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Regional variation in peatland carbon stock assessments, northern Ontario, Canada

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ABSTRACT

Northern peatlands (those located in boreal and subarctic regions) are important components of global soil organic carbon (C) stock. Moreover, they are located in regions witnessing rapid changes in climate and becoming intensely scrutinized for industrial development and alternative energy generation. However, peat C stock is highly variable and little is known about its variability especially among peatland types. This is an issue because it makes the monitoring of peatland carbon stock complicated especially with the changing climatic conditions. Furthermore, it limits the opportunities to successfully estimate peatland C stock across regional scales. We estimated peat C stock using data from 1982 to 1985 from Ontario Geologic Survey field study of peatlands distributed across twelve sites in northern Ontario. Carbon stock (kg C m^{-2}) was estimated using the equation: carbon concentration on gravimetric basis × bulk density × peat depth. The peat sampling depth was about 1 m and had a total data point of around 203 points. Treed fens had the highest mean C stock ± SE of 223 ± 31 kg C m^{-2} while open bogs had the lowest mean C stock ± SE of 157 ± 7 kg C m^{-2}. Mean C stock also varied among peatlands at regional level with the inter-quartile range of about 72–73 kg C m^{-2} for open bogs and fens; and around 94–141 kg C m^{-2} for treed bogs and fens respectively. Minimum detectable differences in C stock were also large, ranging from 50 to 113 kg C m^{-2} for bogs and fens, respectively. The required sample size to detect 20% change in peat C at a power of 70% was more than double (212 plot) for fens than the number of sample plots (82) surveyed. This implies more sample size and information for fens is needed. This could potentially be achieved by the use of geospatial technology in deriving peatland biophysical information.

1. Introduction

Northern peatlands (those located in boreal and subarctic regions) have accumulated organic matter during the Holocene due to the gain in carbon (C) from net primary production (NPP) which surpasses the loss in C from soil respiration. This occurred as a result of low soil temperatures, high soil moisture, and low peat quality for decomposing microorganisms (Gore, 1983). This net C gain over the Holocene from peatlands has resulted in a net global cooling effect during this period because of the sequestration of carbon dioxide (CO_2) (Frolking et al., 2006; Gorham, 1991). Moreover, peatland net CO_2 sequestration during the Holocene has resulted in northern peatlands storing between 200 and 450 Pg C (1 Pg = 1 Gt = 10^{15} g) (Gorham, 1991; Turunen et al., 2002), representing 20 to 30% of the global soil C pool (Post et al., 1982). Greater than 95% of peatland C is stored as peat, while less than 5% occurs in the vegetation (Gorham, 1991). Canada and Russia account for approximately similar amounts of peatland area (85% of total peatland area world-wide) (Joosten and Clarke, 2002; Rydin and Jeglum, 2006). This equates to two-thirds of the world's peatland C stock occurring in Canada and Russia (Kaat and Joosten, 2009). Furthermore, 30% of the peatland carbon stored in Canada occurs in Ontario, making it a huge C stock at present (McLaughlin, 2004).

The predominant peatland types in Ontario include fens and bogs. Fens are geogenous and receive their water and nutrients mostly from surface and ground water sources while bogs are ombrogenous and receive their water and nutrients sorely from precipitation (Vitt et al., 2000). Generally, fens may be acidic and dominated by *sphagnum* (poor fens) or alkaline, basic to neutral and dominated by 'brown mosses' (rich fens). In contrast, bogs are acidic and consist mostly by a combination *sphagnum*, lichens and feather mosses (Belland and Vitt, 1995). Fens are generally wetter than bogs with water table in the range of about 10 cm above to 40 cm below the surface (Vitt et al., 2000) while bogs have a range of about 40–60 cm below the surface for non-permafrost bogs and around 100 cm below the surface for permafrost bogs (Belland and Vitt, 1995).

Boreal and subarctic regions are witnessing rapid rates of temperature increase and altered precipitation patterns that may jeopardize the present carbon stock of northern peatlands. There is also a growing interest to develop and manage peatland-dominated areas in the

Abbreviations: ANOVA, analysis of variance; IPCC, intergovernmental panel on climate change; MDD, minimum detectable differences.

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northern regions (Poulin et al., 2004) which may also put at risk the carbon stored in these peatlands.

Reporting on C stock at regional scales is challenging because much variation occurs in C content within and among peatland types, particularly in expansive peatland complexes (Beilman et al., 2008; Vitt et al., 2000). Some studies have however reported on carbon stock estimation and change using statistical power analysis (Kravchenko and Robertson, 2011; Liski and Westman, 1997; Westfall et al., 2013; Wilson et al., 2013; Woodbury et al., 2007; Yanai et al., 2003). These studies highlighted regional differences in various carbon pools.

Factors, such as landscape position, surficial geology, vegetation composition, climate, and fire interact to affect peat depth and bulk density; two important parts of peatland C stock calculation (Frolking et al., 2001; Gorham, 1991; Ovenden, 1990; Robinson and Moore, 2000). The understanding of the variability of these peatland variables and how they affect peat C stock is required for predicting its response to climate change and anthropogenic influence. Thus, a critical need exists to develop statistical designs having the ability to detect desired changes in C stock.

The overall goal of the study is to assess peatland carbon stock in northern Ontario. We estimated i) peatland carbon stock per unit area from open bogs, treed bogs, open fens and treed fens, ii) we assessed natural variability using inter-quartile analysis, iii) we estimated minimum detectable differences (MDD) for change in C stock, and iv) sample size requirement to detect a 20% change in C stock with a 70% power (McLaughlin and Phillips, 2006; Yanai et al., 1999). We further discussed sample size implications for carbon scaling and the implications of the results to scaling peat C stock to regional landscapes using Ontario as an example.

2. Materials and method

2.1. Site description

We used peatland data obtained from 1982 to 1985 by the Ontario Geologic Survey published in Riley and Michaud (1987) and Riley (1994) to estimate peatland C stock. The Ontario Geologic Survey undertook field study of peatlands distributed on a grid system of transects across twelve sites in northern Ontario. The sites were located between latitudes 47° and 51°N, and between longitudes 79° and 95°W (Fig. 1) and sampling was conducted at the twelve sites which covered an area of about 700,173 ha.

The region is situated on the Precambrian Shield that consists of metavolcanic rocks, minor metasedimentary rocks wedged between extensive granitic intrusive and metaclastic rocks (Blackburn et al., 1985; Mackasey et al., 1974). The northeastern part consists of extensive clay plains known as the Northern Clay Belt and Little Clay Belt. The clayed sediments were deposited during inundation by proglacial Lake Barlow–Ojibway. These are uplands areas characterized by broad, gently to moderate rolling terrain, with soil depth ranging from less than 10 cm to greater than 100 cm deep and forests consisting of pure and mixed stands of conifer and hardwood. Prominent tree species include: *Picea mariana* (black spruce), *Pinus banksiana* (jack pine), *Populus tremuloides* (trembling aspen), *Larix laricina* (tamarack), *Thuja occidentalis* (white cedar) and *Betula papyrifera* (white birch). A modified continental climate as a result of the Hudson Bay to the northeast and the Great Lakes to the southeast dominates the region (Riley and Michaud, 1987). This is characterized by long cold winters and short cool summers with a short growing season (Riley, 1994).

The peatland types commonly found in the area include: open bogs, treed bogs, open fens and treed fens with distinctive peatland characteristics (Table 1). Open bogs have tree cover of less than 10% and may be subdivided into open graminoid bog or open shrub-rich bog. Treed bogs consist of tree cover of more than 10% and maybe sub-divided into low density treed bogs (10–15%), medium density (15–25%) or high density treed bogs of more than 25% cover. Open fens are pattern fens with very high water tables while treed fens consist of tree cover of more that 10% and maybe subdivided in the same classes as treed bogs (Riley, 1994).

2.2. Field design and analysis

The survey was conducted using stratified sampling in the twelve study sites. Laboratory analyses of peatland soil samples were followed using the standard protocols described by Riley and Michaud (1987) and Riley (1994). Study locations were selected based on availability of peatland information, availability of relevant topographic and terrain maps, preliminary air photo interpretation, Landsat coverage and discussions with the Ministry of Natural Resources (MNR) staff. Sample collections occurred at points distributed on a grid system of transects across each site. A base-line transect was surveyed on the long axis of each peatland, and side-line transects surveyed at right angle in order to properly distribute coverage across the peatland. Sample points were surveyed at 100 m interval along the base-line and the side-line transects (Riley, 1994; Riley and Michaud, 1987). In areas not sufficiently covered by the grid, extra traverse points were sampled between transects. Generally, sampling density was 1 sampling point per 8–10 ha on sites greater than 100 ha and 1 sample point per 6–10 ha on smaller sites. These sites were recorded as detailed survey sites. On less survey sites, the sampling density was 1 sampling point per 50–80 ha of peatlands. Representative sampling points were cored on these sites at a minimum of 2 points for each peatland vegetation type covering more than 20% of the site. For each point, records of peatland information such as peat depth, vegetation percent cover and Von Post humification were measured. Peat stratigraphy was also recorded by recovering a full core with a Mini-Macaulay sampler or Hiller sampler. Peat depth was recorded by using a long metallic probe. This was carried out by gentle pushing the metallic probe into the peat and measuring the depth of the peat when the probe hits the mineral layer. A total of about 203 data points for soil depth were sampled. The percentage cover for tall trees and shrubs was estimated using light interception method while the cover for graminoid and herbaceous species, mosses and lichens calculated using the plot sizes. Peat humification was recorded based on the von post scale which ranges from 1 to 10. The degree of peat humification was performed by examining the following features: 1) color and amount of water released by gently squeezing a small hand sample, 2) the amount of recognizable plant-fiber remain and 3) the final squeeze test (Riley, 1994). Full cores of peat samples from points chosen to reflect the general pattern of peat stratigraphy were later taken to the laboratory for analysis of variables such as carbon concentration(organic carbon), pH and bulk density using methods described in Riley (1986). The carbon concentration was measured as a proportion of organic matter content measured by loss-on-ignition at 550 °C. The pH was recorded using a pH meter while the bulk density was measured as a function of peat mass per unit volume.

Based on the survey and laboratory data from Riley and Michaud (1987) and Riley (1994), we estimated C stock for four peatland types i.e. open bogs, open fens, treed bogs and treed fens using Eq. (1) (Robertson et al., 1999).

$$\text{Peatland C stock}\left(\text{kg C m}^{-2}\right) = C_{g/kg} \times BD \times SD. \qquad (1)$$

Where:

- $C_{g/kg}$ = carbon concentration on gravimetric basis (g kg^{-1})
- BD = bulk density (g soil cm^{-3}) or kg soil m^{-3}
- SD = peat depth (m).

2.3. Statistical analysis

Interquartile analysis was performed in order to assess the natural variability of C stock. The interquartile range (i.e. 75th percentile