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PEAT PROPERTIES IN SPRUCE SWAMP FORESTS AS AFFECTED BY LONG-TERM DRAINAGE AND HYDROLOGICAL RESTORATION

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SUMMARY

Spruce swamp forests, once common in northern Europe, have declined drastically, mainly due to drainage for forestry. Rewetting is an attempt to restore some of the values and benefits lost as a result of drainage. To study the effects of drainage and restoration, we measured surface peat properties in drained, rewetted and pristine spruce swamp forests in southern Finland and Šumava Mountains, Czech Republic. Peat bulk density had increased substantially following drainage, but after rewetting it changed back towards pristine conditions. Microbial biomass and activity were highest in the pristine sites. In the rewetted sites a change towards pristine functioning was observable.

KEYWORDS: restoration, rewetting, soil microbial activity, swamp forests

INTRODUCTION

Peatland rewetting, or hydrological restoration, is a growing practice that aims to restore threatened ecosystems, improve water quality in intensively managed catchments or gain credits for the global carbon market. The key to the benefits is to re-establish the structure and functioning of the peatland, which involves reviving the accumulation of peat and the typical peat microbial processes.

Spruce swamp forests, once common in northern Europe, have declined drastically in the past century. In southern Finland, their number has declined by 60% to 80% since the 1950s, mainly due to drainage for forestry (Raunio *et al*., 2008). Pristine spruce swamp forests are habitats of high biodiversity value (Hörnberg, 1998). Because of their position in the landscape, between upland and watercourses, they have a potential to filter catchment waters. As peatlands, they store carbon.

Restoration success is commonly monitored and evaluated as changes in vegetation. However, the recovery of the key soil processes could be slower than vegetation and might take more than a century, as Moreno-Mateos *et al*. (2012) claim based on their extensive meta-analysis on wetland restoration success. The rates of recovery are known to vary according to wetland type (Moreno-Mateos, 2012), but scientific knowledge is lacking for many wetland and peatland types.

Drainage changes the peatland ecosystem in such a way that many ecosystem services provided by the pristine spruce swamp forests are lost. After water-level drawdown, *Sphagnum* mosses recede to drainage ditches and moist patches, which causes peat accumulation to stop (Laine *et al.*, 1995).The input waters are channeled to the ditches, which changes the hydrological regime of the catchment and may lead to leaching of nutrients and organic matter (Dinsmore, 2011). Peat subsidence and compaction take place, at first through physical collapse and compression and later through decomposition, which is likely to affect peat hydrological and microbial properties.

Drained spruce swamp forests have been rewetted in state conservation areas in Finland since the 1990s and in Czech Republic since 1999. We aim to study 1) how drainage has changed the below-ground properties of spruce swamp forests, and 2) if rewetting conducted after decades of drainage has, in 2 to 15 years, restored these properties. For this, we measured peat physical properties, decomposability and microbial activity in a set of pristine, drained, and restored spruce swamp forests in two geographically distinct areas: in Southern Finland and Šumava Mountains. The choice of the two areas enabled us to search for common patterns and differences related to climate and other environmental variables.

MATERIAL AND METHODS

Site description

Our research subjects comprised pristine, drained and rewetted spruce swamp forests in southern Finland (n=3+3+6) and Šumava Mountains, south-western Czech Republic (n=2+2+2). The sites are situated in state conservation areas or in their vicinity. Rewetting was conducted by the Finnish state forest agency Metsähallitus and Administration of the Šumava National Park in the years 1995 to 2008 by blocking or filling the ditches. The drained and rewetted sites had been drained to enhance tree growth more than 50 years prior to rewetting.

The sites in Finland are located in the southern boreal zone, in three clusters situated 100 to 200 km away from each other in an average altitude of 150 m a.s.l. The climate is boreal with a long-term mean annual temperature ranging from 3.3 to 4.3°C depending on the location; annual precipitation ranges from 610 to 710 mm. The Šumava Mountains sites are located on an upland plateau in an average altitude of ca. 1100 m a.s.l. The climate of the upland plateau is cold and humid with a mean annual temperature of 4 °C; annual precipitation is ca. 1200 mm.

The vegetation in the pristine sites consists of Norway spruce (*Picea abies*) as the dominant tree and *Sphagnum* mosses as the dominant forest floor plant, with feather mosses occurring on tree roots, logs and other higher surfaces. The understory is characterized by *Vaccinium* dwarf shrubs. In the Šumava Mountains, cottongrass (*Eriophorum vaginatum*) is widespread and other sedges are common. In the drained sites, feather mosses dominate, *Sphagnum* mosses are rare, and the total moss cover may be scarce. The rewetted sites show different intermediate stages between the pristine and the drained. In some rewetted sites in southern Finland, birch (*Betula pubescens*) and sedges (e.g. *Carex canescens*) have emerged after ditch blocking.

Soil analysis

The upper 30 cm of soil was sampled in August 2010. At each site, 6 samples consisting of 3 1 dm^3 subsamples were collected, sieved through a 5-mm mesh and stored at 4°C until analysis. Bulk density was measured from separate 1.26 dm^3 samples after drying them in 70°C. The soil samples were analyzed for pH, total C, N and S content, and oxalate-extractable P. Soil microbial biomass C and N were measured using the chloroform fumigation-extraction method (Vance *et al.*, 1987). Activity of ligninolytic and cellulolytic enzymes was measured by monitoring oxidation of artificial substrates.

To measure peat decomposability and microbial activity, soil samples were incubated under aerobic and anaerobic laboratory conditions at 10°C for 6 weeks. Concentration of CO_2 and CH_4 in the headspace of the incubation flasks was measured regularly. Dissolved organic carbon (DOC), total soluble nitrogen (TSN), nitrates and ammonium were measured at the start and end of the incubation experiment.

Statistical evaluation and multivariate analysis

To test the differences between treatments in the measured variables, we used simple multilevel models that accounted for the hierarchical structure in the data, using MLwiN 2.10. To explore and summarize the variation of the measured variables, we used principal component analysis (PCA). PCA was performed on untransformed, centered and standardized data using CANOCO 4.5.

Table 1. Results from the statistical tests. Tests showing statistically significant differences (<, >) between the treatment groups (pristine Pr, rewetted Re, drained Dr) in bold font.

variable	order	variable	order
pH	Pr≥Re≥Dr	**aerobic CO_2 production**	**Pr>Re≥Dr**
bulk density	**Pr<Re<Dr**	**anaerobic CO_2 production**	**Pr>Re=Dr**
microbial C	**Pr>Re=Dr**	anaerobic CH_4 production	-
microbial N	**Pr>Re=Dr**	aerobic SOC change	Re≥Dr≥Pr
microbial C/N ratio	Pr≤Re≤Dr	**anaerobic SOC change**	**Pr<Re≤Dr**
betaglucosidase activity	Pr≥Re≥Dr	aerobic TON change	Pr≤Re≤Dr
laccase activity	-	anaerobic TON change	Pr≤Re≤Dr
Mn-peroxidase activity	Re≥Pr≥Dr	aerobic TIN change	-
peroxidase activity	Pr≤Re≤Dr	anaerobic TIN change	-
oxidase activity	**Pr≥Re≥Dr, Pr>Dr**		

RESULTS

Peat bulk density was substantially higher in the drained than in the pristine sites (Table 1). After rewetting it had changed back towards pristine conditions (Table 1). Microbial biomass, activity of oxidizing enzymes and peat decomposability, measured as carbon dioxide production in aerobic and anaerobic incubations, were significantly higher in the pristine sites than in the drained and rewetted treatment groups (Table 1). The same trend of high decomposition activity in the pristine sites was observed in the PCA analysis (Fig.1a).

The drained, restored and pristine sites formed a directional continuum in the two-dimensional ordination space (Fig.1a-b) that explained 34.6% of the variation in the peat properties. The division to drained and pristine sites correlated strongly with the variation in peat properties, whereas the restored sites were a heterogeneous group. In respect of environmental variables, the variation in peat properties was correlated with variation in water table level and the proportional cover of plant functional types (Fig.1b).

The sites in the two geographical areas, southern Finland and the Šumava Mountains, differed in their peat properties but showed similar directional change as a result of drainage and rewetting (Fig.1c). The large variation within the drained sites in southern Finland is largely explained by the sampling strategy: in Finland the ditch line samples were taken partly from the drainage ditches and their surroundings. When these samples are omitted, both areas show similar patterns and the samples from the drained sites in southern Finland occupy only the left corner of their current range (results not shown).

DISCUSSION

We found the peat from the pristine sites to exhibit high decomposition activity per unit mass, while peat from the drained sites showed low activity. Substrate quality can have a large impact on decomposition rates in peatlands (Straková *et al.,* 2012). Pristine sites with their extensive *Sphagnum* cover produce fresh surface peat continuously, which could be the key to the high microbial activity in the pristine sites compared to the drained sites.

Ditches formed a special habitat within the drained sites, which coincides with previous results showing rapid moss growth (Kangas *et al*., 2012 in this compilation) and high methane production (Minkkinen and Laine, 1997) in the ditches of drained peatlands.The two study areas, southern Finland and Šumava Mountains, are similar in their average temperatures but differ in the amount of received rainfall, which affects both vegetation and peat properties. Despite the observed differences, the sites followed similar trajectories in their drainage and rewetting succession.

In the rewetted sites, the most substantial change was observed in peat bulk density. Rapid *Sphagnum* growth after rewetting, observed in *Sphagnum* ecophysiology (Kangas *et al*., 2012 in this compilation) and *Sphagnum* growth measurements (Maanavilja *et al.,* unpublished) in the same sites, has resulted in accumulation of a layer of light *Sphagnum* peat in only some years after rewetting. While the change in peat structural properties is apparent, other peat properties in the rewetted sites had not changed significantly from the drained state towards the pristine. However, results from the principal component analysis and the differences that were observed - but remain under significance limit - suggest that peat microbial processes in these sites are in the process of directional change.

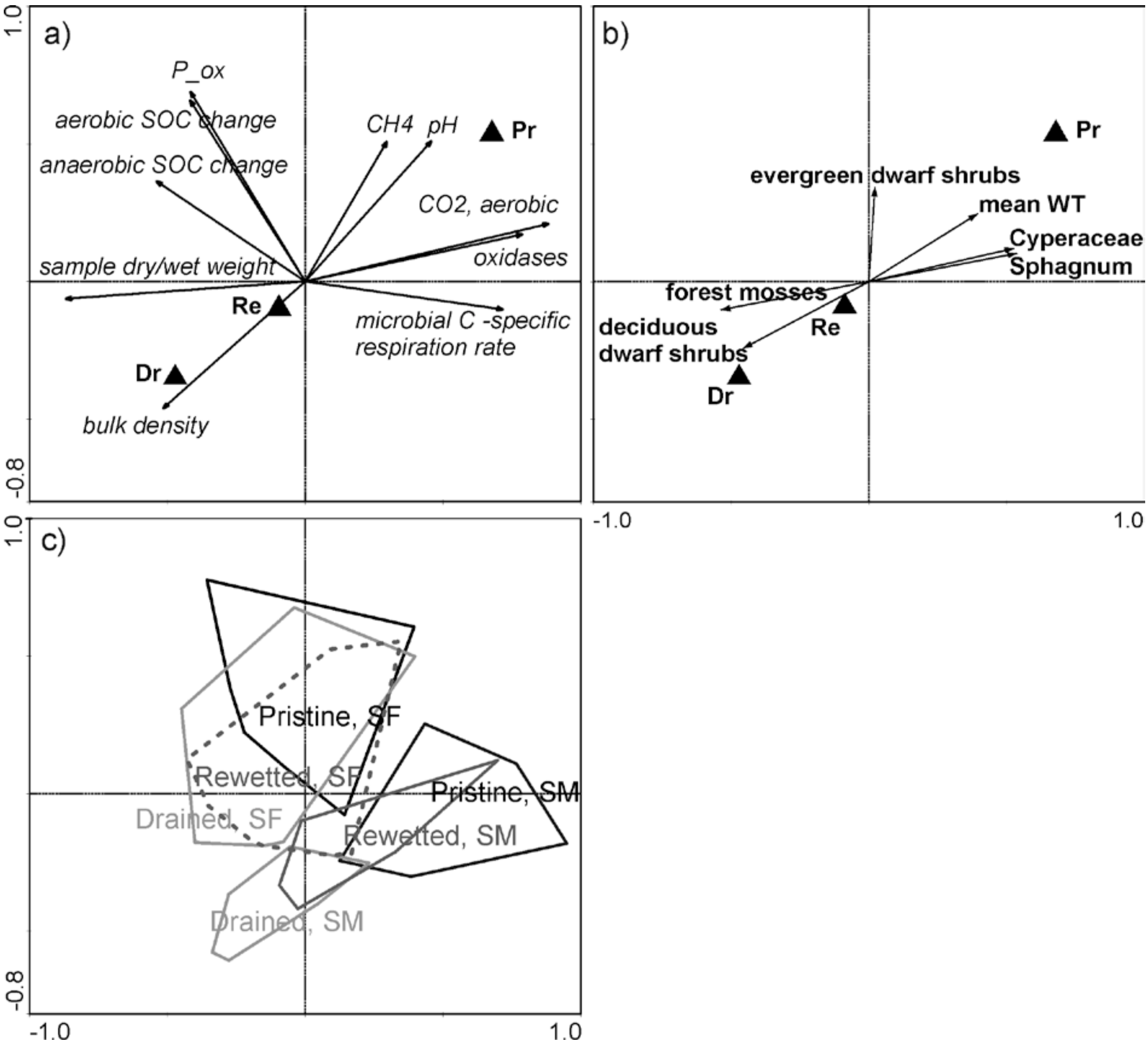

Fig. 1. Principal component analysis (PCA) ordination of the peat properties, showing a) the peat properties with >34% fit, b) water table level and proportional cover of the plant functional groups (10% correlation), c) sample ranges, grouped according to treatment group (pristine Pr, rewetted Re, drained Dr) and geographical area (southern Finland SF, Šumava Mountains SM). P_ox stands for oxalate-extractable phosphorus, SOC for soluble organic carbon, WT for water table level.

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REFERENCES

Dinsmore, K.J., Billett, M.F, Dyson, K.E., Harvey, F., Thomson, A.M., Piirainen, S., and Kortelainen, P. (2011). Stream water hydrochemistry as an indicator of carbon flow paths in Finnish peatland catchments during a spring snowmelt event. *Science of the Total Environment* **409**, 4858–4867.

Hörnberg, G., Zackrisson, O., Segerström, U., Svensson, B.W., Ohlson, M. and Bradshaw, R. (1998). Boreal swamp forests. Biodiversity "hotspots" in an impoverished forest landscape. *BioScience* **48**,795-802.

Raunio, A., Schulman, A. and Kontula, T. (eds.) (2008). Suomen luontotyyppien uhanalaisuus. [Assessment of threatened habitat types in Finland.] *Suomen ympäristö* **8**. Finnish Environment Instute, Helsinki.

Laine, J., Vasander, H. and Laiho, R. (1995). Long-term effects of water level drawdown on the vegetation of drained pine mires in southern Finland. *Journal of Applied Ecology* **32**, 785–802.

Minkkinen, K. and Laine, J. (2006). Vegetation heterogeneity and ditches create spatial variability in methane fluxes from peatlands drained for forestry. *Plant and Soil* **285**, 289–304.

Moreno-Mateos, D., Power, M.E., Comín, F.A. and Yockteng, R. (2012). Structural and functional loss in restored wetland ecosystems. *PLoS Biology* **10**(1), e1001247. doi:10.1371/journal.pbio.1001247

Straková, P., Penttilä, T., Laine, J. and Laiho, R. (2012). Disentangling direct and indirect effects of water table drawdown on above- and belowground plant litter decomposition: Consequences for accumulation of organic matter in boreal peatlands. *Global Change Biology* **18**, 322-335. doi: 10.1111/j.1365-2486.2011.02503.x

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. (1987). An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* **19**, 703-707.