Carbon accumulation in freshwater marsh soils: A synthesis for temperate North America

Amanda Loder[1] and Sarah Finkelstein[1]

[1]University of Toronto

November 23, 2022

Abstract

Peatland soils are of great interest for study and management because of their high carbon contents and known role in the global carbon cycle. However, carbon stocks have yet to be constrained in many wetland ecosystems. Relative to bogs, fens and saline coastal ecosystems, less is known about carbon stocks in freshwater marsh soils despite their global prevalence, and it is not well understood how disturbance of freshwater marshes may affect carbon-climate dynamics. To better understand the potential for freshwater marshes to be net carbon sinks, we review how freshwater marshes and associated soils are classified, and synthesize available data on short- and long-term rates of carbon accumulation in freshwater marsh soils in temperate North America. Although often described as mineral-based, our findings suggest that freshwater marshes are not restricted to mineral substrates, and that inconsistencies in classification may underestimate presumed carbon stocks. Organic carbon contents and bulk density measurements are highly variable, and can range between 1-45% and 0.04-1.5 g cm-3, respectively. Moreover, rates of carbon accumulation in freshwater marshes are often measured over recent time scales (50-100 years; on average 155 +/- 74 g C m-2 yr-1), while long-term rates (measured over centuries and millennia; on average 51 +/- 38 g C m-2 yr-1) are much more scarce. We suspect that short-term rates are markedly greater than long-term rates of carbon accumulation because they do not account for long-term carbon loss and may reflect large increases in sedimentation since European settlement in North America. However, we also suspect that long-term carbon storage in freshwater marsh soils is underestimated, and that freshwater marshes can have long-term rates of carbon accumulation similar to those reported for temperate peatlands. In this presentation, we will show that variability of rates of carbon accumulation, rates of sediment accretion, bulk density and organic carbon content in freshwater marshes needs to be better constrained in order to accurately quantify their regional and global carbon pools. We will discuss the importance for scientists to specify timeframes over which they are measuring rates of carbon accumulation so that the capacity for wetlands to be net carbon sinks can be correctly understood.

Carbon accumulation in freshwater marsh soils: A synthesis for temperate North America

Amanda L. Loder* and Sarah A. Finkelstein

Department of Geography & Planning, University of Toronto, Canada, *amanda.loder@mail.utoronto.ca

Introduction

Major carbon stocks exist in wetland soils, yet have not been constrained in regards to climate mitigation in many types of wetlands. These knowledge gaps impede accurate quantification of carbon pools in wetlands, and the development of robust models to predict how carbon balances in the terrestrial biosphere will be affected by rapidly increasing temperatures.

Freshwater marshes are globally extensive, highly vulnerable to anthropogenic disturbances in the temperate region where large human populations dwell, and increasingly the focus of restoration projects[1]. However, it is not well understood how disturbance or restoration of carbon pools in freshwater marshes may affect carbon-climate dynamics. Carbon contents and rates of vertical accretion in freshwater marshes are often quantified using the top 30-40 cm of sediments[2] even though significant carbon stocks may be unaccounted for in soils deeper than 30 cm. Some studies suggest that freshwater marshes may not always have mineral-dominant soils, especially when down-core sections are considered, and that organic matter content can be >50% in their soils[3,4].

Objectives

1) *Review how freshwater marshes and freshwater marsh soils are defined within the literature and wetland inventories.* Definitions and descriptions may affect perceived and calculated carbon stocks in freshwater marshes.

2) *Identify methods and approaches used to quantify rates of carbon accumulation and vertical accretion in freshwater marsh soils.* Short-term apparent rates of carbon accumulation (past 50-100 years) are often much higher than long-term apparent rates of carbon accumulation (over centuries, millennia) measured down to refusal depth in freshwater marsh soils[5]. Yet, it is unclear whether this difference is related to dating methods, or differences in carbon accumulation, decomposition or organic matter quality in recent versus older sediments. It is also unclear to what extent the higher rates in recent sediments are an anthropogenic signal or an indication of diagenesis over time.

3) *Synthesize available data on soil properties and rates of carbon accumulation of freshwater marshes in the temperate region of North America.* Analyses of contemporary carbon fluxes suggest that freshwater marshes are net carbon sinks on a year-to-year basis[6], but estimates of the magnitude of the long-term carbon sink of freshwater marsh soils are lacking.

Results

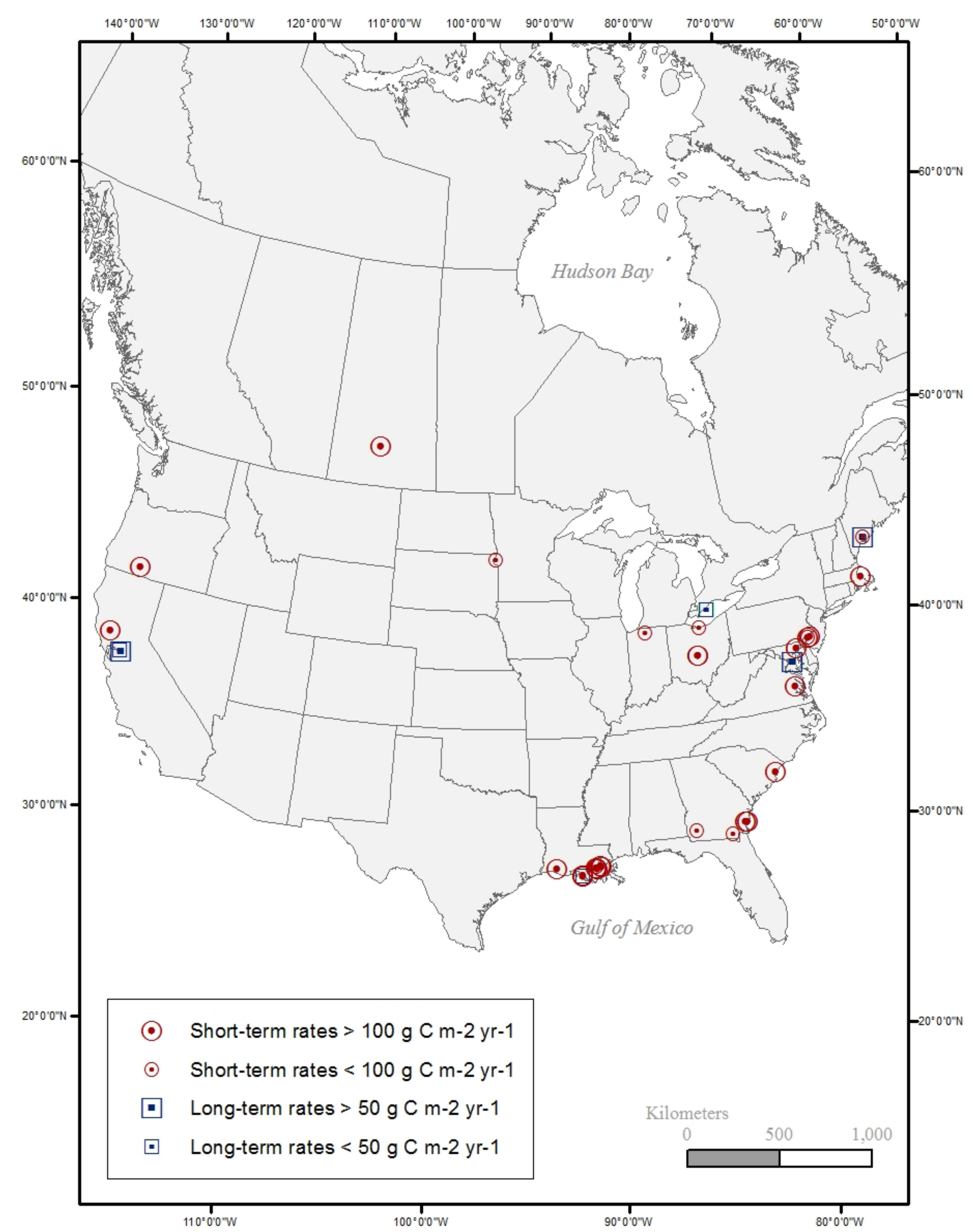


Fig. 1 Map of freshwater marshes and their rates of carbon accumulation located in the temperate region of North America

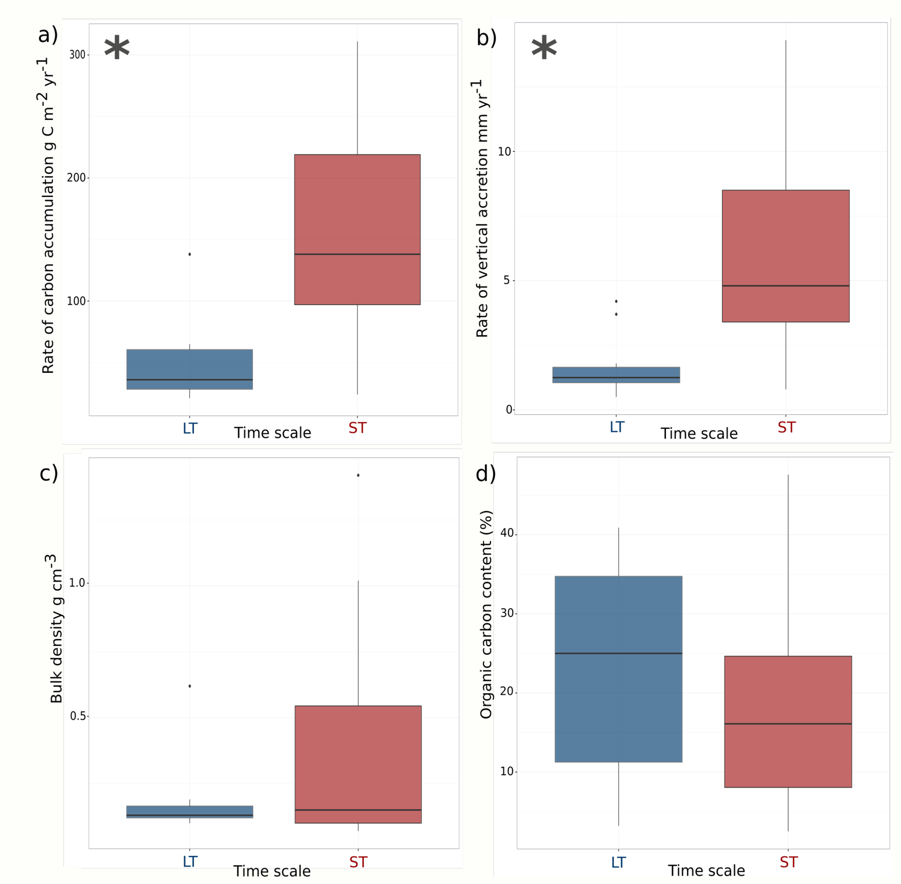
Table 2 Soil properties of freshwater marshes in the temperate region of North America. Mean values and standard deviations are reported.

	Rate of carbon accumulation (g C m^{-2} yr^{-1})		Rate of vertical accretion (mm yr^{-1})		Organic carbon content by dry mass (%)	
	ST	LT	ST	LT	ST	LT
Freshwater marshes	155 ± 74 (*n* = 29)*	51 ± 38 (*n* = 8)*	5.7 ± 3.3 (*n* = 29)*	1.6 ± 1.2 (*n* = 12)*	17.0 ± 13.0 (*n* = 24)	22.4 ± 14.0 (*n* = 11)
Tidal	160 ± 63 (*n* = 15)	75 ± 44 (*n* = 4)	6.3 ± 2.7 (*n* = 15)	1.8 ± 1.4 (*n* = 5)	15.2 ± 8.7 (*n* = 13)	23.7 ± 16.5 (*n* = 4)
Non-tidal	150 ± 87 (*n* = 14)	28 ± 5 (*n* = 4)	5.0 ± 3.8 (*n* = 14)	1.5 ± 1.0 (*n* = 7)	19.2 ± 16.9 (*n* = 11)	21.6 ± 13.7 (*n* = 7)

* indicates a significant difference (Mann-Whitney *U* test)

Table 1 Dating methods and timescales over which rates of carbon accumulation were calculated from studies compiled in this synthesis

Dating method	Timescale
^{137}Cs	Past ~50 years (short-term; ST)
^{210}Pb	Past ~100 years (short-term; ST)
Stratigraphic pollen markers	Post-European settlement (short-term; ST)
^{14}C	Past ~500–6,000 years (long-term; LT)



* indicates a significant difference (Mann-Whitney *U* test)

Fig. 2 Box plots of short-term and long-term a) rates of carbon accumulation, b) rates of vertical accretion, c) measurements of bulk density, and d) organic carbon contents in freshwater marshes in temperate North America. Box plots show the median values, first and third quartiles, maximum and minimum values, and outliers.

Approaches for classifying freshwater marshes

- Freshwater marsh soils are often defined as being *mineral-based*, implying that they lack organic material, although some classification schemes sub-categorize freshwater marshes as having either organic soils with high carbon content or mineral soils with lower carbon content[7].

- While freshwater marshes typically have more mineral-like soils than bogs and fens, measurements of bulk density and organic carbon contents can considerably vary among and within freshwater marsh soils (Fig. 2).

- Categorical labels (e.g., mineral versus organic) should be used cautiously, and in a way that reflects that freshwater marshes can share characteristics of organic-soil wetlands and have variable soil properties.

Conclusions

- Given their large areal extent, and their potential to have high rates of carbon accumulation on both short and long timescales, carbon pools in freshwater marshes may be more significant than previously assumed.

- Freshwater marshes can have high levels of organic matter content in both surface and deep sediments, and may have long-term rates of carbon accumulation that are similar to those reported in temperate peatlands[8].

- Short-term rates (*n*=29) are much higher than long-term rates (*n*=8) of carbon accumulation in freshwater marsh soils. Short-term rates may be elevated due to major landscape alteration and increased erosion that has occurred post-European settlement, and/or labile carbon that is encompassed in surface sediments but not preserved in deeper sediments.

- Timescales need to be clearly defined in order to improve estimates of the capacity for freshwater marshes, and wetlands in general, to be net carbon sinks presently and in the future.

- More field data are required on carbon contents and refusal soil depths to quantify spatial and temporal variability, and constrain the size of carbon pools in freshwater marshes.

Future Research

Research is ongoing to better understand short-term versus long-term carbon dynamics in freshwater marshes using field data and a paleoecological approach. This research is taking place in Southern Ontario (Canada), where peat depths and carbon stocks in freshwater marsh soils are estimated to have been between 0.4-3.5 m and 1,776 ± 118 Tg C, respectively, prior to European settlement[9].

Sediments were collected down to refusal depth at 4.29 m in a freshwater marsh in Central Big Creek, Norfolk County, Ontario, and will be analyzed to measure short-term versus long-term rates of carbon accumulation and to address the following questions:

Sediment core collected from Central Big Creek using a Russian peat corer

- *What proportion of carbon stored in freshwater marsh soils is derived from autochthonous versus allochthonous carbon fractions?*
Methods: Total, organic and inorganic C, C/N ratios, analysis of organic matter quality via Rock-Eval or FTIR

- *Have inputs of autochthonous and allochthonous carbon varied between pre- versus post-European settlement timeframes in freshwater marshes?*
Methods: ^{210}Pb and ^{14}C dating

- *How have long-term apparent rates of carbon accumulation varied in relation to changes in hydrological and fluvial dynamics, and the climate?*
Methods: Synthesis of available local and regional Holocene proxy records

- *How have rates of carbon accumulation been affected by anthropogenic pressures (i.e., intensive land-use, nutrient loading, invasive species)?*
Methods: Use of diatoms as a bioindicator of wetland ecosystem health

References

1 Mitsch & Gosselink 2015 5th edition 2 Wickland et al. 2014 Supplement 2006 IPCC 3 Drexler et al. 2009 Estuar Coast 5:871-892 4 Rippke et al. 2010 Wetlands 30:805-816 5 Jones et al. 2014 Quat Sci Rev 90:90-105 6 Strachan et al. 2015 Environ Res Lett 10:065006 7 Ausseil et al. 2015 Wetlands Ecol Manage 23:947-961 8 Shiller et al. 2014 Holocene 24:1105-1116 9 Byun et al. 2018 Carbon Balance Manage 13:6