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Supporting Information for

Large lake dominates CO_2 emissions from lakes in a subarctic catchment

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Introduction

This supplementary materials include a detailed description of the inventory of lakes and ponds (text S1), the procedure for the Lake Torneträsk sampling and chemical analysis (text S2), and details about the simulation to upscale CO_2 emissions (text S3). To support that, several figures are also included.

Text S1: Lake inventory and estimate of ponds

Ponds under 1000 m^2 appear to be not well detected by the global lake inventory (Verpoorter et al. 2014). Therefore, we manually measured the ponds in four subcatchments of our study area (Figure S1). The subcatchments were selected to be evenly distributed to capture the geographical variability, including flat areas with a higher density of ponds and steeper catchments with a lower abundance of ponds. Using high resolutions ortophotos, ponds were delimited using ArcGIS 10. This was done manually due to the difficulties of automatically detect then on shadowed areas. The four subcatchments account for 225 km^2, and 2450 ponds were measured. The ponds followed a lognormal distribution, with a Mean(log)=5.71 and SD(log)=1.28. Then, we used this distribution to upscale the number and size of ponds of all the catchment, with a total number of 27070 ponds.

Text S2: Lake Torneträsk sampling

Lake Torneträsk was studied in 2012, before the ice break-up and during the ice-free season until mid-October. Due to the complexity and the large size of the lake, we sampled different locations to study the spatial variation of the carbon content in the lake water. In April, 39 samples were taken at 17 different locations on lake Torneträsk for CO_2 measurements, dissolved inorganic carbon (DIC), methane (CH_4) dissolved organic carbon (DOC) and water temperature (Figure S2). The number of samples at each location varied depending on the lake depth since samples were taken every 15-20 m. Sample collection was done with a Ruttner sampler, the samples carefully transferred to 1 L gas-tight bottle (Schott Duran) to avoid bubble formation and, kept in a portable fridge to avoid temperature changes until further sample handling. On each site the ice thickness and the temperature of the water sample was measured. During the ice-free season, the lake was sampled twice, in July and August. Water samples were taken as grab samples with a 1 L gas-tight bottle (Schott Duran) at 1 m depth, using a device to open the bottle remotely. Temperature was instantly measured in the field. The samples were processed within the day of sampling. CO_2 concentrations were measured using the headspace equilibrium technique [Cole et al. 1994] and following the procedure described in Lundin et al., [2013]. The water concentration of CO_2 was calculated using Henry's law [Åberg et al. 2007]. Analysis for DIC, CH_4 and DOC were performed as in Lundin et al., [2013] Between the 25th of June and 10th of October, continuous measurements of CO_2 concentration in the water were done using a continuous infrared gas analyser (IRGA; Vaisala CARBOCAP, GMT220, Helsinki, Finland). The IRGA was inoperative between 28th of August and 19th of September due to a storm. The IRGA was installed in a sealed box, with a sensor deployed in the water at 1 m depth, wrapped with a PTFE foam highly permeable to CO_2 but not to water [Johnson et al. 2010]. The IRGA was located on a raft at location 9 (supplementary information, figure S2) and the measurements were recorded every two hours in a data logger (CR200, Campbell Inc., U.S.), water temperature and pressure were measured at the same place using a HOBO-U20 probe (Onset Computer Corp. U.S.).

Text S3: Whole catchment upscaling of CO2 emissions

To calculate CO_2 emissions for all the lakes of the catchment, we predicted key variables required for the calculation of annual CO_2 fluxes. These variables are: pCO_2 in the water, lake temperature, the k_{600}, and the ice-free season. With these variables, parametrized as in table S1, we developed a model that predicts the yearly flux of CO_2 from each lake, and by including a Monte-Carlo simulation for each individual lake we could assess the uncertainty and the sensitivity of our calculations.
We used a power law relationship between the lake area and pCO_2 of lakes smaller than 1 km^2 (R^2=0.44; linear regression on log-transformed data, table S1) that was used to predict the pCO_2 of all lakes smaller than 1 km^2. For the larger lakes (n=21), we used the mean pCO_2 of the measured lakes larger than 1 km^2 (n=2).
To correct the CO_2 concentration for each lake with temperature, we used the linear relationship of water temperature with the altitude (R^2=0.83, table S1), using the data from Jonsson et al. [2003] and 8Karlsson et al. 2001]. Also, to estimate the number of ice-free days, when the flux to the atmosphere is possible, we also used the relationship between altitude and ice-free season (R^2=0.91, table S1), from the same lakes. In the case of lake Torneträsk, ice free season length has been measured for the past century (Callaghan et al. 2010), and we used the average of the last 20 years (220 days). For the CO_2 flux calculations, we used average pH (measured in Jonsson et al. [2003]), average wind speed (measured at the Abisko Research Station). Karlsson et al. [2013] studied the CO_2 flux that occurs when the ice thaws in small lakes in the catchment, in average, the ice-thaw flux was 35% of the total yearly flux. For lakes smaller than 0.1 km^2 we added an extra 35% of the yearly flux occurring during ice-thaw in spring in these lakes, which is the average of the lakes studied in Karlsson et al. [2013].
Using the above parameters (e.g. pCO_2, lake area, temperature, ice-free season), we used a Monte Carlo Simulation performed for each lake, with 10000 permutations, to predict a yearly flux of CO_2 for all individual lakes in the catchment. All calculations were done using R (R Development Core Team, 2016).

Figure S1. Subcatchments (in red) where ponds were manually measured and counted using ortophotos. Lakes of the global inventory are in blue and ponds measured in pink.

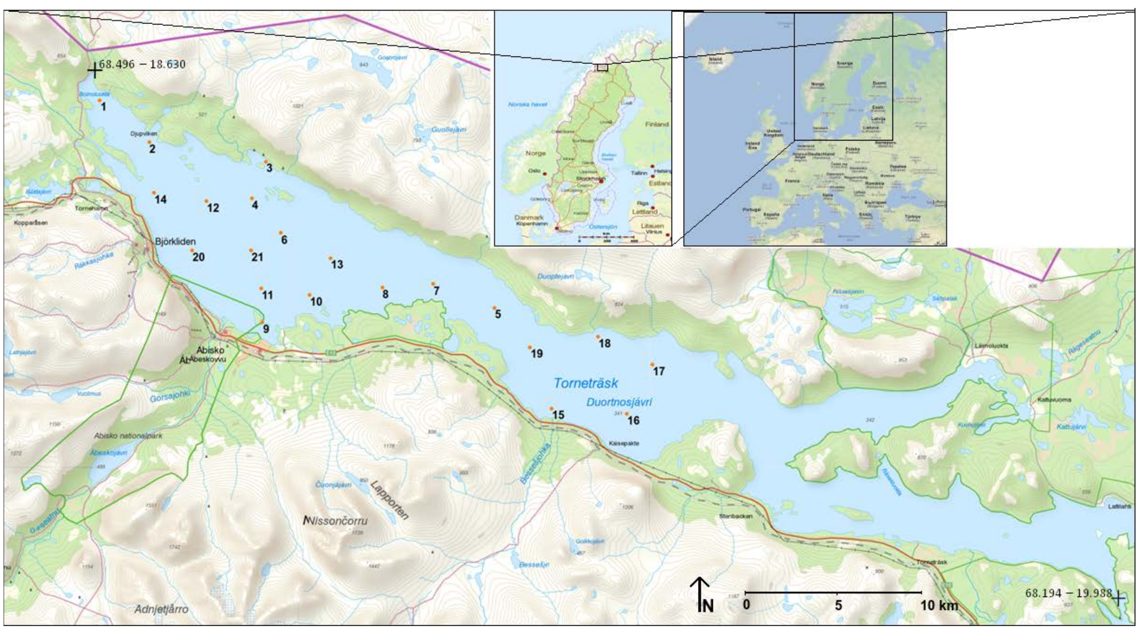

Figure S2. Sites sampled in lake Torneträsk during summer 2012. The raft with the IRGA was located at site 9.

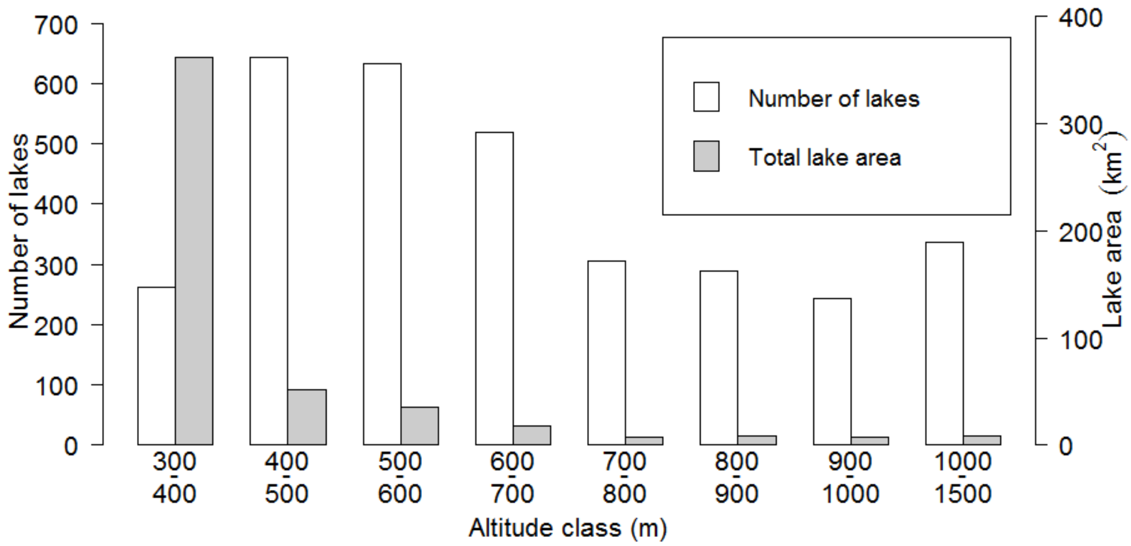

Figure S3. Abundance and area of lakes for altitude classes in the Torneträsk catchment. Ponds under 100m^2 are excluded.

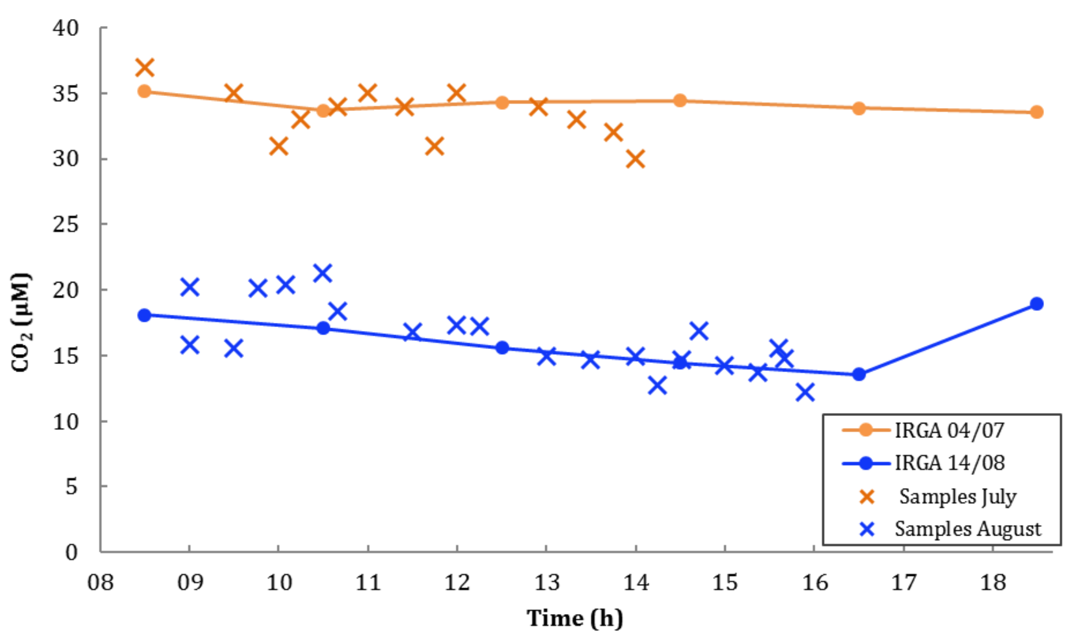

Figure S4. Comparison of CO_2 concentrations obtained from two methods used: Direct measurements of water CO_2 (IRGA) and using the head-space technique from samples spatially representative of the lake, sites sampled shown in figure S2. Orange is from the July field campaign and blue from August. The figure shows that the measures from the IRGA are representative of the lake. The spatial measurements of CO_2 concentrations in July and August were in strong agreement with the continuous measurements by the IRGA. The confidence interval ($CI_{0.95}$) of all the samples from July is 32– 35 ($CI_{0.95}$; n=13), and the mean value for the same period of the IRGA measurements (08:00-14:00) is 35 μM, within the CI. Similarly, the $CI_{0.95}$ from August is 15–17 (n=21), and the mean value of IRGA measurements is 16 μM, inside the confidence interval as well.

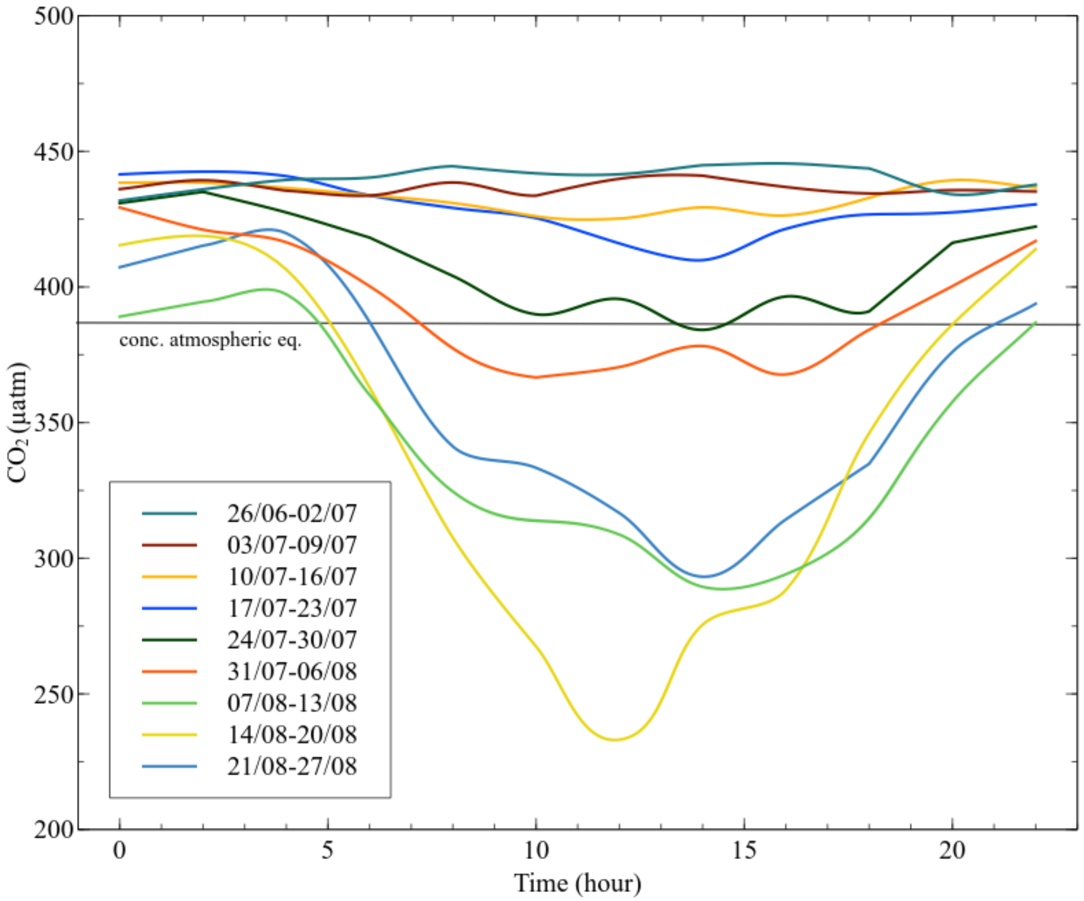

Figure S5. Weekly average of pCO_2 for each hour, measured at Site 9 (figure S2). From 26/6 until 27/8. The line at 383 ppm shows the concentration if the water would be in atmospheric equilibrium. There is a significant decrease of pCO_2 in the central hours of the day, with bigger amplitude during august.

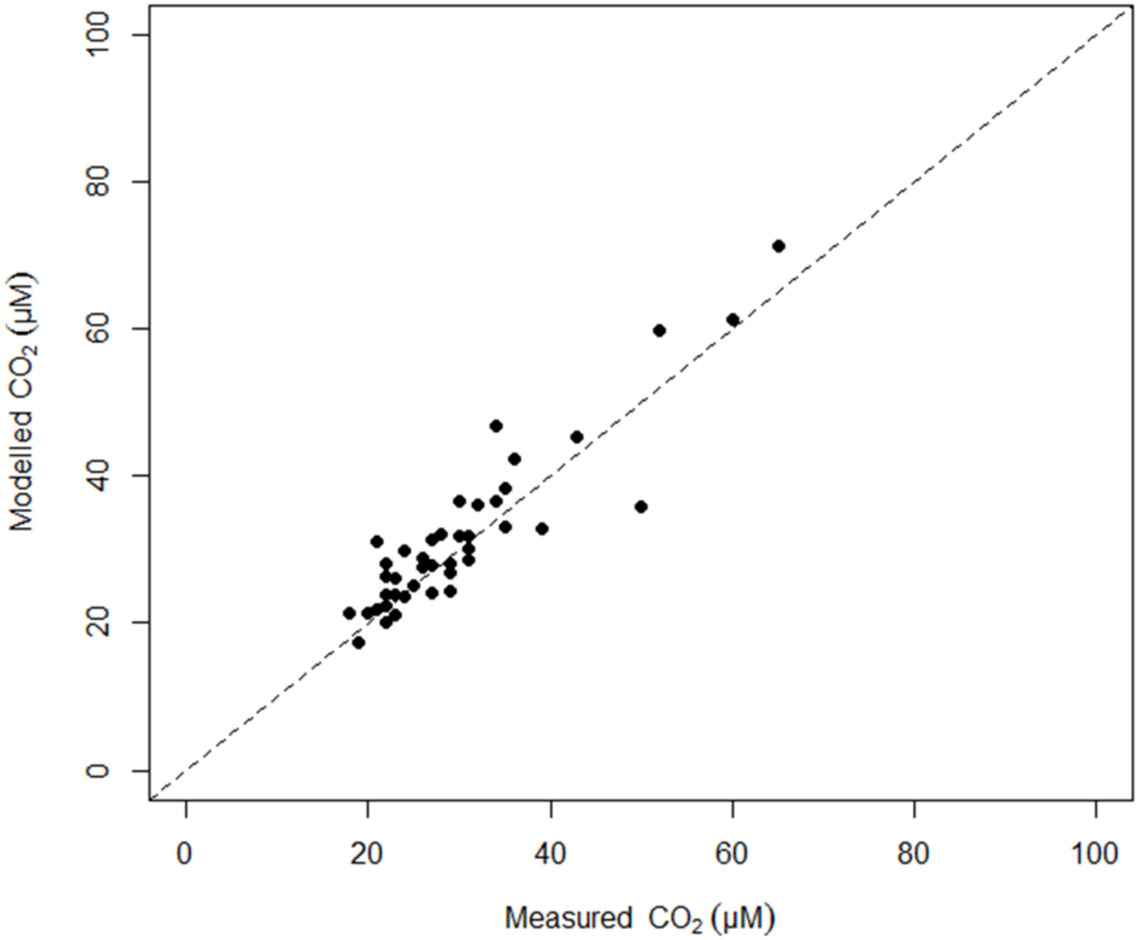

Figure S6. Comparison of the CO_2 concentrations obtained from the model and the measured for the same lakes, R^2=0.82. Dashed line is 1:1.

Table S1. Different relationships found in our dataset used for the upscaling of CO_2 fluxes from each lake, showing the type of the relationship, the equation, and the regression coefficient.

Parameter	Predictor	Relationship type	Equation	n	R^2
pCO_2 lake (ppm)	Lake Area (m^2)	Power law	$pCO2w = 5.87 \times Lake\ Area^{-0.254}$	45	0.44
Ice free season (days)	Altitude (m)	Linear	Season = 150.5 -0.051 × Altitude	28	0.91
Water temperature (°C)	Altitude (m)	Linear	Temp = 11.39 – 0.008 × Altitude	16	0.82

Table S2. Physical and chemical properties of lakes across size classes. The number and area of lakes under 0.001 km^2 is estimated as detailed in Text S1. The CO_2:CH_4 ratio is the published values in Holgerson & Raymond (2016) as the ratio between the flux of CO_2 and CH_4 as CO_2 equivalents. The total CH_4 flux is then calculated as the division of the ratio and the CO_2 flux. For the size class 100-1000 the ratio was not available, and as we found no CH_4 in the lake Torneträsk we assumed that the CH_4 flux was 0.

Lake size class (km^2)	Number Lakes	Total area (km^2)	Mean k_{600} (dm h^{-1})	Mean CO_2 (μM)	CO_2 flux (g C m^{-2} yr^{-1})	Total CO_2 flux (Gg C-CO_2 yr^{-1}) [Confidence interval 0.95]	CO_2:CH_4 ratio*	Total CH_4 (Gg C yr^{-1}in CO_2 equivalence)	Total C flux (Gg C yr^{-1} in CO_2 equivalence)
<0.001	27070	9.1	0.22	45.20	19.09	0.22 [0.13-0.31]	1.70	0.128	0.347
0.001-0.01	1567	18.9	0.30	33.16	11.32	0.24 [0.12-0.36]	3.57	0.068	0.312
0.01-0.1	1050	30.7	0.35	29.16	11.03	0.35 [0.22-0.48]	8.46	0.042	0.394
0.1-1	186	46.5	0.41	25.29	8.72	0.45 [0.25-0.65]	16.65	0.027	0.473
1-10	20	60.5	0.51	21.87	5.87	0.5 [0.24-0.76]	21.13	0.024	0.521
10-100	2	20.2	0.58	21.50	5.75	0.13 [0.08-0.18]	22.41	0.006	0.135
>100	1	330.0	0.63	24.01	6.61	2.18 [1.58-2.78]	-	0	2.182
TOTAL	29896	516.2				4.07 [2.62-5.52]		0.294	4.364

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