UNIVERSITY OF AMSTERDAM

Preventing Acidification and Eutrophication in Rich Fens: Water Level Management as a Solution?

C. Cusell

Summary

For my thesis, I examined the effects of the re-introduction of fluctuating surface water levels in freshwater wetlands. These systems, and especially the rich fen wetlands that I focused on, often consist of a mosaic of aquatic, semi-aquatic and terrestrial vegetation types, including many biodiverse communities with high numbers of endangered species. Rich fens are protected under the European Habitat Directive (transition mires and quaking bogs, type H7140), and are characteristic for well-buffered (with respect to acidity) and nutrient-poor conditions. Next to overall eutrophication, high NH4-concentrations may specifically be toxic to bryophytes and vascular plants in rich fens. For the preservation and restoration of rich fens, it is therefore important to prevent acidification, eutrophication and toxicity.

In densely populated, lowland regions that are dominated by agriculture, such as the Netherlands, surface water levels are kept at an almost constant level throughout the year. Under such conditions, the re-introduction of more fluctuating surface water levels has been propagated to improve water quality in wetlands and to counteract potential effects of acidification, eutrophication and toxicity in fens. Lowered as well as raised surface water levels may, however, also stimulate these adverse processes. Therefore, the main objective of this thesis has been to determine the potential beneficial and harmful effects of lowered and raised surface water levels on the biogeochemical and ecological functioning of fens, with a strong emphasis on the preservation and restoration of endangered brownmoss-dominated rich fens. The studies have been performed in the Dutch National Park Weerribben-Wieden, which is a large and protected Ramsar freshwater wetland in the Netherlands, in which groundwater discharge hardly occurs. Studies have been carried out at two spatial scales: at the regional level of the entire wetland as well as at the level of site conditions of plants.

Chapter 2 The biogeochemical effects of short-term (two weeks) surface water level rises (+ 10 cm; during winter and summer) and drawdowns (-15 cm; during summer) were tested in large-scale field manipulation experiments in floating and non-floating fen sites. The results suggest that two weeks of summer drought do not have a severe effect on biogeochemical conditions, both in floating and non-floating fens.

Two weeks of raised surface water levels may, on the other hand, counteract acidification in base-rich fens, but only if this leads to flooding and infiltration into the peat soil. Flooding only occurred in non-floating fens, and was absent in floating fens. However, flooding in non-floating fens did not automatically result in an increase of the acid neutralization capacity (ANC) of the soil. In most winters, infiltration of base-rich flooding water did not occur, because soils were already waterlogged before the rise of the surface water level. The ANC increased much easier during summer, because higher temperatures and subsequent higher evapotranspiration led to enhanced infiltration of base-rich flooding water. In addition, internal alkalinity generation was higher due to higher microbial activity in the soil. Furthermore, low N- and P-concentrations in the flooding water at the field locations prevented any eutrophication during the floodings, both during winter and summer. In conclusion, the field experiments suggest that temporary increases of surface water levels may be a suitable management tool to enhance the ANC in non-floating fens, especially in summer, as long as nutrient concentrations are not too high in the flooding water and infiltration is possible.

Chapter 3 Since longer periods of inundation and water level drawdown could not be tested in the field, mesocosm experiments have been performed in the laboratory. The impact of long-term (31 weeks) lowered and raised water levels on the biogeochemistry and vegetation of rich fen mesocosms were tested under winter and summer conditions. The results show that long episodes with lowered water levels will lead to decreased alkalinity due to aerobic oxidation processes in the moss layer. In addition, lowered water levels hampered the vitality of brownmosses in rich fens, especially under summer conditions. Long lasting periods with low water levels therefore seem to be harmful to rich fen vegetation.

In contrast, long-term inundation had a positive effect on rich fens by increasing the ANC due to microbial reduction processes and infiltration of base-rich water. The effect was significantly larger under summer conditions, which is presumably caused by the larger evapotranspiration and higher microbial activity. P-rich fens should, however, be handled with caution, since internal P-mobilization may occur during long-term inundations in soils that contain high total P-content and low Fe:P-ratios. Although inundation also resulted in the accumulation of NH4, the occurrence of NH4-toxicity was unlikely because concentrations only increased under winter conditions, when plants are less sensitive. Under summer conditions, radial oxygen loss (ROL) from active plant roots presumably stimulated nitrification and prevented NH4-accumulation.

Chapter 4 A long-term laboratory incubation experiment was performed, to test the effects of (a) anaerobic, waterlogged conditions, (b) aerobic, moist conditions which are characteristic for aeration (oxygen intrusion) and (c) aerobic, desiccated conditions (oxygen intrusion plus water shortage). Mineralization and acidification rates were studied in peat from *Sphagnum*-dominated poor fens and rich fens. Under anaerobic conditions, net N-mineralization rates were much higher in the acid *Sphagnum*-peat than in the base-rich peat from rich fens, while gross N-mineralization rates were significantly higher in the rich fen peat. This is caused by higher microbial N-demand and N-immobilization in rich fen peat. The response upon aeration differed greatly between rich fen peat and *Sphagnum*-peat. In rich fen peat, aeration resulted in a significant decrease of the pH. In addition, aeration led to increased net N-mineralization rates in the rich fen peat, but not in *Sphagnum*-peat. The absence of aeration effects in *Sphagnum*-peat indicates that mineralization rates are more strongly determined by litter quality than by oxygen intrusion. Upon further desiccation, net P-release, which remained unchanged upon aeration, increased significantly in peat from both fen types, probably due to microbial mortality and/or a change in microbial composition. The strong response to aeration in rich fens compared to *Sphagnum*-fens, as well as the strong increase in P-availability upon further desiccation in both fen types, suggest that prolonged periods with drought have severe effects, especially on rich fens.

Chapter 5 To gain more insight into the effect of more fluctuating water levels and related nutrient characteristics at a wetland landscape scale, chemical speciation and binding of relevant nutrients have been analyzed in surface waters, soils and plants along a gradient from water entry locations to more isolated rich fens. Based on plant N:P-ratios, P-availability was lowest in relatively isolated rich fens, which were characterized by P-limited conditions. P-limitation can persist here despite relatively high P-inputs at the peripheral entry locations, because only a small part of these inputs reaches the more isolated waters and fens. This pattern in P-availability is mainly caused by the precipitation of Fe-phosphates, which primarily occurs close to entry locations as indicated by high concentrations of Fe- and Al-bound P in the sub-aquatic sediments near pumping stations, and by biological sequestration, which occurs throughout the wetland as indicated by equal concentrations of organic P in all sub-aquatic sediments. Therefore, these results clearly show that the periphery of large wetlands act as an efficient P-filter, sustaining the necessary P-limitation in more isolated parts.

Chapter 6 To test the nature of nutrient limitation in relation to soil characteristics, fertilization experiments with N, P and K were carried out in different rich fen types. In this way potential eutrophicating effects of flooding with nutrient-rich water can be coupled to specific nutrients involved. There were strong contrasts among the responses of the three rich fens. A floodplain fen with *Hamatocaulis vernicosus* showed no response to P-addition, but N- and K-addition led to grass encroachment and decline of moss cover and species richness. In contrast, a floating fen with *Scorpidium scorpioides* was clearly limited by P, while vascular plant production in a non-floating fen with *Scorpidium cossonii* was co-limited by N and P. In the latter two fens, P-fertilization also resulted in the replacement of *Scorpidium* spp. by *Calliergonella cuspidata*, which may be problematic since *C. cuspidata* is easily overgrown by large acidifying *Sphagnum* spp. The cover of *Scorpidium* spp., however, also declined after extreme N-addition, which was presumably caused by NH4-toxicity.

These striking contrasts among fens corresponded with clear edaphic differences. The N-limited *Hamatocaulis*-fen showed low total Ca:Fe-ratios and labile N-concentrations in the soil, and high concentrations of plant-available P and Fe-bound P. The P-limited conditions in rich fens with *Scorpidium* spp. is presumably caused by the significantly higher total Ca:Fe-ratios in the soil compared to the N-limited floodplain fen with *Hamatocaulis vernicosus*, which resulted in low concentrations of plant-available P and Fe-bound P in the soil. Although precipitation of Fe-phosphates is reported to diminish P-availability in fens, this study shows a positive correlation between P-availability and Fe-concentrations in rich fen soils, indicating that higher Fe-concentrations do not necessarily result in lower P-availability, as plants are able to mobilize this Fe-bound P. In conclusion, the experiment clearly shows that edaphic characteristics dictate the nature of nutrient limitation in rich fens.

Chapter 7 This synthesis integrates and discusses all results and management implications of the previous chapters, with the emphasis on the potential beneficial and harmful effects of lowered and raised surface water levels on the ANC and nutrient status of brownmoss-dominated rich fens. Since brownmoss-dominated rich fens only persist under well-buffered and rather nutrient-poor conditions, managers of rich fens should focus on the preservation and restoration of these conditions. Although no negative effects were found during two weeks of lowered water levels in field experiments, it is nevertheless recommended to prevent prolonged periods with low water levels as much as possible. If soils become too dry, net N-mineralization will increase and pH will decrease due to aerobic oxidation processes. In addition, several weeks of full desiccation will presumably lead to drought stress in *Scorpidium*-mosses and to a large net P-release.

Raised surface water levels, on the other hand, may be beneficial to rich fens, but only under specific conditions. Firstly, a rise in surface water levels should lead to actual inundation with base-rich water. In National Park Weerribben-Wieden, most non-floating fens and *Scorpidium*-dominated floating fens get flooded during surface water level rises of about 15 cm. Similar rises do, however, not lead to inundation of most *Sphagnum*-dominated floating fens, since they migrate with the surface water levels. Secondly, inundation water should not contain too much nutrients. If surface water is eutrophic, the type of nutrient limitation will determine the effect of specific nutrient inputs on rich fens. Thirdly, the base-rich and nutrient-poor inundation water must be able to infiltrate into the soil. In winter, when evapotranspiration is low and soils are generally waterlogged, infiltration is often impossible. In summer, infiltration of Ca-rich water and internal alkalinity generation are much more likely due to higher temperatures and evapotranspiration.

As a general conclusion, I have been able to unravel the differential effects of water table fluctuation in rich fens in relation to surface water quality, peat quality and season, by the combination of correlative field research, large-scale and smaller scale field manipulation experiments, climate room and peat incubation experiments. In this way, my thesis not only contributes to more fundamental biogeochemical and ecological issues related to surface water level fluctuations, but can also be used for decision support in the hydrological management of rich fens.