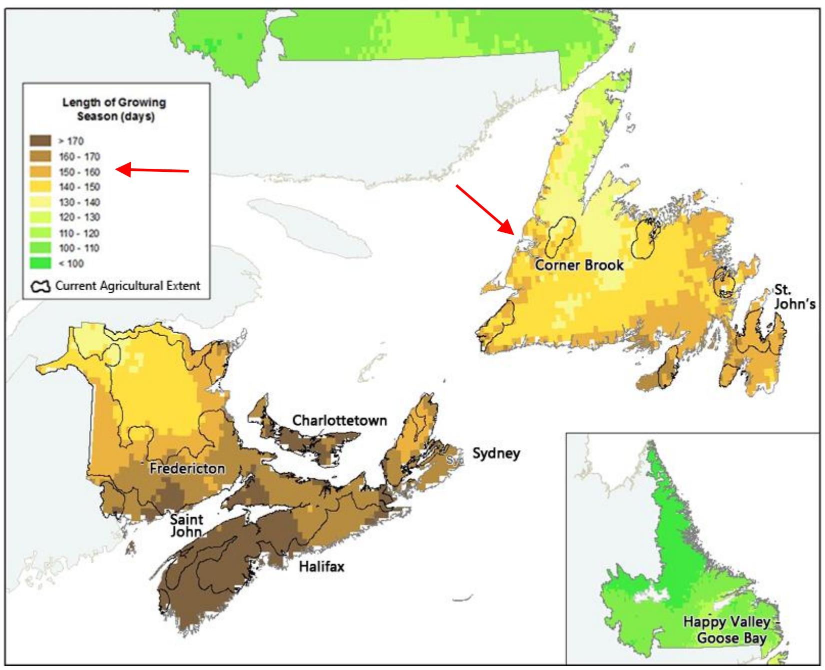

Fig. 3. Growing season (2010-2039) for the Atlantic region (Agriculture and Agri-food Canada).

In Figure 4, the plot design of both research sites is presented. At the drained site, there were three plots considered as three replications and four subplots in each plot to cover four communities, each of which has its dominant species, such as reed canary grass-dominated (Grass), lower herbaceous and graminoid dominated (Herb), sweet gale dominated and labrador tea dominated (Shrub), and drainage ditches (Ditch).

Three plots were also set up in the natural peatland. In each plot, three subplots were set up to cover one hummock, hollow. The subplots were laid out to cover certain dominant species and microforms; hence, there was not any particular pattern for the location of subplots within each plot at both sites. It was a patch of shrub, sedge, and grass within a plot that demonstrated the location of the sedge, shrub, and grass subplots. However, there was a minimum distance of 2 m between subplots. All three replicates of the ditch subplots were located along same ditch, as only one ditch was involved in the sampling. A distance of around 200 m was allowed between the plot layout at the drained site and that of the natural site.

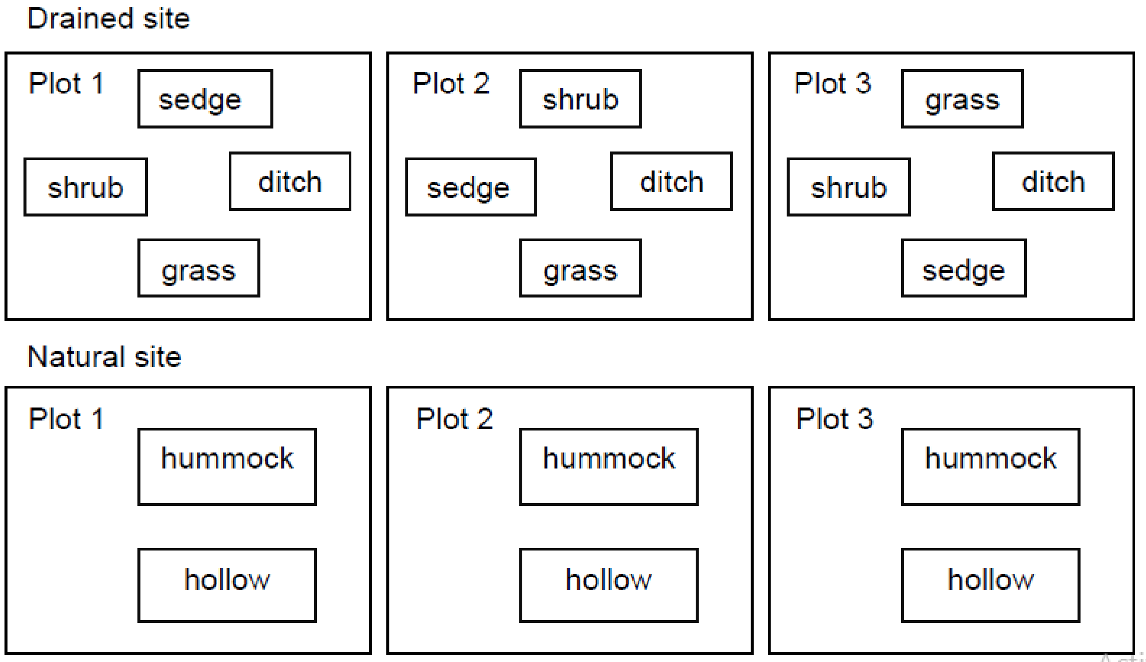

Fig. 4. Experimental design of both the drained and natural sites (not drawn to scale).

In the natural site, two sampling depths at 10-20 cm, representing the oxic layer, and 40-50 cm, representing the anoxic layer, in Hummock (with shrub vegetation), in Hollow (sedge vegetation), and pool (open water) were considered for installation of the samplers. The same sampling procedure was used in the drained peatland in shrub-dominated, grass-dominated, herb-dominated, and ditch (open water). In total, there were 4 treatments at the natural site, and 8 treatments at the drained peatland site.

We used the MacroRhizons(**Rhizosphere** Research Products, Wageningen, **Netherlands)**, with a porous part with an outer diameter of 4.5 mm and a pore size of 0.15 µm, were installed besides each collar to extract the soil water at the 10-15 cm depth. MacroRhizons consist of a microporous tube that is connected to PVC tubing with a male Luer lock that can be attached to a syringe. MacroRhizons are capable of collecting pore-water samples both above and below the water table. Samplings were done by attaching 60mL syringes to each MicroRhizon, which was installed at depth 10-20 and 40-50 cm of soil profile beside each collar, applying vacuum and allowing several hours to collect soil pore water (Fig.5). Soil pore-water samples were transferred to the lab, and were first infiltrated through a Cole-Parmer nylon syringe filter of 25 mm diameter with a pore size of 0.45 μm and then transferred to a 20 ml vial. They kept cool in the fridge until the time of preparation and analysis for DOC. All samples were processed and analyzed within a week after the sampling.

Meanwhile, several environmental factors such as soil temperature at 5 cm depth (T5), Soil moisture (SM), as well as Water Table Depth (WTD) were measured for each subplot. A temperature probe was used to measure the soil temperature at a depth of 5 cm for each subplot, and SM at 5 cm depth were measured at each subplot, using a ProCheck reader (Decagon Devices, USA) connected to a three-pin probe, at the same time when the soil water samples were collected. WTD was measured from the installed perforated pipes using a ruler in each subplot.

Fig. 5. Macrorhizons inserted in (a) the natural and (b) the drained peatland (Photo by author)

2.3 Sample analysis

2.3.1 Measurement of DOC Concentration

Total carbon (TC) in pore water is made up of dissolved organic carbon (DOC), dissolved inorganic carbon, and particulate organic carbon (POC) (i.e. TC= DOC+POC+DIC). When it comes to analyzing the DOC, the other forms of carbon should be removed.

As DOC is commonly defined as organic carbon in water samples smaller than 0.45µm (Thurman, 1985, therefore), the soil water samples passed through a filter membrane which has pores with a diameter of 0.45 µm. The filtered water samples were then measured for the concentration of DOC using a Shimadzu TOC-LCPH analyzer (Shimadzu, Japan). Five concentrations of standard solutions, i.e., pure water, 10, 20, 50, and 100 mg l^{-1} were used to calibrate the DOC analysis. Meanwhile, water samples were acidified (0.1 ml, 2 M HCl) automatically by the machine to remove all dissolved inorganic carbon (DIC).

2.3.2 Estimation of DOC composition indices

In order to yield information on DOC composition: absorbance and fluorescence, samples were analyzed for UV–Vis absorption using Agilent 8453 UV-Visible spectrophotometer (Agilent Technology, San Diego – USA). Absorbance was measured on all samples from λ= 275 to 290 nm (with 1 nm steps) and also 250, 254 and 365 nm on a Varian Cary 100 in a 10-mm quartz cuvette, with distilled water used as blank.

Specific UV absorbance (SUVA) of DOC gives an “average” molar absorptivity for all the molecules contributing to the DOC in a sample, and it is used as a measure of DOC aromaticity (Weishaar et al., 2003). SUVA is determined by dividing UV–Vis absorbance at λ = 254 nm by the sample DOC concentration, multiplied by 100. SUVA values are reported in units of L mg C^{-1} m^{-1}.

$$SUVA = \frac{A254}{[DOC]} * 100$$

Where A254 is the UV–Vis absorbance (cm^{-1}) at λ = 254 nm and [DOC] is the concentration of dissolved organic carbon.

Fluorescence techniques (e.g., synchronous scan and excitation-emission matrix spectroscopy) have been widely used to investigate the sources and optical properties of dissolved organic matter (DOM) or humic substances in aquatic environments (Fellman et al., 2010).

Two indices, Fluorescence Index (FI) and Humification Index (HIX), can be calculated using fluorescence scans. Fluorescence Index (FI) and Humification Index (HIX) can help to investigate the difference in sources and degree of humification.

Indeed, these indices were used to distinguish between microbially derived (FI = 1.5–2.0) and terrestrially-derived (FI < 1.4) aquatic fulvic acids (McKnight et al., 2001).

FI was calculated as the ratio between fluorescence intensities for emission at 470 nm and 520 nm at fixed 370 nm excitation. FI can help to determine the sources of DOC.

$$F = \frac{\mathrm{I}\ 470}{\mathrm{I}\ 520}$$

Furthermore by using fluorescence scans, the HIX, which can be used to represent the relative degree of humification, was calculated as the area under the emission spectra for the range 435–480 nm divided by the sum of the areas for the ranges 300–345 and 435–480 nm, at 254 nm excitation (Ohno, 2002) . The HIX values range from 0 to 1, with a higher value indicating an increasing degree of humification (Olefeldt, Devito, et al., 2013b).

$$HIX = \frac{\sum \mathrm{I}435 - 480}{\sum I300 - 345 + \sum I\ 435 - 480}$$

Where I is the fluorescence intensity at each wavelength (Ohno, 2002).

In order to yield information on DOC Composition, fluorescence was measured on Cytation™ 3 Cell Imaging Multi-Mode Reader which is computer-controlled using Gen5 software.

Fluorescence intensities for each water sample were collected over an emission range from 300 to 480 nm (5 nm increments) at a fixed 254 nm excitation as well as an emission range from 470 to 520 nm (10 nm increments) at fixed 370 nm excitation for calculating the mentioned index (i.e. FI and HIX).

2.4 Data analysis

General linear model (GLM) was run to compare the [DOC] between two sites and among the subplots at the drained and the natural sites in order to investigate the main effect of drainage, depth as well as vegetation composition, day of sampling and the interaction effect of vegetation composition and sampling time on DOC concentration. The comparison was made through Turkey's multiple comparison method to examine which means were different and to estimate how much they were different. Furthermore, similar analyses were run to examine the effect of drainage, depth as well as vegetation composition, time of sampling and the interaction effect of vegetation composition and time of sampling on composition of DOC.

One-way analysis of variance (ANOVA) was conducted to compare the seasonal mean values of the environmental variables, including SM, T_5, and WTD among the subplots of the drained and natural site.

The Pearson correlation analysis (also known as r) used to measure the strength and direction of the association between DOC concentration and the environmental variables (SM, T_5, and WTD).

Furthermore, the main effect of vegetation composition, microforms (subplot scale), and date of sampling on DOC concentration across the 2016 growing season (May – September) was identified through two-way ANOVA, and comparisons of means were made through Tukey pairwise method.

3. Results

3.1 Relation of DOC and Environmental Factors in the drained and natural site

One-way ANOVA indicated that there was a significant difference in the environmental variables including, temperature (T_5), soil moisture (SM), and WTD ($P < 0.05$) among all subplots in drained sites (Table 1).

In the drained site, sedge subplots had a significantly higher T_5 compared with other drained subplots (16.19ºC). The mean T_5 of the ditch subplot (13.49ºC) was found to be the lowest. Ditch subplots also had the highest amount of soil moisture (80.53%), which is statistically different from all other subplots. On the contrary, the mean SM of grass was the lowest (38.52%), while the mean SM of shrub and sedge were statistically identical.

The shallowest average WTD was found in ditch subplots, which is only 3 cm below the reference surface for measuring WTD, which was from the bottom of the ditch where the plants were growing. Grass subplots with average WTD of 13.83 cm were the second shallowest WTD among drained subplots and were significantly shallower than WTD of shrub and sedges subplots (-23.28 cm).

In the Natural site, no significant differences were found in their mean soil temperatures between hummock and hollow subplots ($P = 0.810$).

Table 1. Statistical results of seasonal mean soil moisture (SM) at 0-5 cm depth, water table depth (WTD) and temperature at 5 cm depth (T5) site and subplots scale

	Mean T_5 (ºC)	Mean SM (%)	Mean WTD (cm)
Drained site	14.99 ^{b}	48.42 ^{a}	-16.37 ^{b}
Natural site	16.32 ^{a}	57.68 ^{a}	-24.47 ^{a}
	P =0.006	P =0.001	P =0.001
Sedge	16.19 ^{a}	58.20 ^{b}	-23.28 ^{a}
Shrub	15.09 ^{ab}	54.21 ^{b}	-23.28 ^{a}
Grass	15.16 ^{ab}	38.52 ^{c}	-13.83 ^{b}
Ditch	13.49 ^{b}	80.53 ^{a}	-3.53 ^{c}
	P= 0.002 R^2= 16.42	P= 0.000 R^2= 72.38	P= 0.000 R^2= 51.93
Hummock	16.52 ^{a}	31.49 ^{b}	-33.83 ^{a}
Hollow	16.31 ^{a}	65.35 ^{a}	-15.11 b
	P= 0.810	P= 0.000	P= 0.009

Similar lowercase letters indicate no significant difference while different letters indicate significant difference between the site or subplot averages. *The negative WTD value means that the water level is below ground.

While SM and WTD showed significant differences between these two subplots, WTD was significantly deeper in the hummock subplots (-33.83 cm) compared to hollow subplots (-15.11 cm). Therefore, hollow subplots had significantly higher mean SM in comparison to hummock subplots.

Significant differences were observed between the T_5, SM, and WTD of the drained and natural sites. The natural site experienced significantly higher temperature at the depth of 5 cm and soil moisture (SM) (Table 1). In order to identify the relationship between dissolved organic carbon (DOC) concentration and environmental factors including temperature (T_5), soil moisture (SM), and water table depth (WTD), regression and correlation analysis were conducted.

At the drained site, the results demonstrated that there was a significant positive relationship between soil temperature ($P=0.003$, Fig.6 (a)), WTD ($P=0.019$, Fig.6 (c)), and DOC concentration. Conversly, SM had a negative correlation with DOC concentration ($P<0.001$, Fig.6 (b)). Although the correlation coefficient (r) of each of the environmental parameters showed the effect of all three mentioned parameters on DOC concentration ($r > 0.5$), SM has a stronger relationship with DOC concentration ($r = -0.711$). So, it can be said that SM is a better predictor of DOC concentration which explained almost 50% (R-square) of the variation in DOC concentration at the drained site while T_5 and WTD account for around 30%(R-square) and 21% (R-square) of DOC concentration variation, respectively.

Similar analyses at the natural site did not show any significant correlations between DOC concentration and the environmental variables.

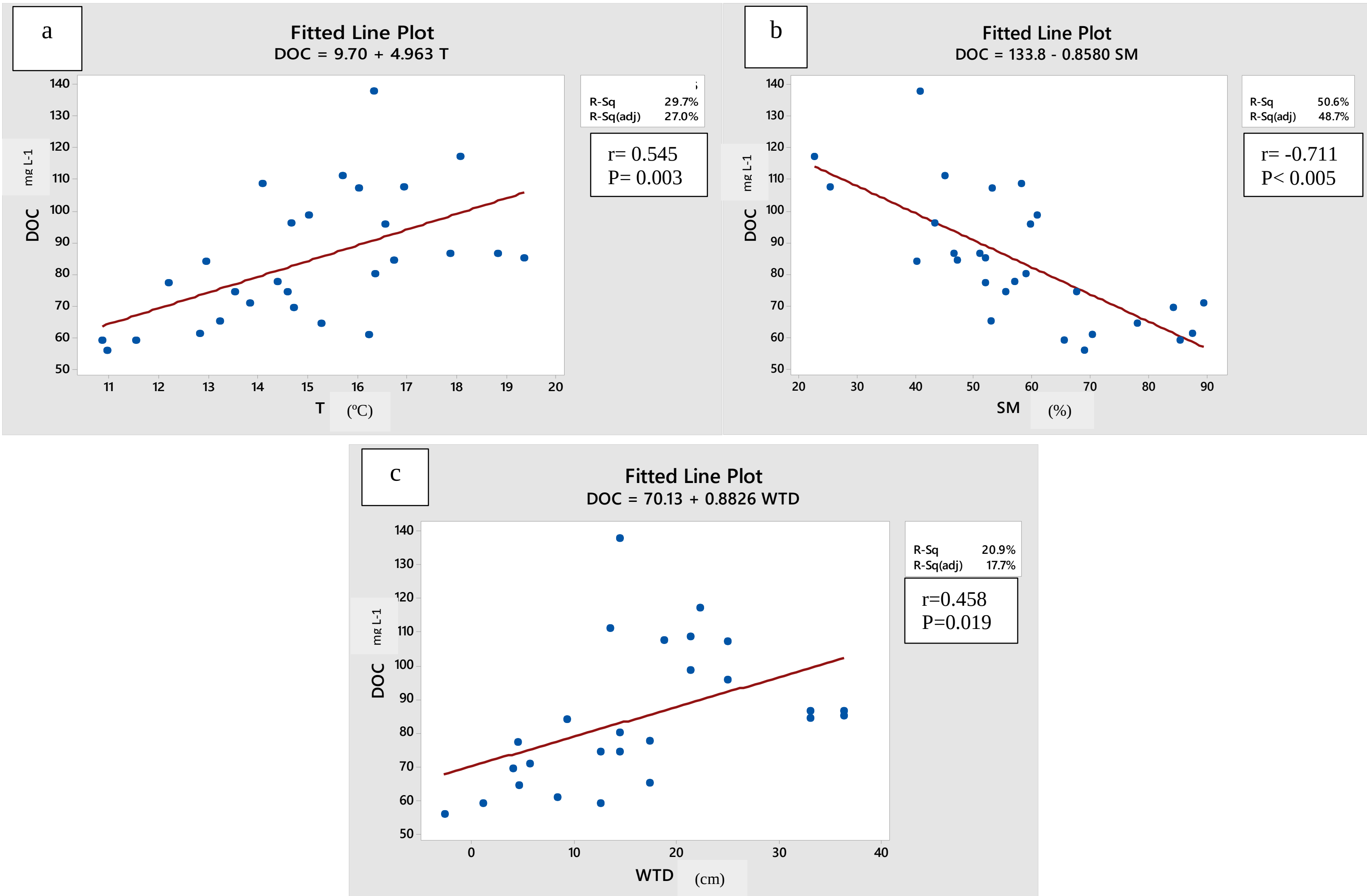

Fig. 6. Correlation between (a) Soil Temperature (T), (b) Soil Moisture (SM), (c) Water Table Depth(WTD) and Dissolved Organic Carbon at the drained site.*All water levels are below ground

3.2 DOC concentration

One-way ANOVA and comparisons of means (Turkey pairwise comparison) were conducted to examine the main effect of drainage on DOC concentration, they were carried at the site scale in both sampling depth (i.e., 10cm and 40cm); the analysis of data showed that the differences between mean DOC concentrations in the drained site and in the natural site were significant at 10 cm ($P< 0.001$) and 40 cm ($P=0.05$) depth. (Fig.7&8, Table 2). Results from shallower sampling depth (10 cm) indicated that the mean DOC concentration from the natural site (55.33 mg L^{-1}), was significantly lower than that one from the drained site (85.89 mg L^{-1}) (Table 2). Likewise, at the deeper sampling layer (40 cm), the drained site showed higher DOC concentration (76.55 mg L^{-1}) as opposed to the natural site (DOC concentration = 40.57 mg L^{-1}) (Fig.8, Table 2). The DOC concentration differed significantly among plots with different vegetation composition in the drained site at the 10 cm depth ($P< 0.001$) (Table 3).

The results, also, showed that the shallower depth (10 cm), had a statistically higher mean DOC concentration at both drained and natural site (Table 2). On average, the deeper depth (40 cm) in the drained site resulted in the lower amount of DOC concentration, which is 76.56 mg L^{-1} as opposed to 85.90 mg L^{-1} at the shallower depth (10cm) (Table 2). Similarly, in the natural site, the mean DOC concentration for samples taken at the 10 cm depth was higher (58.51 mg L^{-1}) than samples taken at the 40 cm depth (40.57 mg L^{-1}) (Table 2). Therefore, when comparing the drained and the natural site, the mean DOC concentration was higher in the drained site rather than in the natural one when sampling the same depth (Fig. 7a and 7b).

The effect of vegetation composition was also observed as significant in the drained site at the deeper sampling layer (40 cm) ($P<0.001$). This significant effect is likely because of a drop in DOC concentration in ditch subplots in comparison with that of the other subplots (at the depth of 10 cm). The exclusion of ditch subplots from analysis resulted in no significant main effect of vegetation composition ($P= 0.086$) (at the depth of 10 cm).

At the 10 cm depth and among all subplots in the drainage site, subplots dominated by reed canary grass (Grass) exhibited the highest mean DOC concentr (104.2 mg L^{-1}). Grass subplots had significant differences with mean DOC concentration of samples from drainage ditch subplots, 65.16 mg L^{-1}. Although herbaceous and graminoid dominated (herb) and sweet gale and labrador tea dominated (shrub) plots did not show any statistically different mean DOC concentrations, there was a significant difference between those and two other subplots (ditch and grass). While grass subplots recorded the highest DOC concentration, the lowest one belonged to drainage ditch subplots, which were one-third lower than mean DOC concentration in grass subplots (Fig. 8, Table 3).

On the other hand, as presented in Table 3, Shrub subplots with mean a DOC concentration of 84.73 mg L^{-1} presented the largest values for DOC concentration among others subplots at the deeper layer of sampling (40cm), but they weren't significantly different from Grass and Sedge subplots (Table 3). Similar to the shallower depth (10 cm), the drained ditch at the 40 cm depth, had the lowest DOC concentration (59.69 mg L^{-1}), which was significantly different from others. (Fig.9 and Table 3). So, it seems that the vegetation composition factor was effective more in changing DOC concentration in the layers near the surface rather than in the deeper layers.

Moreover, based on the results of two-way ANOVA which was conducted to identify the interaction effect of depth of sampling and vegetation composition differences on DOC concentration, it was seen that the interaction between depth and vegetation composition/microforms had a significant effect in both the drained ($P<0.001$) and in the natural site($P<0.001$). This indicates that the effect of sampling depth on DOC concentration was not identical among the subplots. Table 2 also showed that the grass subplot experienced the largest decrease of DOC concentration by increasing the sampling depth (from 10 cm to 40 cm) which was approximately 24.5% decrease. This drop was less than 10% for all other subplots including ditch, sedge, and shrub with 8.5%, 6%, and 8.5% of drop in DOC concentration, respectively. Likewise, hummock and hollow did not have the same trend in decreasing DOC concentration by increasing sampling depth. The mean DOC concentrations were more affected by the increasing sampling depth in hummock (36%), rather than in hollow, in which this drop was recorded to be around 23.5% (Table 2).

The dramatic decrease of DOC concentration that occurred with the increasing depth of sampling in the grass subplot might result in a significant interaction effect of depth of sampling and vegetation composition on DOC concentration (Fig. 8 and Table 3). When the grass subplot was excluded, no significant main interaction effect of vegetation composition and of the depth of sampling was observed on DOC concentration ($P=0.728$), as expected. Indeed, when the grass subplots were ignored, depth had an identical effect on DOC concentration of all the other subplots.

When it comes to the natural site, results showed that in contrast to the DOC concentration from the 10 cm depth at which a significant effect of microforms on DOC concentration ($P= 0.000$) was observed, there was no main effect of different microforms on DOC concentration at the 40 cm depth ($P=0.991$) (Table 3). The results revealed that while the mean DOC concentration in the hummock subplots was 61.60 mg L^{-1} at 10cm depth, the mean concentration of DOC for hollow was statistically lower (49.40 mg L^{-1})at the same depth (Fig.10, Table 3).

Aside from the individual effect of vegetation composition and microtopography on DOC concentration, this effect might vary across the sampling date. Thus, the main effect of the sampling date, as well as the interaction effect between the sampling date and the different vegetation composition / different microforms, was examined through two-way ANOVA.

The date of sampling (Julian Day) had a significant main effect on DOC concentration among the subplots in the drained site at both depths of sampling in this study ($P<0.000$), and in the natural site ($P< 0.002$) at the 10 cm depth, while the date of sampling did not have significant effect on DOC concentration in the natural site at depth 40 cm ($P=0.068$).

In other words, the sampling day will result in statistically different DOC concentrations regardless of different vegetation composition or different microtopography. That means DOC concentration would change considerably among treatments throughout sampling in this research, especially in the layer near the surface; for this reason the temporal variability in DOC concentration should be taken into account.

There was no significant interaction effect between the time of sampling and different subplots with different vegetation composition at the 10 cm ($p = 0.137$) and at the 40 cm ($P=0.938$) depth. Similarly, no significant interaction effect between the date of sampling and different microforms was found at the 10 cm ($P = 0.165$) and at the 40 cm ($P=0.941$) depth. This indicated that the effect of sampling date on DOC concentration was the same for the various Vegetation composition in the drained site or different microforms in the natural site and the changing trend is similar overtime at the depth close to the surface (10 cm). So, only temporal variation (i.e. seasonal pattern) of DOC concentration at subplot and ecosystem scales at the 10 cm depth was investigated in this study (Fig.12 and Fig.13).

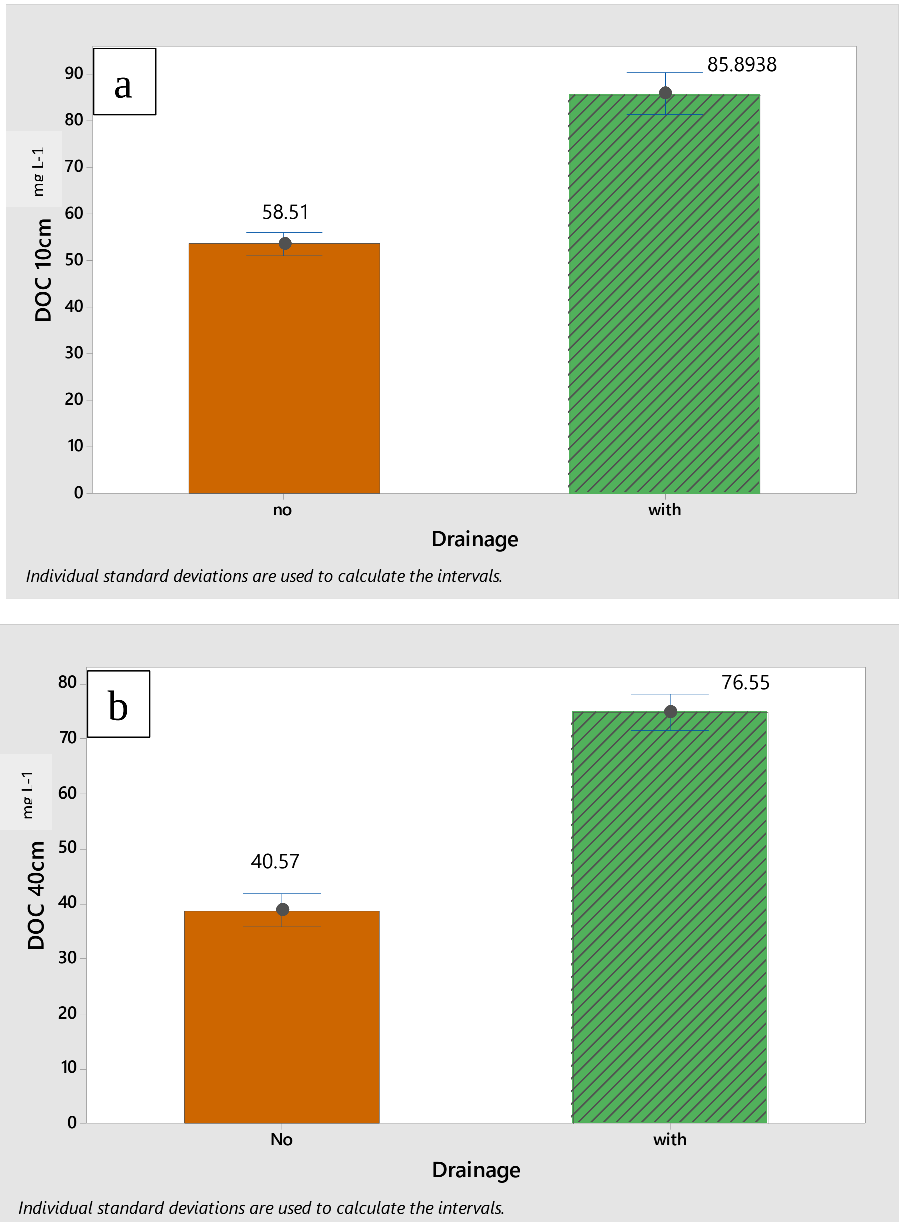

Fig. 7. Dissolved Organic Carbon (DOC) concentration of the drained and Natural Sites at depth 10 (a) and 40 (b) centimeter

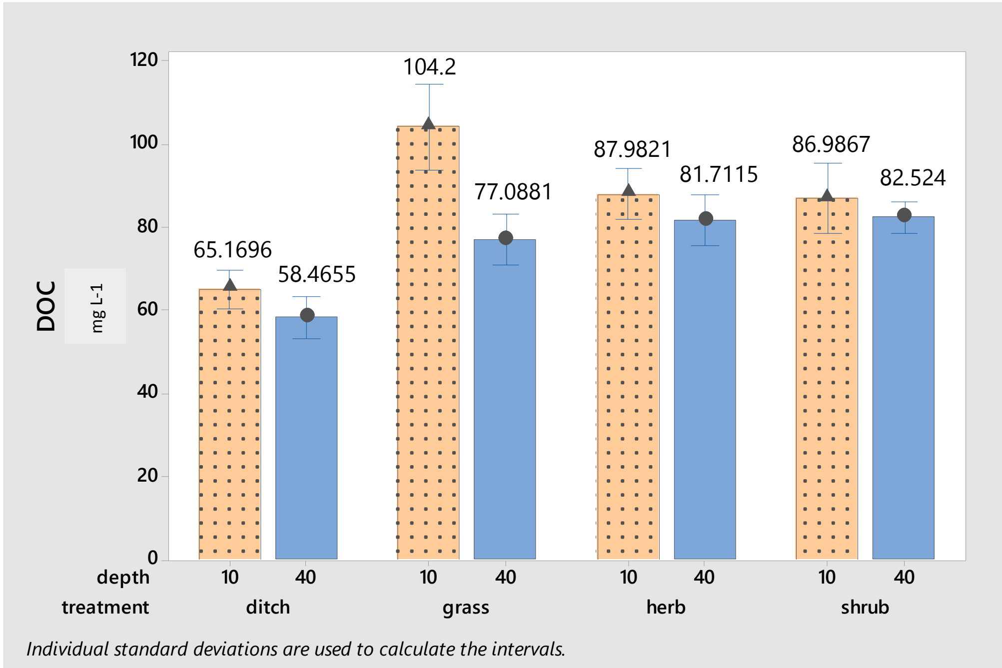

Fig. 8. Dissolved Organic Carbon (DOC) concentration of drained site at depth 10 and 40 centimeters

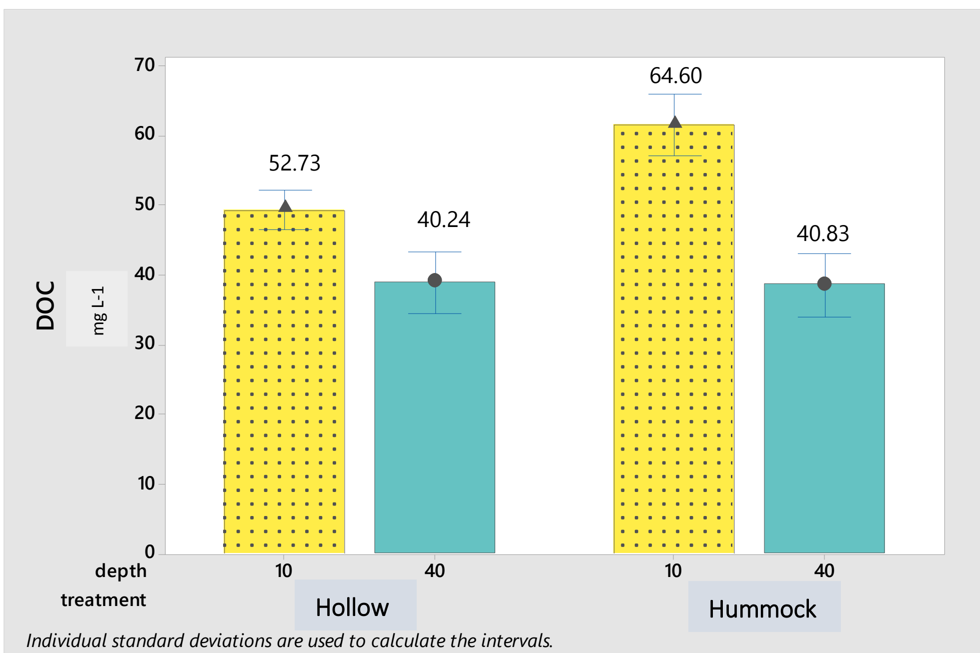

Fig. 9. Dissolved Organic Carbon (DOC) concentration of natural site at depth 10 and 40 centimeters.

Table 2. Summary of the mean dissolved organic carbon for each site at 10 cm and 40 cm depth.

	Drained site		Natural site	
	Depth		Depth	
	10 cm	40cm	10cm	40 cm
DOC ($mg\ L^{-1}$)	85.90 ^{a}	76.55 ^{b}	58.51 ^{c}	40.57 ^{d}

Means that do not share a letter are significantly different

Table 3. Summary of the mean dissolved organic carbon of each subplot and site, for each site at 10 cm and 40 cm depth.

Item	Mean DOC concentration ($mg\ L^{-1}$)		Mean ($mg\ L^{-1}$)	
	Drained site		Natural site	
	10cm	40 cm	10 cm	40cm
Ditch	65.17 ^{c}	59.69 ^{cd}		
Sedge	87.98 ^{b}	82.60 ^{b}		
Shrub	86.99 ^{b}	84.73 ^{b}		
Grass	104.20 ^{a}	78.68 ^{b}		
Hummock			64.60 ^{cd}	40.83 ^{e}
Hollow			52.73 ^{de}	40.24 ^{e}

Means that do not share a letter are significantly different

3.3 Temporal variability in DOC concentration at the drained and natural site

The seasonal pattern of DOC concentration at the subplot scale for both natural and drained sites and for ecosystem-scale are presented (Fig. 10 and Fig. 11). The mean DOC concentration changed with time, and this change was smoother in the natural site than in the drainage site (Fig. 11).

The mean DOC concentrations at the site scale were dynamic in time, especially in the drainage site. At the same sampling depth, DOC concentration showed an increasing trend over time at the drained and natural site. Although, throughout the study, the individual means of DOC concentration were higher in the drainage site than in the natural site, as expected (Fig. 11). In the drainage site, DOC peak was found in late-August; the mean DOC concentration increased from about 66.66 mg L^{-1} at the beginning of sampling, until a peak was reached in late-August (102.5 mg L^{-1}), after that the mean DOC concentration declined to 97.2 mg L−1 (Fig. 11). The maximum DOC concentrations in the drainage site were almost twice as high as the natural site (102.5 mg L^{-1}vs. 62.5 mg L^{-1}), where the DOC concentration reached its peak in early September (Fig. 11). Overall, the increase in the mean DOC concentration was followed by a decrease by the end of the summer (August) for both sites.

For the subplots scale, the DOC concentration increased from the beginning of the sampling in early July until early September, when the DOC concentration peaks had occurred for all subplots. This was followed by a drop in the mean DOC in the middle of September. Therefore, the mean DOC concentration in all subplots showed a similar seasonal pattern. At the beginning of the sampling the grass and sedge subplots had the highest DOC among all others (77.3 and 74.4 mg L^{-1}, respectively), followed by the shrub and ditch subplots. The subplots in the natural sites had less DOC concentration (51.8 mg L^{-1} for hummock and 45.5 mg L^{-1} for hollow) in comparison to those in the drained site. The mean DOC concentration had the same pattern for both hummock and hollow subplots, although hummock had a significant increase in early August to reach a peak in early September (70.7 mg L^{-1}) (Fig. 10).

The most significant increase in the study period was observed among grass (from 74.4 to 137.8 mg L^{-1}) and shrub (59 to 110 mg L^{-1}) subplots. On the contrary, the mean of hollow subplots was shown to have an increase in DOC concentration (from 45.5 to 54 mg L^{-1}) (Fig. 10). Among all subplots in both sites, grass and shrub experienced more increase in the DOC concentration trend in the growing season, as opposed to hummock and hollow subplots, which showed less change in DOC concentration over this period (Fig. 10).

On the other hand, the variability of DOC concentration over the growing season ranged between 67 and 98 mg L^{-1} in the drained pasture site and was larger than that of the natural site (between around 49 and 59 mg L^{-1}) (Fig 11).

In all drained and natural subplots, DOC concentration started to climb at the beginning of the growing season until hitting a peak around late-August (Julian Day=240). Then, there was a trend of a sharp decline in DOC concentration among grass subplots, while in other subplots there showed only a mild decrease (Fig.10).

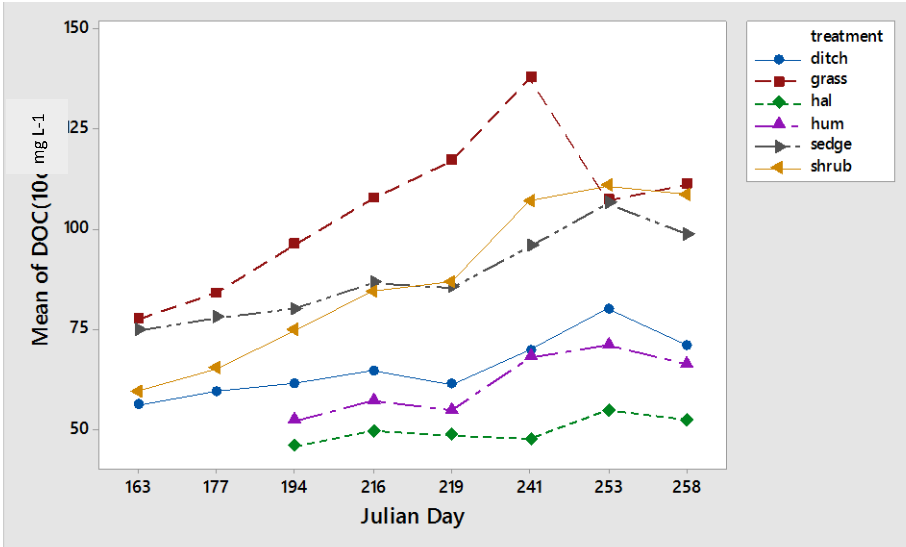

Fig. 10. Seasonal patterns of DOC concentration at subplot scale

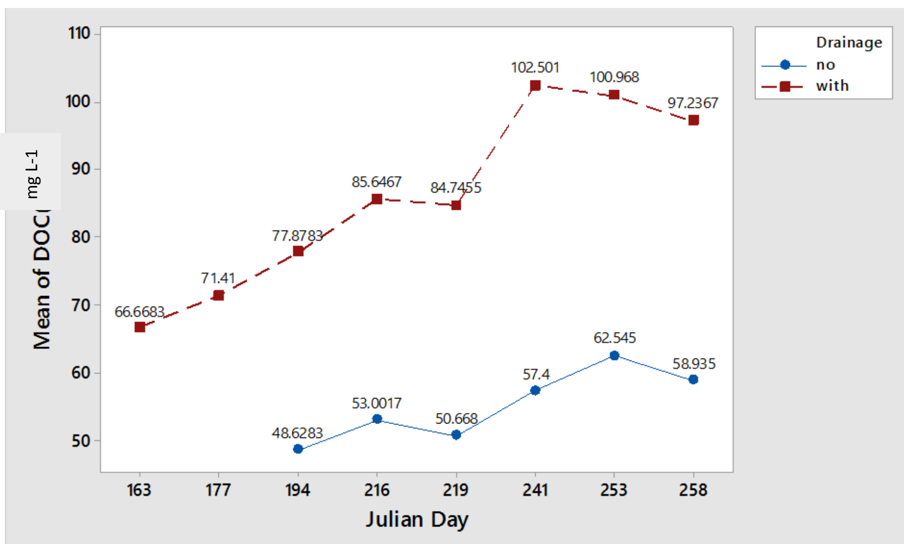

Fig. 11. Seasonal patterns of DOC concentration at ecosystem scale

Similarly, the trend for the temperature at 5 cm at WTD represented almost the same pattern of DOC concentration. Conversely, SM showed the opposite trend related to DOC concentration. This means that on Julian day= 241, while the temperature touched the highest point, the soil water level dropped reaching the lowest point. This resulted in the lowest level of SM, while DOC concentration also reached a peak for all subplots (Fig.14).

Likewise, the sharply decreasing temperature and the rising WTD and SM after mid-August resulted in a gentle dropping pattern in DOC concentration among almost all subplots (Fig.12).

The most significant drop of the WTD among the shrub and grass subplots was around 24cm (from 13 to 37 cm) from the beginning of sampling to the middle of August (Fig.12).

At the site level, it can be seen that the highest soil temperature occurred in mid-August (Julian day=221); after that, it began to decrease in both the drained and in the natural site. Results of DOC concentration indicated that it had an increasing trend from the beginning of the growing season until a peak was reached in late-August and on the first of September in the drained site and in the natural site, respectively (Fig. 12).

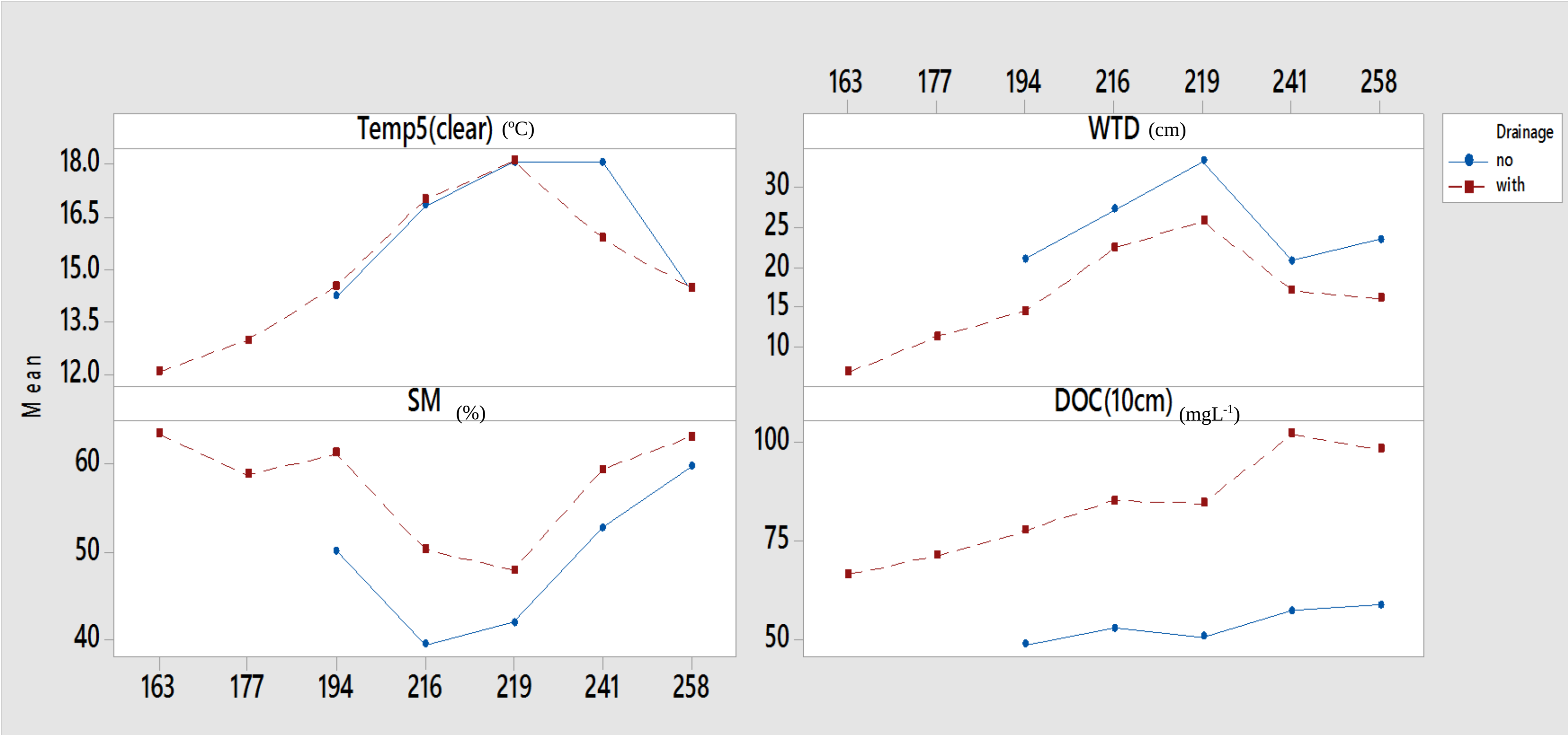

Fig. 12. The seasonal patterns of DOC concentration as well as peat temperature at 5 cm depth, water table depth and soil moisture for the two sites

3.4 Specific UV absorbance ($SUVA_{254}$)

The UV-VIS data indicates that the light absorbance in the 254 nm wavelength was different for various subplots and sites. The $SUVA_{254}$ (L mg C^{-1}) ratio also displayed differences within sites.

Additionally, ANOVA identified that there were significant differences in the $SUVA_{254}$ between the drained and natural site at the depth of 10 and 40cm. ($P<0.0001$) (Table 4). Besides, comparison analysis (Turkey pairwise method) showed that the mean $SUVA_{254}$ for the natural site was significantly higher than that of the drained site at the 10 cm depth (Table 4). This fact states that for a sample with a DOC concentration of 100 mg C L^{-1}, the Abs254 would be 224 (at the 10 cm depth) and 253 au m^{-1} (at the 40 cm depth) in the natural site, whereas the mean Abs254 would be 221 au m^{-1} (at the 10 cm depth) and 220 au m^{-1} (at the 40 cm depth) in the drained site (Table 4). So, higher $SUVA_{254,}$ indicative of higher molecular aromaticity and was found among the subplots in the natural site.

At the subplot scale, one-way ANOVA showed that there was no significant effect of microforms on $SUVA_{254}$ in the natural site at both depths. (For depth 10cm $P = 0.106$ and for depth 40cm $P= 0.341$). Although, hummock showed higher $SUVA_{254}$ (2.58±0.23) relative to hollow in which $SUVA_{254}$ was 2.40 ±0.39, at the 10 cm depth (Table 5).

Similarly, vegetation composition had no significant effect on $SUVA_{254}$ among drained subplots ($P=0.342$) at the 40cm depth, while there was a significant main effect of plot differences (vegetation composition) on $SUVA_{254}$ at the depth of 10 cm ($P= 0.017$). The ditch was recorded with the highest mean $SUVA_{254}$ among the drained site at the depth of

10 cm ($SUVA_{254}$=2.23±0.29), which was significantly different from grass. ($SUVA_{254}$=2.07 ±0.27).

On the other hand, the average $SUVA_{254}$ in Hummock in the natural site has been shown statistically higher $SUVA_{254}$ ($SUVA_{254}$ at 10cm depth=2.58 ±0.23) as opposed to Shrub, Sedge, and Grass which are 2.26 ±0.22, 2.16 ±0.27, and 2.07 ±0.23 respectively (Table 5).

Table 4. Specific UV absorbance ($SUVA_{254}$) at site scale at depth 10 cm and 40 cm

	Drained site		Natural site	
	Depth		Depth	
	10 cm	40cm	10cm	40 cm
$SUVA_{254}$	2.21±0.23 [b]	2.212±0.38 [b]	2.49± 0.31 [a]	2.53± 40 [a]

Means that do not share a letter are significantly different

Table 5. Specific UV absorbance ($SUVA_{254}$) at depth 10 cm and 40 cm at subplot scale

$SUVA_{254}$	Drained site		Natural site		
	10(cm)	40 (cm)	10(cm)	40 (cm)	
Ditch	2.30±0.29 [abcd]	2.32±0.40 [abcd]			
Sedge	2.20±0.23 [bcd]	2.16±0.30 [cd]			
Shrub	2.27±0.22 [bcd]	2.17±0.33 [bcd]			
Grass	2.10±0.27 [d]	2.25±0.32 [bcd]			
Hummock			2.55±0.23 [a]	2.47±0.40 [ab]	
Hollow			2.40±0.39 [abc]	2.60±0.45 [a]	P= 0.086

Means that do not share a letter are significantly different

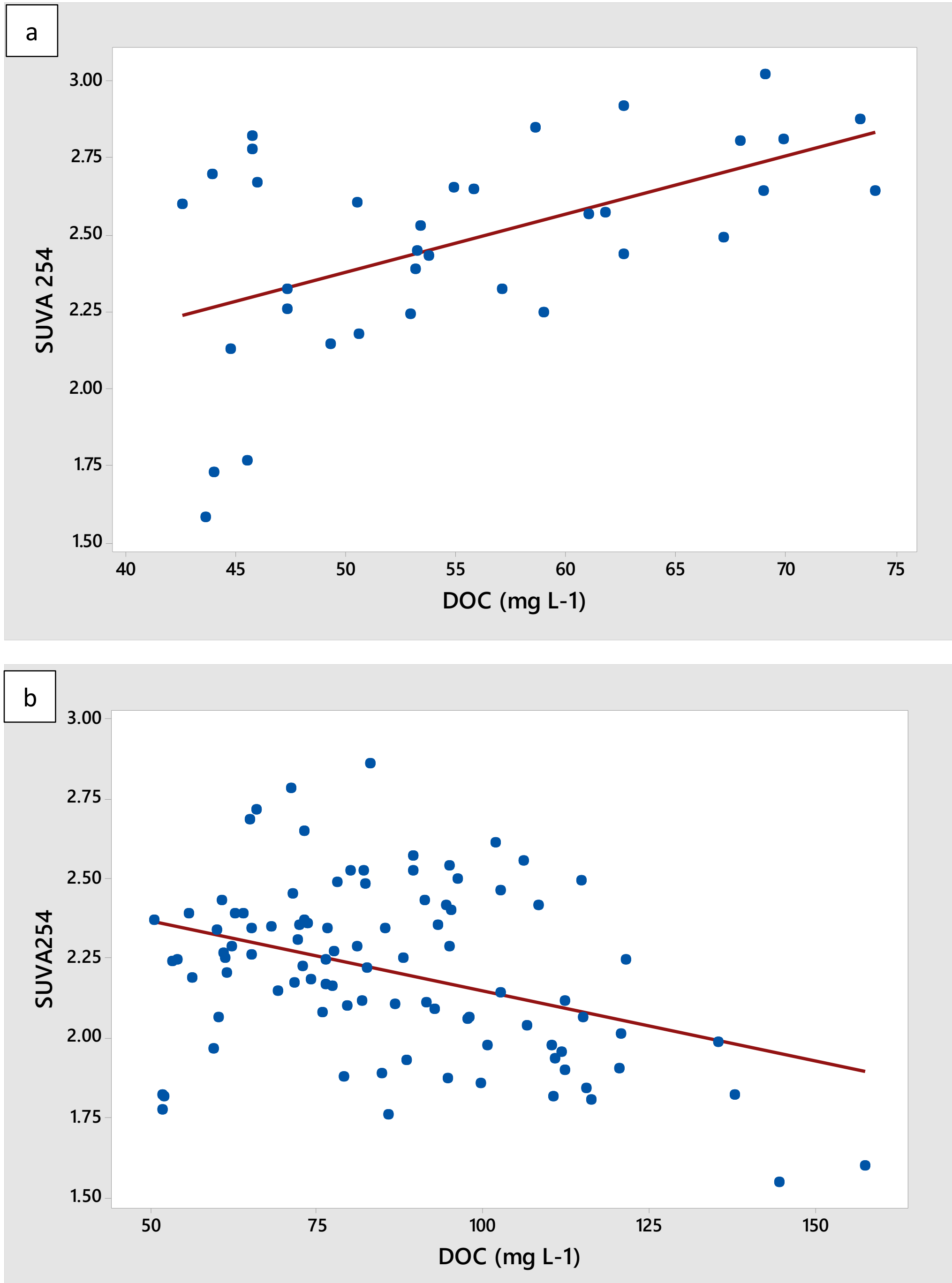

Fig. 13. Relationships between dissolved organic carbon (DOC) concentrations and Specific UV absorbance ($SUVA_{254}$) in the drained (a), and natural (b) site at the peat depth of 10cm

3.5 Fluorescence indices

Fluorescence measurements including HIX and FI, as indicators of DOC quality, were statistically different ($P<0.0005$) between pasture and natural site at the shallower depth (10 cm) where mean HIX and FI were found considerably higher in the drained pasture site compared to the natural site (Table 6 and 8).

The HIX mean value in the drained pasture site was 0.48 ±0.14, which was almost double when compared with the natural site. Although FI was higher at the drained pasture site, the mean FI values were less than 1.5, indicating that plant-derived DOM was dominant over microbially processed DOM for both sites at the 10 cm depth. There was no significant effect of the site (being natural or drained pasture) at the 40 cm depth on HIX ($P=0.06$) (Table 6). HIX and FI were both considerably higher at the 40 cm depth as opposed to 10 cm depth, regardless of the sampling site. Nonetheless, the natural site showed more of an increase in HIX and FI values when examining depth than in the drained site (Table 6 & 8).At the subplot scale, the effect of vegetation composition and microform on HIX was identified as significant ($P< 0.0005$). Likewise, there was a significant effect of vegetation composition ($P<0.0005$) and microform ($P= 0.008$) on FI at the natural and drained site at the 10 cm depth. The pairwise comparison revealed a significantly higher mean HIX value for hummock (0.294 ±0.14) than hollow (0.150 ±0.05) at the 10 cm depth, while microform and vegetation composition did not have the main effect on HIX values at a second depth (40cm) (Table 7). Among all subplots in the drained pasture site, the grass subplots recorded the highest value of HIX, which was 0.61±0.13 (Table 7). HIX for sedge and shrub subplots did not indicate any main differences, while ditch subplots showed lowest mean HIX which was 0.32 ±0.15 (Table 7).

The results demonstrated no statistically main effect of vegetation composition on FI in drained pasture site at both depths (10 cm and 40 cm) (Table 9). Likewise, the microform effect on FI was not significant, although mean FI value was higher for hollow relative to hummock at the10 cm depth (1.42 ± 0.06 and 1.30 ±0.04) and at the 40 cm depth (1.53 ±0.08 and 1.47 ±0.06) (Table 9).

Table 6. Humification Index (HIX) at depth 10 cm and 40 cm at the site scale

	Drained site		Natural site	
	Depth		Depth	
	10 cm	40cm	10cm	40 cm
HIX	0.48 ±0.14 [b]	1.54 ±0.05 [a]	0.27 ±0.10 [a]	1.57 ±0.06 [a]

Means that do not share a letter are significantly different

Table 7. Humification Index (HIX) at depth 10 cm and 40 cm at subplot scale

HIX	Drained site		Natural site		
	10(cm)	40 (cm)	10(cm)	40 (cm)	
Ditch	0.32 ± 0.15 [d]	1.57 ± 0.05 [a]			
Sedge	0.49 ± 0.12 [c]	1.54 ± 0.06 [a]			
Shrub	0.50 ± 0.17 [c]	1.52 ± 0.03 [a]			
Grass	0.61 ± 0.13 [b]	1.54 ± 0.03 [a]			P< 0.0005
Hummock			0.30 ± 0.14 [b]	1.57 ± 0.05 [a]	
Hollow			0.15 ± 0.05 [c]	1.52 ± 0.08 [a]	P =0.024

Means that do not share a letter are significantly different

Table 8. Fluorescence Index (FI) at depth 10 cm and 40 cm at the site scale

	Drained site		Natural site	
	Depth		Depth	
	10 cm	40cm	10cm	40 cm
FI	1.41 ±0.04 ^{b}	1.53 ±0.05 ^{a}	1.36 ±0.05 ^{c}	1.50 ±0.06 ^{a}

Means that do not share a letter are significantly different

Table 9. Fluorescence Index (FI) at depth 10 cm and 40 cm at subplot scale

FI	Drained site		Natural site		
	10(cm)	40 (cm)	10(cm)	40 (cm)	
Ditch	1.41 ±0.05 ^{c}	1.58 ±0.04 ^{a}			
Sedge	1.42 ±0.04 ^{c}	1.52 ±0.06 ^{b}			
Shrub	1.40 ±0.03 ^{c}	1.50 ±0.03 ^{b}			
Grass	1.41 ±0.03 ^{c}	1.52 ±0.03 ^{b}			P = 0.001
Hummock			1.30 ±0.04 ^{c}	1.47 ±0.06 ^{ab}	
Hollow			1.42 ±0.06 ^{bc}	1.53 ±0.08 ^{a}	P =0.334

Means that do not share a letter are significantly different

4 Discussion

4.1 The effect of drainage on DOC

In this study, the increased Dissolved Organic carbon (DOC) concentration at the drained peatland pasture was compared to a natural bog. The mean DOC concentration in the drained peatland pasture increased by 32% at the 10cm peat soil depth, and by 47% at the 40cm peat depth (Table 2). This increase, in part, was driven by variations in SM and WTD (Table 1 and Fig. 6).

Drainage can also affect surface peat temperature due to an increase in the proportion of air-filled pores (Belyea and Clymo, 1998; Jin et al., 2008). In the current study, the long-term water drawdown in the pasture showed a decrease in SM and an increase in peat temperature, which can increase DOC concentration through direct effects of soil moisture on DOC concentration (Fig. 6).

Water table drawdown induced by drainage stimulates enzyme activity, specifically phenoloxidase. The enhanced activities of these enzymes can result in the increased breakdown of phenolic compounds in peat, which generally originate from plant materials. Lower phenolic concentrations remove the inhibitory effect on hydrolase enzymes (Freeman et al., 2001; Peacock et al., 2015) and increase hydrolase activity, resulting in greater litter/SOM decomposition (Min et al., 2015). Eventually, this may lead to the production of more DOC, resulting in more DOC loss (Fenner and Freeman, 2011). Although In the last few years, this mechanism has been questioned as only a few studies have been able to reproduce the Freeman et al. ’s findings (Zak et al., 2019). DOC concentration can also increase due to other biotic factors including increased microbial activity (Frank et al., 2014). There are some abiotic factors including sorption/desorption process was found to the key factor in regulating concentration of the DOC in pore water (Qualls and Richardson, 2003) that may also affect the DOC concentration by changing the rate of DOC release into pore water through the action of sorption. Although the current research did not focus on these aspects, it can be a future subject of study in these research sites. Drainage can alter the balance of adsorption/desorption process between the solid and dissolved phases, toward increasing desorption and releasing more dissolved organic carbon into pore water from potentially soluble organic carbon (SPSOC). This can occur due to effect of drainage on peat structure that change some peat properties including specific surface area (Yurova et al., 2008).

In the current study, the significant increase of DOC resulting from land management (i.e., agricultural drainage) is in agreement with several studies. These reported that a water table drawdown induced by drainage contributed to increasing DOC concentrations in surface water and pore water (Strack et al. 2008; Blodau and Moore 2003; and Wallage et al. 2006; Frank et al., 2014). Hribljan et al., (2014) asserted that the mean DOC concentration was 33.5% and 31.1% greater at depths of 25cm and 50cm, respectively, in the lowered water table plot compared to another plot located within the same peatland complex, and contained a similar vegetation structure. On the other hand, some reviews of existing literature revealed some inconsistencies in the reported results regarding the impact of drainage on the DOC concentration. For instance, Clark et al. (2012) implied a decrease in DOC concentration, which was the result of an episodic water table drawdown in UK peats. This result conflicts with the results of the current study and could be attributed to the change in the water tables during the episodic drought and rewetting of the peat. The current only examined the effects of sustained drainage.

Besides, biomass production is the primary driver behind the addition of DOC into peat from aboveground and belowground vegetation inputs (Hribljan et al., 2014). A higher biomass production was estimated by Gyimah (2018) at the same research site. The higher biomass production followed by the lowering of the water table may have contributed to the elevated DOC concentration in the drained site. In line with the results of the current study, Strack et al. (2008)

concluded that at an 11-years drained site, a lowered water table (~4.5 cm) resulted in the promotion of vegetation growth. This lead to an increase in litter and root exudates that added to the DOC pool. Drainage can also change the annual input following altering vegetation communities (Ritson et al., 2016).The litter layer in drained peatland can provide more soluble organic matter (Cleveland et al., 2004), resulting more DOC transportation from terrestrial to aquatic ecosystem which is not desirable (Dalzell et al., 2011).

$SUVA_{254}$ values indicate the amount of aromatic carbon compounds in the peatland and indicate the composition of the DOC. When comparing the $SUVA_{254}$ values from the natural site with the $SUVA_{254}$ values for the drained pasture site, there was a decreased by 11.25% and 12.6% at the 10cm and 40cm depths, respectively. That indicates more labile carbon compounds in the drained pasture site as opposed to the natural site (Hansson et al., 2010). These findings do not agree with Dieleman et al.'s (2016) results. According to their study, all experimental treatments which experienced manipulated, short-term water table drawdown, had invariably higher $SUVA_{254}$ values, because of exposure to aerobic conditions as a result of drainage. This leads to an increase in the availability of effective acceptors, including O_2, as well as increasing decomposition reaction rates. All these conditions caused more recalcitrant compounds following the rapid break down of simple carbons (Höll et al., 2009). Our results indicate that long term drainage with new vegetation shows a different pattern than short-term water table drawdown.

Moreover, Hribljan et al. (2014) found an increase in labile carbon production as well as a decline in carbon aromaticity in natural peatlands with more saturated conditions. This conflict can be attributed to the fact that abandoned peatland pastures can function more like natural grasslands (Yang et al., 2017). The decrease in $SUVA_{254}$ in grassland systems has been delineated by Fröberg et al. (2011) and Sanderman and Baldock (2008). They indicate that there is a selective adsorption of dissolved hydrophobic aromatic compounds, which are biologically recalcitrant in the soil matrix, and the preferential release of a hydrophilic nonaromatic fraction which attributes to the reduction of $SUVA_{254}$ in grasslands. In other words, by moving water vertically through soil horizons, these recalcitrant compounds are effectively removed via chemical sorption (Cleveland et al., 2004), and more labile carbon can be detected in the soil.

Among drained subplots, shrubs have been shown to have low DOC concentration and high DOC lability. From water treatment prospective, this may be seen positive as DOC from shrub may remove easily due to high aromacity (Ritson et al., 2016).

As a further matter, the drained pasture site in this study experienced a complete vegetation restructuring event after a long-time drainage, with a prevalence of vascular growth forms. This potentially has an impact on plant inputs, mainly root exudates, which consist of a complex mixture of carbohydrates, amino acids, and simple organic acids tending to be labile aliphatic compounds which also caused lower $SUVA_{254}$ in the drained site. Increasing plant community toward enhanced organic matter, gradually leads to deteriorating carbon storage potential in the drained site. This can alter C cycling and convert peatland toward carbon source (Wallage et al., 2006). The lower $SUVA_{254}$ in the drained site can be partially due to this prevalence of simple, non-aromatic DOC compounds belowground (Jones et al., 2009; Robroek et al., 2016).

Furthermore, Ritson et al. 's (2016) study showed that vascular plants could add a large amount of labile material to the litter layer, resulting in greater DOC production. This suggests that shift to vascular plants dominated areas, as a result of long term drainage, may lead to stronger seasonal DOC fluxes from the litter. On the other hand, the higher $SUVA_{254}$, as long as higher HIX, particularly in the depth layers of peat in the natural site, suggestes obtaining DOC from more humified source dominated by larger, humic carbon compond in the natural site rather compared to low molecular weight carbon campound in the drained site. This implies that changing land management (drainage) leads to the change of DOC source and production process within the peat. The changes happened to the DOC concentration and composition are discussed further below (see 4.3).

The negative linear relation between $SUVA_{254}$ and DOC concentration at 10cm peat depth in the drained site (Fig. 13a) indicated that the increase in DOC concentration may reduce the DOC aromaticity by decomposition of labile compounds (Hansson et al., 2010; Moore and Clarkson, 2007). On the contrary, there was a positive relation between $SUVA_{254}$ and DOC concentration at 10cm peat depth in the natural site (Fig. 13b). Thus, alternation of DOC concentration caused by any changes may have more significant implications for ecosystem C cycling in the drained peatlands. Due to the relation between DOC concentration and DOC lability, drained peatlands can export more DOC of lower aromaticity. In the case of the increase in DOC concentration, this is possible that the export of highly biodegradable DOC (Kalbitz et al., 2003; Olefeldt et al., 2013a) increases from drained peatland to downstream ecosystem.

Alongside $SUVA_{254}$, the fluorescence index (FI) and the humification index (HIX) were used to provide insights into the composition and source of the dissolved organic carbon (DOC). The results of this study suggest that HIX and FI were higher in the drained pasture site than the natural site, especially in the layer near the surface (10cm). Although the average FI was higher in the drained site than the natural site, the DOC pools from both sites were representative of more terrestrially than microbially sourced DOC ($FI< 1.5$). The higher FI in the drained site shows that the humified organic matters (microbial-derived) contribute more as the source of DOC rather than litter (plant-drive) in the drained peatland. DOC in the drained site is potentially more labile due to its lower aromaticity. It can result in loss of more labile, plant-derived DOC from the drained peatland.

The higher FI, which indicated less aromatic, microbially sourced carbon, and the higher HIX values in the drained pasture site were not in line with Dieleman et al.'s (2016) study in which the lower FI (more aromatic carbon, terrestrially sourced) and the higher HIX (more humified carbon) reported under lowering water table. They investigated a short-term water table drawdown to predict the effect of future climate change. In their study, an increase in both the labile and recalcitrant DOC was also recorded under the increased temperature condition. They suggested that increased plant input, followed by an increase in temperature has a profound effect on stimulating microbial growth or causing the increase in FI values by supplying microbial-like, labile carbon compounds. In the same way, the increase in plant biomass after long-term drainage can have a substantial impact on increasing FI in the current study.

According to Olefeldt et al. (2013b), there was a strong relationship between peat humification (HIX) and DOC-production, composition, and biodegradability. They concluded that the higher the degree of peat humification, the higher the DOC aromaticity (more recalcitrant) but lower biodegradability. In contrast, the current study showed the higher DOC concentration and the higher humification (higher HIX), but lower DOC aromaticity (lower $SUVA_{254}$) in the drained site. This dictates less aromatic DOC, along with a domination of microbially sourced carbon, while there was an increase in recalcitrant humified carbon (higher HIX) in the drained peatland. In this point of view, it seemed that both the labile and recalcitrant signals increased after long-term drainage in the drained site, which is considered as an abandoned pasture.

Therefore, it can be said that different plant communities and an increase in plant inputs, prompted simultaneous increases in carbon recalcitrance and lability in the current drained site compared to the natural site. These findings were the same as a study providing evidence that showed DOC originated from two sources (Dieleman et al., 2016). There likely are two sources of organic matter (OM) for the initial DOC pool, one is organic acids leached from roots and fresh plant residues, and the second is soluble organic compounds produced microbially during the break-down of fresh, less-soluble material. (Sanderman and Baldock, 2008).

It should be considered that because of less responsive carbon molecules such as some recalcitrant compounds to the EEMs technique employed to measure carbon composition, these techniques can only reveal the subset of carbon molecules that are responsive to them. This means that there may be a more substantial portion of the carbon pool than revealed (Dieleman et al., 2016).

In this study, DOC concentration was often found to be higher in the summer than in the winter, due to enhanced microbial activity and low water fluxes (Kalbitz et al., 2000). It can be concluded that increasing average air temperature following an increase in microbial activities results in an increasing trend of DOC concentration by time in the growing season. Higher DOC concentration in August at both the subplot and the ecosystem scale, was likely because of the high root activity and root exudation which can enhance peat decomposition resulting in higher DOC concentration (Basiliko et al., 2012) (Fig 10. and 11).

4.2 The effect of microforms and vegetation composition on DOC

Our results showed the main effect of peatland vegetation type on DOC concentration; these results were in line with the study of Armstrong et al. (Armstrong et al., 2012) in which Multi-scale relationship between peatland vegetation type and DOC concentration was investigated. On the contrary, Parry et al. (2015) found only a small influence of vegetation composition on determining DOC concentration and water quality. Their results indicated that, at the catchment scale, vegetation might not be the main factor affecting DOC concentration and color in stream waters.

This may be partially due to the variable physical and chemical properties of litter between different vegetation coverage, which can be influential on the rate of decomposition and, therefore, DOC production (Hobbie et al., 2000).

Agricultural practices, such as drainage, can have an impact on changing physicochemical conditions. In the current study, Grass dominated (Reed canary) subplots showed the highest mean DOC concentration among all others in the drained pasture site. Tavi et al. (2010) proposed that Reed canary increased microbial activity and biomass in long-term drained peatland. According to their results, the relative abundance of gram-negative bacteria, which contribute to the initial steps of fresh carbon (labile carbon) turnover, increased in the presence of Reed canary cultivation. This increase in fresh carbon turnover is because of the increase in the availability of substrates derived from RCG (Reed canary grass) mostly in the surface peat where most RCG roots exist. It is potentially the reason that subplots dominated by Reed canary (grass) showed the highest DOC concentration among other subplots in the current study.

Additionally, RCG is considered a fast-growing plant and apportions the majority of its carbon assimilation to structures supporting photosynthesis, generating large amounts of biomass, not only above- but also belowground, with low density, nutrient-rich and labile compounds (De Deyn et al., 2008). The large amount of biomass produced by RCG provides fresh plant litter, which can induce more decomposition of recalcitrant organic matter; more labile carbon can be available as a substrate for microbial biomass (Kuzyakov et al., 2000). More decomposition would trigger releasing DOC into pore water and result in higher DOC concentrations (De Deyn et al., 2008). This likely leads to the highest mean DOC concentrations and more labile DOC in subplots covered by Reed canary (grass) in the current study.

This study observed differences in mean DOC concentration between the two typical microforms, including hummock and hollow in the natural site. The higher DOC concentration was recorded in the hummock, which was dominated by shrub (vascular plants). The study on biomass and production in the natural peatland showed that hummock subplots dominated by shrub (vascular plant), had higher above-ground and average fine root production than hollow subplots (Sullivan et al., 2007). In the current study, the higher average of DOC concentration in hummock subplots can partially be as a result of higher aboveground vascular plant production and biomass in the hummock microform. The results of this study paired well with Strack et al.'s (2008) study, which proposed a significant variation in pore water DOC concentrations along the microtopographic gradient.

Furthermore, higher DOC concentration at the hummock as opposed to the hollow subplots in the natural site can be ascribed to the higher temperature and lower WTD (higher decomposition) in the hummock (Table. 1). The higher transmissivity and storativity[1] in hollows than hummocks are due to the situation of WT in hollows, which are more porous, less decomposed peat (Baird et al., 2013). This may promote higher rates of advection of water and nutrients from surrounding hollows yielding less average DOC concentration in hollow subplots.

The results in this study suggest no statistical differences in $SUVA_{254}$, not only between different plant comunities in the drained pasture site at the 40cm depth but also between microforms in the natural sites at both depths. At the 10cm depth, grass-dominated subplots showed less aromatic

[1] Storativity or the storage coefficient is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer.

and more labile DOC (lower $SUVA_{254}$) than others and more relatively recalcitrant DOC found in ditch subplots.

Bills' (2009) study showed that a study plot colonized by Reed canary grass had more labile biomass than other plots dominated by *S. cyperinus* tissues (a native herbaceous species of peatland). In the current study, the labile biomass can introduce more labile carbon compounds to belowground and result in lower $SUVA_{254}$ (Dieleman et al., 2017) in subplots dominated by Reed Canary (grass). Our results suggested that the quality of the DOC, as measured by $SUVA_{254}$, has not been affected by the vegetation composition of the study site, as there were no differences in $SUVA_{254}$ between subplots in the drained pasture site.

The average $SUVA_{254}$ of hummock subplots was different compared to $SUVA_{254}$ in each grass, shrub, and sedge subplot and was higher compared to hollow subplots at the surface. This can be explained by the fact that organic soil (as a significant exporter of DOC with a little adsorption capacity), has chemically similar DOC to fresh plant leachates (Nelson et al., 1992); in hummock located in natural peatland with Sphagnum-dominated recalcitrant litter (Dorrepaal et al., 2005), the $SUVA_{254}$ is supposed to be different and more recalcitrant to subplots belonging to pasture site. The observation in this study fitted well with this assumption. The more recalcitrant DOC and a higher humification degree are to be likely found in hummock while grass-dominated subplots can have more liable DOC.

HIX and FI, as two other indexes showing the quality of DOC, help to indicate the humification degree and the source of DOC. In this study, grass subplots showed the highest degree of humification compared to other subplots in the drained pasture site's upper peat surface.

Within the natural site, our study reflected the higher degree of humification (higher HIX) in hummock subplots at the 10 cm depth, which is not in agreement with Olefeldt et al.'s (2013) research. They recorded higher HIX, showing more humified compounds in hollow samples than hummock samples in the peat surface. They reported the results, indicating the important linkage among microform (peatland microtopography including hummock and hollow) and peat humification through measuring HIX in the peatland site.

All mean FI values ranged below 1.4 at 10cm. That means that regardless of the different vegetation compositions and microforms in both research sites, DOC was of a plant-derived source relative to the microbial-derived source.

4.3 The Effect of sampling depth on DOC quality and quantity at a drained and natural site

This study showed that the DOC decreased 30.6% in the natural site and 10.8% in the drained pasture site by increasing sampling depth from 10cm to 40cm (Table 2) which means more DOC can be transported in the drained site. This finding suggests that drainage, potentially increase vertical movement of DOC. This can eventually lead to leaving more DOC from peatland and transferred more DOC to another ecosystem.

On average, subplots affected by long-term lowered WT (in the drained pasture site) showed a higher decrease in DOC concentration with increasing depth of sampling. This result paired well with Hribljan et al. (2014), who also reported a decrease of 18.2% between 25 cm and 75 cm depths in lowered WT research sites located in a poor fen peatland, whereas their intact site indicated only a 4.3% decline.

In line with our results, Vestgarden et al. (2010) concluded that, in a boreal environment, by increasing the soil depth, there was a decline in DOC concentration due to a profound decrease in organic matter.

On the other hand, Strack et al. (2008) did not find any consistent pattern of DOC concentrations with depth at hummock and hollow in the natural site; however, during four years of study, they found an increased pattern of DOC concentration with depth in the drained peatland which was much apparent in drier years than average. Furthermore, different DOC concentrations at 10cm and 40cm depth may reflect this fact that there are differences in the microbial community among depths down the peat profile. Because different microbial activities contribute to make changes in decomposition, this results in a difference in DOC concentration (Strickland et al., 2009). Microbial activities have found to be different among depths (Fisk et al., 2003) and have found to decrease with depth (Preston et al., 2012; Wagner and Wolf, 1999).

Sanderman and Baldock (2008) also concluded that DOC concentrations dropped rapidly with increasing depth in the grassland soils. According to their observation, large quantities of DOC are produced from the decomposition of roots/surface litter in grassland; during advective transportation downward with soil water, an initially large DOC partially decreased due to undergoing microbial decay of the most labile fraction. This potentially can be the reason behind the decrease in DOC concentration at the deeper peat soil than DOC near the peat surface (10cm peat depth).

There was a 24.5% decrease in the mean DOC concentration with increasing sampling depth in grass subplots, which was relatively dramatic when comparing all subplots of the drained pasture site. A recent study on the impact of Reed canary grass on microbial abundance showed that the bacterial abundance was significantly increased in the peat layer of experimental plots (Espenberg et al., 2016). The increase in microbial biomass and activity is higher in the surface peat where the impacts of roots and litter of RCG are most pronounced and most likely to provide microbial biomass with more substrates derived from RCG biomass (Tavi et al., 2010). The reduction of microbial abundance by peat depth and the increase in microbial biomass in the surface peat may be one of the reasons which cause a considerable decrease in DOC concentration by depth in the grass subplot.

Based on the results in this study, sampling depth did not have a significant effect on DOC aromaticity, as it showed no main effect of depth on $SUVA_{254}$ (Table 3).

Tfaily et al. (Tfaily et al., 2013) observed that more than 80% of molecular formulate in the surface layer and below 2.9 m depth are the same, showing that much of DOM in the deeper layers of a bog is resistant to microbial degradation. They concluded a more pronounced difference in the composition of surface and deep DOC up to 3-meter depth in the peatland, as all our sampling took from profile shallower than 3 meters, so it can be said that the results from our site substantiate Tfaily et al.' findings (Tfaily et al., 2013). On the contrary, Sanderman and Baldock (2008) demonstrated that DOC became progressively more chemically different from increasing depth in grassland. It is not in agreement with our results from drained pasture sites that function more as grassland and where increasing sampling depth did not have an impact on $SUVA_{254}$.

It is noteworthy that by increasing peat depth, the biodegradability of organic matter decreases due to aging and undergoing humification of the material accreted deep into the soil in comparison to the new material accumulating in the surface layers in peatlands (DeLaune and Reddy, 2008). This fact can explain our results, which showed higher HIX (more humification) and FI (more relative contribution of microbial sources to DOC pool) at a deeper layer at both the subplot and site scale.

Our results corroborated the findings of Olefeldt et al. (2013b) and Dieleman et al. (2016) in which also showed an increasing degree of peat humification was demonstrated with peat depth.

5. Conclusion

This study evaluated the impact of agricultural management and abandonment on DOC concentration and composition. The findings of this study provide a valuable prediction that peatlands under long-term WT drawdown will experience sustained elevated DOC concentrations. This study proved that agricultural drainage was the main factor in increasing DOC concentration both at the peat surface (10 cm) and at the depth of 40 cm.

The quality of DOC was also affected by management activities. We found that agricultural management reduced the DOC aromaticity, which may be caused by the increased production of labile compounds. Drainage of the peatlands shifted DOC from refractory to labile; the relative proportions of these ‘labile’ versus ‘recalcitrant’ DOC compounds (sometimes referred to as high and low DOC quality, respectively) is the most noticeable component of the net carbon balance of northern peatland ecosystems (Dieleman et al., 2016). The mean FI of the drained site indicated that the peatland DOC at this research site was of a plant-derived source over microbially processed DOC throughout the peat layers. However, the FI values varied between 1.3 and 1.5, indicating the domination of plant-drive of DOM in all treatments in this study. Increasing DOC concentration following agricultural drainage shifts the DOM from a microbial-derived source to a plant-derived source.

Similarly, agricultural drainage increases the degree of humification at both peat depths. The HIX values at 10cm ranged between 0.2-0.6 (HIX <1). This indicating that the DOC was not profoundly degraded, which shows a decrease in recalcitrant humified carbon production. Although the results showed that drained and natural peatlands had similar patterns of decreasing DOC concentration and increasing $SUVA_{254}$ by peat depth, DOC at the depth of 40cm decreased more than the peat surface in the drained site. That means that variation in DOC caused by management changes has an intensive effect on deeper peat layers.

The findings further revealed that in the deeper layer of peat, differences in the above-ground vegetable community is not a statistically important factor, whereas the time of sampling can be an active factor causing differences in DOC concentration. In other words, shallower sampling depths showed the most considerable differences in DOC concentration and quality across the drained and natural sites. Increasing HIX and FI at the 40cm depth compared to 10 cm in both site and subplot scales, showed that there is more humified microbially-sourced DOC found at the deeper peat layer.

The results also demonstrate that vegetation composition at the drained site will differ in DOC concentration and composition just as the microforms at the natural site. Among the subplots at the drained peatland pasture site, DOC concentration from grass subplots significantly exceeded the levels of other subplots. Furthermore, lower $SUVA_{254}$ and high HIX values are found under the grass treatments in the layers near the surface, providing further evidence that this plant growth can introduce labile carbon compounds with a high degree of humification into the belowground environment during the growing season.

The results suggest that hydrological changes via peatland drainage can affect the carbon balance of boreal peatland ecosystems by increasing DOC concentration and its lability. This raises the possibility of managing vegetation to control DOC concentration and reduce carbon losses from peatlands. Also, agricultural drainage of peatland changes the physical and hydrothermal properties of the peat (SM and T_5). The difference in DOC concentration and composition between different subplots in the drained site and natural sites suggests that the effect of land management, plant community, and its effects on peat properties should be given more weight in large-scale carbon modeling.

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