

The Effects of Moisture and Organic Matter Lability on Carbon Dioxide and Methane Production in an Atlantic White Cedar Swamp

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Abstract

Atlantic white cedar swamps are part of the globally important wetland ecosystems that store large amounts of carbon in the form of peat and other undecomposed plant matter. Global climate change is a threat to these ecosystems because it has the potential to permanently change the water table, which would be harmful to these swamps. In this study I examined the effects of water table, as well as organic matter lability, on the production of both carbon dioxide and methane gas. Gas flux was measured in the field at five sites along a 20 meter moisture gradient. Soil samples were analyzed for organic matter lability, as well as for pH and soil moisture. I found that there was no relationship between the quality of organic matter (measured here as lignin:nitrogen and carbon:nitrogen ratios) and the rate of gas production from the swamp. I found a linear relationship between the height of the water table and the production of carbon dioxide and methane gases. An increase in water table yielded a decrease in the net efflux of carbon dioxide and an increase in the net efflux of methane. The highest rate of carbon dioxide production, at the upland site, was approximately $1.7 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$. The highest rate of methane production was in the lagg, which was $0.023 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$. Water table is the driving factor of carbon dioxide and methane production in this study, and permanent changes of the water table in these swamps would damage if not destroy these ecosystems as well as cause a positive feedback to global warming.

Key words: *cedar swamp, methane, carbon dioxide, gas flux, decomposition, respiration, methanogenesis, global climate change, water table, organic matter lability*

Introduction

Wetlands as ecosystems are very important factors in the global carbon cycle. While they comprise only 3.6% of the global land area, they can store up to one-third of total terrestrial organic carbon (Schlesinger 1997, Bubier et al. 2003). The carbon stored in wetlands is in the form of undecayed plant matter, or peat. Peat stored underwater in wetlands takes an extremely long time to decompose, therefore plant matter builds up over time (Williams and Crawford 1984). Atlantic white cedar swamps are one type of wetland ecosystem that is unique to the East coast of the United States, ranging from Florida to Maine (Laderman 1989). This type of wetland is only capable of existing in a humid environment, such as that created by the Atlantic Ocean, which is why they are only found close to the coast (A. Laderman, personal communication). These swamps are disappearing because of human influences on their environment. Their large stocks of undecomposed organic carbon are very useful for agricultural purposes. Their peat and preserved timber has been mined for hundreds of years to fertilize gardens and crops, as well as a source of fuel (Johnson 1985). Atlantic white cedar swamps have been converted for agriculture and destroyed due to flooding and runoff from development (C. Hicks, unpublished). And, finally, they may also be destroyed by global climate change.

One of the predicted effects of global climate change due to the rise in temperature is the melting of the polar ice caps as well as potential drought, and therefore a change in the global water regime. It is unknown what the exact consequences will be of a rise in the global temperature; however we may see changes in the precipitation regime, with some areas receiving less precipitation and some receiving more. Also, the height of the ocean may change due to large fresh water inputs from the melting ice caps. These delicate coastal ecosystems may suffer dramatic changes in their water table in the coming years, which will affect the slow rates of decomposition that are characteristic of the Atlantic white cedar swamps.

The fact that wetlands store so much carbon may be important in assessing how they will respond to global climate change. Water levels have a large effect on both aerobic and anaerobic decomposition rates (Schlesinger 1997), and, if lowered, could cause an increase in decomposition of the stored organic carbon and therefore a large release of carbon dioxide to the atmosphere. The ability of wetlands to store large amounts of organic carbon due to high water table, along with the predicted increase in evaporation in interior land areas (Chapin et al. 2002), may indicate a positive feedback response in wetlands to global warming. The changes in the water table, along with the availability of labile organic matter, could determine whether global wetlands switch to a large source of carbon as a result of global climate change.

The purpose of this study is to examine the effects of water table on decomposition through both aerobic and anaerobic respiration and the resulting production of carbon dioxide and methane gas. My hypothesis is that as water table rises, the production of carbon dioxide will decrease and the production of methane will increase, both as a result of the increasingly anaerobic conditions of the substrate. I predict that the highest methane production rates will be in the lagg, which is the area of a cedar swamp that has the deepest standing water (Laderman 1989). Also, as we know that the quality of the organic matter in the substrate plays a large role in determining the rate of decomposition (Schlesinger 1997), and that gas flux is correlated with enriched

soil organic content (Bartlett et al. 1987), my second hypothesis is that a higher quality of organic matter will create a higher rate of production of both carbon dioxide and methane gases. I hope to find that the sites with the highest carbon dioxide and methane fluxes will also have the highest quality of organic matter.

Methods

Site Description

I did this study in Hidden Swamp in Woods Hole, Massachusetts. This swamp is an Atlantic white cedar swamp that is relatively undisturbed compared to the other swamps in the area. Hidden swamp is dominated by the Atlantic white cedar, *Chamaecyparis thyoides*. The swamp is surrounded by a deciduous forest populated mainly by oak, maple and beech trees. Compared with other swamps in Woods Hole, this swamp has a lot of land area within its limits, in the form of hummocks created by the roots of the cedars. These hummocks create a habitat for *Sphagnum* mosses, liverworts, and other bryophytes as well as ferns and briars. The peat within the swamp is made up mostly of litter from the cedar trees, while the peat in the lagg around the perimeter of the swamp is a mixture of both cedar and deciduous leaf litter.

Methods

In Hidden Swamp, I set up a 20 meter long transect with 5 meter intervals that started in the deciduous forest that surrounds Hidden Swamp and ended within the swamp. I had sites at 0, 5, 10, 15 and 20 meters, as shown in Figures 1 and 2. The 15 and 20 meter sites had two components: hummock and hollow. At 0, 5, 15, and 20 meters I placed chamber collars into the substrate to be used for gas measurements. I installed the collars 4 days before measuring gas flux, to ensure that there was minimal disturbance in my gas flux measurements. At 10 meters as well as the “hollow” components of sites 15 and 20 meters, I did not install collars but instead used a chamber equipped with a floatation device crafted from plastic water bottles.

I measured carbon dioxide and methane production, soil and water temperature, pH of soil, soil moisture, percent carbon, nitrogen and lignin of soil, and height of water table in the swamp. I took soil samples only once to analyze for carbon, nitrogen, lignin, pH, and soil moisture. I sampled for gas production and temperature on 5 days within the project time.

Gas Flux Measurements

Carbon dioxide and methane gas production was measured using the standard static chamber method/enclosure method (Bubier et al. 1993, Robertson et al. 1999, Liblik et al. 1997). My chambers were made of dark PVC and had a volume of 9.088 liters. The volume at each site was different due to changes in soil and litter heights, as shown in Table 1. I took a sample every 4 minutes for a total flux time of 16 minutes and a total of 5 samples using 30 mL plastic syringes. These gas samples were analyzed using a

Shimadzu GC 14-A gas chromatograph flame ionization detector and thermal conductivity detector. The parts per million of each gas for each sample was obtained from the GC, which was then converted to micromoles using the ideal gas law.

$$n = PV/RT * 10^6$$

where: P = 1 atm * (ppm from GC)/10⁶

V = specific chamber volume

R = 0.08206

T = air temperature in Kelvin of sampling day

The micromolar concentration of each gas was then graphed as a function of time, and the slope of the line (umoles / minute) was divided by the area of the chamber (0.080424771 m²) to obtain umoles * m⁻² * minute⁻¹. This rate was converted to gC * m⁻² * day⁻¹ by multiplying the rate by 12.01 g C / mole of both CO₂ and CH₄ and by 60 * 24 minutes per day. The daily rates of flux for each site (0m, 5m, etc) were used to get the average rate of CO₂ and CH₄ production at each site.

Soil Sampling

To analyze for organic matter quality, I collected six organic matter samples from each of my five sites (0, 5, 10, 15, and 20 meters). The samples were taken from the top 5-10 cm of soil/peat within one meter of the collars at each site. Undecomposed litter was not sampled. I used a small metal soil corer to collect my samples. I first obtained the wet mass of each sample in the lab and dried them for 36 hours at 65 degrees Celsius. I then obtained the dry mass and used these values to calculate gravimetric soil moisture using the equation

$$(\text{wet mass} - \text{dry mass}) / \text{dry mass}$$

to calculate the grams of water per gram of dry soil at each site.

I then ground each sample using a Wiley Mill and a size 40 screen, to use for C:N analysis, pH, and lignin analysis.

To measure pH I mixed one gram of ground soil with 20 mL of deionized water, and determined the pH using a pH probe.

To analyze the soil for lignin content, I used a simplified version of Jerry Melillo's method for extracting carbon fractions from organic matter. I did an extraction method to separate acid insoluble compounds from my soil samples. A version of this method is outlined by Association of Official Analytical Chemists (AOAC), and was used in a study by A. Forbes and M. Reardon (unpublished). I measured out 400 mg (+/- 0.5 mg) onto weigh paper and placed each into an acid-washed BD-20 tube. I then added 3 ml of 75% sulfuric acid (H₂SO₄) and incubated the tubes in a 30 degree Celsius water bath for one hour, swirling each tube periodically to make sure that the acid and organic matter were well mixed. I then incubated them at 150-250 degrees Celsius in a block digester for one hour. I used two different block digesters which boiled the samples at different temperatures, hence the temperature range for the second incubation. The tubes

were allowed to cool overnight and the next day each sample was filtered into a pre-weighed and ashed Gooch filtering crucible. Deionized water was used to rinse the tubes into the crucibles to ensure that the entire sample was filtered. They were then dried at 65 degrees C for 36 hours, after which I weighed each of the crucibles to obtain the dry weight of the remaining sample. I then ashed the crucibles at 450 degrees Celsius for six hours, in order to obtain the weight of mineral ash present in the samples. To calculate the mass of lignin in each sample I used the following equation:

$$\text{mass of sample (crucible + sample mass - empty crucible mass) - mass of ash (crucible + ash mass - empty crucible mass) = grams lignin}$$

I then found the percent lignin in each of my samples by dividing the grams lignin by the original mass of the sample (400 mg) and multiplying by 100.

The same ground soil samples were analyzed for carbon and nitrogen content on a Perkin Elmer Series II CHN Analyzer 2400. C:N molar ratio was calculated:

$$(\% \text{ C} / 100) / 12.01 = \text{moles C} / \text{g soil}$$

$$(\% \text{ N} / 100) / 14 = \text{moles N} / \text{g soil}$$

$$\text{moles C} / \text{moles N} = \text{molar C:N ratio}$$

The ratio of lignin to nitrogen was also calculated simply by dividing grams of lignin per gram of soil by grams of nitrogen per gram of soil.

To measure water table, I installed PVC wells at 0, 15, and 20 meters along my transect. These wells had slits cut into the bottom end in order to let water enter through the ground. I measured depth to the water table using a water tape. The measurements were converted from feet to centimeters.

$$(\text{depth to water table} - \text{height of well}) * (30.48 \text{ cm/foot})$$

I measured temperature on each of my sampling days using a glass thermometer. Air temperature was measured at the 0 meters site, and soil temperatures were measured at each site at 5 and 10 cm depths. Water temperature was measured once in the lagg and applied to both “hollow” sites as well.

Results

The height of the water table along the transect ranged from 69.34 centimeters underground at the upland (0 meters) site to 25.4 centimeters above the surface of the ground in the lagg (10 meters). The height of the water table at all sites is shown in Table 2. Please note that negative values represent water beneath the surface of the ground and positive values represent standing water above the surface of the ground. The height of the water table as measured along the transect is shown in Figure 3.

The sites in order of increasing height to water table are shown in Figure 4. The order shown in this figure is used to represent changes in other parameters in accordance with changes in water table.

The pH of organic soils and peat at each of the sites is shown in Figure 5. This graph shows an increase in pH value of soil as water table increases. The equation for the trendline for this data set is $y = 0.0032x + 3.7386$, with an r^2 of 0.3965.

The moisture content in soils at each site is shown in Figure 6. The grams of water per gram of soil increased with an increase in water table. The equation for the trendline for this data set is $y = 0.1008x + 7.3115$, with an r^2 of 0.7787.

The average temperatures for air, water, and soil at 5 and 10 cm depths are shown in Figure 7. The temperature changed very little during the course of the sampling period, or between sites (Figure 8). Ambient temperatures ranged from 6 to 10.5 degrees Celsius, while soil and water temperatures were a bit lower, ranging from 4 to 7 degrees Celsius. The upland site soil was the warmest, while the sites with standing water were the coolest on average.

The average CO₂ and CH₄ fluxes along the water table are shown in Figures 9 and 10. There is a negative relationship between CO₂ production and water table. The trendline for the graph in Figure 8 is $y = -0.0125x + 0.8225$, with an r^2 value of 0.9021. The relationship between CH₄ and water table is positive, with a trendline equation of $y = 0.0002x + 0.0079$, with an r^2 of 0.5544. Figures 11 and 12 show the temporal variation at each site. The variation in flux rate at each site does not seem to be temporal, as there is no trend evident in these graphs. .

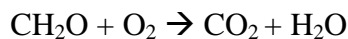
Lignin:nitrogen ratio in comparison with water table is shown in Figure 13. The equation for the trendline on this graph is $y = 0.0785x + 39.729$, with an r^2 of 0.1798. The relationship between C:N ratio and water table is shown in Figure 14. This graph has a trendline equation of $y = 0.0597x + 37.968$ with an r^2 of 0.158. Both of these relationships are positive, but neither is a very strong correlation. The upland site is the lowest value for both lignin:nitrogen and C:N.

Figures 15 and 16 show the correlation between CO₂ flux and CH₄ flux and the ratio of lignin:nitrogen. Figures 17 and 18 show the correlation between the two fluxes and carbon:nitrogen. None of these graphs display a significant relationship between flux and organic matter quality.

Discussion

From my results, we can see that the height of the water table is the most important factor driving carbon dioxide and methane production. The data supports my first hypothesis, which stated that with a higher water table, carbon dioxide production would decrease and methane production would increase. This can be mainly attributed to the fact that most of the carbon dioxide I measured was a product of aerobic respiration.

Aerobic respiration,



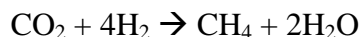
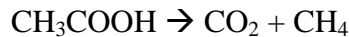
requires oxygen to be present in order for decomposition to occur. The growing water table represents a growing level of anoxia, and therefore CO₂ production is inhibited as water table increases (Freeman et al. 1993). In a further study, it would be interesting to also look at the changing levels of oxygen in water and soil, to map the relationship between anoxia in wetlands and water table, and compare gas flux to this relationship.

The production of methane is an anaerobic decomposition process, and requires no oxygen to be present when it occurs. This process is strongly correlated with water table (Liblik et al. 1997). With a rising water table and rising anoxic zone, the ability of microbes to produce CH₄ is increased. While methane is not the desired electron acceptor (Hedin et al. 1998, Stumm and Morgan 1981), the vertical zones within the water column where other molecules can be reduced are very small in wetlands (Williams and Crawford 1984). In a freshwater system such as a cedar swamp, the zone of sulfate reduction may not be present at all. This is why so much methane is produced in wetland environments, and can explain why we saw such an upward response of methane production once the water table came up above the ground surface in this study (Pulliam 1993).

While we saw an increase of methane production, we must remember that not all of that methane which is produced will rise to the surface of the water. This is true for carbon dioxide as well. There is more than one process involved in the production of methane, as well as in methane consumption (Stumm and Morgan 1981). Fermentation is the first step in the production of methane, as methanogens can't break down sugars directly. Fermenting bacteria break down glucose to make acetate in this process:



This process of fermentation is necessary for methanogenesis, as methanogens can either use acetate (CH₃COOH) or carbon dioxide to produce methane. The two processes, acetate splitting and carbon dioxide reduction, are shown here:



Both of these yield methane, which can be diffused upward and escape to the surface of the water, or can be trapped as bubbles and escape through ebullition, or, finally, can be consumed on its way out of the water by methanotrophs (Bubier et al. 1993). Consumption of methane is more likely to happen in higher water, mainly because there is a greater chance that methane will be consumed during its path to the surface. Therefore, the methane that I measured was only that which successfully escaped from the water. The carbon dioxide that I measured was that which wasn't used up in either photosynthesis (which should not have occurred due to my use of dark chambers) or consumption by anaerobes such as methanogens (Freeman et al. 1993). However, the net flux of methane and carbon dioxide still showed the relationship I expected, despite the potential for error due to incomplete diffusion of gases to the surface of the water.

The lability of organic matter did not seem to be driving the production of carbon dioxide and methane gases. It is true that by only analyzing the soil for percentages of

carbon, nitrogen, and lignin, we cannot really determine whether any of these soils are of good “quality” or not. A more thorough assessment of the soil properties might yield a better understanding for which ones are good or bad, however, considering the length of the study, only a brief assessment was possible.

The decision to analyze the soil samples for lignin content was based on my knowledge of which compounds are most easily broken down by microbes through any process, be it aerobic decomposition or methanogenesis. Certain compounds, such as glucose and cellulose, are not very strongly held together, and therefore microbes can break them down easily. In new plant matter, they are the first to be decomposed. Lignin, however, is an extremely complex structure and is held together very tightly. This is the toughest for microbes to break down and its presence can help describe either the original properties of the organic matter, or the stage of decomposition that the organic matter is in (Aber and Melillo 2001). For example, woody plant matter would have more lignin than leaf tissue.

The ratio of lignin % to nitrogen %, along with molar carbon:nitrogen ratio, can help us understand at least the relative quality of the organic matter along the transect. A high ratio of lignin to nitrogen, compared with either a high C:N or low C:N ratio, would indicate that the litter would be harder to decompose. A high lignin:nitrogen with a high C:N would indicate that the litter could be of woody origin, while a high lignin:nitrogen with a low C:N would indicate that the litter was older and well decomposed, with mostly unusable carbon left. However, a low lignin:nitrogen coupled with a high C:N ratio would indicate that most of the carbon present in the organic matter was not lignin, and therefore would be easier to decompose. Low lignin:nitrogen with low C:N could indicate that the matter was either really well decomposed or that it was not decomposed but originally had a low carbon content (G. Shaver, personal communication). In determining which combination of carbon compounds and nitrogen would be beneficial to this system, we must remember that Atlantic white cedar swamps, and most other wetlands, are nutrient poor ecosystems. A higher nitrogen content may not be the best combination for this system as the plants that live there thrive specifically because there are not many nutrients available. In fact, higher levels of nutrients may even harm the system (A. Laderman, personal communication). The issue of organic matter quality is quite complex, and I was only able to brush the surface of it in this study.

The results that I found only ensure that this is a complicated issue. My original hypothesis was that a higher quality of organic matter would yield higher fluxes of both carbon dioxide and methane. I have determined, however, that organic matter quality is a hard parameter to measure. The relationships that I found between CO₂ and CH₄ fluxes and C:N and lignin:nitrogen ratios are not very strong. The graphs showing these relationships show no trend, as most of the points are grouped together with no particular pattern. I graphed the changes in C:N and lignin:nitrogen as functions of an increase in water table, which are a bit easier to understand. From what I found, there is no clear relationship between water table and either C:N or lignin:nitrogen. Both graphs have a slightly positive slope, but are not tightly fitted to the trendline. Since the trends in my gas fluxes as functions of water table are relatively strong, I decided to compare the organic matter ratios to the water table to determine whether there was a matching trend, which there is not. The C:N ratios of the sites that had a peat substrate were very similar, while the site with a soil substrate was lower. I have concluded that the reason for this

trend is the composition of the original litter at all of the sites, as the peat sites which are mostly within the swamp are definitely composed mostly of cedar needles, where the upland site is directly under a beech tree and the litter is composed mostly of deciduous leaves. The trend in lignin:nitrogen is very much the same. The lowest lignin:nitrogen value is the upland, and the swamp sites are clustered together. However, these relationships contradict themselves. A lower C:N in the upland site would indicate a higher amount of decomposition at this site (which would correlate with the most CO₂ production as well), however, a lower lignin:nitrogen ratio would indicate less decomposition. This odd relationship reinforces the idea that any differences expressed in C:N or lignin:n ratios are due to the differences in the original quality of the litter inputs to each particular site.

Conclusions

The relationship between gas production and changes in water table indicates that the Atlantic white cedar swamp system would be greatly affected if there were long term changes in the water table. The stability of the system relies on the presence of water (Freeman et al. 1993). If, for instance, the water table were to rise permanently due to flooding from development or global climate change, the Atlantic white cedars would drown (Schwarzman 2002). The seeds need dry ground to germinate and would not survive, and adults would be stressed and eventually die from a higher water table (Laderman 1989, Schwarzman 2002). Furthermore, if the water table were permanently reduced, the peat would decompose quickly. As the trees have very shallow root structures due to the high water table, a drop in the water and subsequent loss of peat would cause them to topple and die. Also, many of the species that make their homes in cedar swamps require very specific living conditions, and would be threatened as well. This type of fragile ecosystem would be quickly destroyed due to a long term change in the water table.

Not only would a change in the water table have negative impacts directly on cedar swamps, but it would potentially cause a positive feedback to global climate change (Moore and Knowles 1989). According to a study of global warming potential by my colleague and collaborator, Lisa Brunie, my highest rate of carbon dioxide flux (approximately $1.7 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$) has less of a global warming potential than my highest methane flux (approximately $0.023 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$). The global warming potential for carbon dioxide at my highest flux rate would be $0.46 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$ and methane would be $0.64 \text{ gC} * \text{m}^{-2} * \text{day}^{-1}$ in carbon dioxide equivalents, assuming that methane has a global warming potential 21 times that of carbon dioxide (Bubier et al. 1993). Therefore, if the water in the swamp got even deeper, and still remained mostly anoxic and nutrient poor, then the rate of methane flux that I found for the lagg may be applied to the whole swamp. This would greatly increase the amount of methane being produced by the swamp. Also, if the water table dropped and all of the organic matter was exposed to oxygen, it would decompose very quickly and also release a large amount of carbon dioxide to the atmosphere. In both cases, a permanent change in the water table due to global climate change would create a positive feedback to climate change by adding more greenhouse gases to the atmosphere, and perpetuate the process of global warming. We should also keep in mind that these flux rates were measured at the end of

November, when most of the microbial activity is inhibited. If this study were done in the summer, the rate of flux would have been much higher for both carbon dioxide and methane (L. Brunie, unpublished). This would increase the potential positive feedback to global warming even more, as temperatures are rising already due to carbon dioxide emissions from anthropogenic sources. A more thorough study would look at fluxes in the field and how they respond to seasonal changes in temperature, as well as seasonal fluctuations in the water table. From this study we can conclude that our actions as humans, including increasing carbon dioxide and methane emissions beyond natural levels, will cause serious damage to wetlands and create a positive feedback cycle in which we continue to destroy the last of the world's unique and precious ecosystems.

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Literature Cited

- Aber, J. D. and J. M. Melillo. 2001. *Terrestrial Ecosystems*. Academic Press, Boston.
- Bartlett, K. B., D. S. Bartlett, R. C. Harriss, D. I. Sebacher. 1987. Methane emissions along a salt marsh salinity gradient. *Biogeochemistry* 4: 183-202.
- Bubier, J. L., P. Crill, A. Mosedale, S. Frohking, and E. Linder. 2003. Peatland responses to varying interannual moisture conditions as measured by automatic CO₂ chambers. *Global Biogeochemical Cycles* 17(2): 1066, doi: 10.1029/2002GB001946.
- Bubier, J. L., T. R. Moore, N. T. Roulet. 1993. Methane emissions from wetlands in the midboreal region of Northern Ontario, Canada. *Ecology* 74(8): 2240-2254.
- Chapin, F. S. III, P. A. Matson, H. A. Mooney. 2002. *Principles of Terrestrial Ecosystem Ecology*. Springer-Verlag, New York.
- Freeman, C., M. A. Lock, B. Reynolds. 1993. Fluxes of CO₂, CH₄ and N₂O from a Welsh peatland following simulation of water table draw-down: Potential feedback to climate change. *Biogeochemistry* 19: 51-60.
- Hedin, L. O., J. C. von Fischer, N. E. Ostrom, B. P. Kennedy, M. G. Brown, G. P. Roberston. 1998. Thermodynamic constraints on nitrogen transformations and other biogeochemical processes at soil-stream interfaces. *Ecology* 79(2): 684-703.
- Johnson, C. W. 1985. *Bogs of the Northeast*. Universal Press of New England, Hanover.
- Laderman, A. D. 1989. The ecology of Atlantic white cedar wetlands: A community profile. *Biological Report* 85(7.21).
- Liblik, L. K., T. R. Moore, J. L. Bubier, S. D. Robinson. 1997. Methane emissions from wetlands in the zone of discontinuous permafrost: Fort Simpson, Northwest Territories, Canada. *Global Biogeochemical Cycles* 11(4): 485-494.
- Moore, T. R., R. Knowles. 1989. The influence of water table levels on methane and carbon dioxide emissions from peatland soils. *Canadian Journal of Soil Science* 69: 33-38.
- Pulliam, W. M. 1993. Carbon dioxide and methane emissions from a southeastern floodplain swamp. *Ecological Monographs* 63(1): 29-53.

- Robertson, G. P., D. C. Coleman, C. S. Bledsoe, P. Sollins. 1999. *Standard Soil Methods for Long Term Ecological Research*. Oxford University Press, New York.
- Schlesinger, W. H. 1997. *Biogeochemistry: An Analysis of Global Change*. Academic Press, Boston.
- Schwarzman, B. 2002. *The Nature of Cape Cod*. University Press of New England, Hanover.
- Stumm, W., J. J. Morgan. 1981. *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters*. John Wiley & Sons, New York.
- Williams, R. T., R. L. Crawford. 1984. Methane production in Minnesota peatlands. *Applied and Environmental Microbiology* 47(6): 1266-1271.

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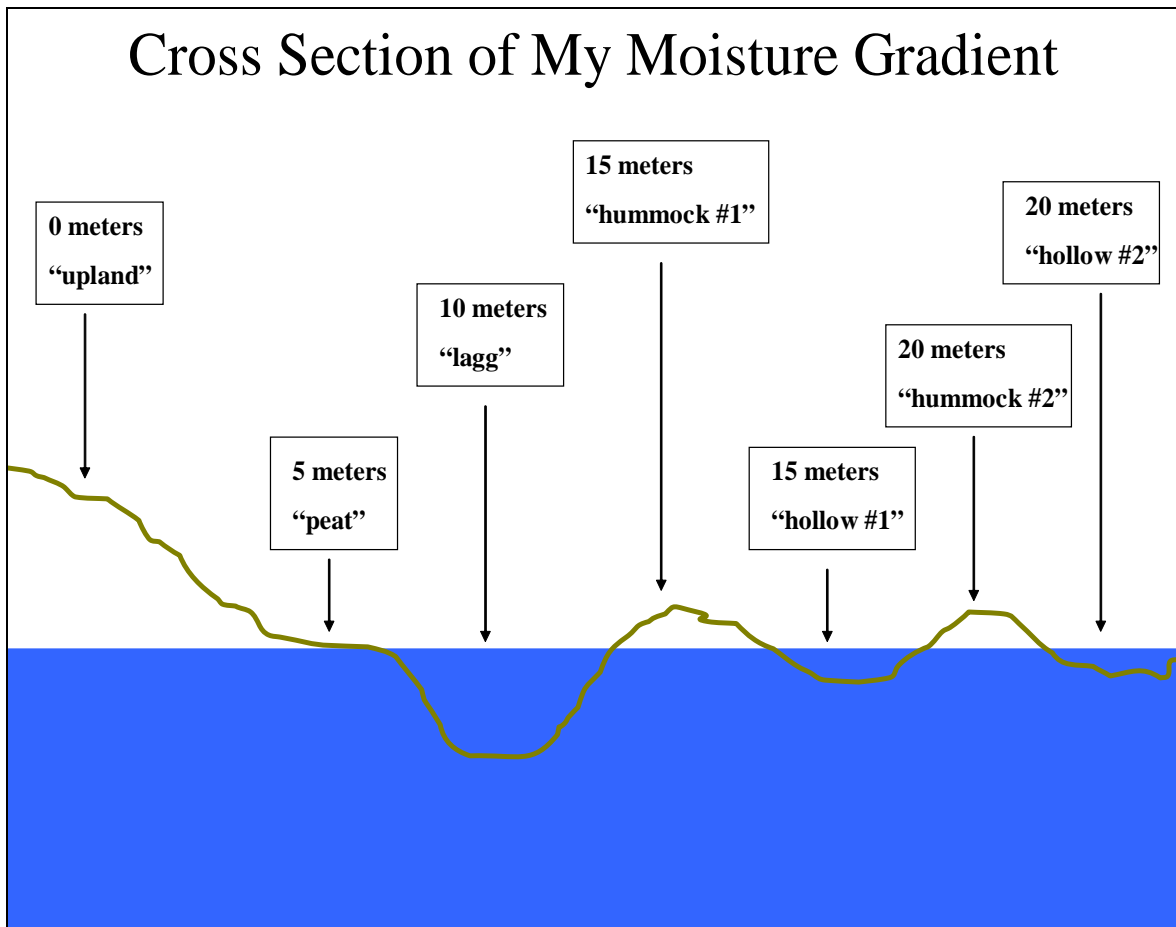


Figure 1. Diagram of my transect (0-20 metres) starting outside Hidden Swamp (left) and moving into the swamp (right). Water table is shown in blue.

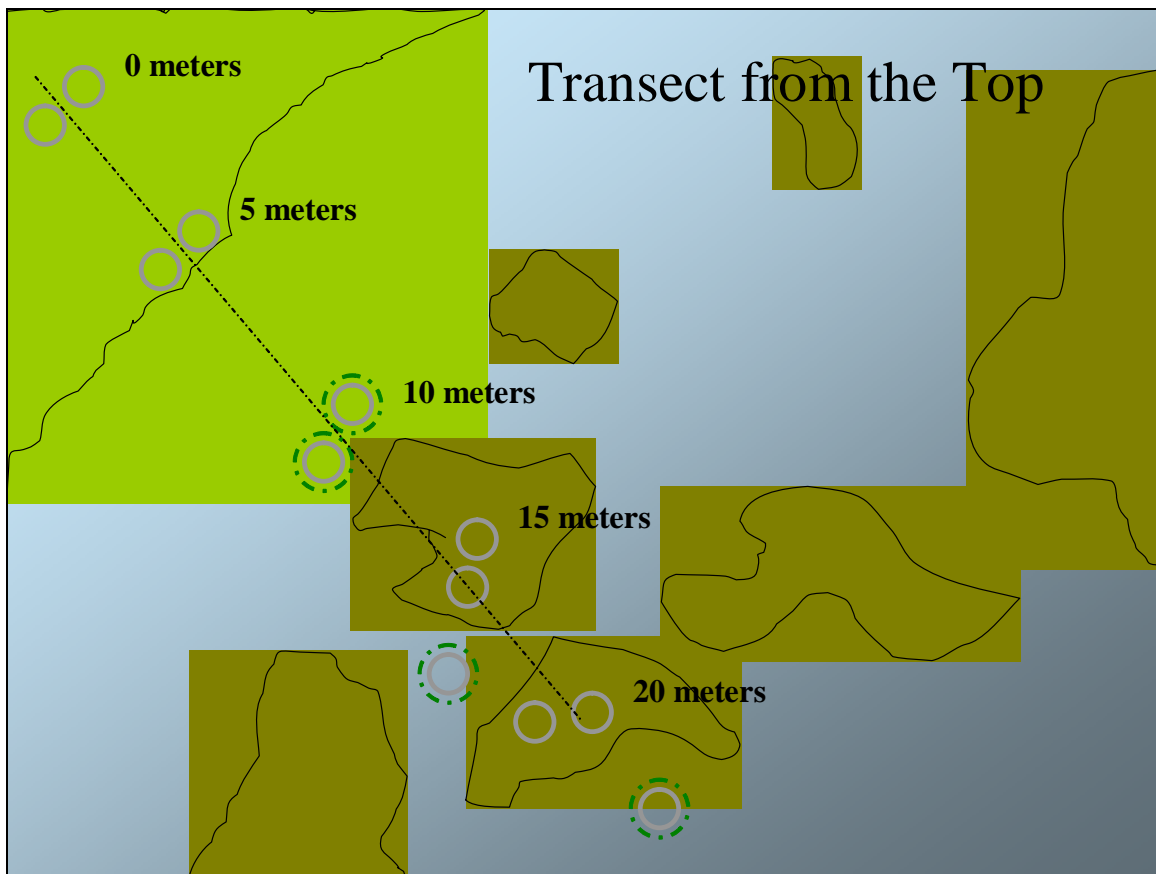


Figure 2. Top view of my moisture gradient. Upper left corner is the deciduous forest outside of the swamp. Chamber collars are represented as gray rings; those rings with green outlines are representing floating chamber sites.

Table 1. Specific volume of chamber at each site; used to calculate rate of flux at each site.

Volume of Chambers	
site/collar	volume (litres)
0m1	12.5865
0m2	11.6214
5m1	11.0484
5m2	11.2394
10m1	4.8255
10m2	4.8255
15m1	11.0584
15m2	12.2246
15m3	4.8255
20m1	11.9230
20m2	11.6013
20m3	4.8255

Table 2. Height of water table at each sampling site. Note that negative value indicates that the water table is underground.

site (meters)	description	depth to water
0	upland	-69.342
5	peat	0
10	lagg	25.4
15 (hummock)	hummock 1	-26.0604
15 (hollow)	hollow 1	17.4625
20 (hummock)	hummock 2	-16.002
20 (hollow)	hollow 2	16.51

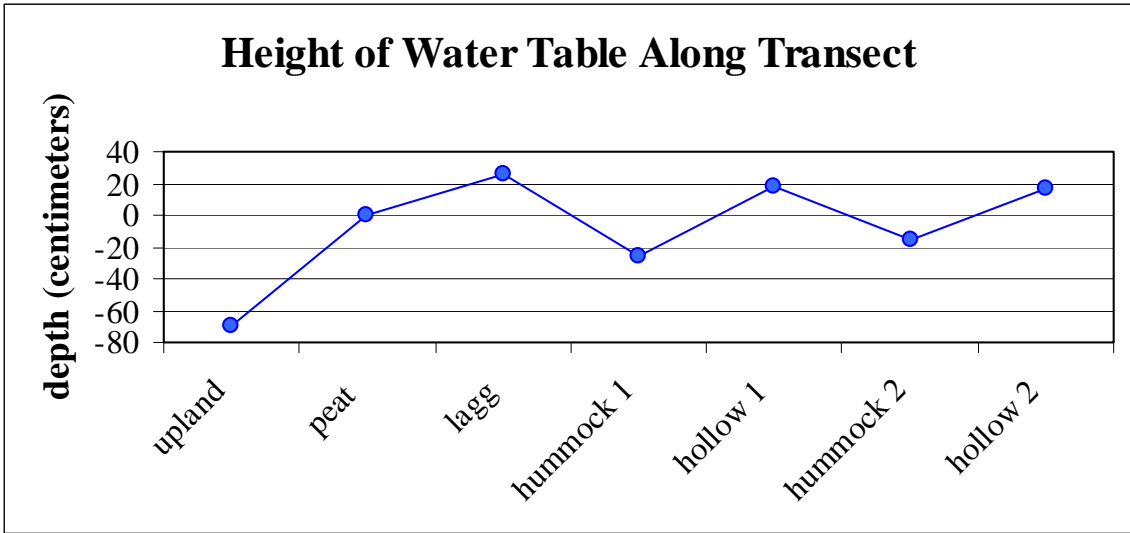


Figure 3. Height of water table in the order of 0-20 meters along my transect.

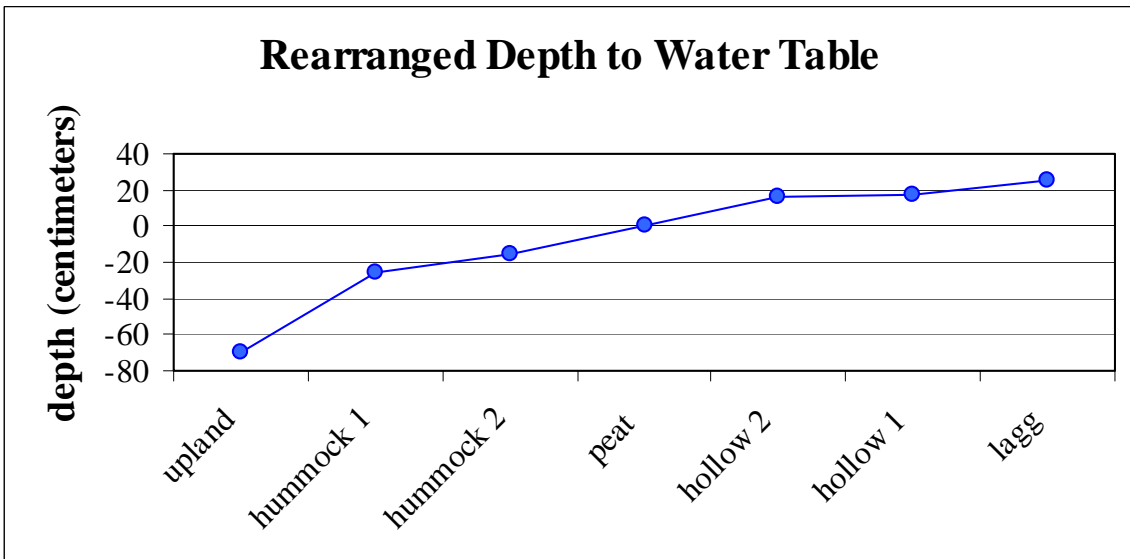


Figure 4. Height of water table rearranged in order of increasing value.

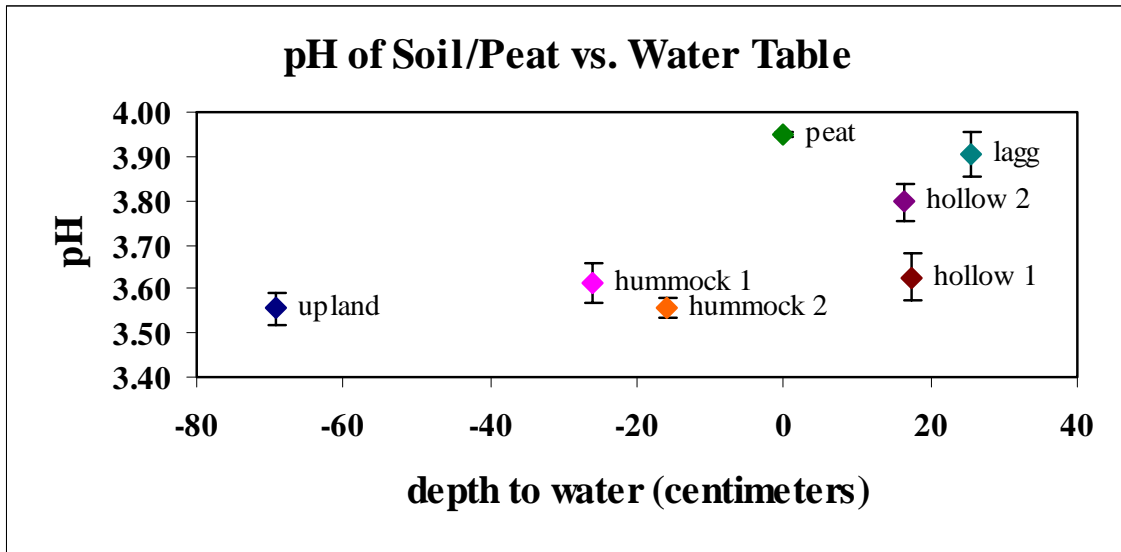


Figure 5. pH of soil and peat at each site along the transect as a function of height of the water table.

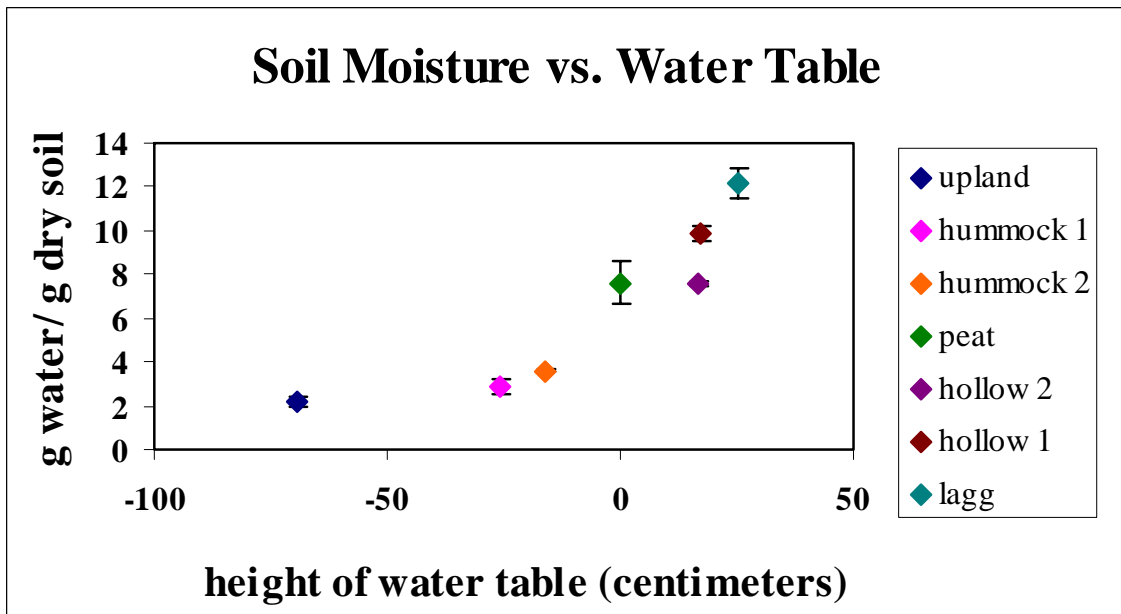


Figure 6. Soil moisture in grams of water per gram of dry soil as a function of height of the water table.

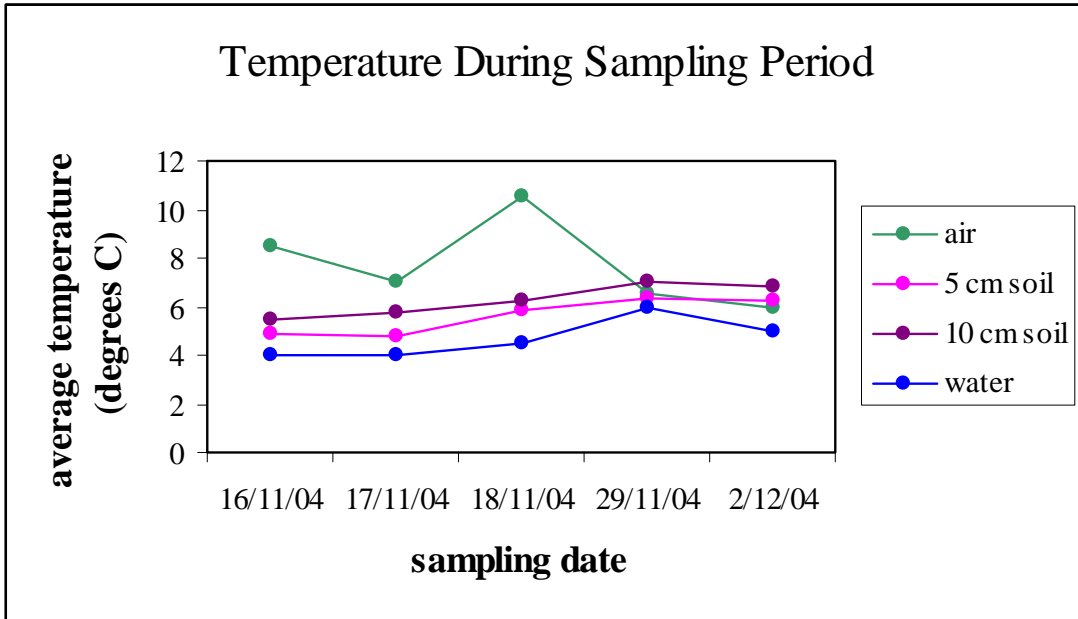


Figure 7. Temperature changes throughout the course of the sampling period.

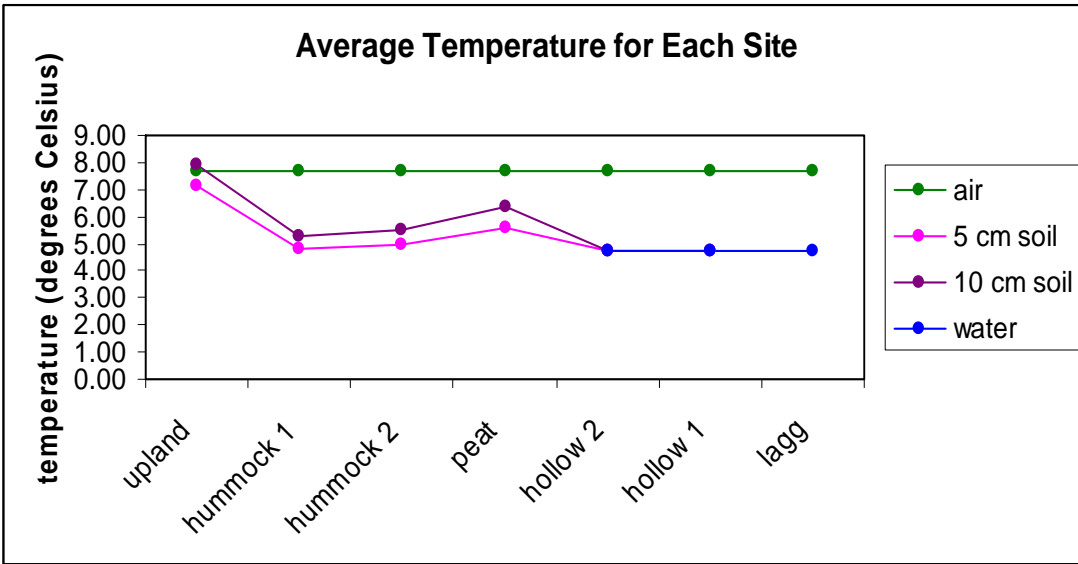


Figure 8. Average temperatures at each site.

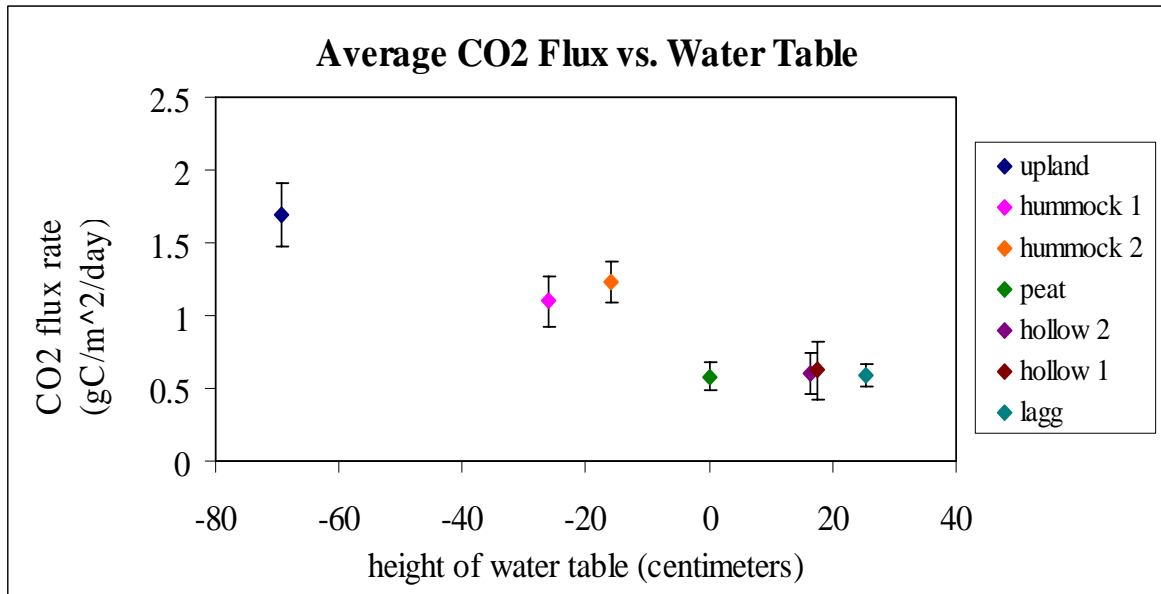


Figure 9. Average CO₂ flux at each site as a function of water table.

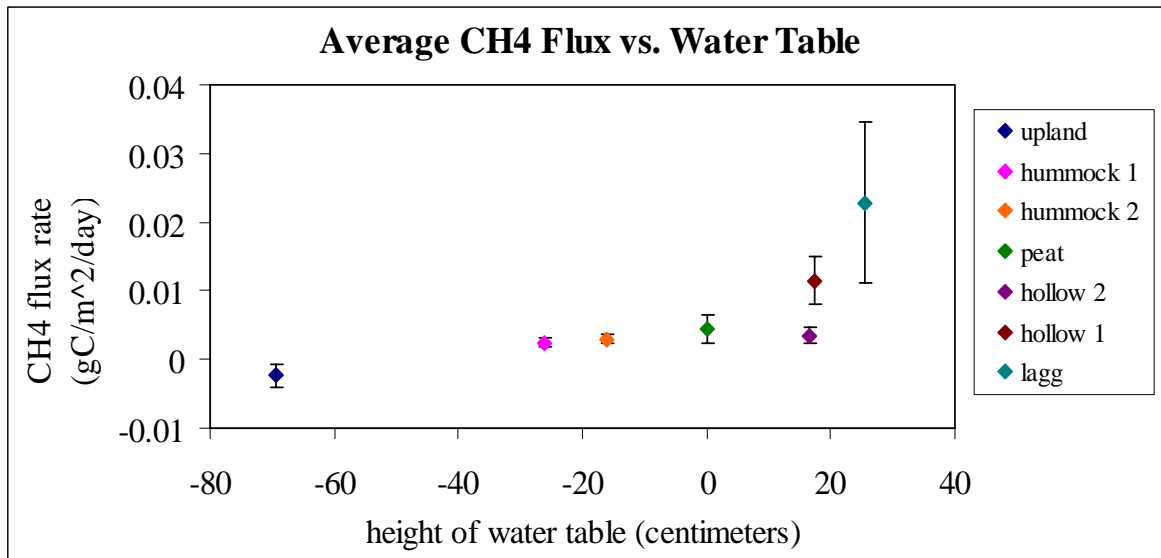


Figure 10. Average CH₄ flux at each site as a function of water table.

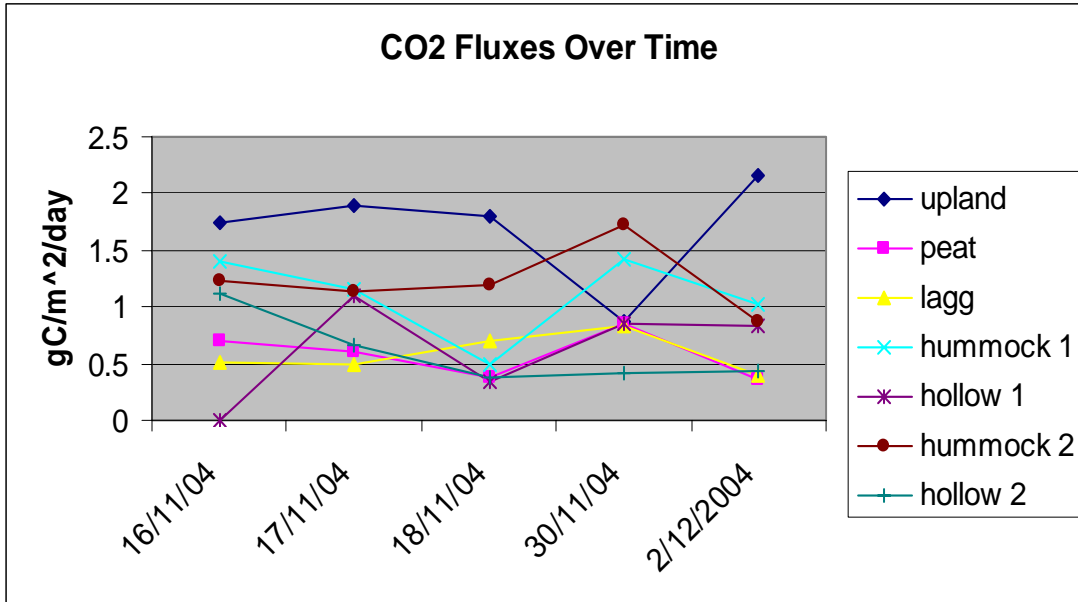


Figure 11. Variation in CO₂ fluxes at each site over the course of the sampling period.

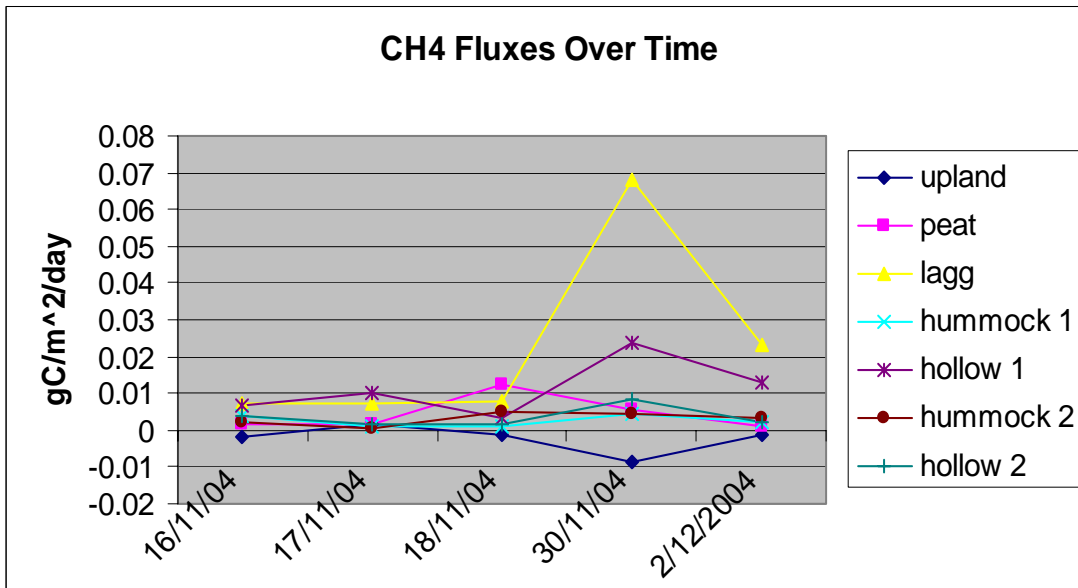


Figure 12. Variation in CH₄ fluxes at each site over the course of the sampling period.

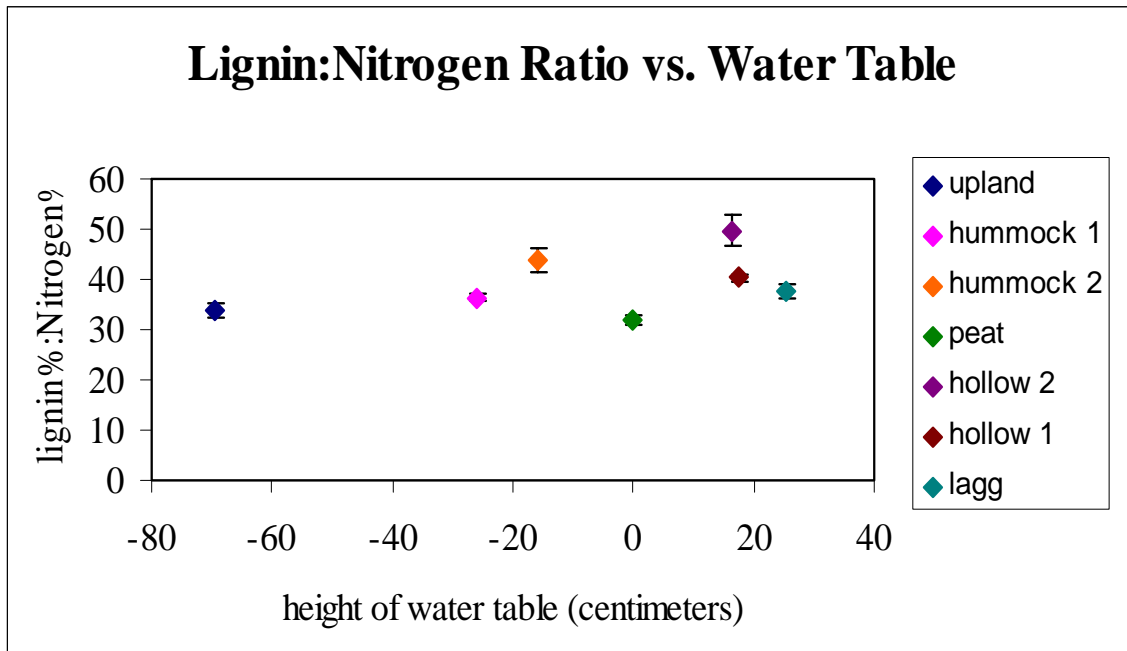


Figure 13. Lignin:nitrogen ratio of organic matter as a function of water table.

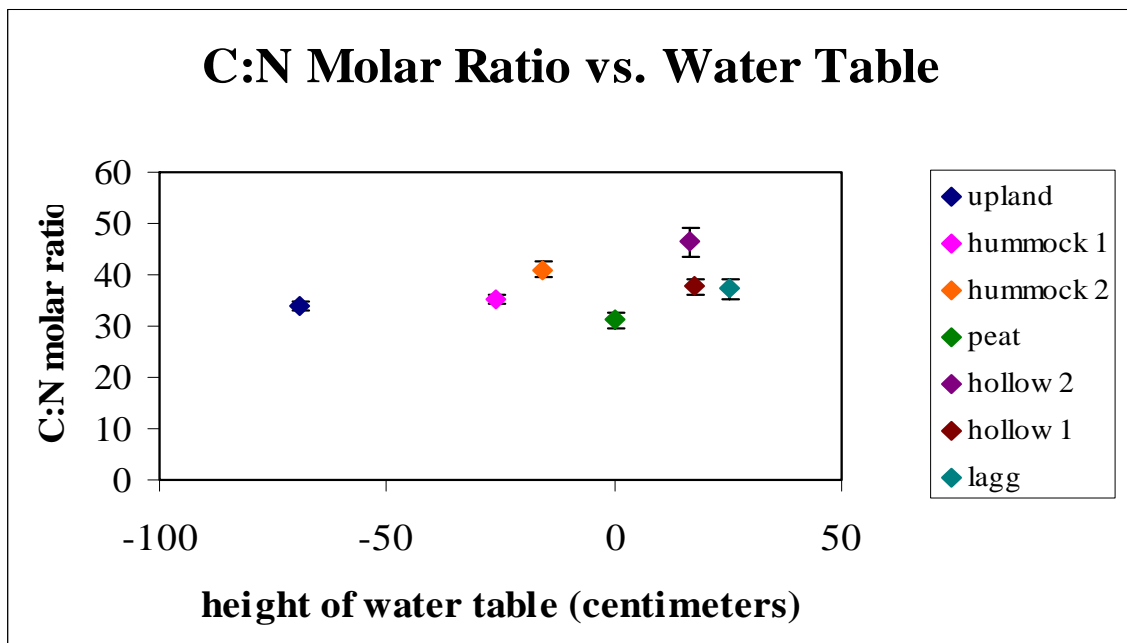


Figure 14. Carbon:nitrogen molar ratio of organic matter as a function of water table.

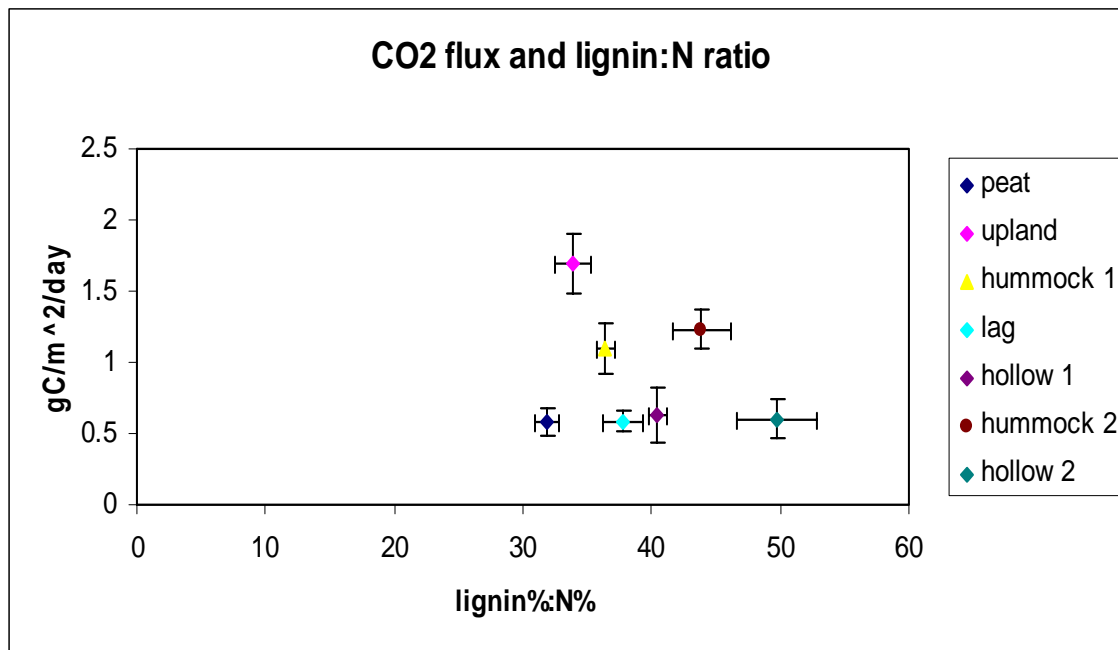


Figure 15. Relationship between CO₂ flux and lignin:nitrogen ratio.

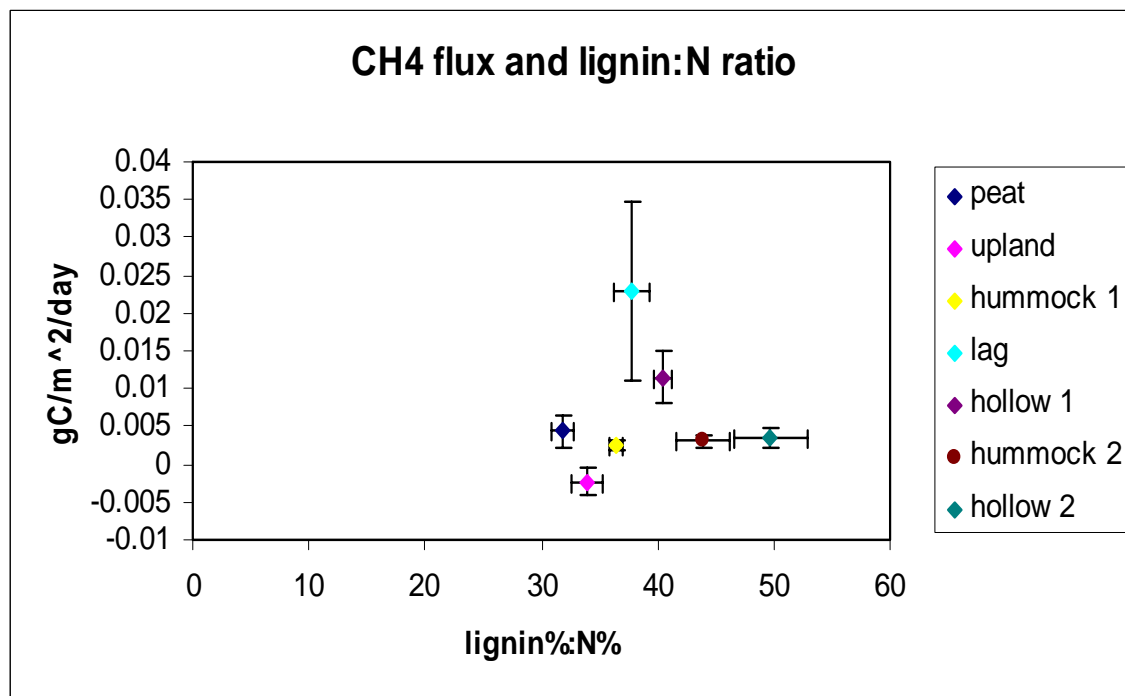


Figure 16. Relationship between CH₄ flux and lignin:nitrogen ratio.

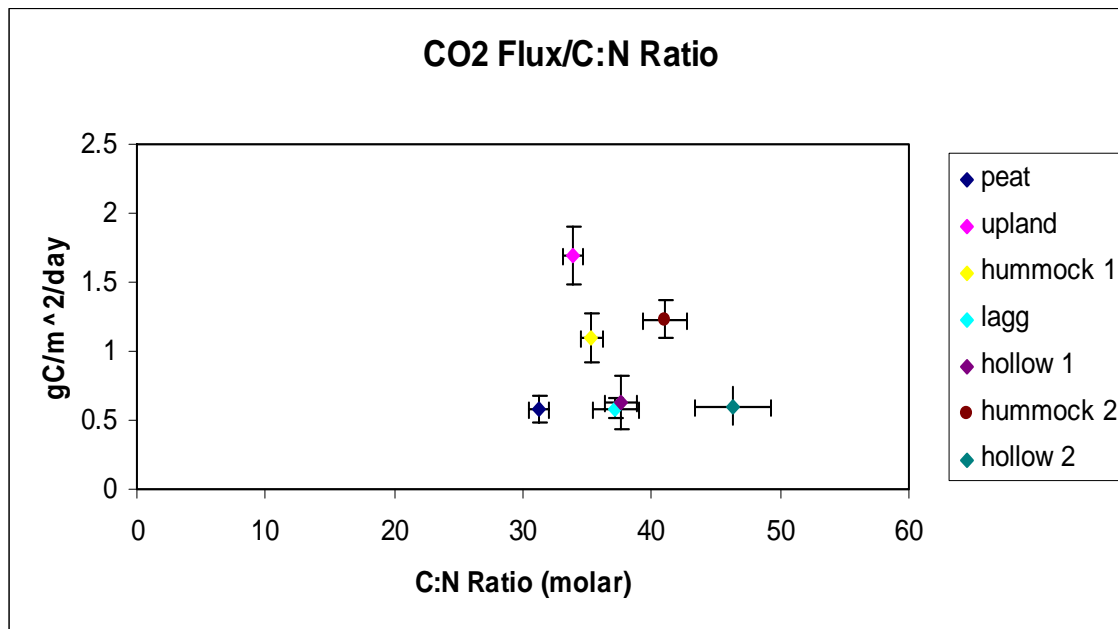


Figure 17. Relationship between CO₂ flux and C:N molar ratio.

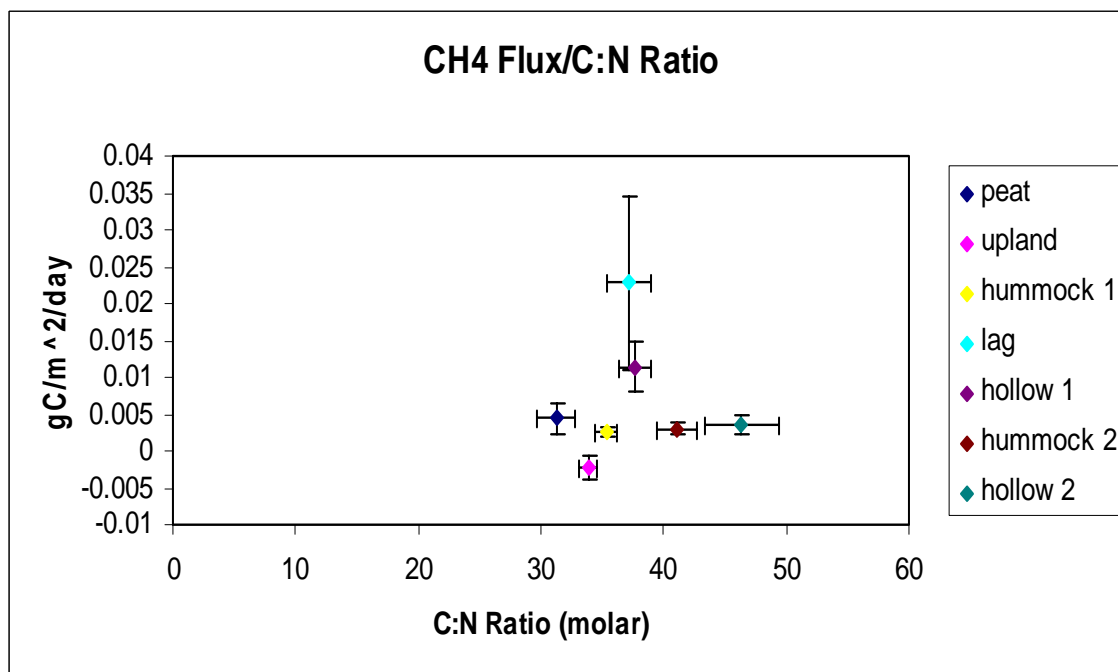


Figure 18. Relationship between CH₄ flux and C:N molar ratio.