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Organic matter accumulation and salinity change in open water areas within a saline boreal fen in the Athabasca Oil Sands Region, Canada

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ABSTRACT

Saline boreal fens represent potential models for post-mining landscape reclamation in the Athabasca Oil Sands Region (Canada) where wetland construction is challenged by salinization. One of the key indicators of reclamation success is the accumulation of organic matter within constructed fens. Thus, a better understanding of the linkages between salt content and organic matter storage in saline boreal fens can be useful for advancing fen construction in this region. As such, this study investigates how salinity fluctuations estimated by diatom-based transfer functions, coupled with changes in hydrological conditions and vegetation inferred from macrofossils have influenced organic matter accumulation rates (OMAR) over the last ~100 years in open-water areas (ponds) within a saline boreal fen near Fort McMurray, Alberta. Median OMAR (181 $g\,m^{-2}\,yr^{-1}$) of the site suggests that the ponds situated within saline boreal fens can accumulate organic matter at a rate comparable to freshwater boreal and subarctic ponds, and the estimated salinity levels (3–21 ppt) did not severely affect organic matter accumulation. Strong significant positive (Lager Pond), strong significant negative (South Pond), and weak insignificant (Pilsner Pond) correlations between OMAR and diatom-inferred salinity were observed, suggesting that relations between organic matter accumulation and salt content are not straightforward, and salinity was not the main control on OMAR. Macrofossil data showed that organic matter accumulation has been mainly driven by water level, type of primary producers and pond regime. OMAR was the highest during the transition from peatland to ponds due to low decomposition rates resulting from high inputs of relatively resistant plant litter, and anoxic conditions. A macrophyte-dominated pond regime was associated with higher OMAR relative to algae-dominated regime.

1. Introduction

Continental fens comprise up to 90% of western boreal peatlands (Vitt et al., 2009) and act as sinks and transformers of organic matter, water, and nutrients (Yu, 2012) at the interface of terrestrial and aquatic boreal ecosystems. Since the 1960's anthropogenic impact on these peatlands has increased dramatically, especially in oil-producing Alberta where open-pit mining has destroyed thousands of hectares of the boreal landscape (Government of Alberta Energy, 2017), > 55% of which are fens (Vitt et al., 2009). Oil companies must reclaim disturbed areas to land of equivalent ecological capacity, and about 30% of the post-mined area must be reclaimed back to boreal wetlands (Alberta Environment and Parks, 2015). Thus, the construction of boreal fens, the dominant type of wetlands in Alberta (Vitt et al., 2009), is crucial for reclamation success. Current attempts to construct self-sustaining boreal fens (e.g., Price et al., 2010) have faced several challenges with salinization being the most significant (Vitt and House, 2015). Increased salt inputs from saline tailings and reclamation materials hinder establishment of moss-dominated fens, making naturally graminoid-dominated saline fens potential models for reclamation (Wells and Price, 2015a; Alberta Environment and Parks, 2015). The ability of ecosystems to accumulate organic matter (OM) is one of the key aspects of ecological capacity and a commonly used metric for assessing the success of peatland restoration or reclamation projects (Wortley et al., 2013). Therefore, it is relevant and timely to determine organic matter accumulation rates in naturally saline fens that can be useful for establishing targets for reclamation. Accumulation of OM within open water areas (ponds) is of particular interest because ponds compose a notable part of saline fens, (Wells and Price, 2015a), and understanding the role of ponds in the OM storage in natural saline fens is necessary

Abbreviations: OM, organic matter; OMAR, organic matter accumulation rate; SAR, sediment accumulation rate; AOSR, Athabasca Oil Sands Region

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for an appropriate estimation of OM accumulation potential of constructed saline fens.

Saline fens are dynamic systems, and the reconstruction of past salinity within open water areas in a saline boreal fen (known as Saline Fen) situated in the Athabasca Oil Sands Region using diatom-based transfer function has revealed notable variation in salinity during the last ~100 years (Volik et al., 2017). Given that increases in salinity can alert plant productivity and microbial productivity (Herbert et al., 2015), OM accumulation in open water areas within the fen may be expected to change in response to salinity fluctuations. A better understanding of the relationships between temporal changes in water salinity and OM accumulation in saline fens can be useful for prediction of constructed fen resilience under future environmental changes (e.g., climate warming) and salinity variation. In addition, estimation of OM accumulation rates under different salinity levels can be helpful for defining acceptable salinity ranges that will not hinder OM accumulation within constructed saline fens.

OM deposition in waterbodies is tightly connected to water depth and productivity of aquatic and adjacent terrestrial plant assemblages (Meyers and Ishiwatari, 1995) that can complicate relations between OM accumulation rate and salinity. Consequently, water level fluctuation and type of vegetation in and near the waterbody should be taken into account while looking at changes in OM deposition with respect to salinity. Information on past local vegetation assemblages may be provided by the study of plant macrofossils such as seeds, leaves, fruits, etc.; moreover, macrofossil analysis has been widely used for reconstructing small-scale environmental changes (Mauquoy et al., 2010). This study aims to estimate the apparent organic matter accumulation rate (OMAR) in open water areas (Lager, Pilsner, and South Ponds of Saline Fen) where past salinity was reconstructed by Volik et al. (2017) and address the following questions: 1) How has OMAR changed over time? 2) Has variability in OMAR been associated with changes in diatom-inferred salinity reported by Volik et al. (2017)? 3) How have changes in OMAR been related to changes in water depth and vegetation revealed by macrofossil analysis? This paper is a part of a study on organic matter accumulation change along a salinity gradient in a saline boreal fen in the Athabasca Oil Sands Region, and results from this paper will provide insight into the role of open water areas in OM storage of the wetlands that is useful for assessment of carbon sequestration potential of constructed saline wetlands and improvement of constructed wetland design.

2. Materials and methods

2.1. Site description

The study was conducted at a saline boreal fen (further, Saline Fen) situated about 10 km south-east from Fort McMurray, Alberta (Fig. 1). The climate of the study area was sub-humid with average January temperatures of −19 °C and July temperatures of +16.6 °C, and a mean annual precipitation of 460 mm (Government of Canada, 2017). The surface area of Saline Fen was about 27 ha, with an irregular shape and elongated northwest-southeast orientation. Electrical conductivity of shallow groundwater (< 50 cm depth from the peat surface) varied from 5 mS cm^{-1} to 120 mS cm^{-1} (Wells and Price, 2015b) while average pond water salinity ranged from 5 mS cm^{-1} to 67 mS cm^{-1}. Surface water and groundwater were dominated by Na^+ and Cl^- although Ca^{2+}, Mg^{2+} and $SO_4{}^{2-}$ were also present. The fen comprised a series of depressions, ridges and ponds, and the vegetation displayed a distinct pattern with ridges dominated by Baltic rush (*Juncus balticus* Willd.), sweetgrass (*Hierochloe hirta* (Schrank) Borbás), narrow reed grass (*Calamagrostis stricta* (Timm.) Koeler), and foxtail barley (*Hordeum jubatum* L.), and depressions dominated by seaside arrow grass (*Triglochin maritima* L.). In areas with the highest salinity, halophyte vegetation (e.g., sea plantain (*Plantago maritima* L.), horned seablite (*Suaeda calceoliformis* (Hook.) Moq.), and red swampfire (*Salicornia rubra* (A. Nelson)) was observed. Small (0.5 m^2 to 1.2 ha) shallow (average depths of 0.4–0.5 m) ponds occupied about 19% of the fen and were situated predominantly in the southern and central parts (Wells and Price, 2015a, 2015b). Most of the large ponds had irregular shape while small ponds were circular-shaped and located in deep depressions with steep margins. The majority of the ponds had semi-permanent features and was dry during late summer.

OMAR was assessed in Lager, Pilsner and South Ponds. Lager Pond covered ~0.95 ha and had average depth of ~0.5 m. It had irregular shape with an elongated embayment in the southern part. This permanent pond had an average salinity of 9 ppt and average pH of 8. While macrophytes (*Typha angustifolia* L., *Schoenoplectus* spp., and *Carex* spp.) grew intensively along the perimeter of the pond, the main axis of the pond was lacking aquatic vegetation. Pilsner Pond had an area of 0.13 ha and average depth of ~0.45 m, and had a segmented appearance with several round-shaped embayments. Nearshore areas of the pond dried out during late summer. The average salinity of the pond was about 16 ppt and average pH was 6. The major part of the pond was lacking aquatic vegetation although *Potamogeton* spp. sporadically occupied embayments. South Pond had area of 1.2 ha and average depth of ~0.43 m. It had an elongated shape with a round embayment in the northern part. The pond had semi-permanent features, and water depth near the shore dropped to zero during late summer. The average salinity of the pond was about 19 ppt and average pH is 7.5. The south-eastern shore of the pond was occupied by *Schoenoplectus* spp. and *Carex* spp. Emergent macrophytes were rare along the north-western part of the pond. *Potamogeton* spp. were common in the northern part of the pond. An extensive brown-green microbial mat covered the majority of the bottom of South Pond.

2.2. Sediment analyses

Estimation of OMAR was performed on sediment cores Lager-1, Pilsner-1 and South-1 that were taken from Lager, Pilsner, and South Ponds, respectively (core locations, core lengths, coring details are in Fig. 1c, Table 1, and Volik et al. (2017)). The cores were extruded and sectioned into 1-cm increments in the field and refrigerated at 4 °C until further processing.

Continuous subsamples of 1 cm^3 at 1-centimeter resolution were taken and processed for loss-on-ignition (LOI) following Heiri et al. (2001) to estimate moisture, organic matter, carbonate and mineral matter in Lager-1, Pilsner-1 and South-1. Continuous sediment subsamples at 1-centimeter resolution (for upper 5 cm of all core) and at 2-centimeter resolution (below 5 cm) were taken from all three core to establish core chronology using measurements of ^{210}Pb, ^{214}Bi, ^{137}Cs activities by gamma ray spectroscopy in the WATER Lab (Department of Biology, University of Waterloo) (see Volik et al., 2017 for details). A constant rate of supply model was used to determine the age of the sediments and sediment accumulation rate (± standard deviation) (SAR) (Appleby and Oldfield, 1978). Organic matter accumulation rate (± standard deviation) (OMAR) was calculated as a product of sediment accumulation rate and the organic matter content (OM) in each sample:

$$OMAR = SAR \times OM \quad (1)$$

For diatom analysis, subsamples of 0.2–0.3 g were taken and processed for slide preparation following the methods of Battarbee et al. (2001). Continuous subsamples at 2-centimeter resolution were taken from cores Lager-1 and South-4. Because the bottom part of core Pilsner-1 was composed of coarse peaty gyttja that could be potentially barren of diatoms, this core was subsampled at 1-cm increments to ensure enough samples were obtained for salinity reconstruction (see Volik et al., 2017 for details). Salinity reconstruction was performed using weighted-averaging transfer functions based on diatoms and an