Investigating Spring GHG Emissions and DOC Export in Extracted Peatland Ditches, Channels, and Settling Ponds

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Abstract

Extracted peatlands are created through the process of draining a natural *Sphagnum*-dominated peatland by removing above ground vegetation, and then draining the peatland through the creation of ditches, channels, and settling ponds. The goal of this study is to investigate the greenhouse gas (GHG) emissions and dissolved organic carbon (DOC) export from these three components within an extracted peatland in Rivière du Loup, Quebec. Furthermore, this analysis is conducted in the spring to understand how GHG emissions and DOC export may vary in comparison to the summer. Four 3-day field trips were done in May and June 2023 to collect all necessary data on the four sites that comprise the ditches, channels, and settling ponds within the complex. This field data is then analyzed within the Geography laboratory at McGill University. This paper concludes the GHG emissions and DOC export vary between all the sites. However, the spring GHG emissions are observed to be lower in comparison to summer emissions within an extracted peatland. DOC concentrations do not seem to vary drastically throughout the spring and summer months. It is suggested that studies in the future conduct more rigorous analysis on multiple elements within an extracted peatland to fully understand its carbon dynamics.

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Acknowledgements

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1. Introduction

This section provides a simple introduction to extracted peatlands and presents the research conducted within this study.

1.1. Peatlands and their Extraction

Globally, peatland extent is estimated to be approximately 4.04×10^6 km^2, where the Northern Hemisphere encompasses 3.00×10^6 km^2 (Melton et al., 2022). These ecosystems exist in a variety of locations, ranging from tropical to harsh polar environments, providing diverse ecosystem services. However, they have grown to be particularly profitable for humans through agriculture, forestry, and horticultural peat extraction (United Nations Environment Programme, 2022). In specific, horticultural peat extraction involves peat being extracted from the environment through an orchestrated process and then shipped to various locations to satisfy global demand. Extracted peatland practices contribute as a large global carbon source, increasing the consequences of the greenhouse gas effect. Not only do extracted peatlands alter carbon dynamics, but they also affect local hydrology, vegetation, and wildlife. These practices are considerable within Canada and particularly within Quebec, and decades of research has been spent on analyzing its affects. Current research has focused on extraction practices on peatlands within the summer months and have neglected the carbon dynamics in the spring. In specific, carbon dynamics within peatland ditches, channels, and settling ponds are understudied. Thus, this study focuses on analyzing the spring carbon dioxide (CO_2), methane (CH_4), and dissolved organic carbon (DOC) fluxes within extracted peatland ditches, channels, and settling ponds in Rivière du Loup, Quebec. The detailed research statement and objectives are described below.

1.2. Research Statement and Objectives

The research statement proposed is “Investigating Spring GHG Emissions and DOC Export in Extracted Peatland Ditches, Channels, and Settling Ponds”.

The specific objectives of this study are:

- To analyze and understand spring CO_2 and CH_4 emissions within different sections of an extracted peatland (e.g., ditch, channel, settling ponds).
- To analyze and understand spring DOC concentrations within different sections of an extracted peatland (e.g., ditch, channel, settling ponds).
- To observe if CO_2, CH_4, and DOC dynamics are different between the spring vs. summer months (e.g., ditch, channel, settling ponds).

1.3. Hypotheses

It is hypothesized that CO_2 and CH_4 emissions will be lower within the spring months due to the colder weather. Extractions practices are also typically lesser within the spring months as time must pass for the peat to thaw from the winter to then be able to properly extract. Thus, the environment will be less disturbed by direct human activity, resulting in less emissions. However, Site 3 (described within the methodology) is expected to produce the most emissions in comparison to the rest of the sites. This is hypothesized due to the constant stagnant state of the water, which receives frequent inputs of organic matter, resulting in microorganisms consuming it and producing CH_4.

In relation to DOC, DOC concentrations are expected to be higher in the spring than in the summer. This is due to the recent spring melt which occurs within April, introducing a large influx of water into the environment, which contains DOC.

2. Literature Review

This section will explore peatlands, emphasizing their significance as carbon (C) stores, and examining the impacts of climate change and land-use disturbances on them. Additionally, a detailed analysis of extracted peatlands is provided to understand the dynamics of methane (CH_4), carbon dioxide (CO_2), and dissolved organic carbon (DOC) within them.

2.1. Peatlands: Carbon Store

Peatlands are known to provide a variety of ecosystem services such as carbon sequestration, water storage, and promotion of species diversity. For the purpose of this review, peatlands' role in carbon storage will be investigated. Peatlands are a persistent carbon sink, playing an important role in climate change dynamics and long-term climate variability. In a recent study conducted by Melton et al. (2022), the authors estimate the current global peatland extent to be 4.04×10^6 km^2, with the Northern Hemisphere comprising 3.00×10^6 km^2 of the total peatland cover. Peatlands develop from a variety of regional and local factors, such as hydrology, climate, vegetation, and soil chemistry, which contributes to the type of peatland that matures in that location throughout time (Vitt, 2006). It is estimated that 500 ± 100 Gt of C is stored in northern peatlands, comprising of around 85% of total global peatland carbon stock (Yu, 2012; Harris et al., 2022). Peatlands have been developing since the last deglaciation in the circum-Arctic due to the low levels of decomposition. Peatlands' net primary production (NPP) exceed decomposition rates, thus forming layers of organic matter (peat) that is rich in carbon (Vitt, 2006). Decomposition is greatly reduced in these regions due to the waterlogged conditions, allowing for a gradual accumulation of dead organic matter over time (Harris et al., 2022). The cool and wet climate lowers plant productivity, however it is still greater than

decomposition rates, and plants like *Sphagnum spp*. (i.e., peat moss) persist in such conditions, allowing for the creation of a large carbon store (Vitt, 2006). Peatlands contribute to sequestering CO_2 from the atmosphere, compensating for its CH_4 emissions due to the waterlogged conditions present, effectively contributing to offsetting climate change (Harris et al., 2022).

2.2. Peatlands: Climate Change and Land-Use Disturbances

Peatlands are put at risk with the increasing climate change effects and land-use disturbances. Peatlands act as a "C service", and when disturbed, are most likely not to recover, converting from terrestrial carbon to atmospheric carbon which exacerbates the greenhouse gas (GHG) effect (Harris et al., 2022). Specifically, carbon identified as "'irrecoverable C', or peatland C stocks lost through land conversion that cannot recover by 2050" (Harris et al., 2022., p. 222) is crucial in protecting against anthropogenic disturbances due to their inability to recover. In particular, Canada should play an integral role in protecting peatland carbon storage as it contains approximately 150 Gt C within its boundaries, comprising a quarter of the Earth's peatland extent (Harris et al., 2022).

With increasing climate change, the sink capacity of peatlands may be reduced as the climate becomes warmer and dryer. However, in some situations, peatlands may grow as a region becomes more humid, increasing the carbon sink. In relation to permafrost peatlands, in some cases, warmer climates result in decomposition rates to grow as permafrost peat thaws, losing terrestrial carbon as it is released as CO_2 into the atmosphere. However, many studies have shown that the carbon sink will grow as the permafrost peatland becomes wetter. Though with a wetter environment, methane, which has 28 times more global warming potential than CO_2, is released from the post-thawed peatlands (Harris et al., 2022).

With climate change, forest fires are estimated to increase in intensity and frequency in the following years. These fires are likely to burn non-permafrost peatlands as the warmer climate will increase the possibility of peat ignition (Harris et al., 2022). Furthermore, in forested areas where peat ignition is less likely to occur, fires can remove above-ground vegetation and stimulate decay of the peat, facilitating an additional source of carbon into the atmosphere (Turetsky et al., 2002). The effects of fires on peatlands not only occur in the summer months but are continuingly harmful in the winter. A recent article published by BBC on February 16, 2024, discussed the presence of 'zombie fires'. This term was coined for fires that are burning peat moss under thick layers of snow. This peat moss, ignited by embers from the most recent wildfire season, persists as snow insulates the fire from the cold (Yousif, 2024). These consequences on peatlands represent only some of the many dangers climate change exacerbates. This positive feedback is likely to continue unless climate change is immediately halted.

Land-use disturbances pose another threat to peatlands. Land-use activities associated with developing hydroelectricity flood extensive areas of land, triggering massive losses of carbon in peatlands. Methane, produced by methanogens in anaerobic conditions, consume the organic matter from the peatland within the reservoir and release it into the atmosphere. CH_4 is also emitted through ebullition, diffusion, and through the tissue of aquatic macrophytes. Furthermore, CO_2 is released through the processes of diffusion between the water-air interface (Maljanen et al., 2010). Provinces like Quebec, Manitoba, and Ontario are known to have a variety of reservoirs and dams on peatlands, thus promoting the production of GHG (Turetsky & St. Louis, 2006).

Since organic soils are generally productive, agricultural activities ensue in peatland areas. To prepare the land for agricultural activities, "peatlands are generally drained and tilled,

and organic soils are often amended with mineral soils or fertilizers" (Turetsky & St. Louis, 2006. p. 367). These activities contribute as another addition of CO_2 into the atmosphere. For similar reasons, forestry operations emit CO_2 due to the drainage of peatland soils. Since tree growth is inhibited in saturated soil conditions, peatlands are drained and then used for commercial forestry operations. However, planting these trees can offset some of these emissions (Turetsky & St. Louis, 2006).

Oil sand mining is another major contributor to peatland destruction. "Current oil sands mining practice includes removal of peat overburden and stockpiling for potential reclamation use", allowing for open-pit surface mining (Turetsky et al., 2002, p. 21-3). These operations both emit CO_2 from the mining itself and peat removal. Rooney et al. (2012) estimate that a "carbon storage loss caused by peatland conversion could be equivalent to 7-y worth of carbon emissions by mining and upgrading" (p. 4936). Furthermore, peatland restoration is highly unlikely due to the lack of policies, incentives, and long-term planning by mining industries (Rooney et al., 2012).

Practices surrounding horticultural peat extraction are of particular importance to this paper. Since peat is highly demanded as fertilizer, energy generation, and raw material for chemical products, peat drainage practices are widely practiced across the world. This involves the drainage of natural *Sphagnum*-dominated peatlands, as the vegetation on the surface is striped and drained, which is then harvested by tractors and vacuums (Turetsky & St. Louis, 2006).

Currently, Canada only accounts for and reports reservoir GHG emissions from hydroelectricity development and horticultural peat extraction emissions in their annual GHG reports. As discussed, many land-use practices contribute to the release of carbon into the

atmosphere, and it is important that these practices are studied and understood. However, for the purpose of this review, only extracted peatlands are investigated. Section 2.3 and 2.4 further dive into the carbon dynamics within extracted peatlands.

2.3. Extracted Peatlands: CO_2 and CH_4 Emissions

As mentioned, peat extraction practices consist of the removal of above ground vegetation and drainage of natural peatlands. After vegetation removal and before extraction, the drainage phase lasts approximately one to five years (Maljanen et al., 2010). Peat extraction can last for several years, depending on the depth profile of the peat, having average lifetimes of 32.5 years (Turetsky et al., 2002). CO_2 is emitted from such practices due to the aerobic decomposition of organic matter now plausible with drained conditions, and thus these sites can become carbon net sources of CO_2. Maljanen et al. (2010) mention that "the net CO_2 exchange from peat extraction areas (bare peat) depend e.g. on the quality of the peat and the time since drainage, as well as the climate" (p. 2721), illustrating that outside factors and soil properties influence GHG fluxes. For example, in Quebec, Canada, climate influences CO_2 emissions in extracted peatlands as "wet years" emit 320 to 430 g CO_2, whereas "dry years" emit 1300 to 1500 g CO_2. Also, emissions from peat extraction sites depend on the age of the extraction sites, as emissions of CO_2 are slightly higher in older sites than younger ones. CH_4 production is reduced in drained peatland soils due to the increase of oxygen within the soil. Oxidizing microbes also increase the process of oxidation of CH_4, as CH_4 is converted into CO_2 and molecular oxygen (O_2) (Maljanen et al., 2010).

However, although the drained peat soils primarily emit CO_2 and are a small source of CH_4, the drainage ditches within extracted peatlands contribute to CH_4 emissions. Ditches emit

between 0.3 to 140 g CH_4 m^{-2} yr^{-1} or a mean of 60 g CH_4 m^{-2} yr^{-1}, thus accounting for the ditch network is important when discussing total emissions of peat extraction sites (Maljanen et al., 2010; Evans et al., 2016).

Even after extraction, abandoned extracted peatlands are a source of atmospheric carbon, as decomposition of residual peat continues and exceeds net secondary production on the peat surface (Turetsky et al., 2002). Careful and calculated restoration and afforestation efforts are conducted to reduce the GHG emissions from post-extracted peatlands, however the "portion of peat C lost during extraction…and drainage is much greater than the peat C that may be recovered" (Harris et al., 2022, p. 225).

Recently, peat extraction activities were reduced. As reported by the Canadian Sphagnum Peat Moss Association (CSPMA) in 2023, frequent and "record breaking rain, and the impacts of Canadian forest fires significantly delayed the harvest season" (para. 2), reducing targeted volumes of extracted peat. Thus, this has influenced GHG emissions from extracted peatlands for the 2023 season, although specific estimates are unknown.

2.4. Extracted Peatlands: DOC Exports

Although discussion of CO_2 and CH_4 emissions are relevant to extracted peatlands, a large proponent of carbon loss also occurs via fluvial transport. Dissolved organic carbon (DOC) is the largest component of waterborne export. DOC is created through biological activity, such as decomposition and plant exudation, and transport to drainage networks is influenced by the hydrological factors and chemical solubility controls of the peatland. Peat-derived DOC is susceptible to photodegradation and is utilized by heterotrophic organisms from the photochemical breakdown of DOC. Thus, once DOC enters a drainage network, high rates of

DOC is lost as it becomes exposed to sunlight, "with average DOC removal ranging from 33 to 75% over periods of up to 10 days" (Evans et al., 2016, p. 583). This degradation process converts most peat-derived DOC into CO_2 within 48 hours upon contact with light, meaning that most DOC from peatlands do not end up entering large aquatic environments, such as the sea. Furthermore, undisturbed northern boreal peatlands' DOC fluxes are 5 g C m^{-2} yr^{-1}. However, when drained, extracted peatlands increase DOC flux by 60%, further promoting carbon loss in extracted peatlands. Re-wetting of drainage ditches are predicted to decrease DOC fluxes, however more empirical evidence is required on this subject (Evans et al., 2016).

Thus, within extracted peatland environments, DOC export contributes to the loss of carbon, often becoming a source of CO_2 within drainage channels. However, much of the research conducted on peat-derived DOC and its export is uncertain and complex, requiring more extensive research (Evans et al., 2016).

2.5. Extracted Peatlands: Knowledge Gaps

Much is still unknown in relation to GHG emissions and DOC fluxes in extracted peatlands. Evans et al. (2016) claim that there is a "need for additional measurements of a range of key fluxes and processes contributing to GHG emissions from peatlands via fluvial pathways" (p. 586), particularly on drainage ditch CH_4 emissions. Year-round monitoring and long-term studies are recommended to account for all carbon fluctuations (Evans et al., 2016), however many barriers exist with *in-situ* field research (e.g., snow), especially in northern boreal peatlands. Furthermore, there is a lack of extensive research towards solutions to remediate and recover extracted peatlands properly. Due to the slow and long-term development of peat layers,

much of the irrecoverable carbon is lost from extractive practices, making restoring such environments difficult in a short-term span.

Through this literature review, there is a lack of information regarding carbon dynamics in the spring. In specific, most research on extracted peatlands is conducted during the summer, and there is minimal discussion of spring melt to early summer carbon dynamics. This study hopes to bridge this knowledge gap and identify the DOC spring export and spring CH_4 and CO_2 emissions. The methodology further develops how this goal is targeted.

3. Site and Methodology

In this section, a detailed site description is provided. Corresponding field sampling and laboratory methods will be explained, with a description on how data was manipulated to display within the results section of this paper.

3.1. Field Site

Fieldwork was conducted in May and June of 2023 to collect data on DOC export and gas emissions from ditches, channels, and settling ponds in a peatland undergoing extraction for horticultural peat. This required four 3-day data collection trips within the two months. The fieldwork was conducted on the Presidents complex of the Premier-Tech company, Riviere du Loup (RDL), Quebec, Canada. RDL is located along the south shore of the St-Lawrence River, approximately a 2-hour drive from Quebec City. The extracted peatlands have been stripped of vegetation and drained, where machines such as “root and stump pickers”, “harrows”, and “two-head vacuum peat harvesters” are utilized to prepare and collect the peat (Premier Tech, n.d.). Premier-Tech has expanded the extent of their practices over decades, identifying different sectors of the complex by the year peat extraction began (Figure 3.1). They have recently converted more natural peat environments into areas of extraction in the summer of 2022 (Figure 3.1). Furthermore, between July 15 to August 16 of 2022, Premier-Tech reformed all the ditches, channels, and settling ponds within the complex, and cleared them of any vegetation.

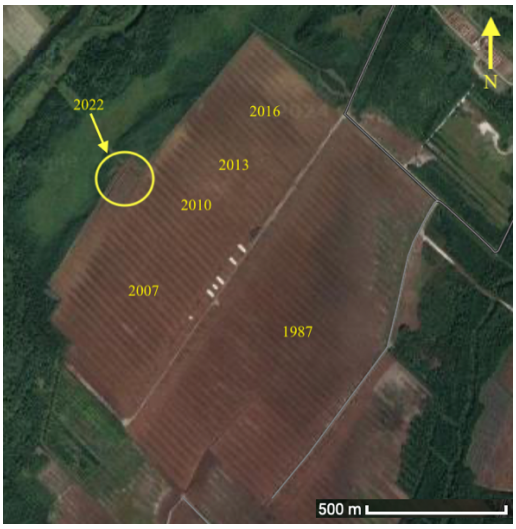

Figure 3.1. Identification of the different sectors within the extracted peatland managed by Premier-Tech (image obtained through Google Maps).

The extracted peatland is divided into many fields, 30 m wide and ranging between 900 and 1200 m in length. Each field is separated by lateral ditches that follow into main collector ditches (discharge channels) on the complex's perimeter. The flow of water from the fields follows the order of drainage ditches, discharge channels, and then the settling ponds (Figure 3.2). The ditches are V-shaped and are approximately 30 cm in width, draining water from the fields of the extracted peatland. The water from the ditches flows to the discharge channels, which range 2 to 3 meters in width. The drained water follows the perimeter of the entire extracted peatland complex, ending up at the settling ponds (SP) where water becomes primarily stagnant (Figure 3.2). It is important to note that the discharge channels receive water from the extracted peatland and the natural peatland adjacent to it.

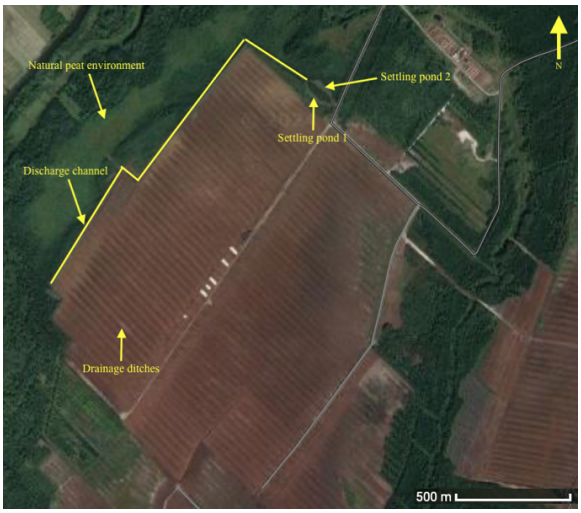

Figure 3.2. Illustration of the elements within the extracted peatland managed by Premier-Tech in RDL (image obtained through Google Maps).

Four sample locations were chosen within the extracted peatland (Figure 3.3). Each site allows for a comprehensive analysis of DOC and GHG exchanges within the whole extracted peatland. Site 1 allowed for data to be collected on lateral drainage ditches, Site 2a and 2b were chosen to analyze water in the discharge channel, and Site 3 contained the settling ponds. These four sites, cover the range of changes of DOC concentrations and gas emissions within the entire extracted peatland.

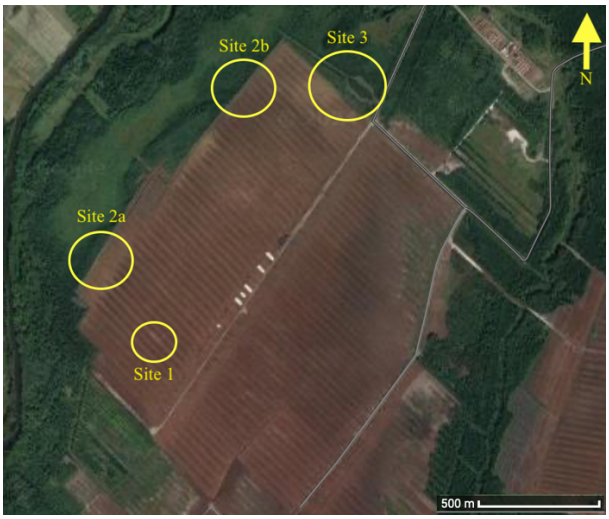

Figure 3.3. Locations of Site 1, 2a, 2b, and 3 within the extracted peatland managed by Premier-Tech in RDL (image obtained through Google Maps).

3.2. DOC Analysis

In the field, 50 ml samples were collected at each site on all the days that field work was conducted. For Site 3 only, multiple samples were taken at different locations within the site (locations identified in Figure 3.4). Prior to collection, the 50 ml bottles were washed with soap and then rinsed with deionized (DI) water three times. Each bottle would be labeled with the date and site of collection, with the time of collection and depth of water (in cm) at that location being recorded in the field notebook. To collect the sample, ditch water is used to rinse the bottle before sampling, and then the sample was taken. Once collected, the DOC samples were stored in a cool environment (fridge or coolers) until brought back to the Geography laboratory at McGill University. Samples were, again stored in a fridge until they were analyzed in July and August of 2023.

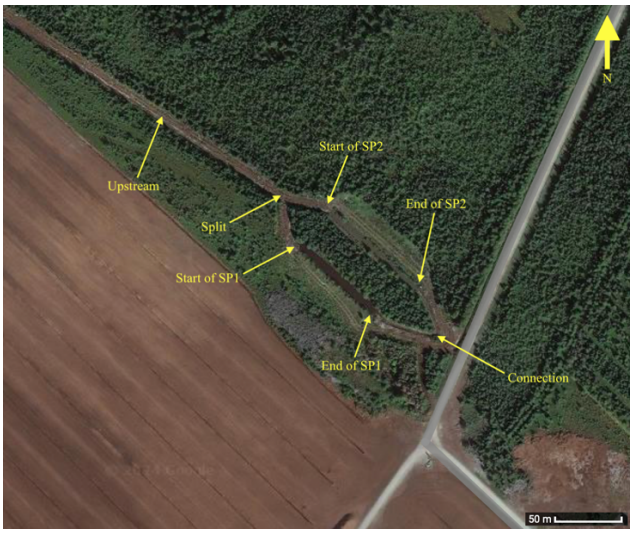

Figure 3.4. Locations of all DOC sample areas within Site 3 (image obtained through Google Maps).

To analyze the DOC samples in the lab, they were first filtered (in July and August 2023). Using a vacuum pump, the samples were filtered through 0.50 micrometre (μm) glass filament filters. This is to remove particulates and retain the dissolved portion of the DOC sample. After filtering, the samples are diluted with HCl to lower the pH to a range of 2 to 3. This is conducted to kill off microorganisms that have the potential to change the DOC concentration. Samples are then arranged in a tray and put into the Shimazdu TOC/TN Analyzer, where the machine determines the DOC concentration through oxidative combustion infrared (IR) analysis (University of Toronto, 2022). DOC and nitrogen values are returned in mg/L for each sample. These values were imported to Excel to create graphs to demonstrate the data. To calibrate the analyzer, DI water and samples with known concentrations of DOC were added (in a different sample bottles).

Water flow was not recorded due to no or extremely low water velocity within the ditches and discharge channels, thus unnecessary to consider in relation to DOC concentration.

3.3. CH_4 and CO_2 Analysis

Gas chambers, connected to the gas analyzer, were used to sample the gas flux at each site. These chambers would be constructed with 18 L water jugs with the bottoms removed and attached to foam, giving the chamber the ability to float on the water. Miniature fans were installed inside the chamber to circulate the air. The top of the chamber is sealed with a non-porous lid with two holes to attach plastic tubing to, which are connected to the gas analyzer. This allowed of the air from the head space to pass through the analyzer. The chamber was wrapped with tin foil to eliminate any light from entering the chamber. This is done so there is no photooxidation or photodegradation occurring within the chamber.

To analyze both CH_4 and CO_2 at all the sites in the extracted peatland, a Los Gatos Research (LGR) CH4/CO2 Ultraportable Greenhouse Gas Analyzer was used. The gas analyzer uses laser absorption spectroscopy to determine CH_4, CO_2, and H_2O within the gaseous sample that it collects (AMOF, n.d.). The gas analyzer is left turned on for one hour to calibrate prior to taking any data, and then attached to the chamber. At each site, the chamber would be placed in four spots, and each spot would be recorded for four minutes, obtaining the flux of CO_2 and CH_4 at the same time. This is done in order to reduce uncertainty and reduce the dominance of outliers within the data. The start and end times of the sampling period (four minutes) are recorded in the field notebook. For Site 3, depending on the reachability of the location in the site as multiple locations were analysed within Site 3 (Figure 3.4), it would be decided if gas flux analysis is plausible to record. It is critical to mention that gas flux was not recorded every day when in the field as good weather is necessary for data collection. The gas analyzer is particularly sensitive to water, and on days of rain, no gas flux was recorded.

The gas flux data is collected in parts per million (ppm) per second and stored within the gas analyzer until it is transferred to a USB. Data is then transferred to Excel. The sampling periods, which were recorded in the notebook, were identified within the Excel file and were isolated to produce values for slope and R^2 for both the CO_2 and CH_4. Sampling periods containing an R^2 value below 0.1 and above 0.7 were kept. This is done since R^2 values explains how close the data points are to the line of best fit, thus the values over 0.7 are close to the line of best fit, and values below 0.1 means that the rate of change is close to zero (no significant flux). Sampling periods which contained an R^2 value between 0.1 and 0.7 were removed. This is done as these R^2 values demonstrate that there exists too much dissimilarity of data to the line of best fit, thus introducing too much error into the slope. Then, the slopes for each sampling period were converted to ppm/min and then to either mg of C/m^2/day (for CH_4) and g of C/m^2/day (for CO_2). These values are then manipulated to create CH_4 and CO_2 graphs, as shown in the results section.

4. Results

The results section displays the data collected within the field in May and June of 2023. CH_4, CO_2, and DOC fluxes are explained and will be further analyzed within the discussion section of this paper.

4.1. CH_4 Flux

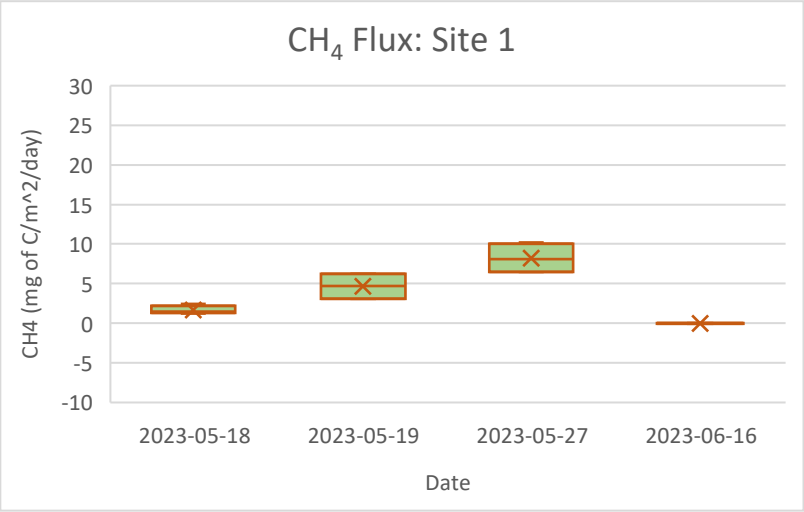

Figure 4.1. The CH_4 flux is shown for Site 1 on May 18, May 19, May 27, and June 16 in Rivière-du-Loup, Quebec. Units for flux are represented in mg of C/m^2/day. Fluxes grow over time until dropping to 0 mg of C/m^2/day. May 27th shows the largest emission levels.

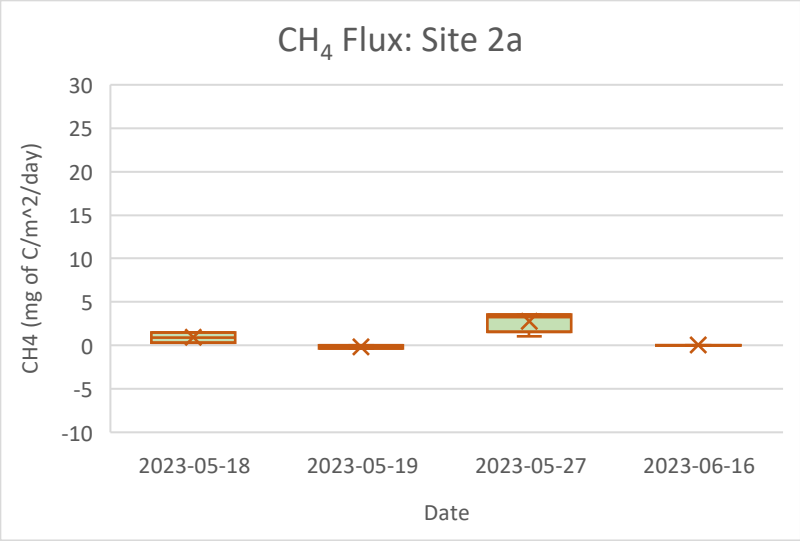

Figure 4.2. The CH_4 flux is displayed for Site 2a on May 18, May 19, May 27, and June 16 in Rivière-du-Loup, Quebec. Units for flux are represented in mg of C/m^2/day. Fluxes are very minimal on all days of data collection, with May 27th having slightly larger emissions.

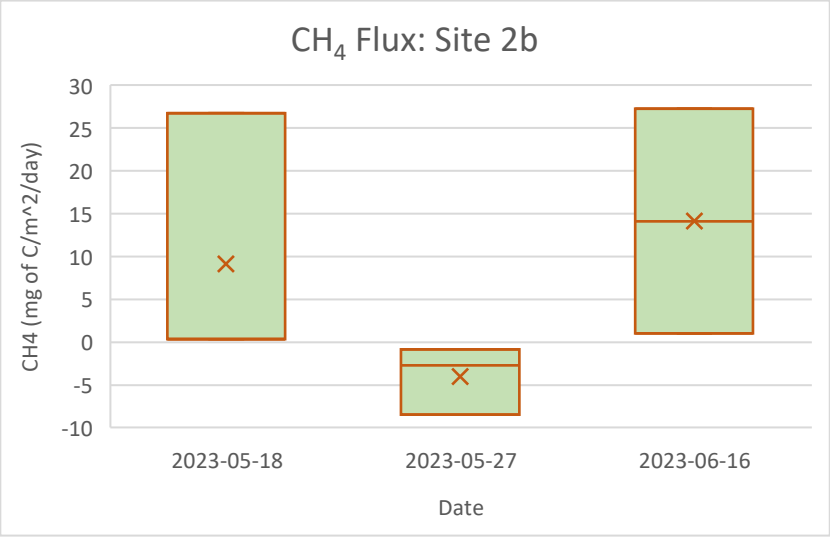

Figure 4.3. The CH_4 flux is displayed for Site 2b on May 18, May 27, and June 16 in Rivière-du-Loup, Quebec. Units for flux are represented in mg of C/m^2/day. Site 2b demonstrates the largest CH_4 emissions between the sites analyzed within the extracted peatland. Data was not taken on May 19th at Site 2b.

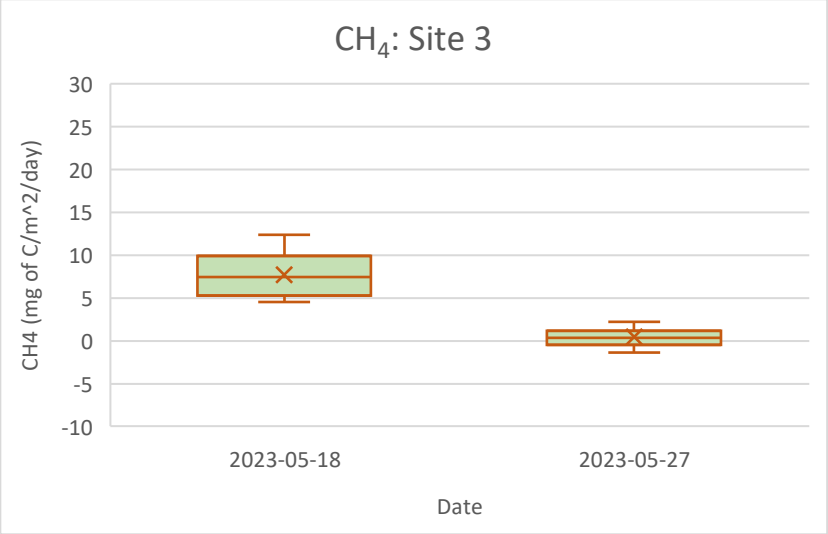

Figure 4.4. The CH_4 flux is presented for Site 3 on May 18 and May 27 in Rivière-du-Loup, Quebec. Units for flux are represented in mg of C/m^2/day. Emissions vary between the days of data collection, as emissions are negligible on May 27th whereas May 18th ranges around the median of 7 mg of C/m^2/day. No data collection occurred on May 19th and June 16th at Site 3.

The CH_4 emissions of all the sites are shown in the same range of -10 to 30 mg of C/m^2/day, allowing for an objective comparison between the sites. Sites 1, 2a, and 3 show relatively similar trends, as the median is always between 0 to 10 mg of C/m^2/day. The interquartile ranges (IQR), which represents the middle 50% of the data, for these sites are small. This indicates that 50% of the data is close to the median. However, Site 2b does not follow the same trend, as the IQR is large, representing a greater dispersion of data. Furthermore, it is the only site that shows a net capture of CH_4 on May 27th, as the box plot is below 0 mg of C/m^2/day. The whiskers, representing 50% of data that is outside of the middle 50%, are relatively small on all the graphs. This means that most of the data collected ranges close to the median, signifying lower variance. Lastly, there are no outliers present within the data.

4.2. CO_2 Flux

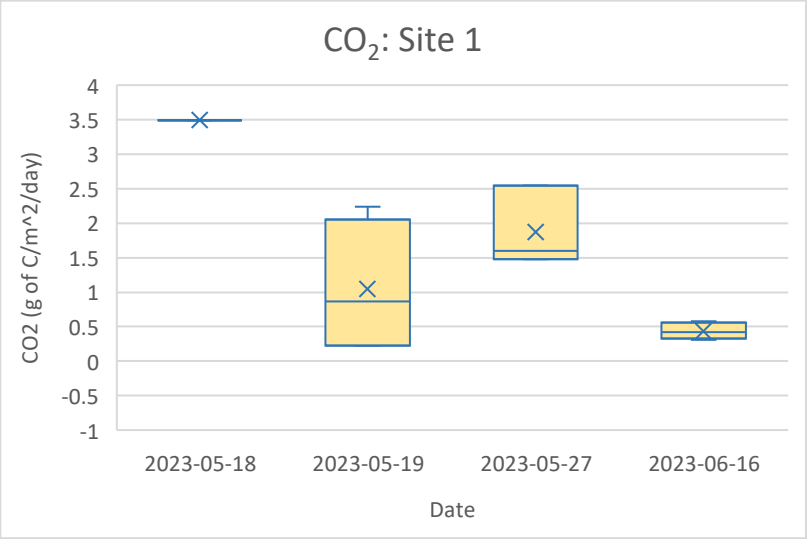

Figure 4.5. The CO_2 flux for Site 1 is shown for May 18, May 19, May 27, and June 16 in Rivière-du-Loup, Quebec. Flux units are displayed in g of C/m^2/day. Emissions vary between all days of collection, however showing a decreasing trend in emissions from the late spring to early summer.

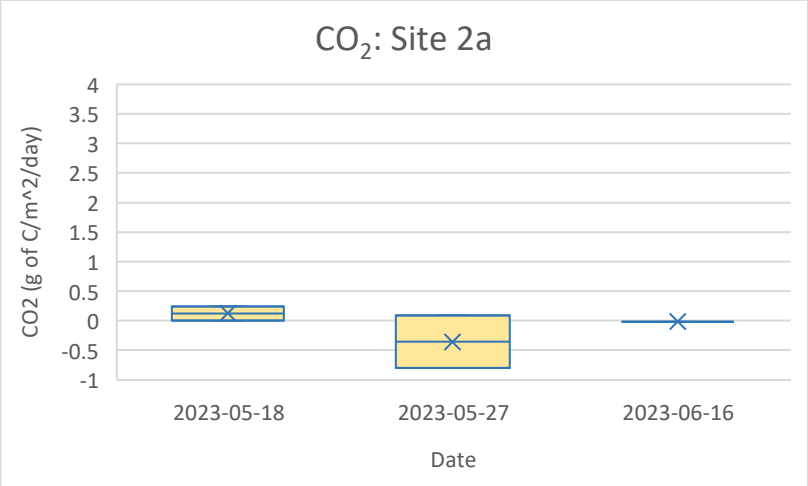

Figure 4.6. The CO_2 flux is presented for Site 2a on May 18, May 27, and June 16 in Rivière-du-Loup, Quebec. Flux units are displayed in g of C/m^2/day. Emissions are trivial at Site 2a. Also, data from May 27th demonstrates carbon capture occurring. Moreover, gas flux was analyzed on May 19th, however through the data examination conducted in the methodology, these fluxes were removed for consideration in the results.

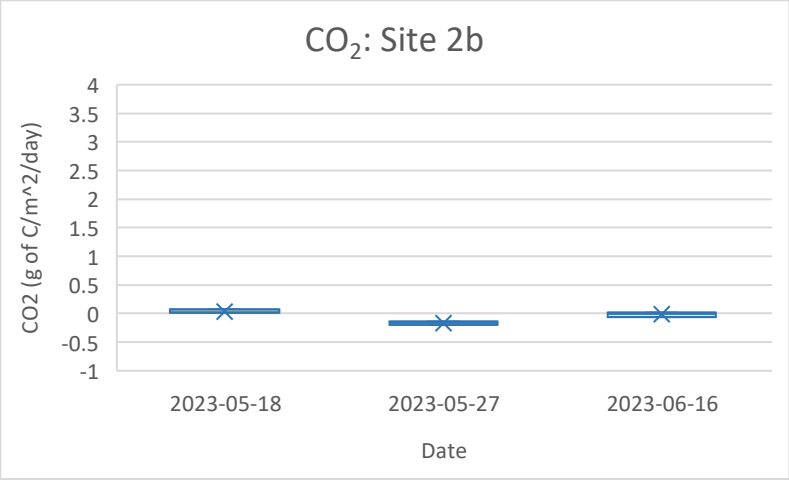

Figure 4.7. The CO_2 flux is displayed for Site 2b on May 18, May 27, and June 16 in Rivière-du-Loup, Quebec. Flux units are displayed in g of C/m^2/day. CO_2 fluxes are negligible for Site 2b, with fluxes on May 27th displaying carbon capture. No data was collected on May 19th, thus not represented within the graph.

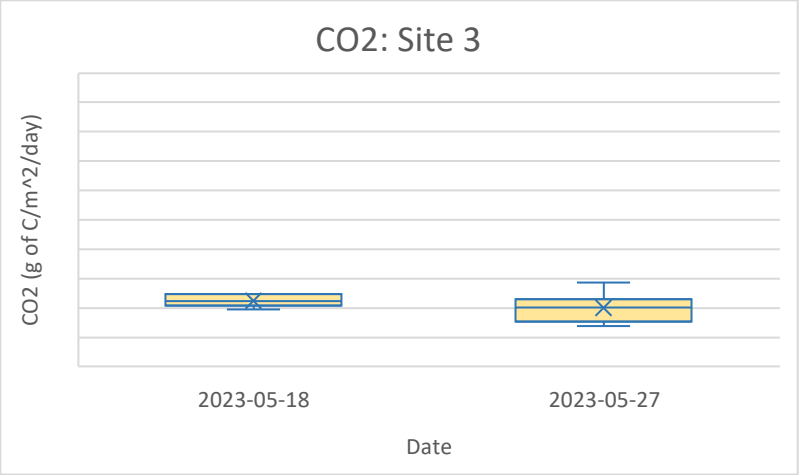

Figure 4.8. The CO_2 flux is displayed for Site 3 on May 18 and May 27 in Rivière-du-Loup, Quebec. Flux units are displayed in g of C/m^2/day. Emissions are close to none at Site 3. No data was collected on May 19 and June 16, thus missing from the Figure 4.8.

The CO_2 emissions from the sites were shown between a range of -1 to 4 g of C/m^2/day. Throughout May and June of 2023, there are extremely low CO_2 emissions from all sites, with Site 1 having slightly higher emissions in the late spring. The IQR is relatively small in all the figures, except for Figure 4.5. Also, the whiskers are minute on box plots at all sites. This indicates that the data is clustered close to the median. Furthermore, Site 2a and 2b are observed to predominantly capture CO_2 on May 27th. No outliers are present within the data displayed.

4.3. DOC Export

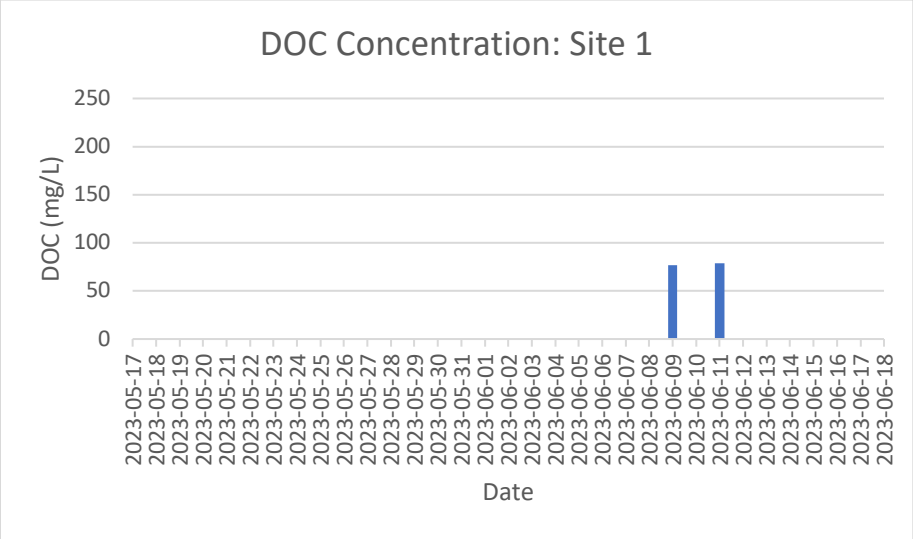

Figure 4.9. The DOC concentrations are displayed for Site 1 between the dates of May 17 to June 18 in Rivière-du-Loup, Quebec. DOC concentrations are represented in units of mg/L. Only two samples were collected through the May to June 2023 field work season. This is due to a lack of water in the ditch network or being absent from the field site. Both samples contained approximately 75 mg/L of DOC.

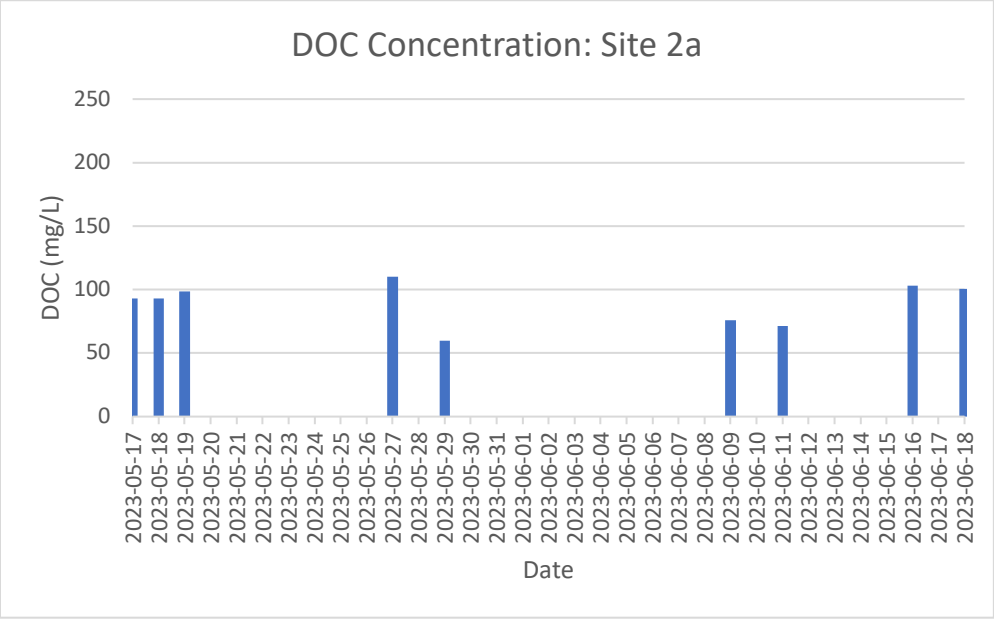

Figure 4.10. The DOC concentrations are shown for Site 2a between the dates of May 17 to June 18 in Rivière-du-Loup, Quebec. Units are in mg/L. Most DOC concentrations ranged from 50 to 100 mg/L. Data is not shown for certain days due being absent from the field site.

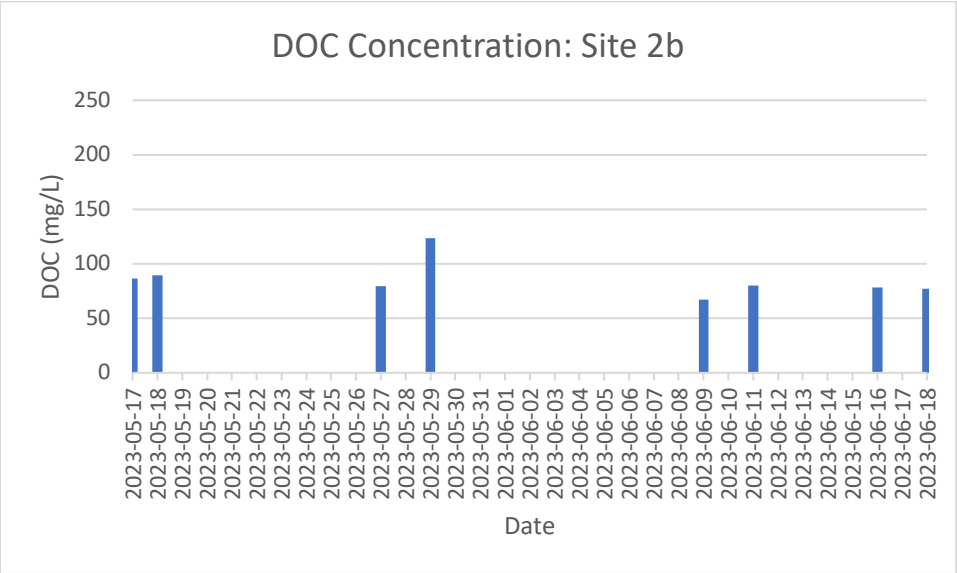

Figure 4.11. The DOC concentrations are shown for Site 2b between the dates of May 17 to June 18 in Rivière-du-Loup, Quebec. Units are in mg/L. Most samples show concentrations of DOC close to 80 mg/L, with May 29th as the main outlier (124 mg/L). Data is not shown for certain days due to no field work being conducted.

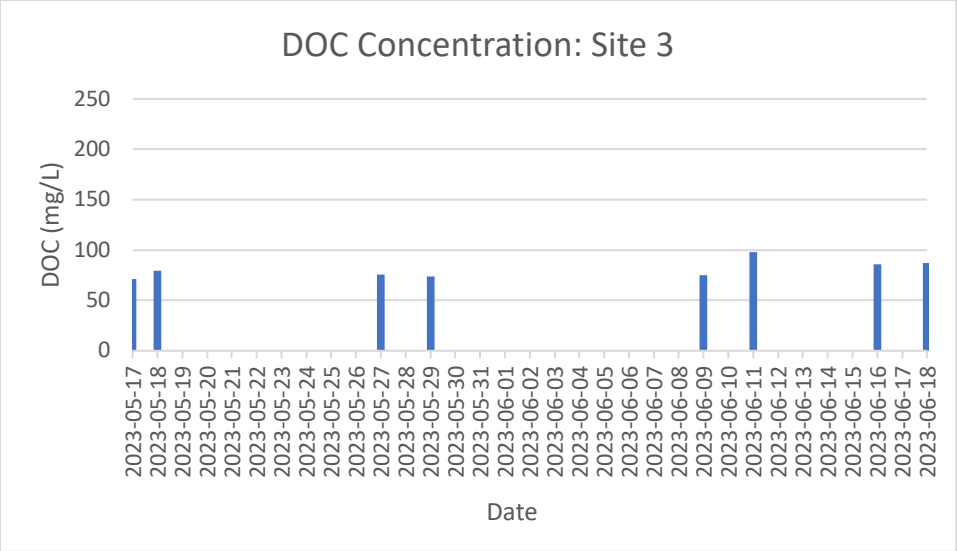

Figure 4.12. The DOC concentrations are presented for Site 3 between the dates of May 17 to June 18 in Rivière-du-Loup, Quebec. Units are in mg/L. DOC concentrations on most sampling days are approximately around 75 mg/L. However, June 11 represents a spike in concentration (98 mg/L). Data is not shown for certain days due to no field work being conducted. Note, values displayed above are averages of DOC concentration as multiple DOC samples were collected at Site 3 per day.

DOC concentrations at all sites are to range between 0 to 250 mg/L. Dates with no data are left within the graph to show the change in DOC concentrations over time. DOC concentration primarily ranged around 70-80 mg/L at all the sites. However, samples collected at Site 2a demonstrate larger concentrations in DOC in comparison to the rest of the sites, ranging closer to 100 mg/L in concentration.

5. Discussion

Due to the heterogeneity between the four sites researched within the extracted peatland, different trends in CO_2, CH_4, and DOC were observed within the results section. This section will extrapolate on and discuss these observations and suggest future research avenues to gain a clearing picture on the dynamics of carbon within extracted peatlands.

5.1. Carbon Emissions

CO_2 emissions are negligible at all sites except in Site 1. The drainage ditch at Site 1 contains a low water table and no surface water. This allows for the ditch to become an aerated zone, which facilitates more oxidation and decomposition, and thus more production of CO_2. This is not possible at any of the other sites due to the constant presence of water within the drainage channel or settling pond. Within Site 1 itself, emissions drop from May to June, which would be explained by the rise in the water table. Site 1 on June 16th has a water level of -3.8 cm (data obtained from Nicolas Perciballi's ongoing study), which is the highest water level in comparison to the rest the days that emissions were measured. This would explain the reduction in emissions as the area becomes more saturated, in contrast to the state of the ditch in May. This trend has been observed in other studies, as increased CO_2 emissions from drainage ditches were correlated with decreased levels of groundwater level (Vanags-Duka et al., 2022). Another important factor to mention within the CO_2 flux is the CO_2 sequestration observed at Site 2a and 2b on May 27th. These are the only two sites that contain the drainage channels, which would explain the presence of the same trend between the two sites on the same day. Although a reason behind this CO_2 fixation is not known and is outside of the focus of this study, it can be hypothesized that this sequestration of CO_2 from the atmosphere is facilitated through microbial

activity. A study by Hamard et al. (2021) concluded that phototrophic microbes, such as cyanobacteria, alphaproteobacteria, are highly prevalent in peatland environments and are estimated to "take up around 75 MT CO_2 per year in northern peatlands" (p. 3424). Water availability is crucial in determining the composition and structure of these phototrophic microbe communities and determining how much of an actor they are in CO_2 fixation (Hamard et al., 2021).

In addition, the results of this study confirm a difference between CO_2 emissions in the spring and summer. A study by Clark et al. (2023) conducted an emission analysis on the same extracted peatland (in Rivière-du-Loup managed by Premier Tech) as this study. The field research spanned the years of 2018, 2019, and 2020 in the summer months. The researchers concluded that CO_2 emissions from drainage ditches within the extracted peatland emitted an average of 2.05±0.12 g C m^{-2} d^{-1}(Clark et al., 2023). These emissions are substantially higher than what is observed within the spring months in the results section of this paper. It is crucial to mention that the paper by Clark et al. (2023) did not analyze emissions from the drainage channels or the settling ponds, having focused on multiple drainage ditches along the drained peatland fields, which could explain the difference in data. However, Site 1, which is within the site extent studied by Clark et al. (2023), still demonstrated a lower average of CO_2 emissions than the emissions presented by Clark et al. (2023). Research conducted by Nicolas Perciballi on the same peatland also confirms that there exist higher CO_2 emissions in the summer than in the spring. CO_2 emissions in August and September of 2022 averaged around 1 g of C/m^2/day and 0.75 g of C/m^2/day, respectively. Thus, it can be concluded that CO_2 emissions are lower within an extracted peatland in the spring than in the summer.

CH_4 emissions are observed to be quite heterogeneous amongst all sites. At Site 1, CH_4 emissions grow in May, until dropping drastically in the month of June. This trend goes against the assumption that methane emissions grow with increasing groundwater levels, not aligning with existing literature, as Vanags-Duka et al. (2022) claim that "CH_4 emissions from drainage ditches increased with increasing GW level and water level in ditches" (p. 1). Factors such as the general climate and/or weather conditions could have factored into altering the CH_4 emissions. However, no conclusive explanation can be provided.

A drastic difference is seen at Site 2b in comparison to the rest of the sites. The water level stays uniform throughout the site with low levels of velocity. However, emissions are seen to vary drastically between the three days of GHG analysis. This variability can be explained as Site 2b is downstream of the new section of the extracted peatland created in the summer of 2022. This has the potential of introducing more labile DOC that can be converted CH_4, as through a complex chemoautotrophic process, it can be possible for DOC to be converted into CH_4 by hydrogenotrophic methanogens (Lyu, 2018). Such trends have been observed in other environments such as aquaculture ponds, as methanogenesis rates increased with higher levels of DOC within the water (Tan, 2023). Furthermore, the minimal CH_4 sequestration present within the site can be explained by microbial methanotrophy, however more investigation must be done to confirm.

The hypothesis of Site 3 having the largest CH_4 emissions in contrast to the rest of the sites is not demonstrated, as it was assumed that due to the constant influx of dissolved organic matter (DOM) and DOC into the settling ponds, microbial activity would thus produce high levels of methane. These low CH_4 emissions can be explained as water is primarily stagnant and cold, providing an unfavourable environment for microbes. Furthermore, in the summer of 2022,

all ditches, channels, and settling ponds were cleared of vegetation and cleaned. This results in the channels and settling ponds to having a base of fresh clay. Thus, the settling pond can contain larger amounts of dissolved inorganic carbon (DIC) than DOC. However, more research is needed to conclude this and what it can mean for methane emissions. Furthermore, most of the DOC pool within the settling pond can be refractory DOC. This type of DOC has a chemical structure that is less appetizing for microbes and has a "slower turnover–ranging from weeks or months to decades" (Pontiller et al., 2020, p. 2). The same trend can be explained by the lack of CH_4 emissions at Site 2a, as the water is primarily stagnant, and the majority of DOC within the channel could be non-labile. However, this is not definitive.

Although CH_4 emissions are variable between all sites, emissions are still lower than what is observed in the summer. In the study by Clark et al. (2023), CH_4 was also measured, and it was concluded that the CH_4 emissions averaged 72.0±18.0 mg C m^{-2} d^{-1}. This disparity in data can be explained since the drainage channels and settling ponds were not studied by Clark et al. (2023). However, Site 1, which was within the site extent in the Clark et al. (2023) paper, still demonstrates very low CH_4 emissions in comparison to Clark et al. (2023). This drastic difference in CH_4 flux must have other explanations. Thus, the time of GHG measurement can be a huge factor, and it can be deducted that CH_4 emissions in the spring are lower than in the summer. Furthermore, the research conducted by Nicolas Perciballi in the summer of 2022 backs up this conclusion. His research revealed that CH_4 emissions primarily averaged around 20 to 40 mg of C/m^2/day in August and September of 2022, with outliers that were as high as 1000 mg of C/m^2/day. Such large values can be partly contributed to the disturbances produced by ditch, channel, and settling pond reconstruction in mid-July to mid-August 2022, however these emissions are still larger to what is observed in the spring.

5.2. DOC Concentrations

As demonstrated in the results section of this paper, DOC concentrations primarily ranged between 70-80 mg/L in the spring, with Site 2a having concentrations ranging closer to 100 mg/L. This can be explained by the low water level and potential pooling of water at Site 2a, which results in more DOC collection. These values match with concentrations seen in past literature. For example, Moore and Clarkson (2007) studied DOC export in New Zealand peatlands between February and March 2006, and discovered that extracted peatlands averaged DOC concentrations of 81 to 129 mg/L. These values are fairly close to what is observed in this study. However, Frank et al. (2017) studied peatlands on Germany, and detected DOC concentrations that averaged between 161 to 192 mg/L, which is substantially higher in comparison to the concentrations discussed in this paper. It is critical to mention that the paper by Frank et al. (2017) sampled DOC bi-weekly between June 2011 to June 2013, not particularly focusing on the spring months. The peatlands studied within the paper also contained high peat-sand mixtures (Frank et al., 2017). These two factors can possibly explain the larger DOC concentrations in comparison to the extracted peatland studied in this paper.

However, in reference to the particular extracted peatland studied within this paper, DOC concentrations do not fluctuate over time. In comparison to field research conducted by Nicolas Perciballi, on the same peatland in Rivière-du-Loup managed by Premier Tech, in the summer of 2022, DOC concentrations are relatively the same to what is observed in May and June of 2023. This indicates that DOC export and concentration does not drastically change between the spring and summer months.

The connections of DOC to CO_2 and CH_4 are critical to mention. As discussed prior, DOC can photodegrade and be released as CO_2 (Evans et al., 2016). In this study, this process

would be hindered as the chamber used to measure the GHG flux is covered in tin foil, prohibiting light from entering. Thus, this can explain why there is a lack of CO_2 emissions within the sites containing water (Site 2a, 2b, and 3). However, this is an assumption on the link between DOC and CO_2. In relation to DOC and CH_4, the connection between the two was elaborated on above.

6. Conclusion

Within extracted peatlands, CO_2 and CH_4 emissions are lower in the spring to what is reported in the summer. This does not follow for DOC, as it is seen to stay relatively the same through time. Due to the differences in structure of Site 1, 2a, 2b, and 3, this paper emphasizes that this heterogeneity explains the observed CO_2, CH_4, and DOC trends. The discussion section provides explanations to rationalize these specific trends within the data, although many other factors can also be in play. This can include changes in weather, climate, vegetation, water levels, and management practices. Spatial and temporal variability can also explain the differences in carbon dynamics between sites, as observed in other peatland studies (Green et al., 2018). Although this study was able to provide insight into carbon fluctuations within extracted peatlands, there remains ample opportunity for future research. It is suggested that studies in the future should analyze more than ditch and field GHG emissions (e.g., drainage channels and settling ponds), as it can provide for a clearer understanding of how extracted peatlands contribute as a carbon net source. Furthermore, more rigorous GHG measurements should be conducted in consecutive days and/or weeks to understand GHG emission changes throughout time thoroughly.

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