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Effect of peat re-wetting on carbon and nutrient fluxes, greenhouse gas production and diversity of methanogenic archaeal community

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ABSTRACT

Many peatlands were affected by drainage in the past, and restoration of their water regime aims to bring back their original functions. The purpose of our study was to simulate re-wetting of soils of different types of drained peatlands (bogs and minerotrophic mires, located in the Sumava Mountains, Czech Republic) under laboratory conditions (incubation for 15 weeks) and to assess possible risks of peatland water regime restoration – especially nutrient leaching and the potentials for CO_2 and CH_4 production. After re-wetting of soils sampled from drained peatlands (simulated by anaerobic incubation) (i) phosphorus concentration (SRP) did not change in any soil, (ii) concentration of ammonium and dissolved organic nitrogen (DON) increased, but only in a drained fen, (iii) DOC increased significantly in the drained fen and degraded drained bog, (iv) CO_2 production decreased, (v) CH_4 production and the number of methanogens increased in all soils, and (vi) archaeal methanogenic community composition was also affected by re-wetting; it differed significantly between drained and pristine fens, whereas it was more similar between drained and pristine bogs. Overall, the soils from fens reacted more dynamically to re-wetting than the bogs, and therefore, some nutrients (especially nitrogen) and DOC leaching may be expected from drained fens after their water regime restoration. However, if compared to their state before restoration, ammonium and phosphorus leaching should not increase and leaching of nitrates and DON should even decrease after restoration, especially during the vegetation season. Further, CO_2 production in soils of fens and bogs should decrease after their water regime restoration, whereas CH_4 production in soils should increase. However, we cannot derive any clear conclusions about CH_4 emissions from the ecosystems based on this study, as they depend strongly on environmental factors and on the actual activity of methanotrophs in situ.

1. Introduction

Re-wetting of peatlands is currently a wide spread method for restoration of wetland ecosystems which were drained due to intensification of forestry and agriculture. Almost 70% of peatlands in the Sumava Mountains (Bohemian Forest, Czech Republic) were influenced by drainage in the past and they are now being restored within the long-term project "Programme of Peatland Restoration in the Sumava National Park".

Under natural conditions, peatlands play an important role in the global C cycle as a long-term sink of atmospheric C and a source of CH_4 (Gorham, 1991) and they have a high potential for nutrient retention and nutrient transport (Mitsch and Gosselink, 2000). Peatland restoration aims to bring back these natural functions (Vasander et al., 2003); however, the success of restoration is affected by many factors, especially by the state of degradation and type of peatland (Schumann and Joosten, 2006).

Drainage also brings about changes in the chemistry of the surface peat, which can have an impact on nutrient availability to plants (Aerts et al., 2006) and affect the quality of surface and runoff water (Lundin and Bergquist, 1990; Prevost et al., 1999). Aeration of the peat and subsequent mineralization and nitrification of organic N result in an increase of NO_3^- concentrations in the pore water of drained peatlands (Olde Venterink et al., 2002; Holden et al., 2004). These processes are intensified by higher groundwater level fluctuation, which is typical for degraded peatlands due to the altered hydraulic properties of the peat (Price et al., 2003; Tiemeyer et al., 2006). The aim of re-wetting is to reduce soil aeration and decrease N mineralization, and hence to decrease N availability for wetland plants. Olde Venterink et al. (2002) showed that re-wetting of dried soil cores can strongly stimulate denitrification but N mineraliza-

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tion did not decrease significantly. Phosphorus (P) is frequently sorbed to Fe- or Al-hydroxides in aerobic condition and becomes temporarily immobilized (Zak et al., 2004). Re-wetting can lead to enhancement of P mobilization due to the reduction of these complexes under anaerobic soil conditions and low redox potential (Olde Venterink et al., 2002; Tiemeyer, 2007). In general, the risk of water pollution by elevated solute concentrations depends mainly on the hydrological conditions of the area after drainage or re-wetting (Price et al., 2003).

The production of CO_2 and CH_4 depends on the position of the water level, soil temperature, microbial activity in the peat, plant community structure and the chemical characteristics of peat (Bubier et al., 1993; Whiting and Chanton, 1993; Yavitt et al., 1997). Drainage causes simultaneous changes in vegetation and decomposition processes, and hence greenhouse gas fluxes in the mire. Drained peatlands tend to emit more CO_2 (Moore and Dalva, 1993; Silvola et al., 1996), while emissions of CH_4 greatly decrease due to limited anaerobic conditions (Nykänen et al., 1995; Minkkinen et al., 2002). The actual results of restorations are encouraging, because they reflect the positive effect of restoration of both fen and bog sites in initiating vegetation succession and carbon balance development towards those of pristine mires. Most of studies were conducted on cut-away peatlands, where decreasing total respiration and higher incorporation of CO_2 to the system due to the increase of plant cover was observed after re-wetting (Tuittila et al., 1999). The C balance after re-wetting is strongly influenced by vegetation structure (Komulainen et al., 1999; Kivimäki et al., 2008). Komulainen et al. (1998) and Tuittila et al. (2000) observed that a higher water level after re-wetting was followed by increased CH_4 emissions. Nevertheless, CH_4 emissions from restored peatlands may remain at a lower level for a long period of time until they have become fully vegetated by mire plants.

A significant relationship has been described between methanogen community composition and environmental characteristics such as vegetation type and temperature, which influence both methanogen community activity and dynamics (Rooney-Varga et al., 2007). Several studies confirmed variation in the methanogen community between peatlands types (bog, fen) related to vegetation (Basiliko et al., 2003; Galand et al., 2005; Yavitt et al., 2005). Methanogen communities have also been described in undisturbed peatlands, as well as the effect of short- and long-term drought on microbial diversity (Fenner et al., 2005; Jaatinen et al., 2007; Kim et al., 2008), but the direct effect of drainage and restoration on methane-producing archaea is still a matter of debate.

Although there have been several studies about the effect of re-wetting on nutrient mobilization (leaching) and microbial processes, including gas emissions or production, their conclusions are not unambiguous. Understanding ecosystem functioning and reaction to re-wetting require consideration of both the hydrology and soil processes together with vegetation structure, as well as their interactions. A comprehensive study of nutrient losses, and CO_2 and CH_4, production and changes of diversity of archaeal methanogenic community, will help to anticipate how peatlands will function after restoration of their water regime.

The purpose of our study was to simulate re-wetting of soils of different types of drained peatlands (bogs and minerotrophic mires) in a laboratory incubation experiment and assess possible risks of peatland water regime restoration (especially its effect on nutrient leaching and CH_4 production potential). To accomplish this, we measured CO_2 and CH_4 rates production, nutrient release and immobilization, the number of methanogens and the diversity of the archaeal methanogenic community in peat samples under laboratory conditions.

2. Materials and methods

2.1. Study sites

Three ombrotrophic bogs and two minerotrophic mires in different states of degradation were chosen for peat sampling as representative of two main types of peatland in the Sumava Mountains (Bohemian Forest):

1. intact bog (BOG),
2. drained bog (BOGdr1),
3. degraded drained bog (BOGdr2),
4. intact minerotrophic mire (FEN), and
5. drained minerotrophic mire (FENdr).

These sites are located in the Sumava National Park in the southern part of the Czech Republic. All of these study sites are included in the long-term project “Programme of peatland restoration in the Sumava National Park”. Two ombrotrophic bogs, Blatenska (BOG) and Schachtenfilz (BOGdr1), are located on the central plateau of the Sumava Mountains, which contains frequent patterned mires and extensive waterlogged spruce forests at an average altitude of about 1150 m a.s.l. The cold and humid climate is characterized by a total annual precipitation up to 1400 mm and mean annual temperature of 3.2 °C. The other three study sites are situated in the hollow of the Kremelna River at an average altitude of about 850 m a.s.l. The mean annual temperature is less than 4 °C and mean total precipitation up to 1100 mm.

Vegetation structure of each site reflects the hydrological conditions. The surface of the intact bog (BOG) is structured with generous hollows (*Leuco-Scheuchzerion* association), lawns with the dominant *Trichophorum caespitosum* and hummocks with *Andromeda polifolia*. Shrubs occur only on the margin, which is surrounded by *Pinus* × *pseudopumilio* and waterlogged spruce forest. On the medium disturbed site (BOGdr1), the lawns with dominant *T. caespitosum* are preserved only in the more hydrologically stable central part (between ditches) and hollows are missing. Ditches are surrounded by shrubs (*Vaccinium myrtillus*, *Vaccinium uliginosum*) and expansion of *Picea abies* is clearly evident on the whole site. The degraded drained site (BOGdr2) has much more changed vegetation structure with dominant shrubs *V. uliginosum* in the central part and *V. myrtillus* along the margin. *Molinia caerulea* expanded on to the whole site together with *Betula pubescens*. The advanced successional stage of degradation on BOGdr2 is probably caused by earlier drainage compared to BOGdr1. The intact minerotrophic mire (FEN) is covered by typical vegetation with dominant *Carex rostrata* and almost 100% *Sphagnum* cover. The drained minerotrophic mire (FENdr) is composed of different degradation states depending on the intensity of drainage, from well preserved parts with *C. rostrata* to a dry part with dominant *Carex nigra*, *Carex brizoides*, *M. caerulea*, *Nardus stricta* and other graminoids.

These peatlands have been drained namely for forestry purposes since the 19th century with local intensive drainage made during the last 50 years. In the case of the drained fen, the purpose of drainage was most probably to increase hay production. No fertilization was done after drainage at all sites.

2.2. Environmental parameters

Characteristics of the five study sites are shown in Table 1. Water table was measured manually (at two week interval) or continuously using dataloggers with a water level sensor (Fiedler, Electronics for Ecology, Czech Republic) in minimally six plastic boreholes at each site. From two to four samples of pore water