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The ecological effects of water level fluctuation and phosphate enrichment in mesotrophic peatlands are strongly mediated by soil chemistry

Ivan S. Mettrop[a,b,*], Melchior D. Rutte[b], Annemieke M. Kooijman[a], Leon P.M. Lamers[b]

[a] Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, P.O. Box 94248, NL-1090 GE Amsterdam, The Netherlands
[b] Department of Aquatic Ecology and Environmental Biology, Institute for Water and Wetland Research, Radboud University Nijmegen, NL-6525 AJ Nijmegen, The Netherlands

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ABSTRACT

Since the re-establishment of a more natural water regime is considered by water management in wetlands with artificially stable water levels, the biogeochemical and ecological effects of water level fluctuation with different nutrient loads should be investigated. This is particularly important for bio-diverse mesotrophic fens, sensitive to acidification and eutrophication. Mesocosm experiments were conducted to study the interactive effects of water level fluctuation and P-enrichment under controlled summer conditions, using peat cores including vegetation from three fens differing in biogeochemical characteristics.

The effects of fluctuating water levels on biogeochemistry and vegetation appeared to be highly dependent on peat chemistry, and more important than the effects of P-enrichment. Only when plant growth was stimulated by a favorable water level regime, P-enrichment led to increased P-consumption by plants. In rich fens with a high soil Ca-content, 7 weeks of lowered water table (−15 cm) did not lead to a drop in pH. However, soil subsidence, increased N-availability and decline of the rich fen bryophyte *Scorpidium scorpioides* give cause to concern. 7 weeks of inundation (+15 cm) offered possibilities for restoration in these fens, since alkalinity and Ca-concentrations increased, while soil P-mobilization did not occur. Even P-enrichment did not result in increased P-availability, presumably due to Ca-related precipitation of P. In rich fens with a high soil Fe-content, water table lowering should be avoided as well, because of soil subsidence, increased N-availability, decline of the rich fen bryophyte *Calliergon giganteum*, plus acidification due to Fe-oxidation. Shallow inundation, however, is also harmful, especially after mowing and with P-rich water, because plant growth was hampered, presumably by toxicity of NH_4^+ and/or Fe(II). In mineral-poor fens with a high soil P- and S-content, shallow inundation should be avoided, because of tremendous internal P-mobilization. Vitality of the dominant bryophyte *Sphagnum palustre*, however, was not affected. Low water tables affected neither vegetation, nor biogeochemistry, showing resistance to short-term drought in these fens.

Given the strong mediating effect of soil chemistry, risks and benefits of re-establishment of fluctuating water levels with clean or P-rich water need to be considered for different fen types separately in water and nature management.

1. Introduction

Mesotrophic fens, which are protected under the European Habitats Directive (*H7140 – Transition mires and quaking bogs*), are subject to serious deterioration in agricultural areas. Water shortage, acidification, eutrophication, and accumulation of toxins are considered to be major constraints on effective management and restoration of these fens (Lamers et al., 2015). Especially in rich fens, the combined effect of acidification and eutrophication is considered problematic, since characteristic species-rich vegetation communities may rapidly be transformed into relatively species-poor *Sphagnum*-dominated communities (Kooijman, 1992). As a result of differences in their hydrogeological setting and climatological conditions, rich fens show range of different

* Corresponding author at: Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, P.O. Box 94248, NL-1090 GE Amsterdam, The Netherlands.
E-mail addresses: I.Mettrop@uva.nl, Ivan@samage.net (I.S. Mettrop).

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hydrological regimes from no fluctuation to fluctuations between −50 cm and >1 m, affecting vegetation and peat accumulation (Lamers et al., 2015). In agricultural areas, however, water level fluctuations are generally constricted within narrow limits by intensive hydrological management. In pristine wetlands, however, water levels vary with the meteoric and groundwater balances in and around these wetlands (Baker et al., 2009), affecting biogeochemical processes and plant succession. Therefore, water management authorities are considering re-establishment of fluctuating water levels in order to optimize the generic ecological quality in non-pristine fens (Cusell et al., 2013a). However, soil biogeochemical characteristics largely differ among different fen types, as influenced by Ca-rich or Fe-rich surface water and groundwater, or by historical flooding with sulfate-rich seawater. Also, with a higher incidence of water table fluctuation, water quality becomes an important factor, especially when fens are inundated from time to time. To support water management authorities in decision-making, therefore, a better understanding of the different biogeochemical and ecological effects of fluctuating water levels with different water qualities for various fen types is essential.

During periods of drought, aerobic oxidation processes prevail due to oxygen intrusion into the soil, potentially decreasing the acid neutralizing capacity (ANC) and pH (Stumm and Morgan, 1996), and increasing N- and P-mineralization (Olde Venterink et al., 2002; Mettrop et al., 2014). These effects could hamper the development of protected brownmoss vegetation in rich fens, especially during summer (Cusell et al., 2013b). However, temporary drought may be beneficial to some extent, since Fe-oxidation can lead to rapid binding of phosphate in the soil (Richardson, 1985), temporarily reducing P-availability in porewater that can be important to maintain P-limitation. Although the general effects are relatively well known, the actual impact of drought may strongly differ among fens with different biogeochemical characteristics. In Fe- and S-rich fens, the effects of drought-induced oxidation and acidification may be stronger than in Ca-rich fens, because Ca is not redox sensitive and changes in pH can be buffered (Stumm and Morgan, 1996). The response of P-availability to drought may also differ among fen types, since the P-binding capacity of the soil under oxic conditions is expected to strongly depend on the Ca and/or Fe contents.

During wet periods, the water table increases and inundation may occur. In the case of Ca-HCO_3^- rich water, inundation and infiltration can increase soil ANC (Cusell et al., 2013a, 2015). In addition, inundation leads to the sequential reduction of nitrate, iron and sulfate as alternative terminal electron acceptors. Since these microbial processes generate alkalinity, the ANC may further increase (Stumm and Morgan, 1996). At the same time, however, P-availability may increase as a result of net P-mobilization (internal eutrophication) due to Fe reduction (Patrick and Khalid, 1974). Especially in Fe-rich soils with high P-contents, this anaerobic P-mobilization can be severe (Zak et al., 2010; Cusell et al., 2013b). Moreover, high sulfate reduction rates and formation of iron sulfides (FeS_x) may result in additional P-mobilization in S-rich soils (Smolders and Roelofs, 1993; Caraco et al., 1989; Lamers et al., 1998b). In addition, anaerobic conditions may lead to the formation of potential phytotoxins such as NH_4^+, H_2S, and Fe(II) (Lamers et al., 2015).

Increased surface water influence, as a result of inundation, can also lead to higher nutrient inputs (external eutrophication) (e.g. Wassen et al., 1996). In relatively nutrient-poor (mesotrophic) fens adjacent to agricultural areas, external P-input can be highly detrimental (Lamers et al., 2015), and its effect strongly depends on biogeochemical characteristics of the peat soil.

The main objective of this study was to test the effects of water level fluctuation and water quality for fens differing in biogeochemical characteristics. To be able to study the interacting effects under controlled conditions, we carried out a mesocosm experiment involving two rich fens differing in soil Fe-content and a mineral-poor fen with a high soil P-content, typical for fen types in many parts of the world. Water level effects were not only studied separately, but also subsequently, to assess whether the effects of drought could be restored by inundation, and vice versa. Studying these different water level sequences over time is also important for the field situation because vegetation development varies greatly over the growing season. We measured soil surface height, ANC, nutrient dynamics and vegetation development. It was hypothesized that increased surface water P-loads would particularly promote vegetation growth. Further, we expected that drought would result in acidification, particularly in Ca-poor fens, because these are considered to be more sensitive than Ca-rich fens (Lucassen et al., 2002). Inundation was hypothesized to result in alkalinization, but also in internal P-mobilization, particularly in Fe-rich fens.

2. Material and methods

2.1. Three fen types

Peat cores were collected from three different locations with characteristic fen types, differing in chemical composition of peat and porewater.

The Stobbenribben rich fen ('ST'; N52°47′5.5″, E5°59′1″; dominated by *Scorpidium scorpioides* (Hedw.) Limpr.) is part of the Ramsar wetland area Weerribben-Wieden, and characterized by supply of lithotrophic base-rich surface water (Van Wirdum, 1991). As a result, relatively high pH and Ca-concentrations were detected in soil porewater (Table 1). The low soil P_{tot} content and high Ca_{tot} content of 247 mmol kg^{-1} d.w. resulted in a relatively high average soil molar Ca:P ratio of 27. Vegetation was dominated by Cyperaceae, predominantly *Carex elata* (All.), and to a lesser extent *Carex lasiocarpa* (Ehrh.), *Carex diandra* (Schrank) and *Carex rostrata* (Stokes).

The Binnenpolder Tienhoven rich fen ('BPT'; N52°10′30.7″, E5°6′0.4″; dominated by *Calliergon giganteum* (Schimp.) Kindb.) is part of the Vechtplassen area, and characterized by discharge of base-rich and Fe-rich groundwater in the former floodplain of the river Vecht. Although Ca-concentrations were relatively high, this site was especially rich in Fe, with porewater Fe-concentrations around 500 μmol L^{-1}. In addition, soil Fe_{tot} content was respectively 6–7 times higher than in the other two locations, resulting in a relatively high molar Fe:P ratio of around 13. Vegetation was dominated by *Menyanthes trifoliata* (L.) and Juncaceae, predominantly *Juncus subnodulosus* (Schrank), and *Juncus articulatus* (L.).

The mineral-poor Ilperveld fen ('ILP'; N52°26′35.7″, E4°55′56.1″; dominated by *Sphagnum palustre* (L.)) was characterized by high porewater S_{tot} concentrations and a relatively high soil S_{tot} content, as a relic of flooding by the former Zuiderzee inland sea in the past. This fen type was further characterized by very high porewater o-PO_4 concentrations of around 40 μmol L^{-1}, respectively 75 and 370 times higher than for the ST and BPT rich fen types, while soil P_{tot} was only 1.3–2 times higher. Vegetation was dominated by *Phragmites australis* (Steud.) and *Carex riparia* (Curtis).

2.2. Experimental setup

In each fen type, 24 peat soil cores of the upper 30 cm, including mosses and vascular plants, were collected in December 2012 using PVC columns with a diameter of 16 cm and a length of 50 cm. Since sampling took place in winter, biomass was still low. The cores were subsequently used in a 14 week mesocosm-experiment.