Soil Biology & Biochemistry 114 (2017) 131–144

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Peatlands in a eutrophic world – Assessing the state of a poor fen-bog transition in southern Ontario, Canada, after long term nutrient input and altered hydrological conditions

Sina Berger [a, b, *], Gerhard Gebauer [c], Christian Blodau [a, b, 1], Klaus-Holger Knorr [a]

[a] University of Münster, Institute of Landscape Ecology, Department of Ecohydrology and Biogeochemistry, Heisenbergstraße 2, 48149 Münster, Germany
[b] University of Guelph, School of Environmental Sciences, 50 Stone Road East Guelph, Ontario N1G 2W1, Canada
[c] University of Bayreuth, Laboratory of Isotope Biogeochemistry, Universitätsstraße 30, 95447 Bayreuth, Germany

A R T I C L E I N F O

Article history:
Received 21 January 2017
Received in revised form
5 July 2017
Accepted 14 July 2017
Available online 14 August 2017

Keywords:
Peatland
Peat accumulation
$\delta^{15}N$
Impoundment
Element abundances in peat profiles
Treed bog

A B S T R A C T

Excessive nutrient supply may threaten the carbon storage function of nutrient limited peatlands. We conducted a detailed study in a bog ecosystem (Wylde Lake peatland, Canada), which was once ombrotrophic and since AD 1954 borders a water reservoir, which is enriched with nutrients. Our objective was to elucidate whether the inner peatland parts maintain typical characteristics of a pristine bog. To achieve this goal, along a transect of study sites, we dated peat cores, determined nutrient concentrations and N input and mapped the vegetation. The peatland's central part showed large N input rates of ~4.3 g $N•m^{-2}•y^{-1}$, but even greater rates of 5.90 ± 0.10 g $N•m^{-2}•y^{-1}$, were found in the periphery. Elements essential for plant growth, such as N, P, S, Ca, Mg, Mn, Fe, Cu and Zn were increased in concentration upwards in the profile of all peat cores, especially near the reservoir, presumably due to supply by the reservoir water. Also, a more graminoid dominated vegetation near the reservoir indicated a transformation of the once ombrotrophic bog into a poor fen. To our surprise and in contrast to previous studies the peatland did not seem to decay after long-term excessive nutrient load, instead it accelerated peat accumulation, leading to maximum growth rates of up to 500 g $C•m^{-2}•y^{-1}$ immediately after flooding of the reservoir. Peatland functioning in terms of carbon storage appeared maintained.

1. Introduction

Peatlands are of vital importance for global carbon (C) cycling as they sequester and store enormous amounts of C, which is, per current estimates 300–460 Gt C, corresponding to 40% of C held in the atmosphere as carbon dioxide (CO_2) (Loisel et al., 2014). Availability of oxygen in the acrotelm and anaerobic conditions in the catotelm influence formation and decomposition of peat, hence, the balance between uptake of CO_2 by vegetation and release of CO_2 and methane (CH_4) through respiration and processes of peat and substrate decay (Rydin and Jeglum, 2013).

Major threats to peatlands are excessive supply of nutrients from the atmosphere as well as from surface water and groundwater. Nitrogen (N) deposition has increased markedly throughout the world (Reay et al., 2008), as well as, deposition of phosphorus (P), which was identified to be another major threat to peatlands (Tipping et al., 2014). Surface and groundwater in many areas with intensive agriculture are loaded with nutrients, and thus impair oligotrophic, pristine peatlands (Koerselmann et al., 1990). Given that there will be a considerable worldwide increase of impoundment surface area though creation of dams and reservoirs, corresponding to a one-quarter measure of the natural lake area, which is 4.2 million km^2, by the year 2050 (Tranvik et al., 2009), serious effects on carbon cycling alterations in surrounding wetland areas are to be expected (see Ballantyne et al., 2014).

To date, however, our understanding of the impact of high atmospheric, surface or groundwater derived N inputs on peatlands is still limited. There is agreement that increased N deposition on *Sphagnum* mosses, which are the most important peat formers, leads to promoted *Sphagnum* growth and C uptake until a threshold of N content in *Sphagnum* tissue is reached (Lamers et al., 2001) and N becomes toxic, finally causing dying of *Sphagnum* mosses and

* Corresponding author. Present address: Karlsruhe Institute of Technology (KIT), Institute of Meteorology and Climate Research (IMK-IFU), Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany.
E-mail address: gefleckterschierling@gmx.de (S. Berger).
[1] deceased.

http://dx.doi.org/10.1016/j.soilbio.2017.07.011
0038-0717/

decomposition of peat, while vascular plant growth is promoted (Rydin and Jeglum, 2013), which further threatens *Sphagnum* mosses by shading them out (Chong et al., 2012). Nutrient-rich litter and vascular plant litter seem to decompose faster than nutrient-poor *Sphagnum* litter, thus increasing decomposition and possibly decreasing C accumulation as peat (e.g. Bragazza et al., 2012). Moreover, increased vascular plant cover might increase production and emission of CH_4 over CO_2 when sedges and other graminoids with aerenchymatous tissue are present (Strack et al., 2006; Strom et al., 2003).

Regarding these identified factors, there is also great uncertainty concerning the temporal scales of bog ecosystem responses to increased N input. Some studies (e.g. Eriksson et al., 2010; Sheppard et al., 2013) found that increased N was harmful to *Sphagnum* mosses already after one decade in N fertilization experiments, shrubs and other vascular plants were strongly promoted. Other authors found that *Sphagnum* response to increased N input would depend on its form, i.e. ammonia or nitrate (Chiwa et al., 2016); in a modelling study, also load and concentration of deposited N were important (Wu and Blodau, 2015), constraining earlier results from field manipulations of typically few and high doses of N. From additional model runs, Wu et al. (2015) further suggested that even after 80 years of additional N input of 6.4 g N m^{-2} yr^{-1} *Sphagnum* could be resilient in a graminoid-dominated peatland. Wang et al. (2014) studied the interplay and possible co-limitations of various macro nutrition elements of plants at increased N inputs, and like previous studies, concluded that ultimately changes in species composition could occur, altering both carbon and nutrient cycling in bogs. For intact wetlands, a filtering mechanism for adjacent surface waters was discussed by Cusell et al. (2014) pointing to the efficiency of wetland peripheries in acting as P-filters, preserving more isolated areas from excessive P-supply. Despite all these existing findings - many of them obtained from modelling approaches only, as well as from laboratory and field manipulation experiments - we lack data and insights of long-term consequences of high N deposition to peatlands gathered from observations in the field.

To address this knowledge gap, we studied a larger peatland complex ("Wylde Lake peatland" in Ontario, Canada), which was once an ombrotrophic bog (Givelet et al., 2003). Nowadays the peatland is embedded in an intensively managed agricultural area. Moreover, in 1954 a neighboring water reservoir was flooded leading to partial impoundment and water level fluctuations, strongly tied to the reservoir water level. The reservoir further has supplied high levels of N and other nutrients, especially in the 1960s (GRCA, personal communication), enabling us to case-study long-term increased nutrient input to a once oligotrophic, poor fen - ombrotrophic bog transition. Through monitoring of water levels, peat dating, determination of ^{15}N enrichment of the vegetation, determination of N input and nutrient concentrations along peat cores and vegetation mapping along a transect of study sites stretching from the reservoir shoreline to 1.5 km further inland we aimed to gain an overall insight in the actual conditions in the peatland as affected by nutrients and impoundment. It is important to mention that a lateral influx of nutrients, which our study area is exposed to, cannot in a trivial way be linked to the sequence of peatland responses to increased atmospheric N deposition as formulated by Lamers et al. (2001). Nevertheless, decreasing influence of the water reservoir with increasing distance from it, allows to study responses of individual sites to different scenarios of high nutrient input.

We hypothesized that (I) the reservoir water would mostly affect the peripheral parts of the peatland complex through water level fluctuations and increased nutrient load while the central bog part of the complex would sustain nutrient poor conditions, and (II) based on plant species richness and peat accumulation this central part of the peatland would still be similar to unaffected sites.

2. Methods

2.1. Study area and land use history

The study area is located in the southeastern part of Ontario, 80 km northwest of the city of Toronto (see Fig. 1). The Wylde Lake peatand area (~500 ha in spatial extent) is part of the Luther Lake Wildlife Management Area and located in its south-southeastern part (43.920,361°N, 80.407,167°W). Climate is cool temperate, average July temperature is 19.1 °C, average January temperature is −8.0 °C and the mean annual temperature is about 6.7 °C. Annual precipitation amounts to 946 mm, with the major portion falling in summer (1981–2010, Fergus Shand Dam, National Climate Data and Information Archive, 2014).

Peat formation started about 9000 years before present on calcareous limnic sediments and total peat depth today is about 5 m (Givelet et al., 2003). Human land use in the area surrounding Wylde Lake peatland started between the 15th and 17th century through Ojibwa natives (Peter Turrell, personal communication). After the arrival of European settlers and during the 19th century the peatland complex experienced partially strong drainage, leading to aggravated spring flood conditions in the entire area. Also, intensive farming started in the surrounding areas. For flood control and water management, in 1954 the "Luther Lake" reservoir, neighboring Wylde Lake peatland, has been created (GRCA, 2016; The Wellington Advisor).

The soils flooded through the establishment of the reservoir contained high levels of nutrients and ever since the catchment of Luther Lake has been and still is facing intensive agriculture. Accordingly, farmland and wetlands draining to the reservoir deliver high nutrient loads so that nutrients tend to accumulate in the reservoir resulting in a lake water quality typical of a mesotrophic to eutrophic water body (GRCA, 2016). The poor water quality supports growth of macrophytes and temporary decline of oxygen levels. Warmwater fish species capable of thriving in warm temperatures and low oxygen as well as high nutrient levels (e.g. *Ameiurus nebulosus, Pimephales promelas* and *Notemigonus crysoleucas*) are abundant. These conditions still prevail, presumably due to ongoing nutrient supply in the catchment area and recycling within the reservoir. The reservoir thus also acted as a source of nutrients to the river downstream. Monthly nutrient analyses of the river water just few meters downstream of the dam between the years 1966 and 1979 revealed annual cycles of nutrient concentrations. Highest concentrations occurred during the winters with maximum values of 1.6, 7.9 and 0.16 mg l^{-1}, of NH_4^+–N, NO_3^-–N and total P (Provincial (Stream) Water Quality Monitoring Network). Unfortunately, there is no current data available; the overall nutrient load is still assumed to be high but likely has improved compared to the 1960s and 1970s. (GRCA, 2016).

Regarding Wylde Lake peatland's vegetation, its shoreline to the Luther Lake reservoir is nowadays dominated by a floating mat of cattail (*Typha latifolia* and *T. angustifolia*) which is growing in a 1000 m long and 300 m wide belt. Adjacent to that, the northern periphery of the peatland, which may be regarded as a former poor fen but now represents an open bog – poor fen transition area, is characterized by a belt of pronounced hummocks, which rise up to ~0.8 m above narrow, small hollows. Those hummocks are several meters long and accommodate a dense cover of gigantically grown *Myrica gale* individuals (up to ~0.8 m in height in contrast to *M. gale's* average height of 0.2–0.3 m in areas further away from the shoreline), which suppress growth of underlying *Sphagnum* mosses. The vegetation of the adjacent more pristine open bog