Sphagnum peatland development at their southern climatic range in West Siberia: trends and peat accumulation patterns

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Received 23 May 2007
Accepted for publication 24 September 2007
Published 26 November 2007
Online at stacks.iop.org/ERL/2/045014

Abstract

A region of western Siberia is vulnerable to the predicted climatic change which may induce an important modification to the carbon balance in wetland ecosystems. This study focuses on the evaluation of both the long-term and contemporary trends of peat (carbon) accumulation and its patterns at the southern climatic range of Sphagnum peatlands in western Siberia. Visible and physical features of peat and detailed reconstructions of successional change (or sediment stratigraphies) were analysed at two types of forest–peatland ecotones, which are situated close to each other but differ by topography and composition of their plant communities. Our results suggest that Siberian peatlands exhibit a general trend towards being a carbon sink rather than a source even at or near the southern limit of their distribution. Furthermore, two types of peat accumulation were detected in the study area, namely persistent and intermittent. As opposed to persistent peat accumulation, the intermittent one is characterized by the recurrent degradation of the upper peat layers at the marginal parts of raised bogs. Persistent peat accumulation is the case for the majority of Sphagnum peatlands under current climatic conditions. It might be assumed that more peat will accumulate under the ‘increased precipitation’ scenarios of global warming, although intermittent peat accumulation could result in the eventual drying that may change peatlands from carbon sinks to carbon sources.

Keywords: Sphagnum peatlands, peat accumulation, peat stratigraphies

1. Introduction

Peatland is a type of wetland that, in effect, sequesters carbon through peat accumulation, owing to greater rates of biomass production than decomposition (Kuhry and Vitt 1996, Bauer et al 2003). Peatlands have created a temporal archive of their development, allowing the reconstruction of their history, or successional dynamics of vegetation through the analysis of sediments (Anderson et al 2003). Peat accumulation processes vary substantially over time according to the climatic fluctuations during the Holocene, although the only two trends of development that have been studied in the boreal and temperate wetlands are in western Siberia (WS). One suggests a permanent increase of the peat-carbon accumulation processes from the early Holocene up to the present time (Walter 1977, Neustadt 1984, Gajewski et al 2001). On the other hand, another concept supports the idea of a gradual extinction of Sphagnum peatland development attaining a stable equilibrium in contemporary carbon accumulation (Mäkilä et al 2001, Tuuren et al 2001, Kremenetski et al 2003). At present, there is
not sufficient observational evidence to confirm either of these statements for the entire region.

Present scenarios for future climate change predict that currently dry mid-continental regions will become even drier due to increased evaporation (Cubasch et al. 2001). At the same time, other studies infer significant perturbations in the water balance, resulting in almost the entire WS region experiencing increased summer precipitation (Wetherald and Manabe 2002) and evolution of the fraction of water surface (Grippa et al. 2007). The future of the boundary area of southern boreal and temperate peatlands under such climate change remains unclear. A better understanding of these phenomena is necessary since these changes alter the peat accumulation rate and the amount of carbon released to the atmosphere, as already detected in Arctic regions (Oechel et al. 1993). Feedback mechanisms between the biosphere, the cryosphere and the atmosphere may further accelerate these processes (Freeman et al. 2001).

The southern climatic range of Sphagnum peatlands in WS is undergoing large interannual variability in the precipitation to evaporation ratio, which represents a transition from wet to dry conditions. Even a minor change in climatic conditions may switch the water balance from one state to another. Given the large degree of uncertainty in understanding present and future states of the area with respect to the carbon cycle, the analysis of the recent history of the southern edge of the peatlands in WS deserves an ample degree of scientific interest.

The objectives of this study are (i) estimation of the long-term peat accumulation patterns and (ii) understanding the contemporary trends in Sphagnum peatland development at their southern climatic range in West Siberia.

2. Field site and methods

Field observations were conducted on the southern slope of the Vasyugan wetland system (56°50′N; 78°30′E) which is situated on the border between southern boreal and boreonemoral vegetation zones (Tuhkanen 1984). There is a strongly pronounced inter-annual variability observed in climatic conditions in the studied area, with cycles of alternating droughts and excessive moistening, although the latter predominates. Mean annual precipitation ranges from 450 to 560 mm yr\(^{-1}\), and total evaporation is 500 mm (Sergeev et al. 1977). The water deficiency often amounts to 100 mm during the summer, while there could be about 200 mm of excess moisture in the next year.

Our study focused on two ombrotrophic peatlands with similar forested bog communities dominated by pine trees (Pinus sibirica) and dwarf shrub-Sphagnum vegetation (a so-called ryam bog). Two types of interaction between the upland forest and peatland (ecotones, e.g. Weber 1897) are present in the study area, as shown in figure 1. One ecotone (figure 1(A)) is located on flat terrain and consists of ecosystems ranging from automorphic deciduous forests to forested bogs. Another ecotone (figure 1(B)) is formed by a similar series of forest ecosystems, although it additionally contains herbaceous (sedge-reed) communities. Both peatlands have a round shape and raised topography. The forest (A) ecotone site is situated 12 km northward of the reed-forest (B) ecotone. They are isolated from other wetlands, waterbodies, and permanent streams.

Peat accumulation processes were studied by detailed field surveys and laboratory analysis of the peat samples. Peat columns were extracted using a so-called ‘Russian’ side-cutting peat sampler with a 50 × 5 cm chamber across all types of vegetation communities. For analysis, continuous 10 cm peat samples were taken from the cores.

The degree of decomposition of a sampled peat was estimated on site in accordance with von Post’s (1922) 10-grade scale, \((H_{1-10})\) and defined more accurately in the laboratory using the ‘microscopic’ method (Tyurennov et al. 1977). In the latter method, the degree of decomposition is determined by evaluating the humus-filled area of a thin peat layer under the microscope, and is expressed as a percentage of the total area in the scene. These fractions refer to cumulative losses since deposition. In this technique, humus is defined as fully decomposed organic matter without cell-like patterns. In our case, three small (1–2 cm\(^3\)) sub-samples were extracted from the sample and the degree of decomposition determined for ten scenes from each sub-sample before calculating the resulting means.

Ash content was determined three times for each peat sample and a mean value calculated. Then, peat samples were washed and examined under an optical microscope.
Figure 2. Stratigraphy (plant microfossil constituents) of peat sediments in forest (A) and reed-forest (B) ecotones. *Sphagnum* mosses: 1—*S. fuscum*, 2—*S. angustifolium*, 3—*S. magellanicum*, 4—*S. fallax*, 5—mesotrophic (*S. centrale*, *S. russowii*). Sedges (*Carex*): 6—*C. globularis*, 7—*C. lasiocarpa*, 8—*C. rostrata*, 9—*C. elata* ssp. *omskiana*, 10—*Eriophorum vaginatum*, 11—brown mosses. Grasses: 12—reed (*Phragmites australis*), 13—*Calamagrostis*. 14—shrubs, 15—birch leaves, 16—wooden remains. The framed numbers below the columns indicate radiocarbon ages of the basal peat (years BP).

(magnification 40–250×) to identify a plant’s macrofossil constituents (Katz *et al.* 1977). Microfossil contents were estimated by determining the fractional area of the remaining vascular plant tissue and mosses. Peat sediments were divided into three groups corresponding to successive stages of mire development: ombrotrophic, mesotrophic, and eutrophic. The ombrotrophic and eutrophic stages were classified as having more than 95% abundance of plant species growing in respective conditions. Otherwise, the sediment was considered to be in the mesotrophic stage of mire development.

AMS 14C datings for basal peat samples were acquired from the NIES-TERRA AMS facility at the National Institute for Environmental Studies in Tsukuba, Japan (Tanaka *et al.* 2000). For preparation of peat sediments before graphitization, all carbonates were dissolved with 1 N HCl solution for one night, then washed with milli-Q water. The graphitization of organic carbon in peat was carried out according to a procedure described by Uchida *et al.* (2004, 2005).

3. Results and discussion

Our analysis revealed that, in most cases, the peat accumulation processes were initiated by sedge communities, although brown mosses were also detected in a reed-forest ecotone (figure 2). Most likely, the sedge communities were developed over the mineral soils with high humus content in post-glacial or lacustrine depressions, via a process of terrestrialization (refer to, e.g., Anderson *et al.* 2003). *Sphagnum* mosses evolved from sedge communities at the next stage of swamping and later became the main dominants in all peat developments.

The stratigraphies of the deepest peat cores (A1 and B1 in figure 2) share many common features. These deposits are mainly composed of ombrotrophic *Sphagnum* peat contributing up to 60% of the total peat profile in the reed-forest ecotone and 80% in the forest ecotone. Upper layers of peat deposits are dominated by *Sphagnum fuscum* which indicates a severely nutrient-deficient environment and provides favourable conditions for organic matter accumulation (Andrus 1986). The low degree of decomposition (5–15% in upper peat layers and 35–45% in the deeper layers), and low ash contents (<3% in ombrotrophic peat), accompanied by high acidity (not shown) are characteristic of deep sediments (figure 3). However, the ash content of the uppermost 10 cm of peat in core B1 is 7%, which is twice as high as in A1, where only 3% was detected. In fact, the ash content was found to be always higher in peat deposits in the reed-forest ecotone than in the forest ecotone. The degree of peat decomposition varied significantly in a vertical profile in reed-forest deposits, especially in core B1, where it was coupled with a changing ratio between *Sphagnum fuscum* and *S. angustifolium/S. magellanicum* residues. This might be caused by recurrent climatic fluctuations such as changes in patterns of precipitation and evaporation. Some fluctuations in the water balance are also reflected by the existence of *Eriophorum vaginatum* in the *Sphagnum* continuum.
Eutrophic and mesotrophic communities are minor contributors to the sediments in the forest ecotone. Grass-dominated peatland was transformed into the ombrotrophic peat bog dominated by pine dwarf shrubs—Sphagnum communities which continuously exist until now. Eutrophic and mesotrophic periods are remarkably visible in the reed-forest ecotone.

In spite of the substantial resemblance between the peat-forming processes at the central part of the two ecotones, considerable differences were found in marginal shallow deposits accumulating at 0.4–0.5 m of peat. Sphagnum mosses are dominant in peat sediments in the forest ecotone (core A3 in figure 2). No evidence of peat degradation or fire activity was found in the analysed samples. Furthermore, only 20 cm of ‘modern’ peat has accumulated at site A4 until now (figure 2). This site originated from an extension of the peat-forming processes toward adjacent birch–aspen forests (i.e. paludification: e.g. Anderson et al 2003). Its history is recorded by mesotrophic wood–Sphagnum sediments directly overlaying the parent loamy soil, which according to Mäkilä (1997) is evidence of high paludification activity. A 3 cm layer containing wood pulp and sedge remains was found between the peat and subsoil layers. It might be considered as the well-decomposed litter residue that was accumulated by the preceding forest ecosystem. All these observations indicate persistent peat accumulation in a forest ecotone.

In contrast, peat sediment stratigraphy in core B3 (0.5 m depth) of the reed-forest ecotone provides some evidence of ‘intermittent’ peat accumulation. The uppermost 10 cm thick layer of the deposit was composed of turf that may indicate peat degradation. In contrast to underlying peat deposits, the turf contained a great amount of live and undecomposed roots of the vascular plants. There were no differences in the plant species found in the peat and turf layers, but considerable differences in the composition of the species were detected. Namely, an increment in sedge contribution (up to 10–15% of sediment value), wooden remains (up to 50%), and shrubs (15%), and a reduction of Sphagnum moss abundance (down to 5%) were found in the turf layer. The fair amount of wooden residue found implies the dry conditions which are favourable for growing trees. Furthermore, two layers containing highly decomposed sediments were found deep in the peat deposit. Most likely, they represent the residual turf layers that were formed during the past dry periods and covered by peat sediments in humid conditions thereafter. The main part of the peatland body remains stable despite variations in water balance (also stated by Botch et al 1995). In our study, however, some signs of drainage as well as higher ash contents in upper peat layers were found in the reed-forest ecotone (cores B1 and B2), although they were not observed in the forest ecotone.

The mean rate of vertical growth was calculated based on radiocarbon dating of basal peat samples (see figure 2 for 14C values) and the actual depth of accumulated sediments for each peat deposit. These rates are comparable in cores A1 and B1 (0.7 and 0.6 mm yr⁻¹, respectively), as well as in cores A2 and B2 (0.4 and 0.3 mm yr⁻¹, respectively). A large variation was detected in marginal deposits, where peat has been accumulating at a rate of 0.7 mm yr⁻¹ in core A3 (forest ecotone), while the rate is only 0.25 mm yr⁻¹ in core B3 (reed-forest ecotone). Generally, the annual rates of peat growth are always higher in peatlands contoured by the forest ecotone. Thus, radiocarbon dating proves the existence of spatial patterns in contemporary peat accumulation.

Overall, our results suggest that southern boreal peatlands exhibit a contemporary tendency towards being carbon sinks rather than sources. On the other hand, warmer and drier climates predicted in global warming scenarios may enhance peat decomposition rates and initiate carbon inputs to the atmosphere (Gorham 1991, Mäkilä et al 2001), given the prediction that even small decreases in net primary production and/or increases in peat decomposition rates (10% over 100 yr)
could be sufficient to switch boreal peatlands from net sinks of atmospheric carbon to net sources (Wieder 2000).

4. Conclusions

Two peat (carbon) accumulation patterns, i.e. persistent and intermittent, were found in two ecotones at the southern climatic range of extension of the Sphagnum peatlands in West Siberia. Forest ecotones are located in the majority of lateral zones of the vast wetland tracts and suggest widespread persistent peat accumulation resulting in net carbon sinks.

Finally, it can be suggested that the recently observed degradation of peatlands could have been caused by decadal and interannual climate fluctuations and may be reversed during the next stage of peat accumulation in the near future.

Acknowledgments

This work was started under the supervision of our late colleague Dr Sergey Vasiliev, and we gratefully remember his contribution. Many thanks are also addressed to Dr A I Syso, Dr Y Ermolov, and S Hudyaev for assistance with field work and other colleagues from the Institute of Soil Science and Agrochemistry SB RAS for their support of this research. We are also grateful to T Kobayashi (NIES-TERRA) for AMS operation, and A Matsuda and M Suzuki (NIES) for preparation of the samples for AMS analysis. Thoughtful comments by Dr S Maksyutov and two anonymous reviewers greatly improved the content of this manuscript.

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