Biodiversity management of fens and fen meadows by grazing, cutting and burning

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Abstract

Question: Can the biodiversity of fens in Europe and North America be maintained through the use of grazing (especially cattle grazing), fire, and/or cutting?

Location: European and North American fens.

Methods: This paper is a review of the literature on the effects of grazing, fire and cutting on fens, to explore the relationship between management and biodiversity in fens.

Results: A reduction of cattle grazing, mowing and burning in fens has led to a reduction in biodiversity in fens. The vegetation of abandoned fens shifts to trees and shrubs after 10-15 years, which shade the smaller and rarer species of these wetlands. While careful use of fire is used to manage fens in North America, it is not widely used in European fens, perhaps because the peat of drained fens may catch fire. Cattle grazing cannot be considered a natural disturbance in North America, since cattle did not evolve on that continent. In Europe, cattle do not generally graze in unaltered fens, but they do use slightly drained fen meadows.

Conclusions: Three approaches have been used to control the dominance of tall woody and herbaceous species in abandoned fens, including the re-introduction of cattle, mowing, and burning. Overgrazing results in a permanent reduction in biodiversity, therefore cattle re-introduction must be approached cautiously. In Europe, but not in North America, mowing has been an important management tool, and mowing has been successful in maintaining species richness, particularly in fens that have been mowed annually for centuries. Fire has been the most common and successful management tool in North America although it is not effective in removing shrubs that have become large. Because the problems and solutions are similar, the literature of both European and North American fen management can be analyzed to better assess the management of fens on both continents. Many management questions require further study and these are listed in the paper.

Keywords: Cattle grazing; Fire; Mowing; Plant species richness; Sedge meadow.

Introduction

The loss of biodiversity of plant species in fens has been reported from many regions of the world (Middleton 2002a; Bragg & Lindsay 2003), and one reason for species loss in fens may be recent changes in land use practices related to agriculture (Vermeer & Joosten 1992; Jensen & Schrautzer 1999). Re-establishing former land management practices such as grazing, mowing and burning is often seen as a promising restoration strategy to increase biodiversity but these practices have a different historical context in various regions of the world. The question arises whether the regional history of management in fens has an influence on current management options because species are adapted to local management practices. Alternatively, the effects of mowing, grazing and burning may not be all that regionally specific so that the relationships of species richness, disturbance, productivity and spatial heterogeneity may be independent of land use history (Pollock et al. 1998).

Fens are defined as peat accumulating systems, which are influenced by groundwater (Joosten & Clarke 2002) but even after slight drainage, many characteristic vegetation types remain on altered fens if low intensity land use is practiced (Ellenberg 1996). In this article, we cover peat forming tall sedge and sedge moss communities but not reeds and carr vegetation types, which are of less interest from a biodiversity perspective (Wheeler & Shaw 1995). Additionally we deal with species-rich vegetation types that develop under low intensity land use on somewhat drained fens such as fen meadows.

Cattle grazing has historically been an important land use in slightly drained fens and fen meadows (Middleton 1999). General views on the effects of cattle grazing range from the idea that low to moderate levels of grazing are beneficial for plants species diversity (Hald & Vinther 2000; Bullock et al. 2001) to the idea that grazing is nearly always detrimental (Noss 1994). The specific effects of grazing may depend on site
productivity; with grazing, the species richness of nutrient-rich sites will increase whereas in nutrient-poor ones, species richness will decrease (Proulx & Mazumder 1998). The relationship between species richness and cattle grazing in fens is especially relevant for management and conservation purposes. While this paper focuses on the relationship of cattle grazing and plant species richness, many other studies have examined the relationship of cattle grazing and faunal communities, e.g., birds (McCoy & Rodriguez 1994; Norris et al. 1998) and insects (Gibson et al. 1992; Painter 1999; Pöyry et al. 2004).

Many characteristic fen species are increasingly rare at the same time that cutting, burning and cattle grazing have become less common in fens. A relevant question in this context is whether fens can be restored by the re-establishment of grazing once woody species have encroached or species richness has declined (van Wieren 1995). One question addressed in this paper is whether cutting, burning or cattle grazing is warranted as management tool in fens, and if so, under what circumstances it is appropriate in either North America or Europe. The role of each as a natural disturbance differs, as does the historical and cultural context of these management techniques.

Historically, the nature of burning, grazing and cutting, as well as the fens themselves, have differed between North America and Europe, but in this paper we seek to find some common ground for management. Fens used by humans for grazing were often drained to some extent, which adds a further complication to the discussion, because the hydrology of many fens has been altered. Slight drainage turned fens into fen meadows (Grootjans & van Diggelen 1995). Especially after fens have been grazed and/or drained, shrubs may invade and reduce biodiversity (Middleton 2002a), so that it is important to find some management alternatives to maintain the biodiversity of formerly grazed fens.

In the present paper, we will review literature about the effects of cattle grazing on fens in Europe and North America and management alternatives to conserve biodiversity. We specifically examine whether mowing and burning are more suitable to manage fens for native plant biodiversity than cattle grazing. First, the history of fire and cattle grazing will be reviewed to help determine if these are natural disturbances of inherent importance to the management of fens. Second, specific biodiversity responses of fen species to management using fire, grazing or cutting will be explored, and a few preliminary management recommendations will be drawn from those studies. Lastly, priority research to fill in gaps in knowledge related to fen management will be outlined.

Cattle grazing and cutting history in fens

To evaluate whether or not cattle grazing can be considered a natural disturbance in fens, we need to review the history of cattle grazing in fens. Before the era of livestock farming (Neolithic times), no domestic cattle grazed in wetlands. Instead, fens and/or neighboring woodlands in Europe were grazed by large ungulates such as Elk (Alces alces) and Red deer (Cervus elaphus; Cromsigt 2000), and in North America, Moose (Alces alces) and Wapiti (Cervus elaphus canadensis; Jackson 1961).

In about 6800 BP, domestic cattle (Bos taurus) were moved into central Europe. Free ranging domestic cattle were able to graze on winter cereals during autumn and early spring as well as on rotational abandoned fields, and they were fed with dried leaves during the winter (Ellenberg 1996). The first sites mowed by hand for brightness and fence grazing were reportedly developed from natural fens and alder woodlands that were dominated by Carex species (Ellenberg 1996). Mowing was the major land use type responsible for keeping the wetlands open and for the development of species-rich fen meadow vegetation in Europe (Bignal & McCracken 1996; Ellenberg 1996). The quality of the fodder cut from undrained fens was so low that hand-cut hay was used only as bedding in animal barns and sheds (Stammel et al. 2003). Free-ranging cattle avoid very wet, undrained fens, whereas drained fens are grazed intensively in summer (J.P. Bakker & Grootjans 1991). The preferred grazing habitats for cattle are productive ones such as flood-plains, salt marshes, temporary marshes and other similar systems, so that fens may never have been as important as other wetland types for cattle grazing.

The history of cattle grazing in fens in North America began with the influx of settlers in North America. Cattle were introduced in the 1700s from the east coast westward; some cattle grazed in Kentucky as early as 1784 (Prince 1997). At first, cattle grazing intensity was light because the cattle were not constrained by fences during the early settlement period. For example, in Wisconsin, cattle roamed freely before the 1870 laws requiring cattle to be fenced within property boundaries (Liegel 1988). After 1880, with the expansion of the railroads and better access to markets, the dairy industry expanded in North America (Prince 1997). After this expansion and with fencing, herd size increased gradually over time, so that the cattle grazing pressure on fens increased (Middleton 2002a).

In both Europe and North America, fen utilization followed economic developments in two directions after World War II. Most fens were drained to increase their productivity in densely populated regions. Pastured fens were abandoned in less densely populated areas in...
mountain regions and areas far away from population centers, and these abandoned fens often lost biodiversity because of encroachment by shrubs (Middleton 2002a; Matějková et al. 2003). After 1945, pasture abandonment was also associated with a reduction of hand cutting and hay making in fens (Slotte 2001). The cutting of fens had already ceased in North America before World War II (Prince 1997; Middleton 2002a). Thus, both intensification and abandonment led to a decrease in species richness in fens (Bekker et al. 1997).

In the context of this paper, we can ask the question of whether or not cattle grazing can be considered to be a natural disturbance in fens, and therefore used to maintain biodiversity in fens by mimicking prehistoric conditions. The answer in North America is an unqualified ‘no’, since cattle originated in the Old World. The answer also is ‘no’ in Europe, but the situation is less clear. While the aurochs (Bos taurus primigenius) originated in Europe, aurochs are unlikely to have ever used fens extensively. Nevertheless, we will consider later in the paper if there may be situations under which it is justifiable to use cattle to maintain the biodiversity of fens, particularly drained fens.

**Fire history of fens**

In North America, fire was probably a much more structuring factor than grazing during the presettlement period. Before the defeat of Chief Black Hawk in 1832, American Indians and lightning fires annually burned fens in Wisconsin and other parts of the Middle Western United States (Curtis 1959; Prince 1997). Also, farmers had once burned pastured fens to improve forage quality, but in places such as southern Wisconsin, this practice abruptly ceased after World War II (Middleton 2002b). After that time, many fens became less species-rich and/or encroached by woody species. Fire in North-American fens can be considered a natural disturbance, and should be considered to help maintain the biodiversity of fens.

Fire is generally considered destructive in peatlands in Europe (Klimkowska 2004), mainly because the peat may catch fire, particularly in drained fens. Once set, the fire may smolder for long periods of time (Anon. 2005). Nevertheless, fire set by lightning strike must have once burned undrained fens in the European landscape as it is reported for mires in Finland (Pitkänen et al. 1999), and so could be considered as a natural disturbance at least for the management of undrained fens. The burning of sedge meadows was regularly practiced in eastern Europe (Poland and Belarus) until recently (Kloskowski & Krogulec 1999; Kozulin & Flade 1999).

**Effects of cattle grazing on fens**

**Effects on vegetation composition**

While one might conclude that the loss of biodiversity in fens may be attributable primarily to land use changes associated with shifts away from cattle grazing, and that somehow re-instigating the practices of small farmers would solve the problem, the situation is actually more complicated than that. Unfortunately, there is little research available to illuminate some of the questions. For example, except for a few studies in calcareous fens (Middleton 2002a; Stammel et al. 2003), we are not aware of any studies on the effects of grazing in undrained fens. Also, the effects of establishing a grazing regime in abandoned fen meadows that were previously mown have been rarely studied (Arnesen 1999; Hald & Vinther 2000). We will therefore extrapolate knowledge on grazing from other systems to fens in some of our following examples.

Cattle grazing favors certain plant traits (Hald & Vinther 2000; Stammel et al. 2003), and thus the activities of cattle lead to shifts in biodiversity and community composition. In North American fens, Poa pratensis increases in dominance with grazing (Schulz & Leininger 1990; Martin & Chambers 2001; Middleton 2002a) because the species invades gaps more quickly than Carex nebrascensis. Poa pratensis has a phalanx growth strategy (clumped individuals with short rhizomes) and Carex nebrascensis has a guerilla growth strategy (unclumped individuals with long rhizomes; Martin & Chambers 2001). Once Poa pratensis has become established in grazed fens and sedge meadows, the species can remain in the community for decades after cattle grazing has ceased (Middleton 2002a).

Cattle defoliate plants, trample vegetation (Arnesen 1999), alter soil structure (Murray 1997), and crush sedge tussocks with their hooves, which can allow the invasion of shrubs. Cattle maintain palatable shrub species in a state of small stature while grazing, but if the cattle subsequently are removed from the fen, the shrubs may grow prolifically to form a dense stand of shrubs (Middleton 2002a). Unpalatable tree species such as Alder (Alnus glutinosa) may even grow up under constant grazing management with low animal numbers because cattle largely avoid eating the saplings (Bunzel-Drücke 1996; Holsten 2003). From a conservation perspective, the invasion of trees in fen areas is mostly regarded as a problem because the biodiversity of characteristic, low-stature fen species is reduced because of low light availability (Kotowski & Van Diggelen 2004). At the same time, cattle create ‘lawns’ of regularly grazed sites and ‘tussocks’ that are rarely grazed (McNaughton 1984; J.P. Bakker et al. 1984), so that
cattle increase the spatial heterogeneity of habitats for plants and animals. In wet meadows, small mammal density was positively affected by cattle at intermediate grazing intensities (ca. 0.5 cattle/ha) and negatively by much higher or lower stocking densities (Schmidt et al. 2005). The species number and abundances of grasshoppers, butterflies, solitary bees and wasps was higher in pastures with lower stocking rates than in intensively grazed pastures (0.7 cattle/ha vs. 3.2 cattle/ha, respectively; Kruess & Tscharntke 2002). However, other studies of freshwater wetlands indicate that grazing intensity hardly affects the species richness of invertebrate communities (Steinman et al. 2003).

Effects on seed dispersal

Large grazers are known to disperse many seeds, both in their manure (Burton 1948; Middleton & Mason 1992; Malo & Suárez 1995; Fischer et al. 1996; Pakeman et al. 2002; E.S. Bakker & Olff 2003; Myers et al. 2004; Mouissie et al. 2005c) and in their fur (Fischer et al. 1996; Middleton 2002a; Mouissie et al. 2005b). The dispersal of many plant species including fen species may once have benefited from the movements of cattle between mountainous summer grazing areas and lowland winter habitats in Europe, the so-called transhumance (Poschlod & WallisDeVries 2002). However, only very few characteristic species of montane grasslands were found as viable seeds in cattle dung while being absent from the local vegetation, either because these species were not consumed or because seeds did not survive (Matějková et al. 2003). Herbivores select productive patches for grazing but may cause a net transport of seeds and nutrients from sites of high to those of low productivity if the latter are used for resting (Mouissie et al. 2005a). Therefore, seed dispersal via cattle dung may be of limited value for restoration because seeds of novel species may not be transported between appropriate systems. Some studies indicate that the seed species carried by cattle are the principal species that invade hoof print gaps (Malo & Suárez 1995), while another study indicates that the establishment of species from seeds is prevented in hoof print gaps because nearby rhizomes quickly invade gaps (Stammel & Kiehl 2004). Nevertheless, grazers such as cattle and rabbits may have a dual role in seed dispersal and gap creation, respectively, and together maintain the species richness of subordinate herbs (floodplain grasslands; E.S. Bakker & Olff 2003). Clearly, not enough research is available to make the case that seed dispersal by cattle can increase fen biodiversity.

The role of cattle in introducing non-native species into wetlands also needs to be considered in the discussion of biodiversity conservation in fens. Especially in North America, cattle have a significant role in introducing non-native species into fens. Some of the non-native species of seeds that are found in the manure of cattle (Mt. Pleasant & Schlather 1994) are maintained in the seed banks of fens for decades after abandonment by cattle (Middleton 2002a). We are not aware of any studies that examine the role of cattle in maintaining native biodiversity in fens in North America.

Effects on nutrient availability

The idea that grazers can transport nutrients from fertile foraging sites to nutrient-poor sites (e.g. resting sites) requires further evaluation from the perspective of the maintenance of fen biodiversity (Bokdam & Gleichmann 2000; Mouissie et al. 2005c). Grazing cattle can add nutrients via manure to the otherwise nutrient-poor environment of a fen community (de Mazancourt et al. 1998). If supplemental feed is fed to dairy cattle, these additional nutrients may further change the status of fens (Middleton 2003).

The relationship of grazing to N-mineralization rates depends on the intensity of cattle grazing, the amount of flooding and the nature of the soil (organic vs. mineral). Because of the importance of local site conditions, grazing has been related to enhanced (McNaughton et al. 1997; Frank & Groffman 1998), decreased (Pastor et al. 1993; Ritchie et al. 1998; van Wijnen et al. 1999) and unaltered N-mineralization rates (Van Hoewyk et al. 2000; C. Bakker et al. 2003). The mineralization rate may depend on the size of the herbivore, the degree to which the vegetation is removed and dung returned, and the subsequent temperature and humidity of the gaps created. If mineralization is affected by cattle grazing, then not only the size of the grazer but also stocking density could affect the mineralization rate (E.S. Bakker et al. 2004). Recent evidence suggests that prolonged grazing also stimulates P-mobilisation and results in elevated P-levels in the upper soil layers of fens (pers. comm. J.P. Bakker), however, the mechanism of this phenomenon is not known.

At the same time that nutrient availability affects grazing, high amounts of nutrients may reduce the foraging efficiency of herbivores by supporting a high plant standing crop (van de Koppel et al. 1996). Related to this idea, after cattle were removed in various types of wetlands, there is often a drop in the number of waterfowl reported related to reduced foraging efficiency of the geese in tall vegetation (Olff 1992; McCoy & Rodriguez 1994). However, after cattle were removed from a monsoonal wetland in India, larger species of geese, e.g. Greylag geese, were more able to handle tall grasses than the smaller Barheaded geese (Middleton 1993; Middleton et al. 1991). The geese preferred to
graze in parts of the wetland that had been previously grazed by herbivores (Middleton 1993). In a Canadian salt marsh, standing crop increased when geese were fenced out of plots, but when the exclosures were removed, the geese did not graze the exclosed areas (Bazely & Jefferies 1986). Cattle may therefore facilitate grazing for other herbivores by reducing the size of plants, and this facilitation by cattle might be especially true in high-nutrient settings with high standing crops of plants (van de Koppel et al. 1996; Bos 2002).

Management conclusions

In both North America and Europe, a variety of management approaches have been used to maintain biodiversity in fens, including cattle grazing, burning, mowing and herbicide treatments. Not all of these approaches can be applied in all situations, and the research that is available indicates that the results of particular management strategies can be highly situation dependent. We have reviewed the available literature to convey the complicated nature of the issue, and address as many scenarios as possible. Much is not known, and gaps in knowledge are outlined in the final section of this paper.

Cattle vs. native ungulates

The re-introduction of appropriate native ungulates in fens could be beneficial, especially in relatively unpopulated regions. Native ungulates require large areas in which to range, and so it is not likely that these could be re-introduced successfully in urbanized areas. Other native ungulates could be re-introduced to fens in both Europe and North America. In North America, moose may once have been important herbivores in fens, and could be reintroduced in remote parts of North America. Moose are dangerous animals and not especially welcome in urbanized areas. Elk eat woody vegetation in European fens (Bokdam & van Braakel 2002), so that these could be useful to manage woody species in fens. Free ranging wild animals such as red deer in Central Europe have little influence on sedge-dominated fen vegetation because hunting pressure and disturbance by people keep the animals in the forests during daytime. When red deer enter open habitat at night, they prefer food of high energy and protein content (Wagenknecht 2000) and avoid vegetation dominated by sedges because of their low nutritional value.

With the simultaneous decline of cattle grazing and biodiversity in fens, it seems logical that a reintroduction of cattle in fens would lead to an increase in biodiversity. While Aurochs and wild horses no longer exist, Heck cattle and Polish Konik horses are available. Heck cattle were bred in an attempt to redevelop the aurochs by mixing various European cattle races. Polish Konik horses are a primitive horse breed from Poland and are sometimes used to graze fens in Europe (e.g. Wicken Fen, Norfolk and Suffolk Broads, England). Both Heck cattle and Polish Konik horses should be regarded as primitive breeds only, and not directly equivalent to their wild ancestors. Both Heck cattle and Konik horses avoid nutrient-poor sedge vegetation in the same way as red deer when nutrient-rich food is available (Vulink 2001). However, both of these large ungulate species resemble their extinct wild ancestors, and so have been introduced to some nature reserves in Europe (J.P. Bakker 1989).

Cattle have been re-introduced experimentally into nature reserves in Europe in an attempt to reduce dominant species and increase species richness; however, species-rich meadows did not redevelop in the Šumava National Park, Czech Republic even several years after cattle were re-introduced. In fact, cattle re-introduction had a negative effect on species richness there, probably because of small-scale differences in grazing pressure (Matějková et al. 2003). Such effects were found also in a mosaic landscape with wet sedge meadows and drier grasslands. The dry sites were overgrazed and the wet sites were avoided and remained ungrazed (J.P. Bakker & Grootjans 1991). Cattle re-introduction may be of questionable value because cattle may reduce species richness. However, over time shrubs sometimes proliferate in abandoned fens (after 10-15 years), so that in that sense, excluding cattle in former pastures may further reduce species richness as shrubs develop and shade herbaceous species (Preiss 1982; Jensen & Schrautzner 1999, Diemer et al. 2001; Middleton 2002a; Matějková et al. 2003). Following the Intermediate Disturbance Hypothesis (Connell 1978), low to moderate levels of cattle grazing could be beneficial to the biodiversity of lightly drained fens that have not been overgrazed in the past. In such cases, the cattle may be able to maintain rare species of herbs within shorter stands of fen vegetation.

Any benefits of cattle grazing to the biodiversity of fens would be highly dependent on the level of grazing induced by the cattle, and this in itself is a complicated issue. The intensity of cattle grazing depends on the productivity and food requirements of the cattle breed, number of cattle, the life stage of the animal, duration of the grazing period, and the productivity and energy content of the vegetation (Proulx & Mazumder 1998). To avoid health problems in the cattle, these cattle pastures would require a considerable amount of mineral soil (Elsäber 2000), but soil heterogeneity could lead to local under- and overgrazing (J.P. Bakker & Grootjans 1991;
Matějková et al. 2003). Therefore, we only advocate using grazing as a management tool in the case of abandoned nutrient-rich fens (not nutrient-poor fens) even from the perspective of animal health. High amounts of grazing pressure results in biodiversity increase in some cases, and this would suggest applying high grazing pressure, except that high grazing pressure increases soil degradation due to cattle trampling. If there are any benefits to the biodiversity of fens from cattle grazing, these benefits would be realized only at very low stocking densities. Because of the irreversibility of soil degradation, we can only advocate using very low grazing densities. Such low grazing pressure is often not sufficient to halt or reverse biodiversity losses (Schaoutzer et al. 2004) so that additional measures to remove excess biomass would remain necessary (Kleyer 2004).

Cutting and mowing

Considering the problems inherent to cattle grazing, mowing or cutting may be more appropriate to manage for biodiversity in fens. Two studies have compared the effectiveness of grazing versus mowing in undrained calcareous fens (Stammel et al. 2003) and in an abandoned fen meadow (Hald & Vinther 2000). Both studies showed that mowing resulted in somewhat higher species richness than grazing. In a study of montane grasslands in Switzerland designed to tease apart the effects of vegetation removal vs. other aspects of cattle disturbance, herbage removal was found to be the most important element of grazing in the maintenance of vegetation (Kohler et al. 2004). These studies suggest that it is the removal of the biomass that is important in the maintenance of biodiversity, and not necessarily the presence of the cattle in the process of biomass removal.

In Europe, hand mowing has been used successfully in the management of fens, sedge meadows, and wet grasslands (Hansson & Fogelfors 2000; Øien & Moen 2001; Mitlacher et al. 2002; Billeter et al. 2003). Mowing reduces litter, increases light availability at the ground level, and so therefore enhances seedling recruitment and species performance (Kotowski et al. 2001; Jensen & Gutekunst 2003); for instance, re-instating a mowing regime with hay increased the population size of the rare fen orchid *Nigritella nigra* ssp. *naira* in Norway (Moen & Øien 2002). Species such as *Viola palustris* perform better at higher light availability (Jensen & Meyer 2001; Kotowski et al. 2001); however, mowing only increases species richness if the species are still part of the standing crop of the community, are in the seed bank, or can disperse to the site (Billeter et al. 2003). While mowing is a widely practiced way of maintaining biodiversity in fens in Europe, we do not know of any projects in North America that use mowing for managing fens.

Burning

In North America, burning is used to manage the biomass of dominant species in fens. Without fire, even fens that have never been grazed in the past begin to lose biodiversity, not because of the proliferation of dominating woody species but because of shading by litter (Middleton 2002b). After a fire in a fen not damaged by grazing, a flush of native herbaceous species appears in the fen for about two seasons (Kost & De Steven 2000; Middleton 2002b). Overgrazed wetlands, however, do not necessarily increase in biodiversity after prescribed fire; instead they may have an increase of non-native species (Maret & Wilson 2000; Middleton 2002b). In cases where woody species are established, burning, cutting, and herbicide treatments may be necessary to remove woody species (Anderson 1990; Bowles et al. 1996).

In North America, prescribed fires are generally set in wet conditions during the spring, after the snow melts but before the growth of vegetation (Doris Ruesch, Wisconsin Department of Natural Resources, pers. comm.). Winter burning does not seem to be successful in reducing the cover of shrubs, even though it does play a role in temporarily increasing the biodiversity of herbaceous species (Middleton 2002b). In Europe, burning is generally considered destructive in peatlands (Klimkowska 2004) and is not commonly used to manage fens. If fire is used, it is recommended for the winter or early spring season, so that the peat does not catch fire (Anon. 2005).

Priority research questions for fen management

Several research questions emerge after a review of the literature of the maintenance of fen biodiversity in Europe versus North America. We list several research areas that have been inadequately addressed in past research, and deserve further exploration in the future.

1. Native ungulate research to determine the potential for native herbivores to increase the biodiversity of fen species, e.g. Moose in northern fens in North America, and Elk in Europe. Research is necessary to determine if native herbivores maintain biodiversity, and in particular, if they reduce the amount of shrubby species in fens abandoned for cattle grazing. Also, the suitability of species of herbivores needs to be examined within the landscape setting, particularly because very large ungulates, e.g. North American moose are undesirable along highways and in urban settings.

2. Research on the re-introduction of cattle into abandoned fen pastures with shrub proliferation to determine if cattle can reduce the amount of shrub cover, and increase the biodiversity of fen species either
from the seed bank or dispersal via the animals or via restoration of species via re-seeding or re-planting.

3. Interaction between the effects of grazing density and water table. As stated before, there is a positive relationship between stocking rate and the amount of biomass reduction. At the same time, high animal density promotes soil degradation, especially for organic soils with high water tables.

4. Cattle are not native in North America, but they could play some positive role in the restoration of drained or formerly overgrazed fens. Research looking at the role of cattle in maintaining native biodiversity and in the dispersal of seeds of fen species is recommended.

5. Mowing and shrub removal studies in North America to determine if these procedures can increase the biodiversity of fens.

6. Research on the historical role of fire in fens, particularly in Europe. Research on the potential role of fire in maintaining biodiversity is necessary in fens of various hydrology (e.g. drained, undisturbed). Detailed information is required on the desirable season and return interval of fire (also useful for North America). Strategies to prevent wildfires in urban areas, as well as to avoid peat fires need to be developed.

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References


van de Koppel, J., Huysman, J., van der Wal, R. & Off, H. 1996. Patterns of herbivory along a productivity gradient:


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