Methane Storage in Fresh Water Lakes at UNDERC-East

BIOS 569: Practicum in Field Biology

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Abstract:

Methane (CH_4) is the second most prevalent greenhouse gas emitted by anthropogenic and natural sources all over the world. Freshwater lakes are a significant source of CH_4 and are not included in greenhouse gas budgets. There is great uncertainty surrounding current freshwater lake estimates of CH_4 production, storage, and subsequent emissions. Our goal is to assess the biological and physical factors influencing CH_4 storage in lakes. Our results indicate that CH_4 production in anoxic sediment is a major controlling factor of CH_4 storage. Our data also suggests that air temperature influences thermal stratification of the lake, thus trapping CH_4 in the hypolimnion. Storage of CH_4 in the hypolimnion may evade oxidation processes during the summer and upon fall turnover large quantities may be a significant portion of annual emissions to the atmosphere.

Introduction:

Methane (CH_4) is a potent greenhouses gas that significantly contributes to global warning. Methane is a hydrocarbon produced by natural and anthropogenic sources, however these sources are not mutually exclusive (Umezawa et al., 2012, West et al., 2012). Methane is a radiative trace gas, which accounts for approximately 20% of global warming and lakes may contribute up to 103 teragrams of CH_4 every year with a 6-16% of global emissions that contributes to the greenhouse effect (Bastivken et al., 2004; 2008). It has been estimated that atmospheric concentrations of CH_4 have increased by approximately 150% since the pre-industrial times (mid-1700s). Recent studies have indicated that the majority of methane production in freshwater ecosystems occurs in anoxic sediment (Bartlett et. al, 1988; Rudd and Hamilton, 1978).

Production of CH_4 in lake sediments is a microbially mediated process that is mainly regulated by anoxia, temperature and some qualities of substrates (Bastviken et al., 2004). In sediments of the lakes have high organic materials that produce high a lot CH_4 and the lakes that have low organic materials are going to produce less CH_4 (Smith and Lewis, 1992). Methane produced in the sediment diffuses out of the sediment and is subsequently stored in the hypolimnion. During the late spring air temperatures rise and the water temperature rises in the epilimnion of lakes. In that moment the thermal stratification begins separating the water column into two distinct layers, the aerobic epilimnion and anoxic hypolimnion. The cooler temperatures in the hypolimnion allow for a greater accumulation of gases such CH_4. Recent studies indicate that several physical and biological influence the depth and stability of the epilimnion and hypolimnion (Michmerhuizen and Striegl, 1996). With a larger and cooler hypolimnion and stronger stratification, a higher concentration of CH_4 may be stored in the hypolimnion (Moore et al., 1989). Lakes that produce more methane and store greater quantities of CH_4 are thought to release a greater quantity of CH_4 during fall turnover. During this time, CH_4 is potentially released with minimal CH_4 oxidation. Thus, lakes with larger hypolimnions and subsequently higher CH_4 storage may have a more significant impact on the greenhouse gas budget.

Our **goal** is to determine the biological and physical factors controlling production and subsequent storage of CH_4 in the lake.

Methods:

Study Sites:

The six studies lakes (Morris, West Long, East Long, Bolger, Crampton and Humming Bird) are located at the University of Notre Dame Environmental Research Center (UNDERC) that are located near to Land O' Lakes WI, U.S.A.

Methane Storage:

Water sample for methane concentration were collected at one-meter intervals using gas tight syringes and were equilibrated with a nitrogen headspace. We measure the storage of CH_4 using the Network GC System 6890N Agilent. We used Geographic Information Systems (GIS) data to calculate the surface of the littoral and pelagic zones. Based on volume of the lake at each depth and the concentration of the profile we estimated the total of CH_4 stored in each lake for each date.

Methane Production:

We collected sediment from each lake in the littoral and pelagic zones of the six lakes. During each sampling of each lake we incubated a total of 8 slurries. Upon returning to the lab we purged each sediment bottle with nitrogen to maintain anaerobic conditions for each incubation. We incubated the slurries for 14-day intervals and extract with a gas syringe and we measured the gas using the Network GC System 6890N Agilent to determine the production of each day on the lake. We inferred CH_4 production by linear regression of the concentrations over time. We used GIS data to determine the littoral and pelagic sediment area of each lake. We then weighted the CH_4 production rates by the respective littoral and pelagic sediment area to estimate total CH_4 produced in the sediment during a given sampling date.

Methane Emission:

Every 10-days we set 8 flux chambers in the littoral (4) and pelagic (4) zones on the surface of the lake. The gases were collected in the flux chambers 24-hours after the chambers were initially set on the lake. Upon returning to the laboratory we analyzed all the emissions gases using an Agilent 6890N Gas Chromatograph System with a flame-ionizing detector. We inferred CH_4 emissions rates based on time the flux chamber incubated on the lake. Concentration in chamber divided by time chamber sat on surface of lake.

Rates of diffusive efflux were calculated by the following equation: $F = k (C_{obs}-C_{equil})$ where k is the mass transfer coefficient, C_{obs} is the concentration of CH_4 measured in the surface water, and C_{equil} is the CH_4 concentration expected if water is in equilibrium with the atmosphere (Cole and Caraco 1998) k600 values were estimated for each chamber based on Schmidt numbers and observations from the chambers (Cole and Caraco 1998) and flux chambers with estimated k600 values higher than theoretical k600 values were considered chambers with high percentages of ebullition and were not included in the diffusive or total emissions calculations. We used GIS data to determine the littoral and pelagic sediment area of each lake. We then weighted the CH_4 emissions rates by the respective littoral and pelagic sediment area to estimate total CH_4 emissions in the sediment during a given sampling date.

Statistical Analysis:

One of the analyses that we are going to do is linear regression to have the predictable variables. We utilized linear regression to estimate CH_4 production and emission rates. To determine relationships between CH_4 production, storage, and emissions we use linear regression. To model physical and biological factors controlling we utilized multiple linear regression analysis.

All statistical analyses were conducted in the R statistical environment using the base packages (R Development Core Team, 2008).

Results:

The temperature of lakes stratification and the temperature of each one were taken each to weeks in the summer of 2013. All lakes show a strong relationship went the temperature increasing in the epilimnion they become less dense and the hypolimion expand more each day (figure 1). The hypolimnion is expanding as a result of atmospheric temperatures warming throughout the summer.

Lakes like Bolder, Morris and Hamming Bird demonstrate high storage of CH_4 and the over the time past (Figure 2). The linear increases indicate that the rates of storage are going higher affecting the thermo stratification. This show a significant relation between the time and the storage of CH_4. Also we calculate the concentration over the emissions. This indicates a significant result telling that over the concentration .

The linear regression shows the responsible that there two major variable those are occasioning the storage of methane that are the temperature and the production of methane. This two is the responsible of making the hypoliumion to expand affecting the thermo stratification to go smaller. This result shows a very significant result that the temperature and the production of methane are closely related (Table 1).

Discussion:

Methane storage increased over the course of the summer and was primarily influenced by weekly mean air temperature and sediment CH_4 production rates (Table 1). As the ambient temperature increased during the summer the stratification of lakes stabilized the lake. The cooler hypolimnion expanded over the course of the summer as the epilimnion shrank (Figure 1). As the summer progressed, the difference between epilimnion and hypolimnion temperatures increased creating a more stable thermal barrier, which reduced the proportion CH_4 emissions to the atmosphere (Figure 2). This behavior can see in all the lakes examined during the 6 weeks of this study.

Lakes that produced more CH_4 also stored a larger proportion of CH_4 as the summer progressed. As the hypolimnion expanded during the summer there was a greater volume for CH_4 storage. However, production and emissions also increased during the course of the summer (unpublished data, Kipp 2013). At some point we suspect that there will be a maximum saturation of CH_4 reached in the hypolimnion of some of the shallower lakes. Thus, the storage rate will approach zero. New CH_4 produced at this time should escape hypolimnion and the maximum diffusive CH_4 emissions rate should be observed (unpublished data, Kipp 2013).

Ultimately, CH_4 production, temperature, and hypolimnion volume may greatly impact annual CH_4 emissions, especially during the fall, when the dimictic lakes turnover and subsequently hypolimnion CH_4 stored during the summer is rapidly released into the atmosphere. What proportion of CH_4 stored during the summer and is released during fall turnover is unknown and should be accounted for in CH_4 budgets.

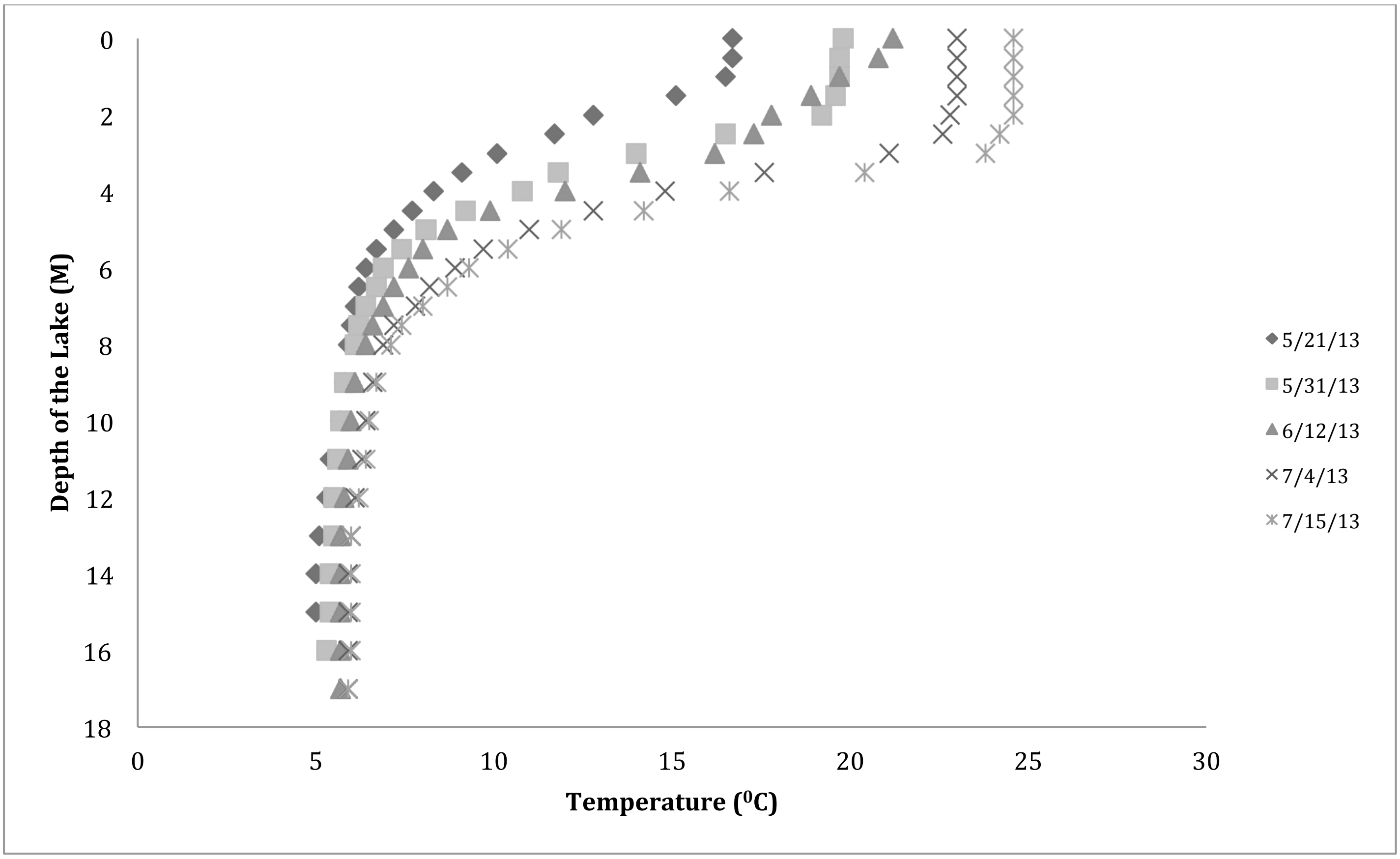

Figure 1. An example of temperature change influencing lake stratification. Increases in temperature over the course of the summer increases the volume of the hypolimnion as well as the stability of thermal stratification. All the lakes follow this pattern and this graph is representing Crampton Lake.

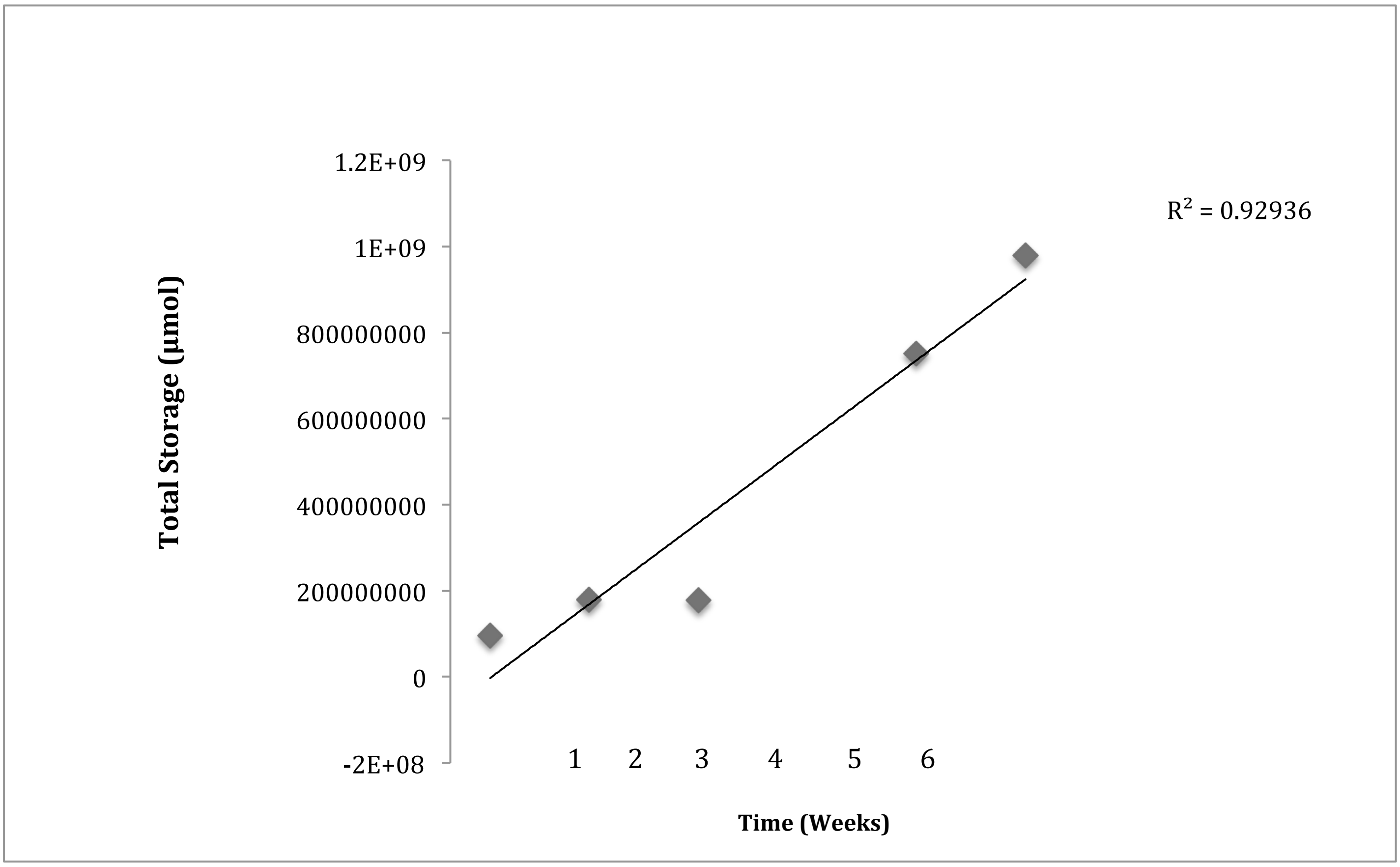

Figure 2. Methane stored in the hypolimnion over the course of the summer. Points represent average storage for all lakes on a given week (n=48) (R^2= 0.96956).

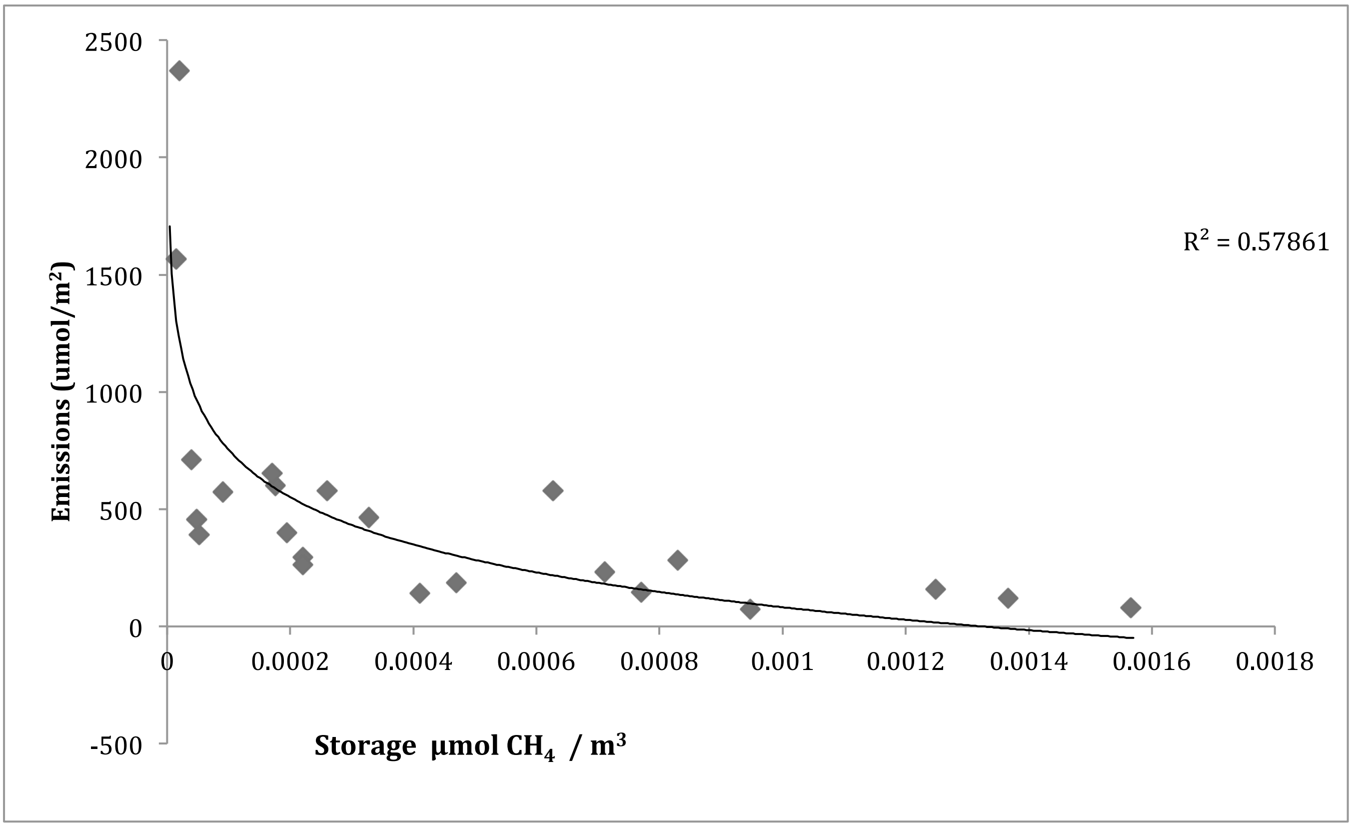

Figure 3. The contribution of CH_4 going to storage and emissions over the course of the summer. As the summer progresses a larger proportion of CH_4 produced in the sediments is stored.

Degrees of freedom	F Statistic	R^2	P
23	27.47	0.6792	$8.026e^{-7}$

Table 1. A multiple linear regression with CH_4 production and prior week average air temperature as predictor variables of CH_4 storage (response variable) The linear regression indicates there is a significant relationship between the air temperature, CH_4 production and CH_4 storage.

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References:

Bartlett, K.B., Cril, P.M., Sebacher, D.L., Harriss, R.C., Wilson, J.O. and Melack, J.M. 1988. Methane flux from the central Amazonian floodplain. Journal of Geophysical Research 93: 0148-0227.

Bastviken, D, J. Cole and M. Pace. 2004. Methane emissions from lakes characteristic, two regional assessments, and global estimatr. Global Biogeochemical Cycle. 18. 1029-2004.

Bastviken, D., J. Cole, M. L. Pace and M. Van de Bogert. 2008. Fates of methane from different lake habitats: Connecting whole-lake budgets and CH4 emissions. Journal of Geophysical Research. 113: 1-13.

Casper P, S.C Maberly, G. H Hall, B.J Finlay. 2000. Fluxes of methane and carbon dioxide from a small productive lake to the atmosphere. Biogeochemistry. 49, 1–19.

Craig A. E, Lance F. W. Lesack and P. Marsh. 2006. Lake abundance, potential water storage, and habitat distribution in the Mackenzie River Delta, western Canadian Arctic. 43: 1-14.

Cole, J. and N. F. Caracco . 1998. Atmospheric exchange of carbon dioxide in a low-wind oligotrophic lake measured by the addition of SF. American Society of Limnology and Oceanography, Inc. 43: 647-656.

Dunfield, P, R Knowles, R. Dumont. and R. T Moore. 1993. Methane production and consumption in temperate and subarctic peat soils: response to temperature and pH. Soil Biology and Biochemistry .3: 321-326.

Emmerton, A. C, L. F. W. Lesack and P. Marsh. 2007. Lake abundance, potencial water storage, and habitat distribution in the Mackenzie River Delta, western Canadian Artic. Water Resources Research. 43: 1-14.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Juutinen, S., M. Rantakari, P. Kortelainen, J. T. Huttunen, T. Larmola, J. Alm, J. Silvola and P.J. Martikainen. 2009. Methane dynamics in different boreal lake types. Biogeoscienciences. 6: 209-223.

Marrotta, H, L. T. Pavia and M. M. Patrucio. 2009. Changes in thermal and oxy gen stratification pattern coupled to CO_2 outgassing persistence in two shallow lakes of the Atalantic Tropical Forest, southeast Bazil. Limnology. 10: 195-202.

Wahlen, M. 1993. The Global Methane Cycle. Earth Planet. Sci. 21: 407-426.

Michmerhuizen, M. C and R. G. Striegl.1996. Potencial methane emission from north-temperature lakes following ice melt. American Society of Limnology and Oceanography, Inc. 41: 985-991.

Moore T. R. and R. Knowles. 1998. The influence of Water Table Levels on Methane and Carbon Dioxide Emissions from Peatland Soils. Deparment of Geography, MgGill University. 69: 33-38.

Gircils. S. S. 1979. Thermal Stratification in Lakes. University of Windsor. Electronic Theses and Disserations, Canada

Schulz, S, H. Matsuyama and R. Conrad. 1996. Temperature dpence of methane production from precursors in a profundal sediment (Lake Constance). FEMS Microbiology Ecology. 22: 207-213.

Striegls, G. R and C. M. Michemerhuizen.1998. Hydrologic influence on methane and carbon dioxide dynamics at two north-cenral Minnesota lakes. Oceanogr. 43: 1519-1529.

Umezawa ,T, Toshinobu M , Shuji A, T. Nakazawa. 2012. Contributions of natural and anthropogenic sources to atmospheric methane variations over western Siberia estimated from its carbon and hydrogen isotopes. Global Biogeochemcal Cycles. 26: 1-15.

Rudd, W. J and R.D. Hamilton. 1978.Methane Cycling in a Cutrophic Shield Lake and its Effects on whole lake metabolism. Fisheries and the Environment, Freshwater Institute. 23: 337 - 348.

West, E. W, J. J. Coloso and S. E. Jones. 2012. Effects of algal and terrestrial carbon on methane production rates and methanogen community structure in a temperate lake sediment. Freshwater Biology. 57: 949-955.