Title: Summer 2023 Greenhouse Gas Fluxes at Cedar Bog Lake, MN

Abstract:

Freshwaters are significant natural sources of greenhouse gasses (CO_2, CH_4, and N_2O) to the atmosphere. Small freshwater bodies like Cedar Bog Lake are increasingly being recognized as having large greenhouse gas emissions compared to their small size and measured emissions can vary widely in order of magnitude. To assess trends in greenhouse gas emissions at Cedar Bog Lake, concentrations and emissions of CO_2, CH_4, and N_2O were measured roughly weekly over a two-month period from the middle of July until the middle of September in 2023. Over the two-month sampling period, Cedar Bog Lake was a net source of CH_4 (mean 775.19 [sd 556.00] mg CH_4 m^{-2} d^{-1}). CO_2 fluxes varied more between being a source and a sink but was overall a source over the sampling period (mean 411.60 [sd 696.29] mg CO_2 m^{-2} d^{-1}). N_2O concentrations were measured *in situ* but average fluxes were not calculated since there was no appreciable difference between sample flux (floating chamber measurement) and in headspace concentrations at depth between the sample and the atmosphere. Both CH_4 and CO_2 concentrations were highest at the lowest measured depth (1.2m) and concentrations peaked in mid-August which corresponded to the hottest part of the summer and the lowest concentration of O_2 in the hypolimnion. In general, there was a high degree of both spatial (within lake) and seasonal heterogeneity in the floating chamber measurements used to calculate the greenhouse gas fluxes from Cedar Bog Lake.

Introduction:

Freshwater lakes and ponds are important sites of biogeochemical activity and emissions of major greenhouse gasses such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Freshwater lakes cover only 4% of Earth's land area (Verpoorter et al., 2014), they are estimated to annually emit over 0.5 Pg C of CO_2 (DelSontro et al., 2018) and 0.3 Pg C of CH_4 (Rosentreter et al., 2021) to the atmosphere. Ponds and small lakes with an area less than 5 ha comprise over 90% of all freshwater bodies on Earth (Downing et al., 2006). Owing to their ubiquity, small inland bodies of water are key hotspots of biogeochemical cycling.

Allochthonous carbon inputs from the surrounding watershed can increase decomposition and respiration rates (van Bergen et al., 2019). High respiration rates in the water column and the sediments can consume oxygen and create anoxia, which can lead to anaerobic CO_2 and CH_4 production (Duc et al., 2010). Emergent macrophytes have been shown to transport gasses (CH_4) from the sediments to the atmosphere (Desrosiers et al., 2022). Submerged macrophytes can increase CH_4 emissions in oxygenated waters by encouraging methanogenesis and by providing another pathway for ebullition (Hilt et al., 2022). CH_4 is a much more potent greenhouse gas compared to CO_2 with a warming potential 84 times higher over a 20-year time period (Myhre et al., 2013).

Methods:

Cedar Bog Lake is located in northern Anoka County, MN roughly 42 km (26 miles) north of Central Minneapolis and is located in the Greater Minneapolis-St.Paul Metropolitan Region. Cedar Bog Lake is a natural lake within the Cedar Creek Ecosystem Science Reserve with a surface area of 1.46ha and a maximum depth of 1.20m (Rabaey and Cotner, 2022). Cedar Bog Lake is characterized by its shallow depth, heterogeneity of submerged aquatic vegetation cover, and its soft sediment layer at the maximum depth. Sampling occurred roughly weekly for a 2 month period starting in mid-July and ending in mid-September 2023. Profiles were taken at the deepest point of Cedar Bog Lake to measure a suite of physical environmental parameters (water temperature, dissolved oxygen (DO), pH, chlorophyll a, and conductivity) (Manta probe, Eureka Water Probes, Austin Texas, United States). Measurements were taken every 10 seconds, and profiles were taken slow enough to ensure that a measurement was made every 0.05-0.10m. DO values under 2 mg L^{-1} were considered anoxic (Nürnberg, 1995).

Greenhouse gas emissions of CO_2 and CH_4 were measured using a floating chamber technique (Erkkilä et al., 2018; Grinham et al., 2018; Gorsky et al., 2019). The floating chamber used was constructed out of a 5-gallon white bucket with a headspace volume of 10.02 L within the chamber. This floating chamber was connected to our lab's portable greenhouse gas analyzer (DX4040 FTIR Gas Analyzer, Gasmet Technologies Oy, Vantaa, Finland) via the inlet and outlet connections creating a closed loop cycling setup. Floating chamber measurements were taken at three different locations in the lake: in the pelagic zone, the near-dock littoral zone, and an area of the lake at a middle depth that had high macrophyte cover. All floating chamber measurements were taken for at least 5 minutes and up to 10 minutes if rates were low. Efforts were made to ensure that floating chamber measurements were taken at roughly the same part of the lake each sampling trip. If the measurement was in a macrophyte dominated area, the floating chamber was placed over an open water location within the macrophyte patch. Concentrations of CO_2 and CH_4 were measured at three different depths (subsurface, 0.5m, and 1.2m) using the headspace technique (McAuliffe, 1971). The two deepest water samples were collected using a Van Dorn water sampler and the surface sample was collected by hand approximately 10cm below the surface. 125mL of water was collected in a 140mL syringe, any bubbles were removed from the syringe and water was expelled from the syringe for a final water volume of 105mL. 35mL of air was added to the syringe and shaken well for 2 minutes to equilibrate gasses in the air and in the water sample. From there, 30mL of headspace was transferred to a second syringe using two three-way stopcocks on each syringe. Gas samples were immediately injected onsite in the portable gas analyzer with a closed loop injection system (Wilkinson et al., 2019).

Results/Discussion:

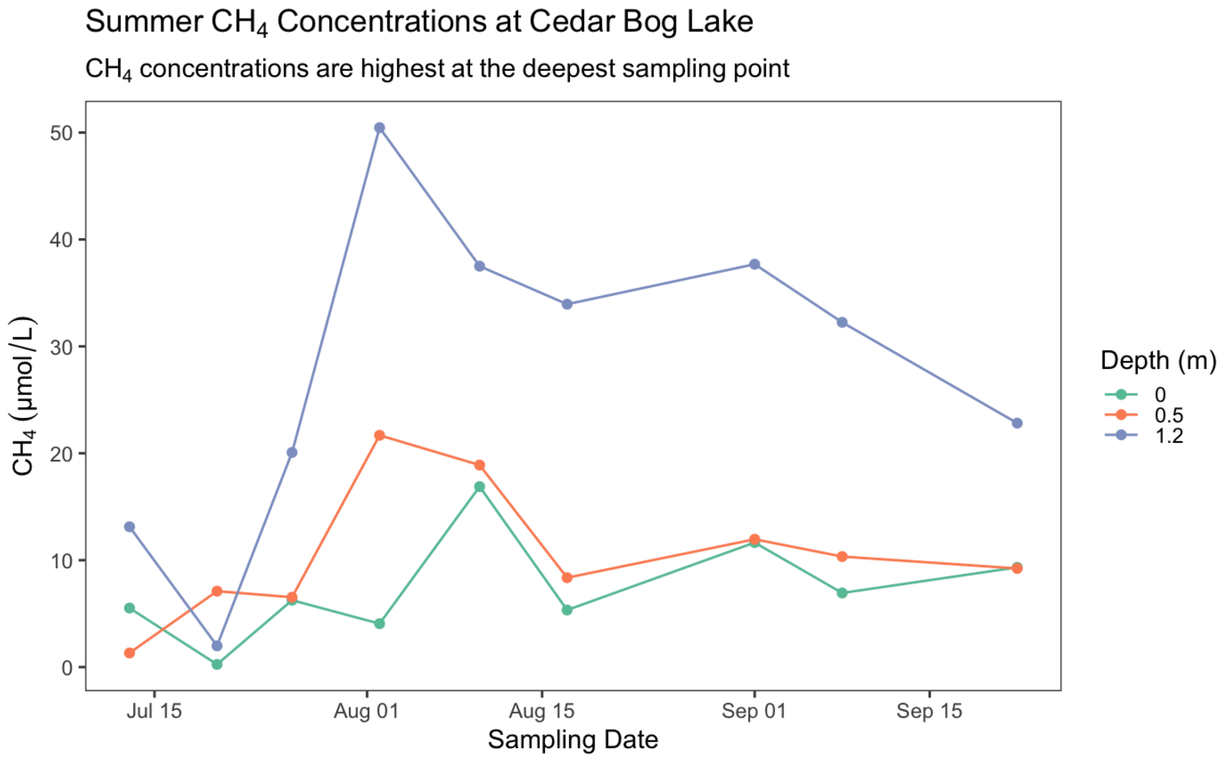
Table 1: Areal Greenhouse Gas Fluxes

Areal GHG Fluxes (per minute and daily)

Gas	Average Flux (mg m-2.min-1)	Average Daily Flux (mg m-2.d-1)	SD Flux (mg m-2.min-1)	SD Daily Flux (mg m-2.d-1)
CH4	0.5383241	775.1867	0.3861137	556.0037
CO2	0.2858333	411.6000	0.4835319	696.2860

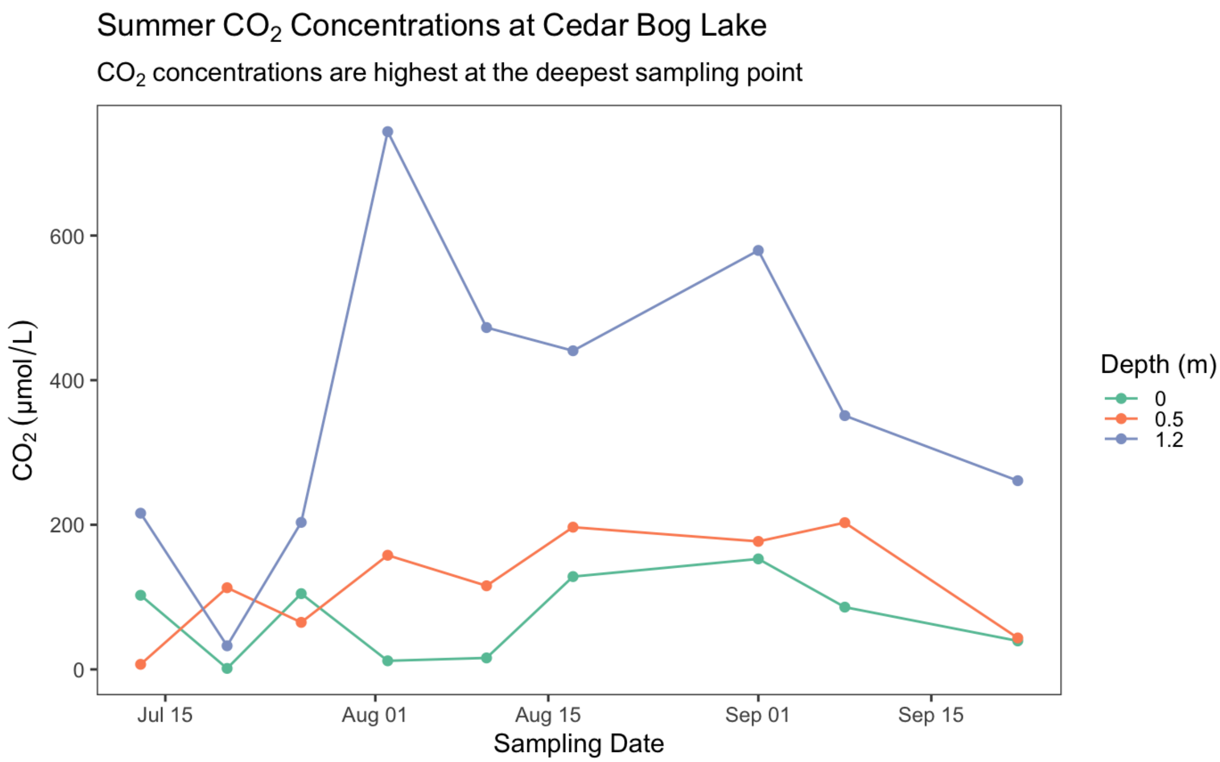
Caption: The average flux from the three different floating chamber measurements shows that Cedar Bog Lake was a net source of CH_4 and CO_2. Both fluxes show a large variation (standard deviation).

Figure 1:



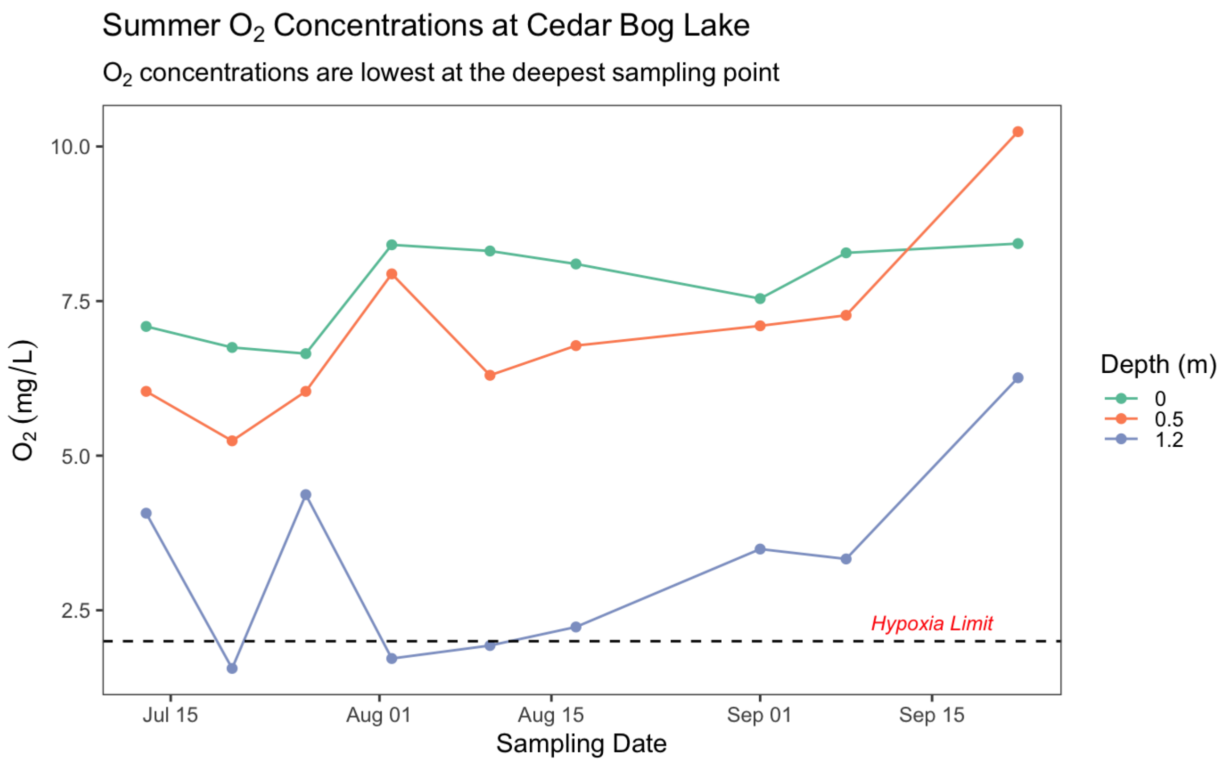
Caption: CH_4 concentrations increased with depth in Cedar Bog Lake. Concentrations peaked in the hypolimnion in early August and remained much higher than the other two depths throughout most of the sampling period. Some stratification was observed between the 0.5m and subsurface sample in early August otherwise these two depths showed similar concentrations for the rest of the sampling period.

Figure 2:



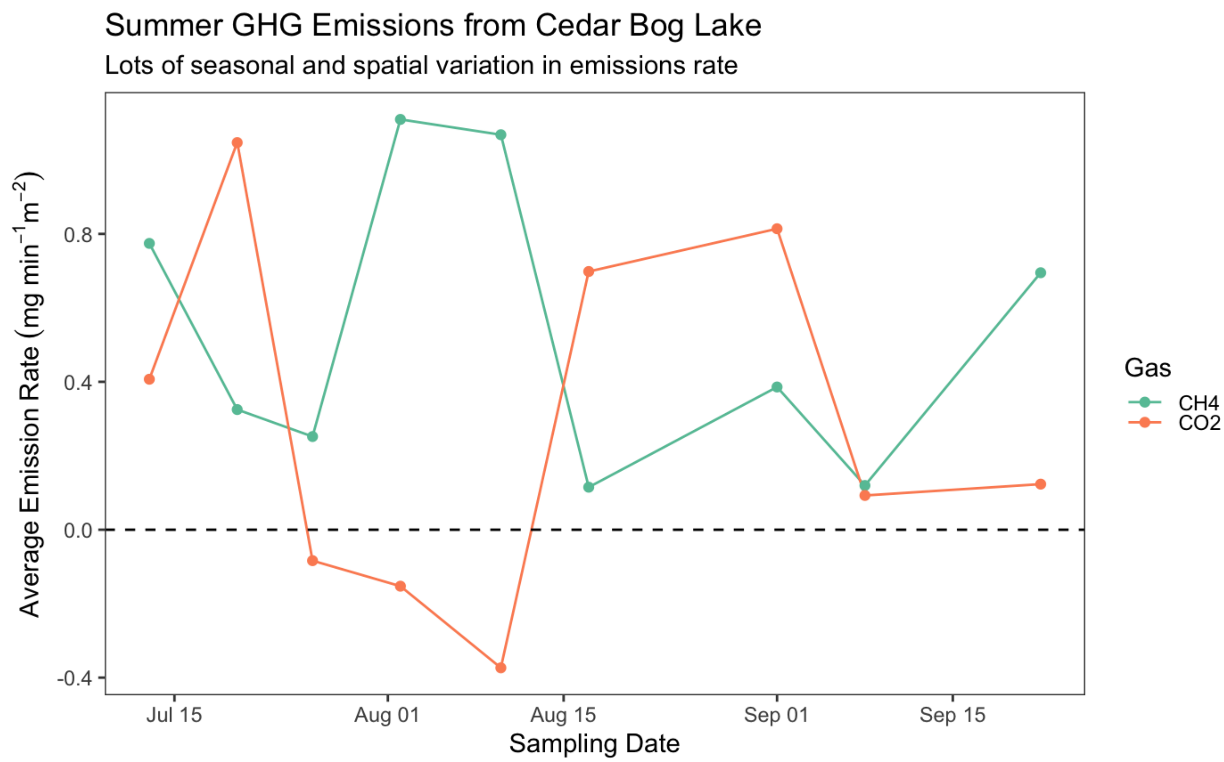
Caption: CO_2 concentrations increased with depth in Cedar Bog Lake. Concentrations peaked in the hypolimnion in early August and remained much higher than the other two depths throughout most of the sampling period. Some stratification was observed between the 0.5m and subsurface sample in early August otherwise these two depths showed similar concentrations for the rest of the sampling period. These trends closely resemble the trends shown in Figure 1.

Figure 3:



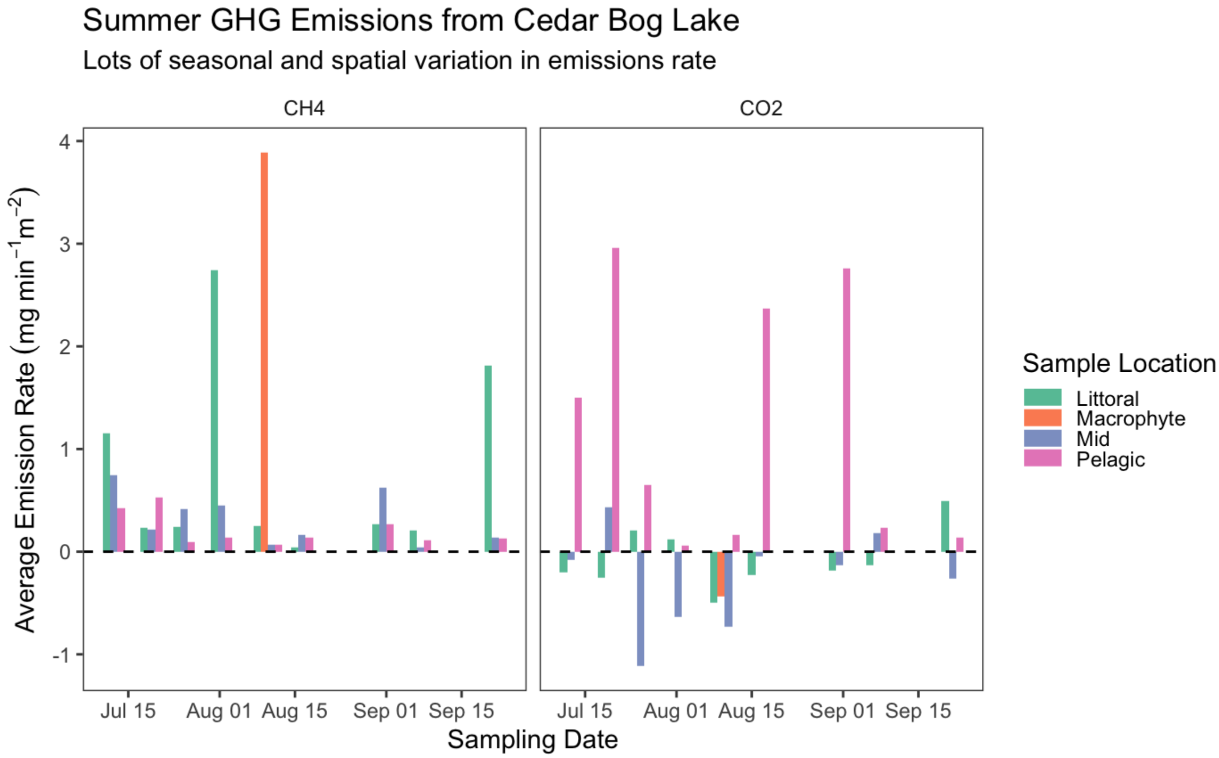
Caption: O_2 concentrations were lowest in the hypolimnion (1.2m sample) over the sampling period. In the warmest part of the year (mid-August) the O_2 concentrations fell below or hovered around the hypoxia limit (<2 mg/L). This corresponds with the methane trends seen in Figure 1. This lack of O_2 is explained by the intense thermal stratification observed in August. O_2 concentrations in the hypolimnion increased dramatically in mid-September showing stratified conditions were lessening.

Figure 4:



Caption: This figure is showing the average flux of CH_4 and CO_2 from the three floating chamber measurements across the two-month sampling period. CH_4 average flux was highest in early to mid-August. CO_2 was a net sink at this same time, likely due to high photosynthesis rates from the macrophytes in the lake. Generally, these fluxes mirrored each other, when one was high the other was low.

Figure 5:



Caption: This figure shows the fluxes across the sampling period across each sample location. The left panel shows CH_4 fluxes and the right panel shows CO_2 fluxes. CH_4 fluxes were highest in the littoral (shallow) zone of the lake whereas CO_2 fluxes were highest in the pelagic (deep) zone of the lake. The large CO_2 flux from the pelagic zone could be CH_4 from the hypolimnion that has been oxidized as it traveled up through the water column. Also, one floating chamber measurement was taken directly over a macrophyte (orange bar) and this was the highest methane concentration measured across the whole sampling period.

Future Directions:

There are a few measurements I would like to take to further improve this project. First, I would like to continue making measurements (headspace injections at different depths and floating chamber measurements) during the winter (2023) and during the coming spring (2024) so I can explore these trends seasonally. Additionally, I would like to complement this work with a diel study where I take a floating chamber measurement every 2 hours over the course of a day. This could be juxtaposed against my measurements to see how different these rates are at different times of day. My sampling largely occurred in the early to mid afternoon. Diel studies have shown that daytime fluxes of CO_2 underestimate total daily fluxes while overestimating total CH_4 fluxes (van Bergen et al., 2019; Sieczko et al., 2020). I would also like to measure changes between total dissolved phosphorus and particulate phosphorus pools throughout the seasons. Lastly, I would like to measure alkalinity throughout the seasons. Cedar Bog Lake is fed by groundwater. In dry conditions, the water table lowers and Cedar Bog Lake receives less of its total water from groundwater. This is an important source of carbonate in the lake. Both the changes in alkalinity and the two aforementioned phosphorus pools likely influence carbon cycling in Cedar Bog Lake and collecting this additional data would better inform drivers of greenhouse gas fluxes.

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