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How helophytes influence the phosphorus cycle in degraded inundated peat soils – Implications for fen restoration

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A B S T R A C T

When severely degraded fens are rewetted, they often become shallow lakes with an average water depth of less than 1 m. The additional high nutrient availability in highly decomposed peat soils of these newly formed ecosystems favours the fast establishment of a small number of helophytes while the return of lost target species like low sedges and brown mosses could be delayed for decades. We hypothesise that the phosphorus (P) uptake of the newly developed vegetation substantially influences the P cycle in rewetted fens. Therefore, we investigated how much of the P released in upper degraded peat soils is pumped across the redox-interface between the soil and surface water (='P barrier') during the growing season (~150 days) by six helophytes (*Phragmites australis*, *Typha latifolia*, *Glyceria maxima*, *Carex acutiformis*, *Carex riparia*, and *Phalaris arundinacea*) in five rewetted fens. We then assessed how this would affect the different plant-available P fractions in the rooted degraded peat layers. The highest P uptake during the growing season (duration 150 days from May to September) was recorded for *T. latifolia* and *G. maxima* (3.0 and 2.8 g m^{-2}, respectively). Overall, the P uptake was in the range of the P mobilisation rates we measured in highly decomposed peat soils (range: 0.8–15.6 g P m^{-2}, $n = 30$), but four to 10-fold higher than diffusive net P fluxes at the interface between soil and surface water. Accordingly, helophytes are able to compensate for the high P mobilisation in degraded peat soils during the growing season, by incorporating this P into biomass. On the other hand a large part of the plant-P stock is released after die back through leaching and mineralisation, which increases the P load of these newly formed shallow lakes and possibly also of adjacent water courses. We estimated that it would still take 20–50 years to exhaust the large pool of plant-available P in highly decomposed peat soils if aboveground biomass was removed. Without any further management apart from fen rewetting it is unlikely that the fens will return to low nutrient levels within a human life time.

1. Introduction

The eutrophication of lakes and rivers is still a problem in most regions of Central Europe due to non-point source phosphorus (P) pollution from intense agricultural land use (Lamers et al., 1998). One important strategy to improve water quality as required by the EU Water Framework Directive (2000) is to restore natural nutrient sinks like minerotrophic peatlands, i.e. fens. Originally, they covered about 495,000 km^2 of Europe, or 5% of the total land area. An even higher proportion of more than 10% was found in northern Germany where fens once acted as important buffer zones between the mineral soils of uplands and water ways (Fig. 1). However, drainage and intensified agricultural use of fen areas led to the loss of the sink function and other ecosystem services, thus increasing the load of phosphate and other nutrients entering adjacent surface waters (Kalbitz and Geyer, 2002; Kieckbusch and Schrautzer, 2007). Today ~60% of European peatlands are drained or suffer from lowered groundwater tables in

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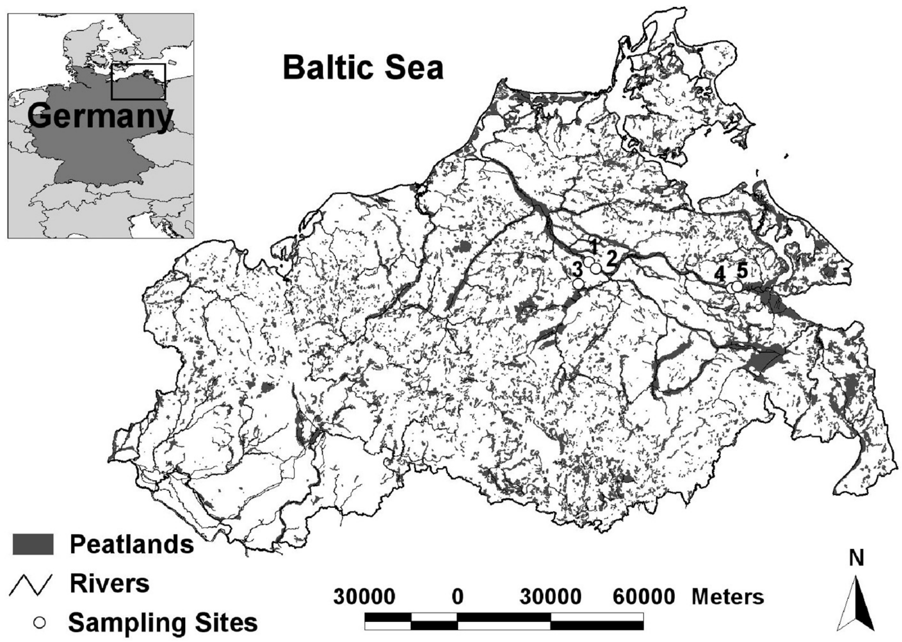

Fig. 1. Location of the sampling sites in the peatland-rich state Mecklenburg-Vorpommern in NE Germany (more than 95% are drained); sampling sites: 1 = Beestland, 2 = Wendewiesen, 3 = Zarnekow-Upost, 4 = Menzlin, and 5 = Jargelin.

their catchments (in some countries the total is >90%, e.g. Great Britain, France, The Netherlands, and Germany) (Joosten, 1997). In order to restore the nutrient sink function, about 20,000 ha of degraded fens have been rewetted in NE Germany. However, due to non-reversible changes of peat characteristics and substantial soil subsidence, rewetted fens often become shallow lakes with an average depth of less than 1 m (Zak et al., 2010). The additional high mobilisation of both P and nitrogen (mostly as ammonium) in the inundated degraded peat soils of these newly formed ecosystems (Zak and Gelbrecht, 2007) favours the development of stands with only a few different plant species, generally helophytes such as *Phragmites australis*, *Typha latifolia*, *Glyceria maxima*, *Carex* spp., and *Phalaris arundinacea* (Timmermann et al., 2006). Although there is no clear evidence if P or other nutrients limits plant growth in these systems (Steffenhagen et al., 2012) we focus here on P since downstream freshwater systems are mostly P-limited.

The high P mobilisation in rewetted fens is mainly attributable to the reductive dissolution of redox-soluble Fe(III)-P compounds in the upper soil layer of highly decomposed peat (Zak et al., 2008). Depending on the intensity of the land use or the drainage history respectively, this layer can be 20–50 cm thick and is characterised by a P mobilisation potential that is up to 100 fold higher than under natural conditions (Zak et al., 2010). This phenomenon can be mostly explained by oxygen-mediated peat mineralisation under drained conditions rather than by P fertiliser application (Zak et al., 2008), even if it accounts for up to 30 kg P ha^{-1} y^{-1} as documented in some agriculturally-used fens in East Germany. P concentrations in the porewater of rewetted severely degraded fens can be higher than 10 mg/L in contrast to the values under 0.1 mg/L usually found in natural fens (Zak et al., 2010). These values also substantially exceed the P concentrations in fen-feeding groundwater, although it is also well known that nutrient fluxes from agriculturally used catchments are considerably higher today than in pre-industrial times (Gelbrecht et al., 2005). The majority of dissolved P in porewater of rewetted peat soils is retained at the soil surface due to oxygen-mediated precipitation of Fe(III)-P compounds. In ‘iron-rich fens’ (molar Fe:P ratios in anoxic porewater >3), P is trapped more or less completely due to iron precipitation (Zak et al., 2004; Geurts et al., 2008). In this case, the inundated soil surface acts as a ‘P barrier’ similar to the surface of lake sediments, as long as this zone remains oxic (Fig. 2). Another important retention process in rewetted fens might be the P uptake by helophytes. Due to their nutrient removal capabilities, helophytes are often used in constructed wetlands to purify wastewater (Tanner, 1996; Wild et al., 2001; Állvarez and Bécares, 2006). However, most of the plant P stock may be released after die back at the end of the growing season through leaching and mineralisation (Koerselman and Verhoeven, 1992; Wrubleski et al., 1997; Kirschner et al., 2001). Consequently, helophytes contribute to the eutrophication of inundated peatlands by ‘smuggling’ P from the rooted soil layer across the redox interface at the soil surface into the overlying surface water. Mowing and removal of plants would interrupt the P recycling process after die back of plants. Whether this measure is effective in restoring rewetted fens as low-nutrient systems depends on the P uptake of the dominant helophytes in relation to the amount of P available in the upper, highly decomposed peat layer. Using data from previous studies on P mobilisation and the different P pools in rewetted peat soils (Zak et al., 2008, 2010), we aim to answer the following questions:

(1) How much of the P released in soil porewater is pumped across the fen surface into the aboveground biomass by different helophytes, relative to net diffusive P fluxes, during the growing season?
(2) How much would the annual removal of specific helophytes lower the P fractions available to plants in the degraded rooted surface peat layer? In other words, how long would it take to restore low nutrient levels in rewetted fens if plants were removed annually as an additional restoration measure?

The study emphasizes the important, albeit ambivalent, role of plants in the P cycle of rewetted peatlands both as compensators and stimulators of P mobilisation.