

Greenhouse Gas Fluxes from Small Agricultural Ponds in the Northern Great Plains

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Introduction

Inland aquatic environments play a pivotal role in the carbon cycle by connecting the terrestrial biosphere with the ocean and atmosphere. Considerable research has focused on quantifying CO₂ and CH₄ production and sequestration in aquatic environments, but to date, the majority of studies are limited to a relatively small geographic area in pristine or low-impact areas (Seekell et al. 2018). Additionally, nitrous oxide (N₂O) is greatly underrepresented in the global database of GHG emission estimates for inland waters (DelSontro et al. 2018), despite the fact that it is a more potent greenhouse gas (GHG) than CO₂ and CH₄, and has the potential to offset carbon sequestration in aquatic systems. Including N₂O in aquatic GHG inventories may be particularly important in agricultural landscapes where excess nitrogen fertilizer can accumulate in water bodies and undergo incomplete denitrification to produce N₂O. Thus, in order to fully quantify the role of aquatic systems in global carbon and GHG budgets, more research is required for all three greenhouse gases, particularly in less well-studied areas, including areas heavily influenced by agricultural activities (Seekell et al. 2018).

Here, we present the results of a comprehensive survey of 101 agricultural reservoirs (referred to locally as “dugouts”) for CO₂, CH₄, and N₂O concentrations and flux rates. Despite their small total surface area, the elevated productivity and alkalinity of water bodies in the Prairies make them biogeochemical hot spots for nutrient processing and carbon sequestration (Finlay et al. 2010, 2015). In this research, we aim to quantify the contribution of dugouts to the broader landscape GHG and carbon fluxes. These results will contribute to our global understanding of how managed water bodies in agricultural areas are contributing to landscape carbon and greenhouse gas budgets.

Methods

Sampling sites

A total of 101 manmade agricultural reservoirs distributed across southern Saskatchewan, Canada, were sampled for GHG flux and water chemistry in July and August 2017. Sites spanned latitudinal and longitudinal ranges of 49.04037 to 52.71911° and -109.85177 to -103.37831, respectively, and covered a total land area of 235,000 km² (Fig. 1). Sites ranged in size from 90 to 13,900 m², and covered broad land use types including grassland, pasture, and crop land (Table 1). The sample area is dominated by intensive agriculture (80%, Government of Saskatchewan 2018) and contains >65,000 manmade agricultural reservoirs (‘dugouts’) to provide onsite surface water storage. The region experiences a semi-arid climate, with an average annual rainfall ranging 200-500 mm across the prairie ecoregion of the province. The cultivated plains are characterized by countless shallow lakes and small pond-like water bodies, which are highly evaporative and generally receive most of their surface water from spring snow melt. Soils consist of glacial till comprised of carbonates derived from limestone bedrock, which leads to the hard-water properties observed in many of the surface water bodies in the region (Last and Ginn, 2005; Finlay et al., 2015).

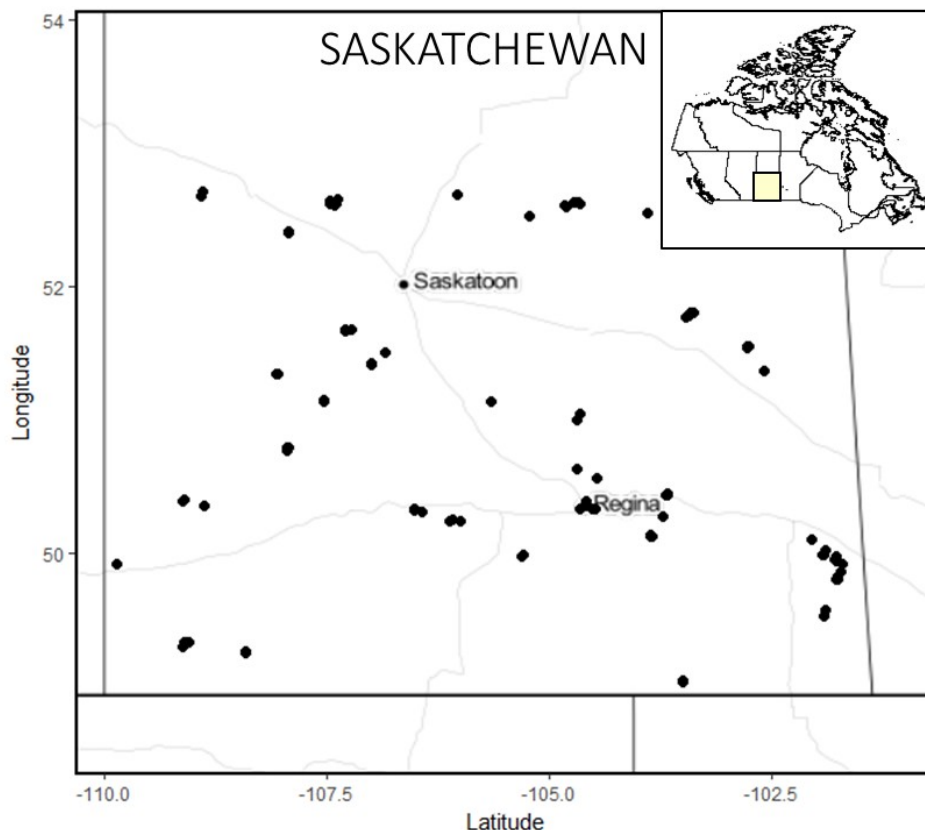


Figure 1: Map of sampled dugout locations in southern Saskatchewan, Canada

Field measurements

A YSI (Yellow Springs Instruments) multiparameter sonde was used to measure water temperature, oxygen concentration, salinity, and pH at the surface, and at every 0.5m to just above the sediment surface of each dugout. Water samples were also collected using a battery-operated pump for surface water samples. Water samples filtered through 0.45 μm filters were analyzed for nitrogen (TDN) by photocombustion, while carbon (dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC)) was analyzed using a total carbon analyzer (Shimadzu 500A) as per Environment Canada protocols (Environment Canada 1979). Chlorophyll *a*, a measure of algal biomass was determined trichromatically on a spectrophotometer from particulate organic matter collected on a 1.2 μm filter following Jeffrey and Humphrey (1975).

Samples for dissolved gases (CO_2 , CH_4 , N_2O) were collected at approximately 0.3-0.5 m below the surface at the deepest point of each reservoir by filling a 1.2 L glass serum bottle using a submersible pump (Appendix 1). Atmospheric air was added (60 mL) to the sealed bottle to create a headspace and shaken vigorously for 2 minutes. Two analytical replicates of the equilibrated headspace were extracted with an airtight syringe and dispensed to 12 mL evacuated glass vials. Headspace concentrations were measured using gas chromatography with a Scion 456 Gas Chromatograph (Bruker Ltd.) and calculated using standard curves. Dry molar fractions were converted to dissolved concentrations as a function of local atmospheric pressure

and gas solubility at the measured water temperature and salinity. Solubility coefficients from Weiss, 1974, Yamamoto, 1976, and Weiss & Price, 1980 were used for CO₂, CH₄, and N₂O, respectively.

Flux calculations

Average daily fluxes were calculated using water column gas concentration (C_{water}) and average reservoir gas transfer velocity (k) using the following equation:

$$f_{gas} = k(C_{water} - C_{air})$$

where f_{gas} is the flux of CO₂, CH₄, or N₂O (mmol m⁻² d⁻¹) and C_{air} is the ambient air concentration. Average global mixing ratios of 406, 1.85, and 0.33 ppm for CO₂, CH₄, and N₂O were used for ambient concentrations (measured at Mauna Loa NOAA station in Hawaii during the period June to August 2017). We used k derived from the k_{CH_4} calculated from direct flux measurements in the field. Floating chamber measurements (Appendix 1) were carried out at a subset of sites (10) and derived an average calculated k_{CH_4} of 0.85 ± 0.75 m d⁻¹. Briefly, a total of 30 incubations were taken, with changes in gas concentration recorded by taking 5 gas samples every 2.5 minutes. The five concentrations for each gas was then used to calculate the flux for each incubation using linear regression:

$$f_{gas} = \left(\frac{sV}{mVS} \right) t$$

where s is the slope of the of the gas change in the chamber (μatm min⁻¹), V is the volume of the chamber (L), S is the chamber surface area (m²), m is the molar volume of the gas at current atmospheric pressure, and t is a conversion factor from minutes to day. Due to small CO₂ and N₂O fluxes measured at our chosen sites, a change in concentration was often too low to be detected with confidence over a 10-minute incubation period. Instead, we used the measured CH₄ flux for deriving estimates of k due to a stronger detection in the gas accumulation rate. Excluding incubations with a non-linear growth rate or poor correlation coefficient, a total of 21 measurements were used. k_{CH_4} (m d⁻¹) was calculated using the inverted equation of Fick's law for gas diffusion:

$$k_{CH_4} = f_{CH_4} / k_H (p_{CH_4water} - p_{CH_4air})$$

Where f_{CH_4} is the measured CH₄ flux (mmol m⁻² d⁻¹), k_H is Henry's constant, and p_{CH_4water} and p_{CH_4air} are the CH₄ partial pressures (μatm) in the water and ambient air, respectively. From k_{CH_4} , the gas transfer velocity was converted to k_{CO_2} and k_{N_2O} (k_X) by using their respective Schmidt numbers (Sc_X), assuming a Schmidt exponent of 0.67 as follows:

$$k_X = \left(\frac{Sc_X}{Sc_{CH_4}} \right)^{0.67} k_{CH_4}$$

Results and Discussion

A summary of the mean, median and ranges of water chemistry and greenhouse gas concentrations as measured from the 101 dugouts in 2017 is found in Table 1. The sites were generally small (mean = 1336 m²), shallow (mean depth = 2.11 m), and alkaline (mean pH = 8.74), and were well oxygenated at the surface (mean O₂ saturation = 91.8%). These systems were typically sub-saline (mean salinity = 0.87 ppt), but several sites were saline (up to 8.57 ppt).

Most sites were classified as eutrophic to hypereutrophic with elevated nutrient concentrations (mean TP = 284 $\mu\text{g L}^{-1}$, mean TN = 3082 $\mu\text{g L}^{-1}$) and algal biomass (mean Chl *a* = 99.05 $\mu\text{g L}^{-1}$).

Table 1: Summary of reservoir chemistry and physical properties as measured in 2017. Measurements include percent saturation of dissolved oxygen (DO), and concentrations of dissolved organic and inorganic carbon (DOC, DIC), chlorophyll *a* (Chl *a*), total phosphorus (TP), and total dissolved nitrogen (TDN).

Parameter	Units	Mean	Median (minimum and maximum)	<i>n</i>
Area	m^2	1,336	1,080 (90-13,900)	97
Depth	m	2.11	2.10 (0.18-5.10)	100
Temperature	$^{\circ}\text{C}$	20.10	19.90 (15.70-29.50)	101
Surface DO	%	91.76	87.70 (2.30-344)	101
pH		8.74	8.74 (6.95-10.19)	101
Salinity	ppt	0.87	0.45 (0.07-8.57)	101
DOC	mg L^{-1}	31.77	29.27 (4.59-90.39)	97
DIC	mg L^{-1}	54.84	50.09 (17.54-150.57)	97
Chl <i>a</i>	$\mu\text{g L}^{-1}$	99.05	36.88 (2.23-2,484)	101
TP	$\mu\text{g P L}^{-1}$	284	80.00 (8.70-6,480)	97
TDN	$\mu\text{g N L}^{-1}$	3,082	2,360 (417-14,280)	97
CO ₂	μM	43.48	14.94 (1.33-326)	96
CH ₄	μM	4.40	1.99 (0.09-54.45)	95
N ₂ O	nM	9.87	6.59 (0.58-111)	93

While several sites were emitting large quantities of CO₂, over half of the dugouts were ingassing CO₂ from the atmosphere (Fig. 2). DIC concentrations were also high (mean 54.84 mg/L), so the relatively low CO₂ concentrations at these sites is likely attributable to the elevated pH of the water in this region, as most inorganic carbon will be in the form of HCO₃⁻ and CO₃²⁻ rather than CO₂ (Finlay et al. 2010). All sites were observed to be CH₄ sources to the atmosphere (Fig. 2), with a wide range of efflux rates (0.07 to 47.0 mmol m⁻² day⁻¹). The majority (73%) of sites were ingassing N₂O from the atmosphere (Fig. 2), but a few were releasing N₂O at high rates (max N₂O flux = 87 $\mu\text{mol m}^{-2} \text{ day}^{-1}$).

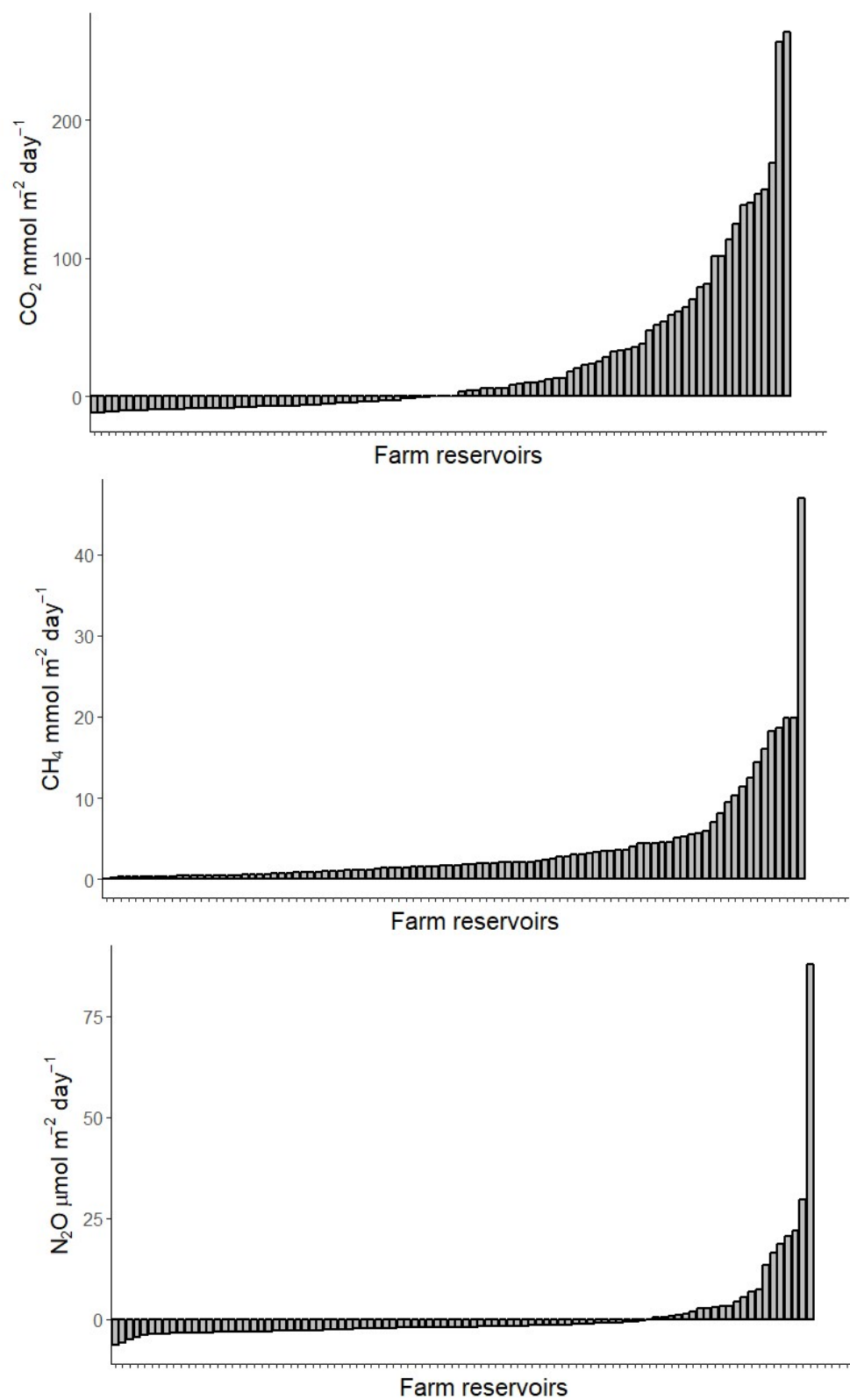


Figure 2: Calculated fluxes of CO₂, CH₄, and N₂O for surveyed dugouts.

These results represent the spatial variability of greenhouse gases in 101 dugouts during one time period: all samples were collected during the day in late-summer in 2017. This gives us a good estimate of gas fluxes over a spatial gradient, but does not provide insights into temporal variability. Diel variability of CO₂ in particular is known to be large, particularly in productive water bodies (e.g. Raymond et al. 2013) as primary productivity and respiration change over light-dark cycles. Seasonal and interannual trends are also common in CO₂ fluxes (e.g. Wiik et al 2018) as changes in ice cover, temperature, algal community composition, productivity, and weather all contribute to greenhouse gas production and consumption and subsequently fluxes. It is therefore difficult to currently extrapolate our results to annual fluxes of these greenhouse gases, nor to state whether these results reflect the “average” condition in this region. In particular, 2017 was a very dry year in southern Saskatchewan, with below average precipitation across the region. It is currently unclear whether wetter conditions will increase or decrease flux rates through loading of solutes from the catchment, or dilution with increased runoff. Future research on these study sites will examine temporal (diel, seasonal, and inter-annual) variability, along with more detailed analyses to elucidate the underlying controls of these fluxes.

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Appendix 1: A) Headspace equilibration bottle for gas extraction in the field, and B) floating chamber

