

Automatic chamber measurements of Net Ecosystem (CO₂) Exchange at a Subarctic Mire in Northern Sweden

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Abstract— Permafrost stores 50% of the global soil organic carbon [1]. Increasing climate temperatures in the arctic region have given rise to permafrost thaw, exposing once stable organic carbon to decomposition, and potentially altering the global carbon budget. In this study, we present a secondary data analysis of high frequency net ecosystem (CO₂) exchange measurements made using a quantum cascade laser spectrometer (Aerodyne Research Institute) connected to a nine member autochamber system positioned in the three dominant vegetation communities at Stordalen Mire in Northern Sweden (68° 21'N, 18° 49'E). Over DOY 121 - 260 during the year 2013, the magnitude of net ecosystem (CO₂) exchanged followed the moisture gradient with increasing CO₂ uptake from the dry Palsa site (- 0.3 ± 1.6 mg C m⁻² h⁻¹), to the wet intermediate melt feature with Sphagnum spp. (- 22.1 ± 0.9 mg C m⁻² h⁻¹), to the fully wet Eriophorum spp. site (- 49.9 ± 4.2 mg C m⁻² h⁻¹), with highest uptake occurring in the fully thawed Eriophorum/Sphagnum (Ch. 9) collar (- 87.2 ± 6.0 mg C m⁻² h⁻¹) (overall mean ±1 SE, n = 1267, 2334, 1211, 772). All mean fluxes were statistically different from each other (p < 0.0001). At all sites, PAR was the best environmental predictor of NEE. Although increased warming has resulted in permafrost thaw, any possible loss of old carbon in the form of CO₂ from thawing or thawed sites was more than offset by a greater net uptake of CO₂ occurring in the wetter sites.

Index Terms— Permafrost, wetland, bog, fen net ecosystem (CO₂) exchange, diurnal, peatland, peat, respiration, thaw gradient

I. INTRODUCTION

Northern latitude (>~50°N) wetlands are characterized by cold, wet conditions that result in low decomposition rates for plant litter. These conditions promote the sequestration of carbon (C) in the form of organic matter (i.e. peat) and result in the development of widespread peatlands, wetlands thick with water-logged organic soil layer (peat) made up of decomposing plant material. Peatlands in

the Northern Hemisphere have removed atmospheric CO₂ for the past 10,000 years [2]. Approximately twenty-four percent (24%) of the Northern Hemisphere contains permafrost, which has accumulated 1700 Petagrams (Pg) of organic C, which is more than double the size of the whole atmospheric carbon pool and more than twice the amount of previous estimates in high latitude [3, 4, 5].

Approximately 50% of the world's soil carbon pool is contained in northern permafrost regions [1]. The amount of carbon reserved in the cryogenic soil is estimated to be as high as 88% of the 1672 Pg of carbon found in northern latitudes; 450 to 700 Gt of the carbon is stored within the northern peatlands [4, 6].

As of 2000, average temperature levels in the Swedish sub-arctic region have reached a point where statistical data shows the temperature has crossed the 0°C mean annual threshold for permafrost stability [7]. According to the Intergovernmental Panel on Climate Change the average temperature of land and ocean surfaces has increased historically; approximately 0.85°C (1.53°F) over the last 100 years [8]. Northern peatlands have been locations of interest due to their contemporary C balance and their potential feedbacks due to climate change [4].

With the temperature increase in arctic regions, the result is permafrost thaw. Peatlands in the Northern permafrost regions have been currently experiencing increased thaw rates [7, 9, 10]. The recession of permafrost has been the subject of observation in prior studies of arctic and subarctic regions [11]. Large scale permafrost degradation has been predicted for the 21st century in models by the Arctic Climate Impact Assessment [12].

A more prevalent concern is the environmental and physical changes that would occur from positive or negative feedback of accelerated climate change. Changes in vegetation could include increased plant growth and vegetation

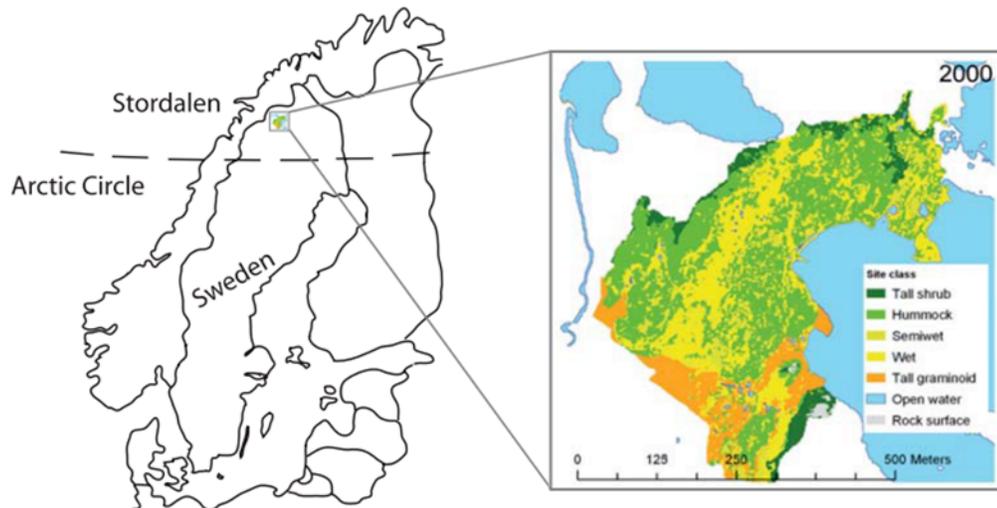


Figure 1. A map of the study site Stordalen mire. Classifications Hummock, Semiwet and Wet, and Tall Graminoid correlate with the three vegetation communities of interest: the palsa, Sphagnum, and Eriophorum sites, respectively.

decomposition [10]. In correlation with the decomposition of vegetation, carbon released into the atmosphere has the potential to turn into carbon dioxide (CO₂) or methane (CH₄). The addition of carbon dioxide and methane to the atmosphere will create positive feedback to global warming [7, 8]. Scientists question whether the northern peatlands will remain an overall carbon sink or if they will shift to a carbon source.

A site of interest to help understand the effects that climate change has had on arctic wetlands is the Stordalen Mire located in northern Sweden. The mire is a heterogeneous landscape, where the vegetation varies due to the site being in a zone of discontinuous permafrost, which creates differences in plant life, moisture, nutrient and permafrost statuses [10]. The hydrological component and climate temperature have impacting effects on the environment and the atmospheric sink function of the peatlands [10]. The thawing of permafrost increases the hydrologic levels which produce more pond-like areas [7]. It has been shown that moisture impacts microbial activity [13]. Permafrost thaw in peatlands is best identified by changes in the structure of the ecosystem [10, 14, 15]. When permafrost thaw increases rapidly, the result is a wet habitat due to a high water table [10]. This leads to a shift to a wetter environment (i.e. from a bog to a fen) and, subsequently, a shift in vegetation growth as well as a change in the microbial community [10]. These areas take in more CO₂ via photosynthesis and heterotrophic and autotrophic respiration [16]. The increase in moisture and nutrients due to the degradation of permafrost enhance conditions for CO₂ and CH₄ to be emitted in the atmosphere [17].

In this study, we performed a secondary data analysis of net ecosystem (CO₂) exchange (NEE) measurements and environmental conditions (i.e. PAR, air and ground temperature) collected along a natural permafrost thaw gradient from DOY 121 - 260, year 2013.

II. METHODOLOGY

A. Site Description

Stordalen Mire (10 km east of Abisko of northern Sweden (68° 21'N, 18° 49'E, altitude 363 m above sea level) has been the focus of many investigations and research concerning decadal vegetation, trace gas emissions, and climate change due to its location within the Arctic circle (Fig. 1)[7, 10, 13, 14, 15, 16]. Stordalen is characterized as a palsa mire underlain with patchy, sporadic permafrost. The areas within the mire nearby each other have a variety of moisture and nutrient status ranges [10].

The annual temperature at Abisko Scientific Research Station of 0.07°C with 308 mm of accumulated precipitation (1986-2006 20 year mean) [16]. The research focused on three different sub-habitats that have the most dominant presence in Stordalen and common to northern wetlands. The three communities are i) drained palsas underneath woody herbaceous (permafrost), ii) intermediate permafrost sites where the water table fluctuates close to the ground, dominated by Sphagnum, and iii) wet sites where the ground completely thawed in the summer, wet areas containing Eriophorum. For the sake of this research we will refer to the three sites as the palsa site, Sphagnum site, and Eriophorum site. Together, the three vegetation communities cover 98% of Stordalen Mire. The palsa site coverage extends 49% of Stordalen, the Sphagnum site expands over 37%, and Eriophorum reach 12% of the mire [15]. The fourth site is a transition collar between the Eriophorum and Sphagnum sites [11].

When the permafrost thaws, the added moisture gives Stordalen the characteristics of a peatland [19]. The thawing of the frost-covered soil causes the peatlands to collapse and form bogs and fens [20]. As the permafrost thaws, the

ombrotrophic bogs morph into minerotrophic fens due to subsidence increasing the flow of water in the area. The transition from bogs to fens has been occurring in other northern peatlands as well [20]. Thawing of permafrost soil can alter the appearance of the wetland community. Observing the landscape properties and hydrological conditions determines the characteristics and course of the wetland habitat after the thawing of the permafrost [20].

B. Automatic Chamber System and Quantum Cascade Laser Spectrometer Measurements

The automatic chamber system has been fully described in earlier papers [16, 21]. In brief, a system of eight automatic gas-sampling chambers made of transparent Lexan with aluminum frames was inserted into the ground at depth of 5-10 cm in the three predominant habitat types at Stordalen Mire in 2001 ($n = 3$ each in the palsa and Sphagnum habitats, and $n = 2$ in the Eriophorum habitat). Each chamber covers an area of 0.14m² (38cm x 38cm), with a height of 25 – 45 cm. The chambers are connected to the gas analysis system, located in an adjacent temperature controlled cabin.

The chamber system was updated in 2011 with the addition of a ninth chamber [$n = 3$ each at the Palsa and Sphagnum site, $n = 2$ Eriophorum site, $n = 1$ at the Eriophorum/Sphagnum collar, designated as Ch. 9). Each chamber covers an area of 0.2m² (45cm x 45cm) and has a height of 15 to 75 cm. At the palsa and Sphagnum site the chamber base is flush with the ground and the chamber lid 15cm in height) lifts clear of the base between closures. At the Eriophorum site the chamber base is raised 50 – 60 cm on Lexan skirts to accommodate vegetation of large stature (Fig. 1) [15]. The system works by each chamber being opened and closed automatically via a double acting pneumatic piston connected to a compressor by nylon tubes. The chambers are closed every 3 hours for 5 minutes, approximately 3% of everyday.

CO₂ concentrations were measured using a Quantum Cascade Laser Spectrometer (QCLS; Aerodyne Research Inc.) connect to the automatic chamber system [22]. The instrument has been described in detail and was calibrated using a 3-point calibration curve every 90 minutes [13]. In brief, the QCLS uses a continuous wave mid-infrared room temperature laser to measure across absorption lines of trace gases. The instrument was stationed in Stordalen Mire in 2011 and is connected to the automatic chamber system [13].

The palsa site chambers are located within the palsa site in and correspond to the hummock site class (I) described in [23, 24]. The Sphagnum site chambers are located within the bog site in or site S in and correspond to the semi-wet and wet site classes (II and III) described in [15, 23, 24]. The Eriophorum site chambers are located within the fen site in or site E and correspond to the tall graminoid site class (IV) described in Johansson et al. [15, 23, 24].

C. Measurements of Net Ecosystem (CO₂) Exchange

The NEE between an ecosystem and the atmosphere is the net result of the competing flux processes of gross primary production (GPP, photosynthetic CO₂ uptake) and total ecosystem respiration (TER, autotrophic and heterotrophic CO₂

production). Net uptake of CO₂ fluxes were calculated using a linear regression of change in the headspace mixing ratio with time during a period of 2.5 min (i.e., 10 readings of 15 s averages of 3s measurements of mixing ratios). Eight 2.5 min regressions were calculated, each start staggered by 15s. CO₂ emissions were determined from the 2.5 min period after each chamber closure with the highest r^2 value for the slope of change in the headspace mixing ratio with time, i.e., the most linear portion of the curve.

The steepest slope was used to calculate net uptake of CO₂, i.e., the portion of the curve with the highest uptake. The reason for treating C uptake differently from release is that plants and mosses saturate very quickly at high light and by choosing the steepest slope we were assuring that the most accurate, near time zero CO₂ uptake rates were calculated. When it is dark, photosynthesis does not occur so the highest r^2 ensures that flux represents the increase in CO₂ concentration over time that is closest to linear. The method described above is consistent with the standard procedure used to calculate flux with auto-chambers. All fluxes (positive or negative; $n = 13,527$) with $r^2 < 0.87$ (minimum necessary for 95% confidence limits) were eliminated, resulting in 47% of the data being discarded ($n = 6,411$).

D. Environmental Variables

In addition to the trace gas data, ground and air temperature were recorded within each chamber, while photosynthetically active radiation (PAR) was measured at the top of the automatic chamber system shelter. The data was continuously logged by the automatic chamber system previously described.

E. Data Analysis

We distinguished day and night CO₂ fluxes to account for diurnal fluctuations. The sun does not set during this time of year in areas located 180km above the Arctic Circle, but during the period where the sun is at its lowest angle, calm cool periods are induced due to surface cooling. Based on light and temperature variability during 24 hour periods, daytime was determined to be from 10:30 am to 3:30 pm and night time was from 9:30 pm to 2:30 am [11]. For this study, CO₂ uptake by the ecosystem is negative and emitted CO₂ is positive. Measurements were taken with the automatic chamber system and were analyzed through JMP Pro 12 (SAS Institute Inc.). Relationships between the independent variables and CO₂ flux using a one-way analysis of variables (ANOVA) ($\alpha = 0.05$) were examined.

III. RESULTS

A. Environmental Conditions

Average PAR from DOY 121 - 260 (1st May - 17th September) was 214 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$, indicating a very cloudy observation period. Average high PAR ($x > 1000 \mu\text{mol photon m}^{-2}\text{s}^{-1}$) was 1147 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$, with the maximum PAR recorded at 1743 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$ (Fig. 2). High PAR peaked between DOY 162 - 168 (11th - 17th June) and declined until DOY 231 (19th August). For the rest of the

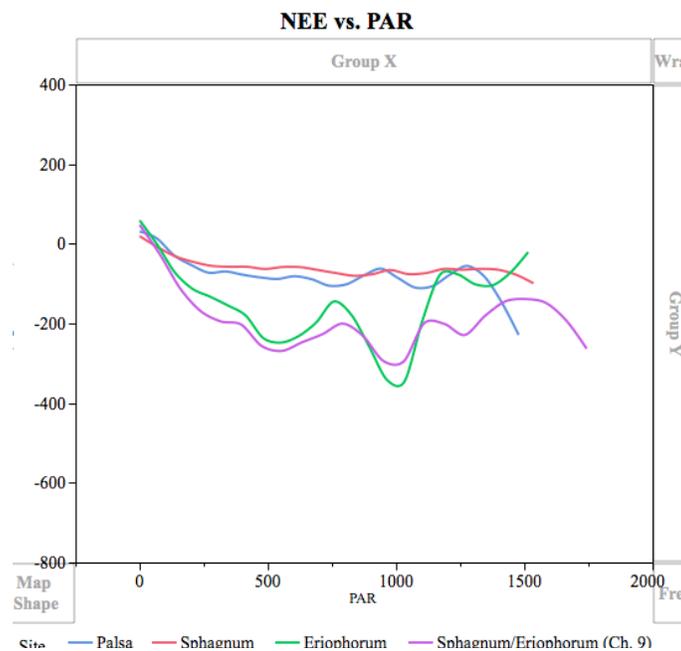


Figure 2. Shows correlation between NEE and PAR over all sites (Palsa, Sphagnum, Eriophorum, and Sphagnum Eriophorum). NEE stands for net ecosystem (CO_2) exchange. PAR stands for photosynthetically active radiation in x axis. Data was filtered to only show $\text{PAR} > 0$.

season, no daily PAR observations were greater than 1000 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$. Mean air and peat temperature were 10.4 ± 0.18 and 9.0 ± 0.17 $^{\circ}\text{C}$, respectively, with July being the warmest month.

B. Spatial Variability of Flux Ranges

The total number of flux measurements for this analysis were $n = 5,567$ ($n = 1267$ for the palsa site; $n = 2334$ for the intermediate thaw Sphagnum site; $n = 1221$ for the fully thawed Eriophorum site; and $n = 772$ for fully thawed transition collar (Ch. 9), respectively. Carbon dioxide fluxes increased in magnitude along the thaw gradient from the semi-wet Sphagnum site to fully thawed Eriophorum site. However, atmospheric C uptake and release flux ranges were higher for the fully dry palsa site (-274.6 to 147.2 $\text{mg C m}^{-2} \text{h}^{-1}$) relative to the semi-wet site dominated by Sphagnum moss (-188.6 to 115.4 $\text{mg C m}^{-2} \text{h}^{-1}$). We observed mixed uptake and emission flux ranges occurring in the fully thawed site dominated by Eriophorum and the fully wet transition collar designated as Ch. 9. The maximum C uptake of -642.3 $\text{mg C m}^{-2} \text{h}^{-1}$ was recorded at Ch. 9, while the highest atmospheric CO_2 release (281.2 $\text{mg C m}^{-2} \text{h}^{-1}$) occurred in the Eriophorum site. Recorded C uptake was -609.8 $\text{mg C m}^{-2} \text{h}^{-1}$ in the Eriophorum site and 253.6 $\text{mg C m}^{-2} \text{h}^{-1}$ was released from Ch. 9.

C. Net Ecosystem (CO_2) Exchange

The overall mean fluxes of each site were significantly different from each other with a $p < 0.001$.

All sites over the analysis period were net C sinks with uptake increasing along the permafrost thaw gradient (Fig. 3). Significant differences ($p < 0.0001$) in average NEE across all sites were observed.

The palsa site underlain by intact permafrost was close to a potential small atmospheric sink with a mean NEE of -0.3 ± 1.6 $\text{mg C m}^{-2} \text{h}^{-1}$ (all errors reported as s.e.m). -22.1 ± 0.9 , -49.9 ± 4.2 , and -87.2 ± 6.0 $\text{mg C m}^{-2} \text{h}^{-1}$ for the partially thawed Sphagnum and the fully thawed Eriophorum and Eriophorum / Sphagnum (Ch. 9) sites, respectively.

Through regression analysis, we examined the independent variables (i.e. PAR, air and ground temperature) in terms of the whole season, as well as grouped by the individual sites. Across the sampling period, PAR had the strongest correlation ($r^2 = 0.30$), followed by air temperature ($r^2 = 0.18$). Ground temperature had the lowest overall correlation to the results with an r^2 of 0.04.

At the palsa site, PAR again, had the strongest correlation ($r^2 = 0.50$). In contrast to the whole season, ground temperature had the second strongest correlation ($r^2 = 0.30$). For the Sphagnum site, PAR continued to have the strongest correlation ($r^2 = 0.50$) followed closely by air temperature ($r^2 = 0.42$). The regression data for the Eriophorum site was similar to the overall green season with the two strongest correlations being PAR ($r^2 = 0.40$) and air temperature ($r^2 = 0.30$). The Eriophorum/Sphagnum site, similar to the other sites and the mire green season regression analysis had PAR as the strongest correlation ($r^2 = 0.31$). Air temperature had the second strongest correlation ($r^2 = 0.30$).

D. Diurnal Variability of Fluxes and Correlation with Environmental Variables

We examined diurnal signals in the flux regimes of the overall site by dividing the data into day and nighttime as described in the methods section. As mentioned previously in the data analysis section, daytime is identified as being between 10:30 a.m. and 3:30 p.m. During the day, vegetation was able

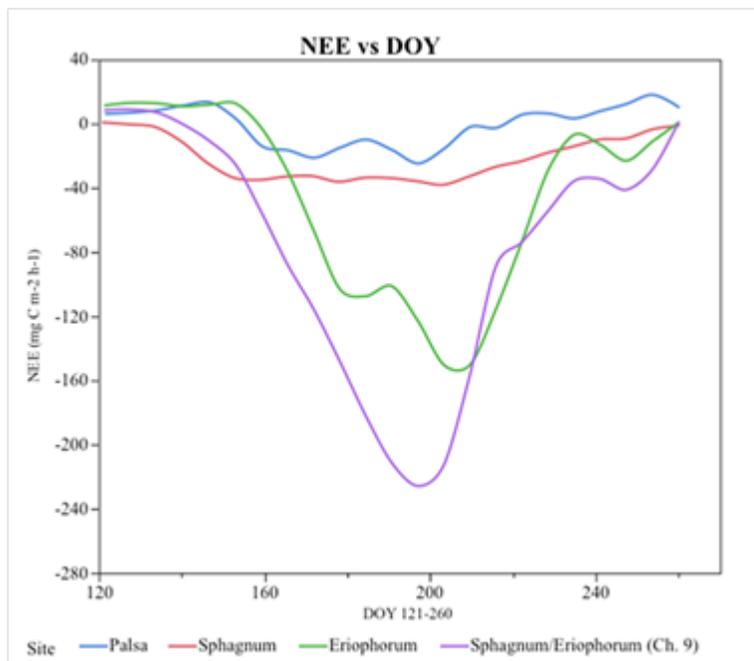


Figure 3. Shows relationship between NEE and DOY over all sites over green season. DOY stands for day of year in x axis. Data was filtered to show days 121-260.

to absorb more light due to higher PAR versus during the cooler periods that were considered night time (Fig. 3). During the growing season, the flux during the day ranged from $-599.3 \text{ mgC m}^{-2} \text{ h}^{-1}$ at its minimum and $41.2 \text{ mgC m}^{-2} \text{ h}^{-1}$ at its maximum with an average of $-135.2 \text{ mgC m}^{-2} \text{ h}^{-1}$.

Regression analysis was performed on the data to determine the effect the environmental variables had on the CO_2 flux. At the Palsa site, PAR had the strongest data correlation ($r^2=0.50$). Ground temperature ($r^2=0.30$) had the second strongest correlation to the data. PAR continued to maintain the strongest correlation to the data in the Sphagnum site with $r^2=0.50$, followed closely by air temperature ($r^2=0.42$). In the Eriophorum site PAR again had the highest r^2 (0.35), the second strongest being air temperature ($r^2=0.28$). The regression analysis data of chamber 9 (Eriophorum/Sphagnum) mirrored the Eriophorum site where PAR had the strongest correlation ($r^2=0.31$) and air temperature ($r^2=0.30$) as the second strongest.

Day time was defined earlier as being between 10:30 a.m. and 3:30 p.m. The maximum flux was recorded as $41.20 \text{ mgC m}^{-2} \text{ h}^{-1}$ for the entire site with a minimum flux of $-599.29 \text{ mgC m}^{-2} \text{ h}^{-1}$ and a mean of $-135.17 \text{ mgC m}^{-2} \text{ h}^{-1}$. At night, all sites emitted CO_2 to the atmosphere. The CO_2 emissions increased along the thaw gradient. In the palsa site, the minimum flux was $-43.89 \text{ mgC m}^{-2} \text{ h}^{-1}$ with a mean of $32.17 \text{ mgC m}^{-2} \text{ h}^{-1}$ and a standard error of 1.23. The Sphagnum had a larger minimum of $-58.80 \text{ mgC m}^{-2} \text{ h}^{-1}$, but had a significantly smaller mean of $17.99 \text{ mgC m}^{-2} \text{ h}^{-1}$. The standard error of the Sphagnum site was 0.63. The minimum flux continued to increase in the Eriophorum site ($-83.96 \text{ mgC m}^{-2} \text{ h}^{-1}$) and the mean increased to $52.59 \text{ mgC m}^{-2} \text{ h}^{-1}$, with a standard error of 1.86. Ch. 9 had the largest minimum of CO_2 flux at $-255.77 \text{ mgC m}^{-2} \text{ h}^{-1}$. The mean was slightly lower than the Eriophorum site ($51.97 \text{ mgC m}^{-2} \text{ h}^{-1}$), but maintained a higher standard error of 2.92.

IV. DISCUSSION

A. Spatial Variability of Fluxes

As mentioned before, the CO_2 flux increased along the thaw gradient going from the driest site to the wettest. This is likely due to the differences in vegetation levels among the sites. Since plants take up CO_2 to perform photosynthesis, the assumption is that the sites that have more vegetation are likely to have more C uptake in comparison to the sites with less vegetation. Those sites with more vegetation are generally the wetter sites with a larger active layer in comparison to the permafrost layer if there is one (Sphagnum, Eriophorum, Ch. 9). In contrast to this assumption, the data revealed that the palsa site had a higher C intake ($-274.6 \text{ mgC m}^{-2} \text{ h}^{-1}$) relative to the Sphagnum site ($-188.6 \text{ mgC m}^{-2} \text{ h}^{-1}$). This result was different from our expectations since the Sphagnum site has vegetation (Sphagnum moss) whereas the palsa site has is generally barren due to the continuous layer of permafrost. The only determined reasons for this outcome would be that the palsa site has actually collapsed; the palsa site is transitioning to a Sphagnum site due to permafrost thaw, or there was an error with data acquisition. The highest C uptake was found at the transition collar, Ch. 9, $-642.3 \text{ mgC m}^{-2} \text{ h}^{-1}$ where there was a combination of plant life. The Eriophorum site had the highest C emission ($253.6 \text{ mgC m}^{-2} \text{ h}^{-1}$) but also the second highest C uptake ($-609.8 \text{ mgC m}^{-2} \text{ h}^{-1}$). The high C emission can be attributed to CH_4 which is produced and released in wet areas and the Eriophorum was the wettest site. The minimal thaw gradient in the Eriophorum allowed for more diverse plant life to grow leading to more photosynthesis and CO_2 uptake.

B. Seasonal Net Ecosystem (CO₂) Exchange

The NEE for the whole mire during the green season reported C uptake throughout the progression of the year. The average NEE for the whole mire for 2013 green season was $-32.207 \text{ mgC m}^{-2} \text{ h}^{-1}$. This shows that on average during the green season, C uptake was strongly present in Stordalen Mire. The palsa site had the smallest NEE value of $-0.3 \pm 1.6 \text{ mg C m}^{-2} \text{ h}^{-1}$. This result was in line with expectations of the study since the site had little to no vegetation so photosynthesis would be minimal. The resulting values for NEE of the other sites were also expected due to the location of the sites along the thaw gradient. As the sites had more permafrost thaw, more vegetation would appear and be able to uptake C. In terms of the regression data, it was noted that PAR was the environmental variable with the strongest correlation to not only the data of the whole mire, but also the individual sites as well. At the sites, PAR accounted for up to 50% of the data in comparison to the 30% of the entire mire. While ground and air temperature had an influence on the C flux, PAR appeared to have a more direct influence since it correlated to the amount of sunlight each site received.

C. Diurnal Variability of Fluxes and Correlation of Environmental Variables

During the day the C flux was mainly C uptake. There was some C emission ($41.20 \text{ mgC m}^{-2} \text{ h}^{-1}$) which could be attributed to the wetter sites which produce CH₄. The negative C flux, identified earlier in this paper as being uptake, -599.29 can be explained by the vegetation of the mire performing photosynthesis. During this time period (10:30 a.m. to 3:30 p.m.), the sun was at its highest angles allowing for more exposure to photosynthetic radiation. Overall, the mean flux was C uptake ($-135.17 \text{ mgC m}^{-2} \text{ h}^{-1}$) since the uptake was higher than emission.

All of the sites emitted C to the atmosphere, with emissions becoming stronger down the thaw gradient. Since nighttime, as previously discussed, is relative since the sun does not set during this time of year, any C uptake can be attributed to the photosynthesis that occurred during this period. The site with the strongest C emission was the fully wet Eriophorum site ($52.59 \text{ mgC m}^{-2} \text{ h}^{-1}$) where the most carbon in the form of CH₄ would potentially be produced. Ch. 9, a combination between a partially thawed and a fully thawed site (Sphagnum and Eriophorum, respectively). Notably, this site also had the highest uptake ($-255.77 \text{ mgC m}^{-2} \text{ h}^{-1}$) which could be due to the combined vegetation. At the Sphagnum site, the average flux was $17.99 \text{ mgC m}^{-2} \text{ h}^{-1}$ and the site a negative flux closer to the Eriophorum site ($-58.80 \text{ mgC m}^{-2} \text{ h}^{-1}$) both of which had similar thaw gradients. The palsa site, which had little to no vegetation due to being completely covered in permafrost, had some C uptake ($-43.89 \text{ mgC m}^{-2} \text{ h}^{-1}$) as well as emission which could be attributed to soil respiration due to increase in thaw caused by climate warming.

V. CONCLUSION

The purpose of this research was to determine whether or not the Stordalen Mire would maintain the status of an

atmospheric C sink or become an atmospheric C source after the effects of climate change. In conclusion, the data for the green season of 2013 revealed that the entire Stordalen Mire site remained a carbon sink. The calculated mean of NEE was recorded as $-32.207 \text{ mgC m}^{-2} \text{ h}^{-1}$ for the whole peatland showing consistent uptake during the green season. The same can be concluded for each individual site within mire. The palsa site recorded $-0.394 \text{ mgC m}^{-2} \text{ h}^{-1}$ which was the lowest atmospheric sink site. Next came the Sphagnum site with $-22.12 \text{ mgC m}^{-2} \text{ h}^{-1}$. The highest average C uptake present in the mire was found at the Eriophorum site with $-49.935 \text{ mgC m}^{-2} \text{ h}^{-1}$ and the Eriophorum/Sphagnum (Ch.9) site with $-87.196 \text{ mgC m}^{-2} \text{ h}^{-1}$. The Eriophorum and Ch.9 sites were the largest carbon sinks of the mire, with the transition collar, Ch. 9, having the largest uptake of CO₂. The regression analysis performed showed that out of the three environmental variables tested, PAR explained most of the data with the highest r² value for the whole mire and each individual site. This could be due to the strong impact photosynthesis has on the uptake of carbon.

VI. FUTURE WORKS

For the future work we plan to study the water table depth to have an understanding of the hydrology of the sites. Hydrological functions influence microbial communities that can have an effect on the production either CO₂ or CH₄. The water table depth also provides clarity to the extent of the permafrost thaw. In addition to the water table depth, we also plan to look at measurements of the active layer. The active layer depth increases as the permafrost thaws. Documentation of the changes in the active layer on an extensive period of time can indicate the amount of permafrost that is lost. Both of these would be used as environmental variables to further develop insight on their effect on NEE.

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