# Atlantic White Cedar swamp: Effects of temperature and water table position on decomposition

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**Abstract:** Atlantic Cedar Swamps are peat based wetlands. These systems store large amounts of carbon dioxide as a result of slow and incomplete decomposition. The anoxic nature of these wetlands forces microbes to use alternative electron acceptors, resulting in methane emission. In this study, I examined the effects of water level and temperature on decomposition and release of these greenhouse gases. I incubated 10 peat cores in various temperature treatments. In the high and low temperature treatments I drained water from two of the cores. Methane and carbon dioxide fluxes were measured from the cores using a gas chromatograph. After the initial incubations I re-saturated one of the dried cores from each temperature and continued to measure the gas fluxes. I measured the DIN concentration from the other cores that were not apart of the re-saturation experiment. The flux data showed that the higher temperature incubations had larger fluxes of both carbon dioxide and methane. The largest flux was measured in the dry core that was in the high temperature treatment. Re-saturation of the cores decreased the emission of carbon dioxide, and showed that the cores can react quickly to changes. DIN measurements demonstrated that higher temperatures cause more loss of nitrogen through the process of denitrification. Extrapolations were made based on the flux rates and calculated Q10 values to estimate the global warming potential for various scenarios. The largest global warming potential was calculated for the wet and warm scenario. This data has large implications for global warming and decomposition of the peat within these systems.

**Keywords:** Atlantic White Cedar swamp, DIN availability, Carbon fluxes, decomposition, Global warming potential, global warming

## Introduction:

Atlantic White Cedar swamps are a rare species that often occur in peatlands. They are found within a narrow belt along the East Coast. These species can only survive in moist conditions and are greatly affected by hydrological fluctuations (Laderman 2002). Cedars are able to exist in these conditions because of the large peat accumulation that holds in the water (Duttry, 2002). The peat has a high capillary action to absorb and retain large amounts of water, this allows for the existence of the cedar trees. With out the large peat buildup the ability for the system to maintain a high water level would decrease, possibly leading to extinction of the cedars.

Decomposition has large implications on these swamps because of the vital role that peat has on the existence of these rare ecosystems. The water logged nature of these systems leads to slow or incomplete breakdown of organic material. Wetlands play a significant role in the global carbon cycle. The slow decomposition leads to peat accumulation, which allows for carbon storage. Wetlands store 1/3 of the soil carbon pool (Bubier *et al.*, 2003). Wetlands also emit significant concentrations of carbon dioxide and methane. Carbon dioxide is produced by mineralization of the carbon from the decomposed organic matter (Schlesinger 1997).

$$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+36ATP$$

The high water level creates anoxic portions of the peat; this forces microbes to use alternative electron acceptors. The anoxic conditions are a result of the difficulty in the diffusion of oxygen through water. The oxygen deficiency and use of alternative electron acceptors leads to the production of $CH_4$. Wetlands are the single largest atmospheric source of methane, producing an estimated 115- 237 Tg C/ year (IPPC 2001 sited in Christensen, 2003). Methane is produced by two processes: acetate splitting and $CO_2$ reduction (Schlesinger 1997).

$$CH_3COOH \rightarrow CO_2 + CH_4$$
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

The production of methane is an interaction between the production, consumption, and diffusion through the peat (Bubier, 1993).

Changes in temperature and water level are constraints on the production of $CO_2$ and $CH_4$ (Moore, 1993). Microbes are inhibited by colder temperatures and increased temperatures enhance their metabolic processes (Chimner, 2003). Increased water level causes a decrease in microbial activity and enhanced methane production. These changes in temperature and water level occur naturally throughout the seasons.

The methane concentrations in the atmosphere are less then the concentrations of carbon dioxide. Even though there is less methane in the atmosphere the global warming potential is 21 times greater then that of carbon dioxide (EPA website, Second Annual IPCC Report). This has implications for the future with potential climate changes, changing the dynamics of wetland system, and microbial communities.

Another greenhouse gas emitted form wetlands is nitrogen. Nitrogen becomes available through decomposition and the break down of organic material. The nitrogen becomes available in proportion to the carbon lost, due to the C: N ratio of the peat. Microbes take up the available nitrogen and produce $NH_4$ through the process of ammonification. Some of this ammonia can be immobilized by microbes or it can be taken up by other microbes. These microbes oxidize the ammonia through the process of nitrification. The product of nitrification is nitrate. This nitrate can be immobilized, leached, or taken up by the microbes and converted to nitrogen gas through denitrification.

The purpose of my investigation was to examine the controls on the production of methane and carbon dioxide. This was performed through laboratory incubations of peat cores and gas flux measurements. The second question that I investigated was the effect of temperature and carbon flux on DIN availability. This was answered through measurements of ammonia and nitrate in the peat. I also examined the global warming potential of future scenarios, to predict possible changes in the emission of global warming gases by the system.

## Methods:

This experiment observes the effects of increases in temperature and decreases in water table on decomposition rates of Hidden Swamp. Hidden swamp is found behind Devil's Lane parking lot on Marine Biological Laboratory property. The swamp has a natural hydrological gradient due to the hummock and hollow landscape. Hidden swamp is considered to be a pristine environment; it is less impacted by anthropogenic influences and is actively reproducing (Hicks, 2003).

### *Gas Fluxes*

On November 16, 2003, I took ten cores that were approximately 50cm in length from similar hummock regions of the swamp where there was a high water level. The cores were taken using a 15.5 cm diameter stainless steel coring device. Once the cores were taken the peat was transferred into PVC cylinders where they remained for the length of the experiment. As I relocated the peat into the cylinders, I tried to standardize the headspace to approximately 6 cm in all of the cores in order to allow the gases to build up in an equal area.

Upon returning into the lab four of the cores had water drained from the peat. I removed the water by using a combination of gravity drainage and pumping the water out with a hand pump. Gravity draining was the most successful method. I put a tensiometer into the middle of the core, which allowed for the water to pool and drain more effectively. In total approximately 600 ml was removed from each of the four cores, this was performed by gravity drainage and by pouring off surface water. I refer to these cores as dry but they aren't necessarily dried but are just less saturated on the peat surface. After I drained the water, the holes from the tensiometers were filled with extra peat taken from the swamp. Next, all of the cores were place into their correct incubations where they remained for the duration of the experiment. I put two cores with a water level decrease and two controls into a 4° C and 21.1 °C incubation. The other two cores were put into a chamber with a temperature of 10° C and had no water level alterations (Table 1).

The following day I measure $CO_2$ and $CH_4$ concentrations from the headspace of each core. An airtight lid sealed the cores and a 10ml syringe of gas was taken every ten minutes for an hour. I injected these samples into a Shimadzu 14A gas chromatograph, with a flame ionization detector and a thermal conductivity detector. This machine measured the $CO_2$ and $CH_4$ concentrations in each sample. I used the ideal gas law to convert the concentration of $CO_2$ and $CH_4$ into mass units. The concentrations in mass units were graphed over time and the slope of the linear regression is the flux (Livingston and Hutchinson 1995). The initial gas flux data is not used in this experiment, due to an error on my part. The fluxes used were taken from November 29th until December 1st. After this time one of the cores from each temperature treatment that initially had water drained off, was re-saturated. The cores that were re-saturated had approximately 1,000 ml of DI added, I added the DI until the water level reached above the peat surface.

Additional water was added then drained off because throughout the experiment I added DI to the wet cores that were just temperature incubations and not to the dry cores. This extra water added was to account for evaporation. Gas samples were taken from these cores from December 4th, 5th, 6th, 8th, and 9th and measured on the GC.

### *Nitrogen Analysis and Peat Composition*

Ammonia and nitrate were analyzed for the other six cores that were not being used in the re-saturation experiment. I took samples from every two cm within the top six cm and performed a KCL extraction by adding 50 ml of KCL to every 5 g of peat. After letting the samples shake for an hour I filtered the extractant with the use of GF/C filters. The filtered extractant was then put into test tubes for further analysis, 6ml was sub sampled for nitrate analysis, and 3ml was used for ammonia analysis. Ammonia was measured by using the Shimadzu 1601 Spectrophotometer (Solarzano 1969). Nitrate concentrations were measured using a Lachat QuikChem 8000Autoanalyzer.

While sampling the peat for the nutrient analysis I also took a sample for bulk density and soil moisture. The bulk density measurements are inaccurate because it was difficult not to compress the peat when taking the sample. I used a 10 by 10 block to cut out the sample and measured the height to calculate the volume. Next, I weight the samples and recorder the wet weight. The samples were then dried for two days and the re-weighted. Some of this dry peat was then ground using a Wiley Mill and packed for CHN analysis using a Perkin Elmer Series II CHN Analyzer 2400.

### *Calculations- Nutrient*

Before measuring the DIN I calculated the expected concentration. This was calculated using the carbon fluxes and a known C: N ratio (Hicks 2003 SES). After I measured the DIN and the peat characteristics, this actual data was used in the calculation of the increase in DIN during the experiment time. These calculated values were compared to the sum of the measured ammonia and nitrate concentrations.

### *Calculations- Global warming potential*

I calculated the $Q_{10}$ temperature function for both $CO_2$ and $CH_4$ measured in the wet and dry cores. The $Q_{10}$ was calculated by graphing the Ln of the fluxes over time. The slope of the linear regression line is the Ln of the $Q_{10}$ and the y-intercept is the Ln of the $R_0$.

$$R = R_o {Q_{10}}^{T/10}$$

I found the rate for the three different temperatures used in the experiment. Next, I used annual temperature data from 2003 (SES lab weeks 7&8 from WHOI) to extrapolate the flux of carbon for each day of that year. These calculations were performed for the CO2 and CH4 fluxes from the wet and dry cores. Next I added five degrees the daily temperature values and calculated this for each of the scenarios to see how the rates would change with an increase in temperature.

I calculated the global warming potential for each of the annual fluxes. The global warming potential was calculated by converting grams of carbon to CO2 equivalents and multiplying by 21 to solve for the global warming potential of methane (EPA website as sited in the IPCC Second Annual Report).

## Results:

### *C: N ratio*

The C: N ratios of the different cores show that they have a similar composition. The C: N ratio ranges from 23.8 to 32 g C per g N for the cores (Table 2). This ratio shows that the peat has a high mass of carbon to a small mass of nitrogen.

### *Seasonal temperature and soil Moisture:*

The 2003 temperature data shows the seasonal temperature fluctuation in degrees Celsius (SES lab weeks 7 and 8, from WHOI). The graph shows the temperatures for each day within each month from January to December (Figure 1). In the winter the temperatures are lower and then in the summer they increase, but eventually decrease back down in the fall and winter. The ground water level also fluctuated seasonally (Figure 2). The water level is higher in the winter and decreases in the summer Figure two shows this change, the water level is represented in metres above sea level and expressed in a monthly average.

### *Gas Fluxes*

Fluxes for $CO_2$ or $CH_4$ are graphed in grams of carbon from $CO_2$ or $CH_4$ per metre squared per day. Figure three shows the fluxes of carbon dioxide from all of the different core treatments for each day measured. Each point is an average of the replicate cores. In this graph both of the 21.1° C incubations had the highest fluxes. The 21.1° C dry core had even higher fluxes of carbon dioxide than the control where the water level was unchanged and at the surface of the peat. The methane fluxes are more variable then the carbon dioxide but they also show increases in the flux at the higher temperature (Figure 4). This figure shows the average $CH_4$ fluxes for the replicate cores on each day measured. The 21.1° control core has the highest flux for two of the days measured, this core is completely saturated and had no changes in water level. The 21.1° dry core had higher methane fluxes on only one of the days measured. Comparing the two 4° incubations the control has larger fluxes of $CH_4$ then the dry incubation.

### *Re-saturation*

The dry cores were re-saturated; the water that was initially taken out was added back into the cores. This water addition caused the carbon dioxide fluxes for those cores to decrease (Figure 5). Figure five shows the average fluxes of carbon from $CO_2$ for the days measured before and after the re-saturation. The 21.1° core decreases to a flux that is close to that of the control 21.1° core. The 4° dry to wet treatment also has a decrease in the carbon from $CO_2$ flux. The methane data for this treatment is much more variable then the $CO_2$; there is only a slight increase in the $CH_4$ after re-saturation (Figure 6). Figure six shows the average methane fluxes for each core from wet to dry conditions and also the temperature controls for that treatment.

### *Nutrient Analysis*

The amount of DIN varies throughout the different treatments. The 10° cores were measured to have the largest concentration of DIN. The 21.1° control core has more DIN then the dried core and the lower temperature cores both have similar values for DIN (Figure 7). Comparing the measured and the calculated vales that were based on the

C: N ratio and the carbon fluxes, the largest deviation is observed in the 21.1° dry core. The measured value is much lower then the calculate vales. The measured value for the 21.1° control core is also less then the calculated value. All of the low temperature treatments had measured values that were close or slightly above the calculated values. This is represented in figure 8, the lower temperature cores are above zero and the 21.1° core are below the zero line.

### *Q10 and global warming potential*

Table three shows the Q10 values for each of the treatments. The Q10 values were used to extrapolate the annual flux for 2003 and the global warming potential for the $CO_2$ and $CH_4$ were calculated based on those fluxes (Table 4). Table four shows the annual flux of $CO_2$ and $CH_4$, the global warming potential for each of the fluxes, and the total global warming potential. The total global warming potential for the wet core plus five degrees is twice that of just the wet core. The same is true for the dry core plus five degrees it is double the global warming potential of dry core. Comparing the wet core to the dry core, the wet core is almost double the global warming potential of the dry core; this is also true for the wet and dry increased temperature simulations.

## Discussion:

### *Gas Fluxes*

The purpose of this experiment was to examine the effects of temperature and water level on the release of $CO_2$ and $CH_4$. Microbes are inhibited by colder temperatures and increased temperatures enhance their metabolic processes (Chimner,2003). I observed higher fluxes of both $CO_2$ and $CH_4$ in the higher temperature treatments. Larger fluxes of $CO_2$ and $CH_4$ in the 21.1° incubations are attributed to the increased rate of microbial processes with the higher temperature. The colder incubations show less of a difference between the treatments because the microbes are suppressed by the lower temperatures.

The water level greatly affects the microbial activity and alters the microbial community. With higher water levels it is more difficult for the diffusion of oxygen to take place, creating more anoxic conditions. These anoxic conditions cause the microbes to use alternative electron acceptors, resulting in more methane production. I observed higher fluxes of methane in the control cores where the water level was to the peat surface. The methane fluxes are more variable then carbon dioxide because it actually the net flux that I measured. The net flux is dependent upon the interaction between production, consumption, and transport (Bubier, 1993). Methane can be oxidized as it diffused through the peat, resulting in more CO2 production. The measured fluxes of CO2 were larger for the 21.1° incubation resulting from the greater aeration of peat when the water level is decreased. The microbes have a more oxygen available which is more energy efficient process then using methane. There could also be more methane consumption by the methanotrophes, these microbes are found in aerobic portions of the peat and the decrease in the water table allowed for more of these conditions to exist.

The C: N ratios of the cores showed that the cores have similar compositions. The composition of the organic matter is not what is creating these differences in the fluxes that are observed. This helps to prove that the treatments are effective and is causing the changes in the production of carbon dioxide and methane.

### *Seasonality*

Throughout the year the temperature and water level naturally changes. These changes as observed in this experiment have large implications on the rates of decomposition and the release of greenhouse gases. In the summer the temperature increases and the water level decreases due to more evaporation, this will cause a greater release in carbon dioxide, as illustrated by the 21.1° dry treatment. These changes simulated by this experiment are variations that occur seasonally and probably to a greater extent. The dry core in this experiment didn't experience the extent of water level decline that occurs naturally. The highest temperature treatment only reaches 21.1° and also the lowest used was 4°. These treatments that used in this experiment were only moderate in comparison to the natural changes in temperature and water level. The moderate treatments created large differences in the fluxes of greenhouse gases, especially carbon dioxide. If these moderate treatments illustrate large deviation in the fluxes the differences that occur naturally are probably to a greater degree.

### *Re-saturation*

The re-saturation experiment was used to simulate fluctuations in the water table and confirm the effects of the lowering of the water table. In the high temperature treatments the carbon dioxide decreased towards fluxes that I measured in the control cores. Similar trends of decreasing carbon dioxide caused by re-wetting were also observed in an experiment performed by Freedman, which simulated climatic changes in water table draw down (Freedman, 1993). My results for this re-saturation experiment show that the system can respond on a relatively short time scale to changes in the water level.

### *Nitrogen Availability*

The second part of my experiment was measuring the DIN, the purpose of this was to test if more nitrogen becomes available as the organic matter is broken down and the carbon is lost. These experiments show that the expected amount of nitrogen was measured in the lower temperature incubations based on the C: N ratio and the carbon flux. In the higher temperatures, especially the dry core, there was much less DIN measured then expected. This deviation between the measured and expected DIN can be caused by processes that were not measured. DIN can be taken up by microbes through immobilization or released to the atmosphere through denitrification. Nitrification and denitrification are both processes that are temperature dependent and influenced by the moisture content of the peat (Smith, 1997). The temperature increases allows for an increase in microbial activity, these microbes are transforming the nitrogen into different forms from ammonia, to nitrate, and then to nitrogen gas. A strong relationship between N mineralization and $N_2O$ emissions suggests that increased N cycling is expected with increased temperatures and precipitation, resulting in increases in nitrogen gas emissions (Matson, 1989). The decrease in the water level of the dry core could allow for greater rates of nitrification to take place because this process requires oxygen and with the removal of water there was more peat aeration to the surface but most of the lower peat was left anoxic. Nitrate is necessary for the process of denitrification and with a greater concentration more denitrification would be possible. Denitrification occurs when nitrate is used as an alternative electron acceptor, similar to methane, anoxic conditions are necessary (Smith, 1997). This peat is extremely saturated, which could allow it to be very anoxic even when I removed some of the water.

These changes in conditions greatly affect the microbial community. The increased temperatures allows for more N-cycling by microbial processes, eventually leading to greater emission. The release of nitrogen gas also has implications on global warming because it is a global warming gas.

### *Global Warming Potential*

The changes in temperature and water level that I have studied in this experiment not only have large seasonal implications but are also important to the process of global warming. Both of these gases are global warming gases and controls on their emission include temperature and water level (Moore, 1993). I extrapolated the global warming potential for various situations and for wet and dry scenarios. From these calculations the largest global warming potential would occur in the warm and wet scenario. This scenario also had the largest flux of methane. The large flux of methane is caused by the increase in anoxic conditions created by the water addition. These results have repercussion for global warming as the climate is expected to become warmer and possibly wetter. Global temperatures are predicted to increase 1-3.5° C by 2100 (IPCC review, Houghton et al. 1996).

Some climate change scenarios predict that the climate will become wetter with increased evaporation, but others also predict that the climate could become drier. Based on my extrapolations if the climate becomes drier and warmer there would be half the global warming potential of the warm and wet scenario. This decrease in the global warming potential is due to the decrease in methane production in this scenario. The drying of the peat allows for more aerobic conditions and leads to more carbon dioxide production and less methane production. This could possibly lead to enhanced decomposition because of the presence of oxygen, allowing for the microbes to act more efficiently. The drying could cause a greater reduction in the peat accumulation with the increased microbial activity breaking down the built up organic matter.

If these predictions are accurate, whether the climate does become wetter or drier, there is still a greater warming potential in both of the warmer scenarios. This increase in global warming potential and green house gas emission will enhance the trapping of the heat in the atmosphere, perpetuating climate change. The increased carbon emission and decomposition could cause this and other peatland systems to shift from a sink to a source of carbon. This will have large consequences on the global carbon cycle with the loss of this large carbon sink.

The consequence of increased temperatures and decomposition has large implications for global warming but will also have huge effects on the existence of these rare Cedar swamps. If the peat that has accumulated decreases due to enhanced decomposition it could cause a reduction in the systems ability to hold in water. For the cedars to exist moist conditions are necessary and the lack of these conditions could cause extinction of these extraordinary swamps.

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| **Temperature (C°)** | **No water level change** | **Drained (Dry)** |
|---|---|---|
| 21.1 | ☆ | ☆ |
| 10 | ☆ | |
| 4<br>(Considered base temp.) | ☆ | ☆ |

Table 1: Various treatments used in the experiment
Each star is equal to two cores in that treatment

| Core | C:N |
|---|---|
| 4°Control | 29.2 |
| 4° Dry | 23.8 |
| 10° -1 | 30.5 |
| 10°- 2 | 29.8 |
| 21.1° Control | 30.8 |
| 21.1° Dry | 32 |

Table 2: C: N ratios for the various treatments

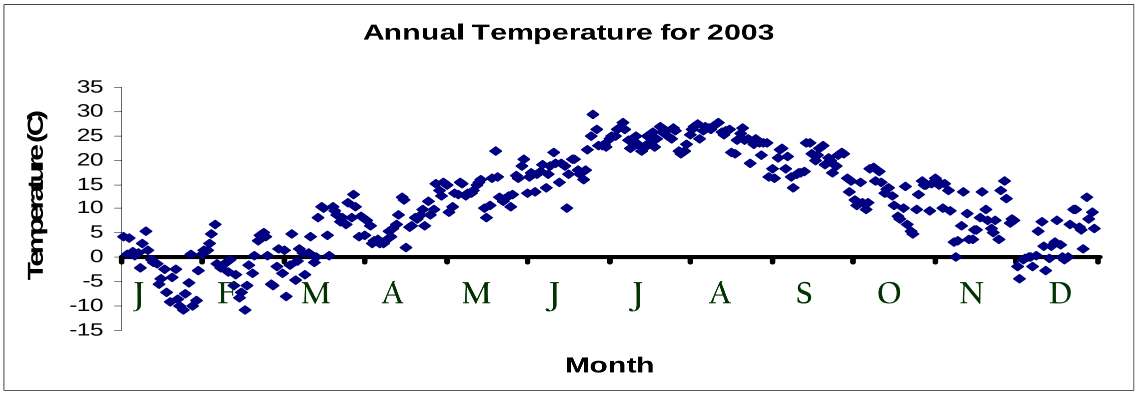

Figure 1: Annual air temperature for 2003

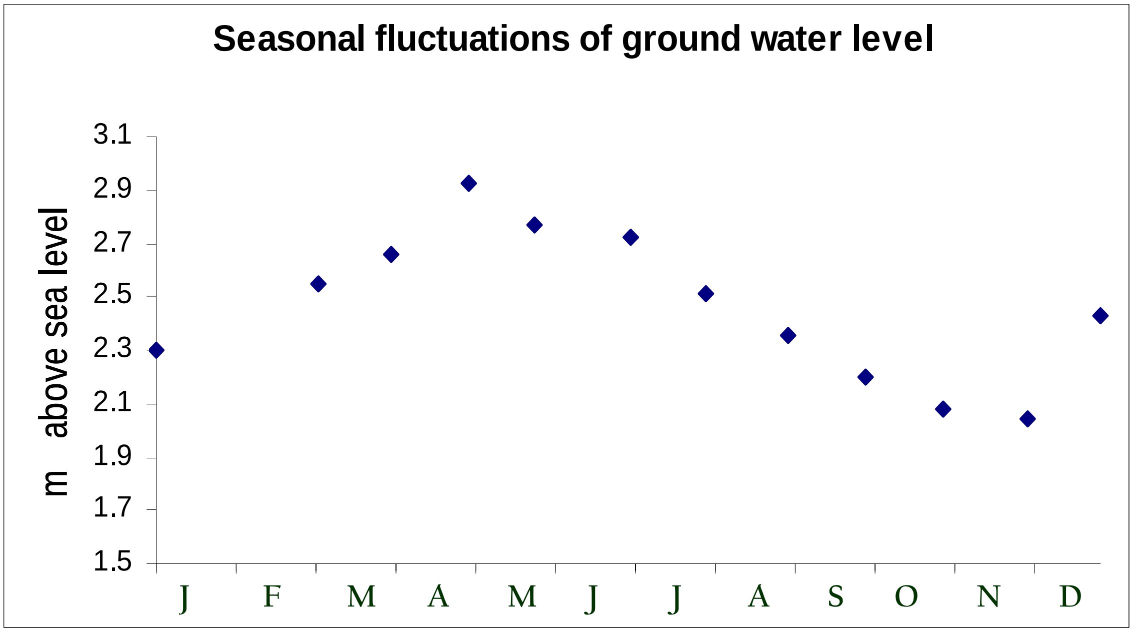

Figure 2: Annual changes in the ground water level for 2003

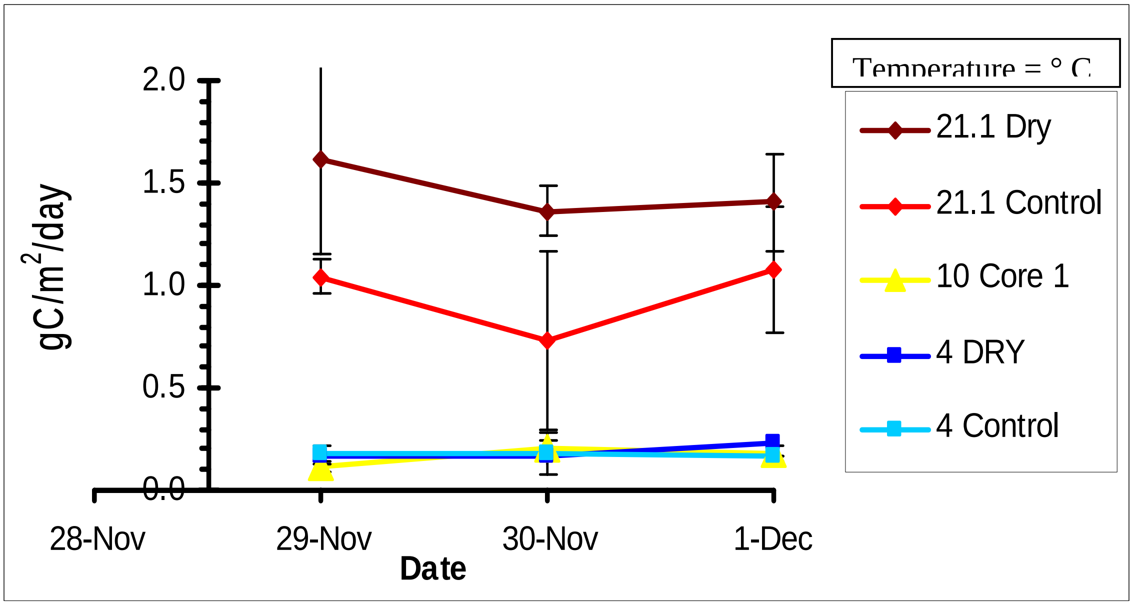

Figure 3: Initial fluxes of carbon dioxide for each treatment. Each point represents an average of the replicate cores

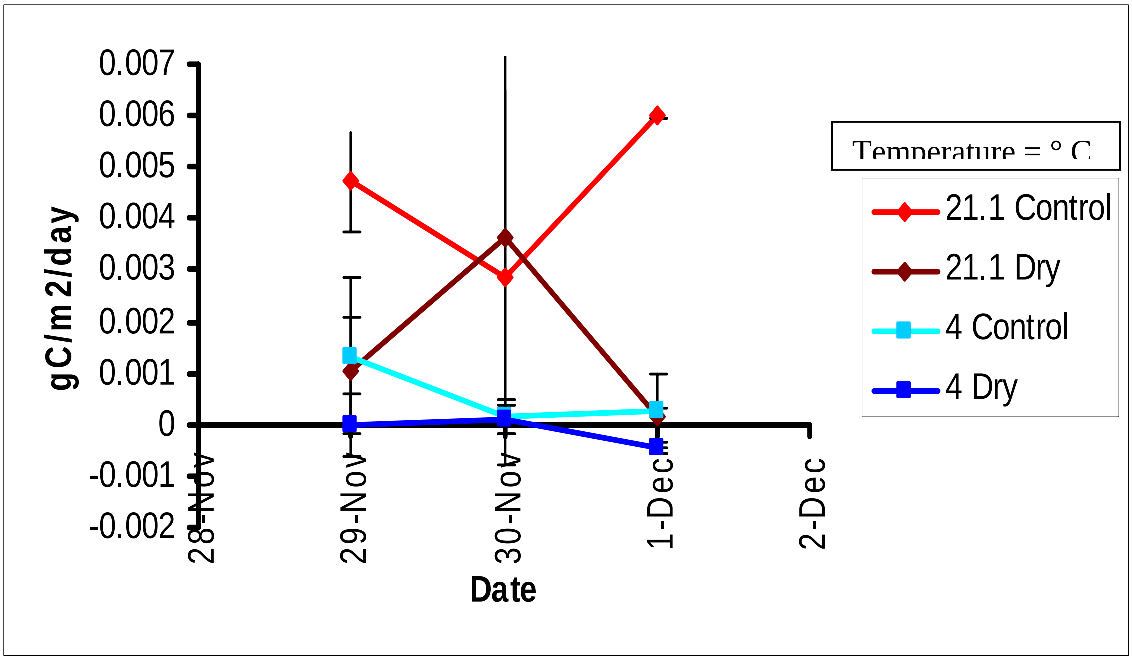

Figure 4: Initial fluxes of methane for all of the treatments. Like figure 3, each point represents the average of the replicate cores

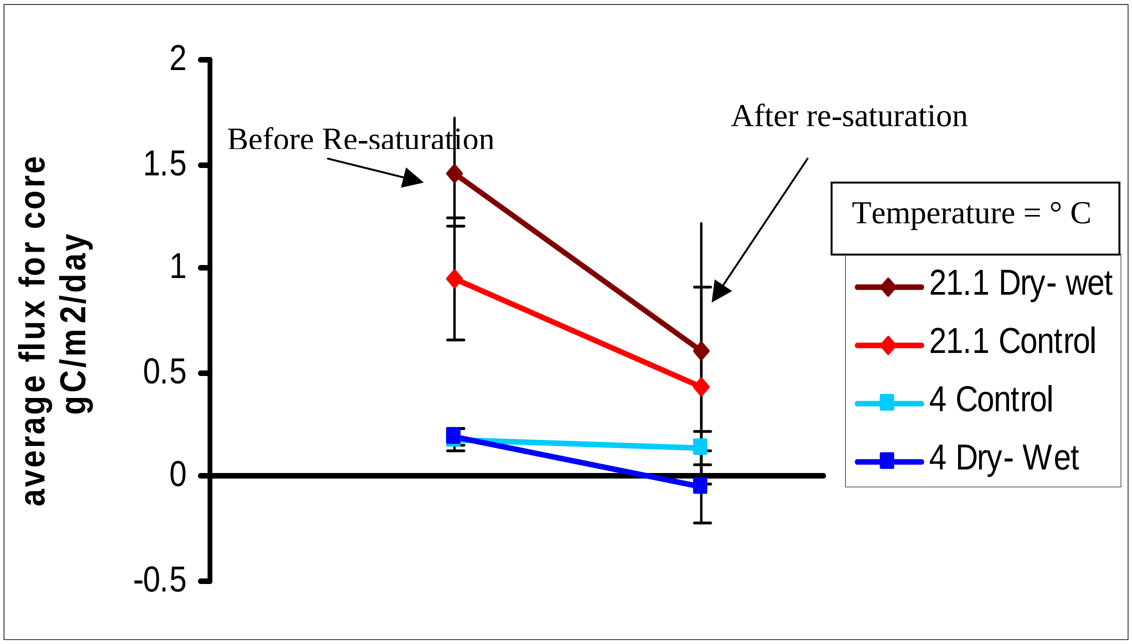

Figure 5: Average of carbon dioxide fluxes before and after re-saturation

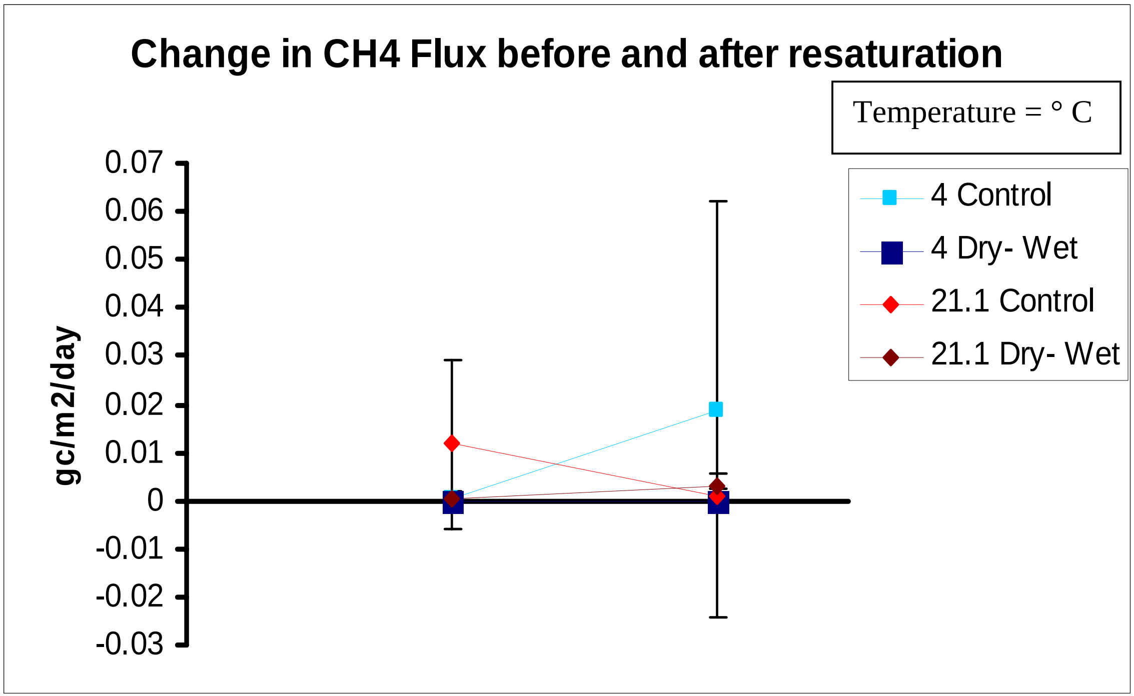

Figure 6: Average methane fluxes before and after re-saturation

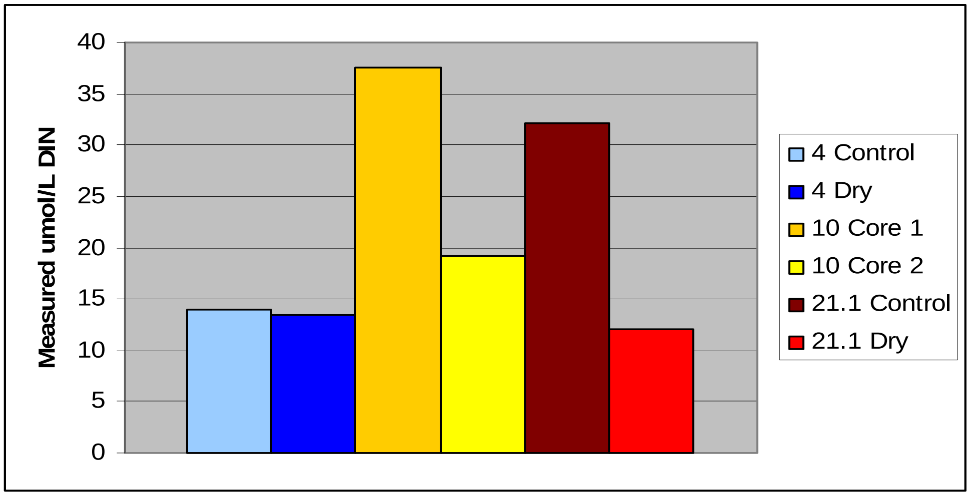

Figure 7: Measured DIN concentrations

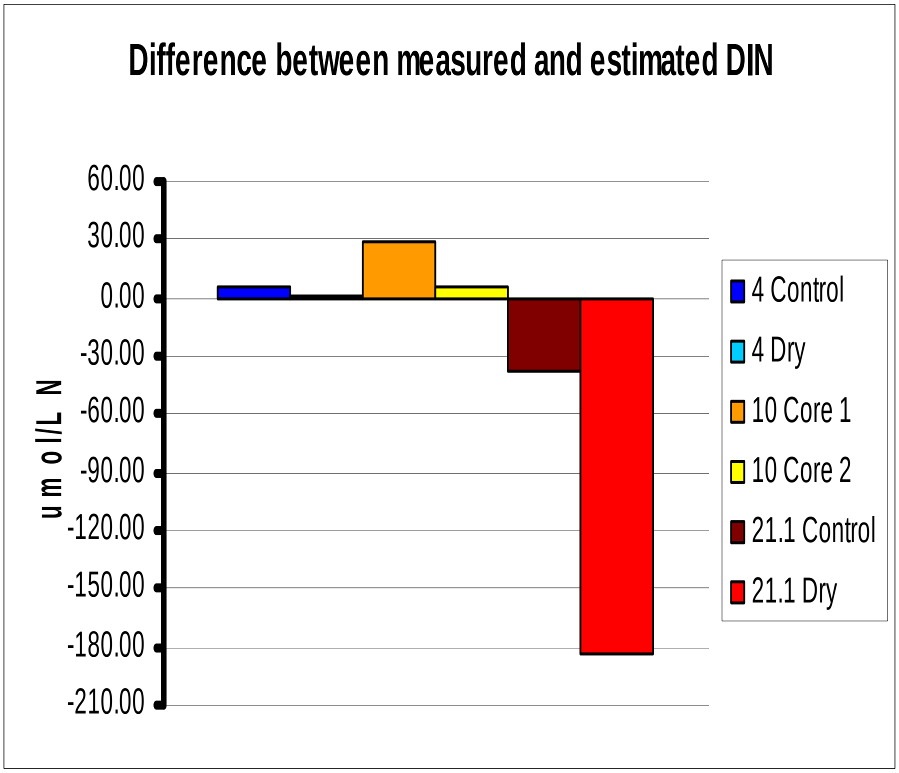

Figure 8: Deviation between measured and calculated DIN values

| Scenario | Q10 Value |
|---|---|
| Wet cores CO2 | 2.89 |
| Dry cores CO2 | 3.29 |
| Wet cores CH4 | 4.97 |
| Dry cores CH4 | 1.23 |

Table 3: Q10 values for various scenarios

| | **g C-O2/m2/yr** | **gC-CH4/m2/yr** | **CO2 Equivalents** | | |
|---|---|---|---|---|---|
| **Scenarios** | **Annual CO2 Flux** | **Annual CH4 Flux** | **GWP CO2** | **GWP CH4** | **Total GWP** |
| **Wet Core-Base** | **171.15** | **3.16** | **46.68** | **88.52** | **135.20** |
| **Wet + 5 °= Hot** | **291.35** | **7.05** | **79.46** | **197.41** | **276.87** |
| **Dry Core** | **298.55** | **0.04** | **81.42** | **1.23** | **82.65** |
| **Dry + 5 ° = Dry & Hot** | **541.49** | **0.05** | **147.68** | **1.37** | **149.05** |

Table 4: Calculated global warming potential for annual fluxes of carbon dioxide and methane