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Restoration of acidified and eutrophied rich fens: Long-term effects of traditional management and experimental liming

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A B S T R A C T

Rich fens are known for their high botanical diversity encompassing many endangered species. For decades, several management measures, including mowing and burning, have been applied to maintain a high biodiversity by means of slowing down the natural succession from calcareous rich fens to acidic poor fens or woodland. In this study, we assessed the long-term effects of these traditional management measures, and explored the effectiveness of liming as a measure to restore rich fen vegetation. Effects of summer mowing, and of burning after winter mowing, were assessed by comparing current (2013) and historical (1967) vegetation data. Effects of experimental liming, using different levels of lime addition (0, 1000, 2000, and 4000 kg Dolokal/ha), were monitored in the field during 7.5 years. Summer mowing led to more acidic and nutrient-poor conditions as indicated by a shift from rich to poor fen vegetation, including a well-developed bryophyte cover dominated by *Sphagnum* with some threatened species. Burning (after winter mowing) counteracted acidification but increased nutrient availability, as indicated by dominance of vascular species characteristic of productive tall-herb grasslands and a sparse bryophyte cover with common species. We conclude that the traditional measures were unable to maintain rich fen composition in the long term. Given the fact that the restoration of hydrological conditions, favouring rich fens, is not always feasible, liming could be an alternative to counteract acidification and improve rich fen conditions in the short term. This measure, however, appeared to be unsustainable as the re-establishment and dominance of *Sphagnum* spp. seriously complicated the development of rich fen vegetation in the longer term.

1. Introduction

Fens show a high habitat and species diversity, and are home to many rare and endangered plant species (Bootsma et al., 2002; Bedford and Godwin, 2003). As they show a natural terrestrialisation from open water into different successional stages of vegetation composition, fens often comprise a myriad of vegetation types. The formation of floating mats and the subsequent increase in peat thickness leads to increased influence of base-poor rainwater, and reduced influence of base-rich surface water and/or groundwater, which still remains dominant in the margins and deeper in the peat mat. This process creates a biogeochemical gradient that enhances the development of different successional stages from rich fen (dominated by *Cyperaceae* and brown mosses), via poor fen (with or without hummock forming *Sphagnum* species), towards eventually carr woodland (Verhoeven and Bobbink, 2001; Grootjans et al., 2006). Rich fens are generally more species-rich than poor fens or woodlands. These earlier successional stages are, however, seriously threatened and biodiversity has strongly declined in many rich fens as a result of fast succession to either poor fens or woodlands (Beltman et al., 2001,b; Middleton et al., 2006a,b; Lamers et al., 2002, 2014).

Due to anthropogenic influences including major changes in hydrology, agricultural pollution of groundwater and surface water, and increased atmospheric deposition of sulphur and nitrogen, many fens have degraded as a result of concomitant desiccation, acidification and eutrophication (Hogg et al., 1995;

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Kooijman and Paulissen, 2006; Klimkowska et al., 2007; Lamers et al., 2002, 2014). This has significantly changed the rate, course and outcome of succession, resulting in accelerated transition of Brownmoss dominated rich fens to *Sphagnum* dominated poor fens (van Diggelen et al., 1996; Kooijman and Paulissen, 2006; Bobbink et al., 2010; Lamers et al., 2014). If *Sphagnum* spp. become dominant, acidification is accelerated by their high rain water retention, cation exchange and active excretion of uronic and phenolic acids, enhancing peat accumulation (Hemond, 1980; Verhoeven and Liefveld, 1997; Bootsma et al., 2002). In addition, eutrophied fens often show a low species diversity as slow-growing vascular plant- and bryophyte species, adapted to low nutrient concentrations, are outcompeted by tall-growing, highly productive species (Hogg et al., 1995; Bobbink et al., 1998, 2010; Cusell et al., 2014a).

To counteract these anthropogenic effects, and in particular to maintain the original lifespan of early successional vegetation, such fens depend on active management including mowing, grazing or burning (Hogg et al., 1995; Middleton et al., 2006a). For decades, mowing has been a traditional management tool in European fens. The removal of biomass and resulting increase of light availability is thought to increase biodiversity, but only if species are still present or able to disperse or germinate (Middleton et al., 2006a). However, few studies have tried to explore long-term effects of mowing management on vegetation development in fens (van Diggelen et al., 1996; van Belle et al., 2006). Burning after winter mowing can be useful to remove litter, and fire is also thought to slightly raise the soil pH and base-cation concentrations (Raison, 1979). However, not much is known about the potential role of burning in maintaining rich fen biodiversity (Middleton et al., 2006a).

Acidification is recognised as an important issue in fens nowadays. More intrusive measures, such as top-soil removal have enhanced acidification due to stagnation of rainwater, re-establishment of *Sphagnum* (Beltman et al., 1996b; Beltman et al., 1996b), and the exposure of the formerly reduced peat soil to oxygen that may oxidise reduced sulphur (Mylona, 1996). A more recent measure to counteract acidification is the application of lime, which may improve base-rich conditions by increasing acid buffering, and preventing *Sphagnum* spp. from becoming dominant (Beltman et al., 2001; Dorland et al., 2004). In this way, base-rich conditions may be restored, enabling minerotrophic rich fen species to re-establish (Beltman et al., 1996a, 2001; Patzelt et al., 2001). However, an increase in soil pH may at the same time stimulate peat decomposition and increase mineralisation (Ono, 1991; Smolders et al., 2002). As only few studies have explored the effectiveness of liming on vegetation and biogeochemistry, in our study we experimentally tested this measure to restore rich fen vegetation from *Sphagnum*-dominated poor fen vegetation, by applying different levels of lime and monitoring the development over a period of 7.5 years. In addition, we assessed the long-term effects of traditional management measures aimed at maintaining species richness in fens. Effects of summer mowing, and of burning after winter mowing, were assessed by comparing current (2013) with historical (1967) vegetation data. Our results will be discussed with respect to their implications for future management to restore rich fen vegetation in fens.

2. Methods

2.1. Research area

The research was carried out in the wetland reserve and Natura 2000 area the 'Nieuwkoopse Plassen' in The Netherlands (52°9′N, 4°49′E). This area is characterised by alternating ridges of peat and peat extraction ponds, with an extensive network of canals and ditches throughout the reserve, as well as several large shallow fen lakes (den Held et al., 1992). The current vegetation types, representative of different successional stages found on peat mats, can only be maintained by human interference, as areas without management have all developed into carr woodland (Wiegers, 1992). The surface level is ± 1.5 m below sea level, which is 0.4–4 m higher than surrounding agricultural areas that have subsided due to drainage. As a result, the Nieuwkoopse Plassen reserve has become an infiltration area dependent on precipitation and relatively nutrient-rich, buffered surface water from the river the Oude Rijn to maintain sufficiently high surface water levels.

2.2. Comparing current with historical vegetation data

2.2.1. Sampling strategy

The vegetation of the Nieuwkoopse Plassen was investigated by den Held in 1967 (den Held, 1970), by recording the cover and composition of bryophytes and vascular plant species in randomly selected plots throughout the reserve. In 2013, 49 of these historic fen sites were reassessed. The selection was based on their current management type (23 summer-mown, and 26 winter-mown and burned), the vegetation composition in 1967 (equal distribution of the different successional stages) and the accuracy by which the sites could be found again. Selected sites ranged in size from 2 to 30 m^2 (average size of 10 m^2). It was not known exactly how long summer mowing and burning after winter mowing had been carried out since 1967. We do know, however, that the measures had been carried out annually for at least 10 years before the start of this part of the research.

2.2.2. Vegetation assessment

Composition and cover of bryophytes (April–May, 2013) and vascular plants (June–July, 2013) were assessed using the ordinal scale used by den Held (1970): codes 1–4 represent <5% cover with 1: 1 individual, 2: 2–5 individuals; 3: 6–50 individuals, 4: >50 individuals; 5: 5–12% cover; 6: 13–25% cover; 7: 26–50% cover; 8: 51–75% cover; 9: 76–100% cover. The numbers of individuals for categories 1–4 were adjusted to account for the differences in size between the relevés by multiplying them with a factor calculated as the log of the area of the relevé, divided by the log of the standard relevé area (4 m^2). The nomenclature follows van der Meijden (2005) for vascular plants and Siebel and During (2006) for bryophytes, but *Sphagnum capillifolium* and *Sphagnum rubellum* were considered one species. Additional information about red-list status and common habitats was gained from Synbiosys (version 2.5.8. Alterra, Wageningen).

2.3. Liming experiment

2.3.1. Experimental set up

In October, 2006, 12 plots of 3 m × 3 m were created on a thick, (formerly) floating mat, from which the top soil (10–30 cm) had been removed in the winter of 2000–2001. At start of the experiment, the mat had been (re-) acidified and become dominated by *Sphagnum* species. Vegetation was mown during summer every year, which continued during the experimental period. Liming treatments were randomly distributed over these plots (three replicates for each treatment): control, 1000 kg/ha lime (1 k), 2000 kg/ha lime (2 k), and 4000 kg/ha lime (4 k). The amount of lime for each treatment was equally spread over the plots as a powder (Dolokal; $CaCO_3$ 84%, $MgCO_3$ 10%, MgO 5%, <0,16 mm).

To assess treatment effects on soil chemistry, a pooled soil sample (2–3 subsamples) of the upper 10 cm was collected from each plot just before the treatment (t = 0), and at t = 0.5, 1, 2, 2.5, 4.5, and 7.5 years. Additionally, at t = 4.5 and 7.5 years, soil pore water