Biogeochemical Constraints for Restoration of Sulphate-Rich Fens

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Summary

In the beginning of the 19th century, increased agricultural activities were accompanied by building and deepening of drainage ditches, resulting in reduced groundwater tables in many fens along the river Meuse. Especially during dry summers, the reduced groundwater tables led to strong desiccation of groundwater-fed fens, including black alder carrs. As a consequence, the characteristic species-rich vegetation was replaced by a more species-poor and drought-resistant vegetation. Next to influencing groundwater quantity, the increased agricultural activities also led to changes in groundwater quality. Increased manuring of pastures and ammonia emission have led to increased leaching of nitrate to the groundwater. Nitrate reacts with marine geological pyrite-containing deposits in the subsoil resulting in mobilisation of sulphate. Thus, the concentrations of nitrate and sulphate in the groundwater have increased during the last decades depending upon the concentration of nitrate leaching to the groundwater and the amount of pyrite in the subsoil.

Some years ago, restoration measures were taken in some desiccated fens. As recovery of the regional groundwater table is often impossible, water levels in many fens were increased by simply damming surface water. Under semi-natural conditions, groundwater input is restricted in summer and periodic drought takes place. However, by damming surface water, permanent high water tables were maintained and no periodic droughts took place anymore. Damming of surface water was accompanied by the disappearance of the characteristic vegetation at the seepage zones and by massive growth of common duckweed (Lemna minor) and fast growing wetland grasses including reed sweetgrass (Glyceria maxima) and floating sweetgrass (Glyceria fluitans).

In this thesis, biogeochemical processes occurring in sulphate-rich groundwater fed fens are studied under two hydrological conditions: semi-natural conditions with a continuous input of base-rich and iron-rich groundwater, and conditions in which groundwater input is strongly decreased as a consequence of damming surface water. The aim of this study was to find out which factors and processes are responsible for the observed change in vegetation (from plants characteristic of mesotrophic to highly eutrophic conditions) and to determine biogeochemical constraints for the restoration of desiccated sulphate-rich fens.

Under semi-natural conditions, the continuous input of groundwater supplies fens with bivalent cations (iron, calcium and magnesium) and electron acceptors for the microbial breakdown of organic matter (iron, nitrate, sulphate). High inputs of bivalent cations via the groundwater lead to saturation of the sediment adsorption complex in seepage zones, preventing the binding of NH$_4^+$, which is then continuously removed via the flowing groundwater. So a high input of bivalent cations via the groundwater results in restricted ammonium availability in fens. The continuous input of iron(hydr)oxides also increases the
capacity of the aerobic sediment top layer to bind phosphate resulting in a decreased mobilisation of phosphate from the sediment to the water layer. Next to this, reduced iron is capable of binding sulphide in the sediment restricting mobilisation of phosphate in the sediment due to the interaction of sulphide with iron-phosphate complexes. Under semi-natural conditions the formation of iron-sulphides is restricted as sulphate reduction is inhibited in the presence of high iron and nitrate concentrations which are energetically more favourable electron acceptors. Immobile iron-sulphides are oxidised as a consequence of periodic drought during summer, regenerating immobile iron(hydr)oxides capable of binding phosphate, while mobile sulphate is removed via the flowing water layer when groundwater input increases. Oxidation of iron-sulphides also leads to the production of acid. The sensitivity of sediments to drought, acidification and mobilisation of heavy metals depends upon the amount of iron-sulphides and the buffering capacity of the sediment. In contrast to seepage zones that never dry out, periodic drought of parts outside seepage zones mostly will not lead to strong acidification as no accumulation of iron-sulphides takes place. Periodic drought also leads to oxidation of ammonium and formation of nitrate which diffuses to deeper anaerobic sediment layers where it is denitrified resulting in the production of nitrogen gas that disappears into the atmosphere (a process called coupled nitrification-denitrification). Under these mesotrophic conditions, fens are dominated by a species-rich Calthion-vegetation characterised by species like marsh marigold (Caltha palustris), swamp horsetail (Equisetum fluviatile), greater spearwort (Ranunculus flammula) and many Carex-species including elongated sedge (Carex elongata) and cyperus sedge (Carex pseudocyperus).

Increasing water levels in desiccated fens by damming surface water leads to a decreased groundwater input and thus to a restricted supply of base cations and the electron acceptors (iron and nitrate). The lower input of bivalent cations leads to increased binding of ammonium to the sediment adsorption complex resulting in a higher ammonium availability in the pore water. Reduction of sulphate is no longer inhibited as iron and nitrate are depleted. Produced sulphide will reduce iron from iron-phosphate complexes resulting in phosphate mobilisation. By maintaining permanent high water tables, no periodic drought occurs during summer. As a consequence, iron-sulphides are not oxidised and the concentration of iron capable of binding phosphate remains low. Thus in stagnating surface water, nutrient availability in the sediment is high and accumulation of nutrients to the stagnating water layer takes place. The increased sulphide concentrations in the sediment are toxic to the characteristic Calthion-vegetation. Black alder (Alnus glutinosa) dies, falls down and light intensity increases. The increased light intensity, in conjunction with the increased nutrient availability, leads to massive growth of Lemna minor and fast growing wetland grasses. Glyceria fluitans and Glyceria maxima are capable of detoxifying sulphide outside the plant as they have high radial oxygen losses at the roots. Lemna minor can completely cover the water surface when phosphate concentrations in the water layer are high. As a consequence, less oxygen diffuses into the water layer and the water layer can become anaerobic which further stimulates the mobilisation of phosphate from the sediment to the water layer.
For a successful restoration of desiccated fens, they have to be gradually rewetted, with regular desiccation periods included, in order to allow an Fe pool to build up in the desiccated sediments. The adverse effects of $\text{SO}_4^{2-}$ accelerate with rising water tables. Building up an Fe pool makes the previously desiccated parts of fens less sensitive to $\text{SO}_4^{2-}$ reduction in periods when groundwater inputs are relatively high. In addition, stagnation of surface water should be avoided. Water tables can be raised without causing stagnation of surface water by raising them to below the potential groundwater table. This maintains a positive groundwater pressure, which enables continuous flow-through of groundwater, supplying base cations and electron acceptors to the system. Finally, periodic drought during summer is important in oxidising reduced Fe compounds in the sediment and thus in re-increasing the content of Fe(III) capable of binding $\text{o-PO}_4^{3-}$. Periodic drought can be achieved by making use of a controllable dam.