Restoring fen water bodies by removing accumulated organic sludge: what are the effects for aquatic macroinvertebrates?

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Pristine freshwater fens harbour many species of aquatic macroinvertebrates. Effects of eutrophication and desiccation have strong negative impacts on macroinvertebrate assemblages. To restore degraded fens, the removal of accumulated organic sludge by dredging seems a necessary step. However, degraded fens may harbour relic populations of rare and characteristic species as was found for raised bogs and shallow soft water lakes.
This study investigates the effectivity of dredging by comparing dredged and undredged water bodies in two areas (SW & MP). To help interpret the observed differences, a third least impacted area is sampled in addition (WD). Abiotic conditions clearly differed between areas, but when comparing dredged and undredged water bodies, only turbidity was lower in dredged water bodies. Coverage of submerged vegetation was higher in dredged water bodies, especially in MP. For aquatic macroinvertebrates, strong differences between dredged and undredged water bodies were found for both SW and MP. Dredged water bodies in MP resembled WD most strongly, in abiotic conditions, vegetation, and invertebrates. Nevertheless, a number of species commonly occurring in WD were mainly associated with undredged water bodies, indicating incomplete restoration of certain key factors.
Results indicate that dredging contributes to ecological restoration of fens. To maximise effectiveness of dredging, internal and external supply of nutrients should be minimized, removal of organic sludge should be near-complete, while retaining small patches of vegetation and recesses as sources of individuals to facilitate recolonisation. Furthermore, this study shows that taking fauna into account can yield new information which is not uncovered by researching solely abiotic conditions and vegetation. In contrast to raised bogs and shallow soft water lakes, no relic populations of rare and characteristic species were found in degraded, undredged fen water bodies. These differences may

be related to differences in ecosystem functioning, with characteristic fen species having a lower persistence and a higher recolonisation rate.

Keywords: coexistence, dredging, habitat diversity, marsh, relic populations, restoration management

Pristine freshwater fens are ecosystems with a high diversity of aquatic macroinvertebrates (Van der Hammen 1992). Species occurrences are hardly constrained by extreme abiotic conditions in pristine fens, contrasting with other ecosystems, where species are lacking due to abiotic extremes such as high acidity (*e.g.* raised bogs), low nutrient availability (*e.g.* shallow soft water lakes, called '*vennen*' in Dutch), or high flow velocity (*e.g.* streams). Consequently, biotic interactions (*viz.* competition, parasitism or predation) will be important structuring factors (Southwood 1977). Factors on different scale levels may contribute to a high biodiversity (Cornell & Lawton 1992). Transitions from open water to structurally complex vegetation types give rise to many different habitat types, where the impact of various biotic interactions (*e.g.* fish predation) varies, providing focal points for species specialisation. The resulting niche differentiation prevents competitive exclusion on a local scale and may thus contribute to the high biodiversity (Gausse 1934). Vegetation succession is stimulated by water level fluctuations and set back by (rare) flooding events, ensuring the continued presence of a high habitat diversity. On a more regional scale this prevents competitive exclusion through recurrent dispersal and may thus contribute to the high biodiversity (Huston 1979).

Eutrophication and desiccation cause degradation through a cascade of effects which cumulate into the formation of a thick layer of fine organic sludge (summarized in Fig. 1 and treated in more detail by Lamers *et al.* 2001). A thick layer of accumulated organic sludge can have negative impacts for aquatic invertebrates. Shelter, oviposition substrate, and food for herbivores are no longer provisioned by submerged macrophytes. Low oxygen levels, high sulphide levels or release of toxic substances by cyanobacteria can increase mortality, especially for bottom dwelling detrivorous species, which are further influenced by changes in sediment quality. In general, the transition from open water to land becomes more abrupt, leading to a loss of habitat diversity (Higler 1977).

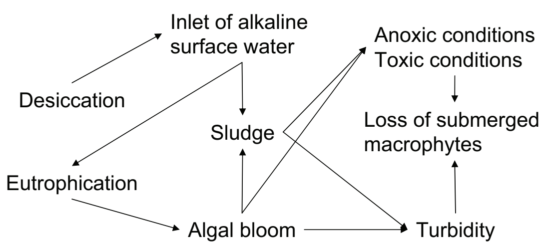

Figure 1. Chain of effects caused by eutrophication and desiccation.

Removal of accumulated organic sludge by dredging therefore seems a necessary step in the ecological restoration of fens. This restoration measure is frequently executed in fen water bodies and has been shown to reduce turbidity, improve water quality and increase coverage of submerged macrophytes (Boeyen *et al.* 1992, Milsom *et al.* 2004). However, the effects on aquatic invertebrates are poorly known. Furthermore, studies in raised bogs and shallow soft water lakes show that degraded situations can still harbour relic populations of rare and characteristic species, which may be at risk when restoration measures are large-scaled and cause rapid changes (Van Duinen *et al.* 2003, Van Kleef *et al.* 2006, Verberk *et al.* 2006). This paper addresses the following questions:

- What are the effects of dredging in fen water bodies on water quality, vegetation and aquatic macroinvertebrates?
- Do degraded fen water bodies harbour relic populations of rare and characteristic species?
- How do results compare with more pristine fen water bodies?
- What are the implications for management?

METHODS

Samples were taken in 2005 in three Dutch nature areas: Sluipwijk (SW; 52°02'N, 04°46'E), Molenpolder (MP; 52°09'N, 05°05'E) and Wieden (WD; 52°39'N, 06°02'E). MP is a marshland with a nature conservation goal where accumulated organic sludge has been removed in large parts by means of dredging between 1992-1997. SW is an open fenland with meadow birds as a conservation goal, where parts have been dredged in 2004. WD is one of the least impacted fen systems left in the Netherlands. Both dredged and undredged sites where sampled in SW and MP during both spring and autumn, whereas sites sampled in the reference area WD were sampled in autumn (Table 1). WD sites were not dredged since 1945 and considered undredged.

On each site, surface water and sediment pore water was sampled for chemical analysis. Vegetation was recorded using Tansley classification. Macroinvertebrates were sampled using a standard pond net of 30 x 20 cm with a mesh size

Table 1. Area, type of management and sampling season for de sampled sites.

Area	Characteristic	# Sites	Management	Sample period
Sluipwijk (SW)	open fenland	3	Dredged in 2004	June & Sept-Oct 2005
Sluipwijk (SW)	open fenland	3	Undredged	June & Sept-Oct 2005
Molenpolder (MP)	marshland	3	Dredged between 1992-1997	June & Sept-Oct 2005
Molenpolder (MP)	marshland	3	-	June & Sept-Oct 2005
Wieden (WD)	least impacted fen	3	-	Oct 2005
Total		15		

Table 2. Overview of species associated with dredged or undredged water bodies and water bodies in Molenpolder (MP) or Sluipwijk (SW). Taxonomic groups are indicated in parentheses: Mol: Mollusca, Hir: Hirudinea, Oli: Oligochaeta, Zyg: Zygoptera, Hem: Hemiptera, Col: Coleoptera, Cha: Chaoboridae, Tri: Trichoptera, Lep: Lepidoptera. Underlined: uncommon in Wieden (species captured in only 1 site or with less than 10 individuals), **bold**: rare or absent in Wieden (species not captured), others: common in Wieden (species captured in more sites and 10 or more individuals)

MP	SW	Both
	Associated with undredged water bodies	
Ferrissia wautieri (Mol)	*Erpobdella testacea* (Hir)	*Bathyomphalus contortus* (Mol)
Gyraulus crista (Mol)	***Haliplus ruficollis* (Col)**	*Planorbis carinatus* (Mol)
Physa fontinalis (Mol)	***Helochares punctatus* (Col)**	*Segmentina nitida* (Mol)
Planorbarius corneus (Mol)	*Hygrotus decoratus* (Col)	***Dero digitata* (Oli)**
***Nais barbata* (Oli)**	*Noterus crassicornis* (Col)	***Dero obtusa* (Oli)**
Chaoborus flavicans (Cha)	*Agraylea multipunctata* (Tri)	***Slavina appendiculata* (Oli)**
	Holocentropus picicornis (Tri)	*Ilyocoris cimicoides* (Hem)
		***Haliplus immaculatus* (col)**
		Cataclysta lemnata (Lep)
	Associated with dredged water bodies	
Stylaria lacustris (Oli)	***Hygrotus versicolor* (Col)**	*Radix ovata* (Mol)
Gammarus pulex (Cru)		*Nais variabilis* (Oli)
Pyrrhosoma nymphula (Zyg)		*Erythromma najas* (Zyg)
Cyrnus crenaticornis (Tri)		
Cyrnus insolutus (Tri)		
Erotesis baltica (Tri)		
Holocentropus dubius (Tri)		
Leptocerus tineiformis (Tri)		
Tricholeiochiton fagesii (Tri)		

of 0.5 mm. Microhabitats which were structurally different (*e.g.* floating *Stratiotes aloides*, submerged leaves of *Myriophyllum* spp. or *Potamogeton* spp., floating leaves of *Nuphar lutea*, open water, shore, stands of emergent vegetation), were sampled separately, with samples consisting of a 1m sweep, and the collected material was pooled per site. Depending on the variation in microhabitats total sample length varied between 4 and 10 meters but in most cases amounted to 5 m.

Samples were washed and sorted in the laboratory. Hirudinea, Oligochaeta, Crustacea, Odonata, Coleoptera, Chaoboridae and Trichoptera were identified to the lowest taxonomic level possible, which was mostly the species level. Chironomidae were identified for the samples collected in spring and in SW and MP only. Hemiptera were identified for samples collected in autumn only. A complete species list is given in Verberk & Esselink (2007).

Because dredged sites were not sampled before dredging, dredged and undredged sites were compared for SW and MP, assuming that the situation prior to dredging was very similar to undredged sites within that area (space-for-time-substitution). To determine qualitative differences in vegetation structure and coverage, plant species were classified in submerged species and floating-emerged species, Tansley scores were converted to coverage percentages using Franken *et al.* (2006), and vegetation data for both sample periods were pooled.

Cluster analysis of untransformed macroinvertebrate abundance data was performed with BioDiversityProfessional Beta 1 (McAleece 1997), using the Bray-curtis similarity index and the complete linkage algorithm (Jongman *et al.* 1995). Species association with dredging (dredged or undredged) or area (SW or MP), or both was determined (Table 2). Species were associated with a certain category (dredged, undredged, SW, MP, or a combination), if at least half of all occupied sites, harbouring at least 75% of all captured individuals fell into one of these categories. Calculation of association was not performed for species captured only in 1 or 2 sites or with 10 individuals or less. For species with an association, their status in WD was determined.

RESULTS

Abiotic conditions differed strongly between the different areas (Fig. 2). SW had both highest concentrations of ortho-phosphate (the nutrient regulating the transition from clear to turbid water in the Netherlands) and highest turbidity of the surface water. This is related to continued fertilisation of the meadows and the inlet of alkaline surface water, rich in sulphate and nutrients, which has most probably led to direct eutrophication and stimulated internal mobilization of nutrients from the sediment. Concentrations of ortho-phosphate were lowest in WD, as most of it was bound in the sediment where high concentrations of

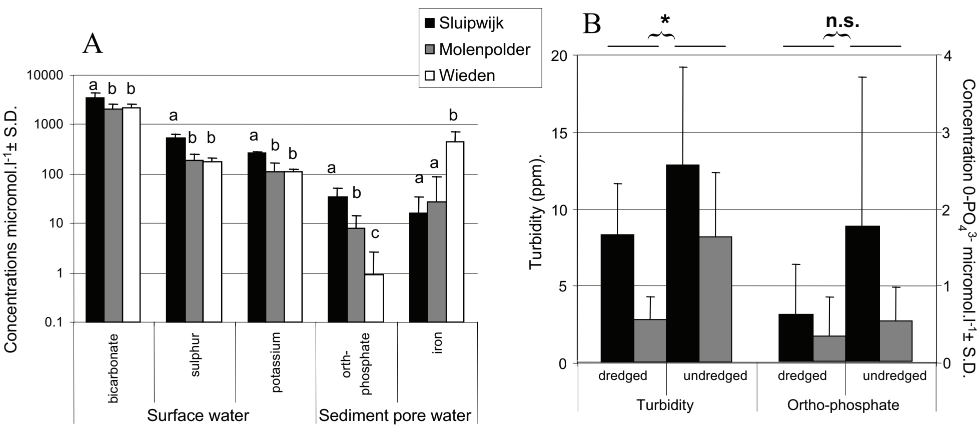

Figure 2. Differences in abiotic conditions between the three research areas (a, note the log scale) and between dredged and undredged water bodies in SW and MP (b). Significant differences (Student t test, P<0.05) between areas are indicated by different letters (a) and with an asterisk (b, data from SW and MP pooled).

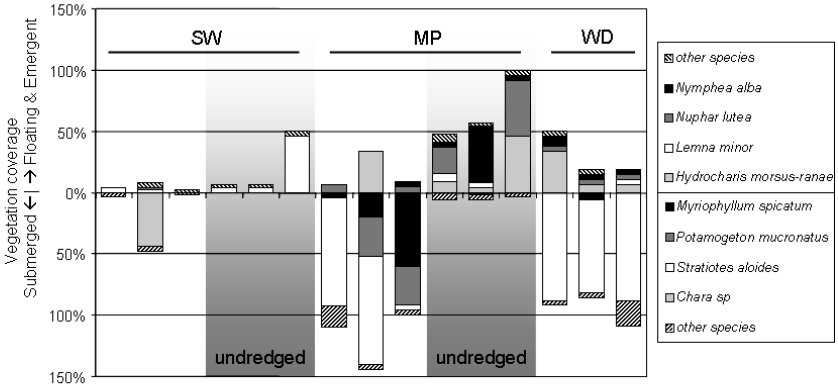

Figure 3. Differences between sites in vegetation structure (submerged or floating/emergent) and species composition.

Figure 4. Contrasting field situations in MP between an undredged site (left) and dredged site (right). Photograph taken on May 27th 2005 by W.C.E.P. Verberk.

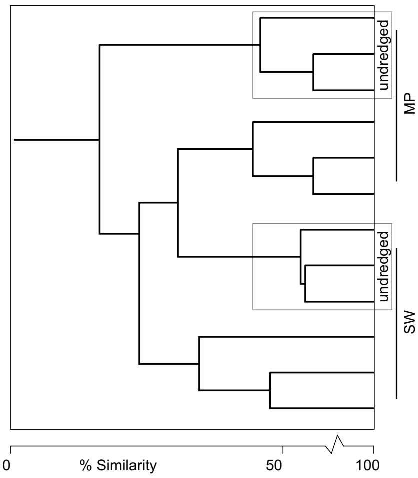

Figure 5. Dendrogram showing the similarity in macroinvertebrate abundances between sites of MP and SW.

dissolved iron occurred (Fig. 2a; Lamers *et al.* 2006). When comparing dredged and undredged water bodies, dredged water bodies had lower turbidity, especially in MP. Concentrations of ortho-phosphate followed a similar, non-significant trend (Fig. 2b).

Vegetation structure and coverage also strongly differed between the different areas (Fig. 3), but here differences between dredged and undredged water bodies were more pronounced, especially in MP (Fig. 4). Vegetation in dredged water bodies in MP was most similar to WD, with a high coverage of submerged macrophytes, consisting predominantly of *Stratiotes aloides*, *Myriophyllum spicatum* and *Potamogeton mucronatus*. Undredged water bodies were completely (SW) or largely (MP) devoid of submerged macrophytes.

Macroinvertebrate assemblages differed strongly between dredged and undredged water bodies, both in SW and MP (Fig. 5). These results indicate that initial (undredged) conditions substantially differed between both areas and following dredging different assemblages have developed. All species associated with dredged water bodies in MP were also captured in WD, with most species being common (Table 2). Additionally, no nationally rare species were found with their populations restricted to undredged sites (no relic populations). Many species associated with undredged water bodies were not captured in WD or were uncommon in WD. Nevertheless, a number of species associated with undredged water bodies were common in WD, for example the gastropods *Segmentina nitida* and *Physa fontinalis*, the water beetle *Noterus crassicornis*, the caddis fly *Holocentropus picicornis* and the water bug *Ilyocoris cimicoides*. These species are associated with, but not limited to undredged water bodies and are certainly not threatened nationally (Nijboer & Verdonschot 2001). Nevertheless, this indicates that a number of species characteristic for more pristine fens such as WD do not profit from dredging.

DISCUSSION

Accumulated organic sludge is frequently removed from water bodies by dredging in degraded fens of the Netherlands. Results show that differences between dredged and undredged water bodies were least pronounced for abiotic conditions (some differences in turbidity), more pronounced for vegetation (especially strong differences for submerged macrophytes in MP) and most pronounced for aquatic macroinvertebrates (strong differences between dredged and undredged for both SW and MP). A longer recovery period following dredging in MP, compared to SW, may explain why the ecological quality of dredged water bodies in MP better resembled that of WD. However, initial conditions were better (less inlet of eutrophying surface water, no fertilisation of bordering meadows) and a more complete removal of accumulated organic sludge was achieved in MP (Verberk & Esselink 2007), making it unlikely that a similar recovery will be achieved in SW in the course of time. Furthermore, results showed that several species commonly found in WD were associated with undredged sites. The reduced occurrence of these species in dredged sites may indicate either slow recolonisation (especially for SW where the recovery period was short) or incomplete restoration of certain key factors. A possible factor is the absence of coarse organic debris in dredged water bodies, which is naturally found in pristine fens and may function as food or shelter, or both. Dredging is a necessary step in the restoration of fen water bodies, but its effectiveness largely depends on whether other problems have been tackled and how it is executed. Internal eutrophication (mobilisation of nutrients from the sediment) and external supply of nutrients (inlet of enriched surface water or fertilisation) should be minimized through hydrological improvements (allow lower water tables in summer, reducing the need for inlet, or pre-treatment of inlet water). Therefore, when dredging is part of a larger restoration project, it can be quite successful in restoring abiotic conditions, vegetation and macro-invertebrates (see also Verberk & Esselink 2007). To maximise effectiveness of dredging, the removal of organic sludge should be near-complete, to be effective in reducing turbidity and nutrient concentrations, while retaining small patches of vegetation and recesses as sources of individuals to facilitate recolonisation.

Differences between dredged and undredged water bodies were most pronounced for aquatic macroinvertebrates. Macroinvertebrate assemblages differed strongly between dredged and undredged water bodies in SW, though they were similar in terms of abiotic conditions and vegetation. These differences in macroinvertebrates reflected the removal of resident species by dredging and subsequent recolonisation (Verberk & Esselink 2007). Furthermore, results on macroinvertebrates supported the conclusion that dredged water bodies in MP resembled those of WD most, but also indicated that recovery was not yet complete. This demonstrates that taking fauna into account yields new information which is not unveiled by research focussing only on abiotic conditions and vegetation, and that the latter two can not be used as a simple proxy for (the restoration of) fauna assemblages. The advantages of taking fauna into account are that many different species are considered, each with a specific response to various key-factors (structural complexity of vegetation, water quality, turbidity, substrate), integrated over longer time periods and larger spatial scales (Van Duinen *et al.* 2004).

In this study, no relic populations of rare and characteristic species were found in undredged sites, contrasting with studies on macro-invertebrates in raised bogs and shallow soft water lakes (Van Duinen *et al.* 2003, Van Kleef *et al.* 2006, Verberk *et al.* 2006). Persistence and recolonisation determine the occurrence of relic populations (Van Duinen *et al.* 2007). Species with both a high tolerance and poor dispersal capabilities are able to persist under deteriorating conditions but will rarely recolonise restored sites, together resulting in a distribution restricted to degraded sites. Compared to fens, raised bogs and shallow soft water lakes are predictably harsh environments persisting over long time periods, selecting for species traits such as low dispersal capabilities, slow growth and high tolerances to acidity and temporary drought. These traits are not selected for in fens, where species have to cope with competition, predation and parasitism (selecting for traits such as fast growth, protected oviposition and parental care). As a result, abiotic extremes resulting from degradation (low oxygen levels, high toxicity) will cause characteristic fen species to disappear. In addition, characteristic species are -on average- expected to have a higher dispersal to cope with the more dynamic nature of fens (water table fluctuations, periodic flooding and subsequent rapid succession). This has promising consequences for restoration management, as risks to lose rare species from degraded situations are low, while recolonisation is expected to proceed more rapidly, provided all key factors are restored.

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