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# Restoration of degraded raised bogs: do aquatic invertebrates tell a different story ?

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## Abstract

Vegetation development and time elapsed after rewetting are generally regarded as important factors in the progress of fauna restoration. We compared invertebrate species assemblages between water bodies created by rewetting measures in raised bog areas in the Netherlands, differing in vegetation development and time elapsed after rewetting. Next to that, we sampled water bodies which have not been subject to restoration measures, but are remnants of the former use of the bogs, like peat cutting pits. Macroinvertebrates as well as microinvertebrates (Rotifera, Copepoda and Cladocera) were studied. As a reference macroinvertebrates were sampled in an intact raised bog system in Estonia.

The number of characteristic invertebrate species was not clearly related to the presence of a characteristic raised bog vegetation. The microinvertebrate fauna seems to recover quickly after rewetting, but this is not the case for macroinvertebrates. Until now rewetting measures, having attained different success regarding the vegetation, resulted in a fairly similar macroinvertebrate species assemblage, including only a part of the species spectrum of an intact raised bog. Remnant water bodies, like former peat cutting pits, that are not influenced by rewetting measures were inhabited by relatively high numbers of characteristic macroinvertebrate species, even when no characteristic vegetation is present. Safeguarding habitat diversity during the restoration process and restoring habitat diversity of complete raised bog systems will help to conserve and restore the characteristic fauna diversity more successfully.

## Introduction

Restoration measures are taken in many cutover peatlands to rehabilitate the characteristic raised bog flora and fauna. As *Sphagnum* species are key species in raised bogs, restoration measures are generally focussed on creating suitable hydrological conditions for re-colonization and growth of *Sphagnum* by means of blocking drainage ditches or building dams to retain rain water (Lamers et al. 1999, Rochefort et al. 2003, Vasander et al. 2003). Although the main part of species diversity concern fauna species, especially invertebrates, only little attention has been paid to effects of restoration measures on fauna (Kiel & Matzke 2002, Van Duinen et al. 2003). Since most restoration projects do not include a fauna monitoring programme, it is generally unknown whether they have had any effects on the fauna, whether positive or negative. Also, little attention is being paid to fauna diversity in the planning of management measures.

Restoration of characteristic fauna is generally expected to follow restoration of the abiotic conditions and characteristic vegetation in course of time. A stable water table close to the peat surface generally offers the best chance for successful restoration of a *Sphagnum* dominated vegetation (Wheeler & Shaw 1995). Apart from the water table and its fluctuations, quality of water and the remaining peat are important aspects in the restoration of raised bog vegetation. In cases of deeper inundation presence of floating peat or light penetration and $CO_2$-availability in the surface water are key-factors in *Sphagnum*-growth (Lamers et al. 1999; Smolders et al. 2001 and 2002). High levels of atmospheric nitrogen deposition may hamper restoration of ombrotrophic bog vegetation (Lamers et al. 2000; Limpens et al. 2003; Tomassen et al. 2003).

To assess the effects of restoration measures on fauna and identify the key factors in successful conservation and restoration of fauna we started a comparative study on aquatic macroinvertebrates in an intact raised bog system (Nigula in Southwestern Estonia) and several raised bog areas in the Netherlands in which either or not rewetting measures have been taken. This study showed that the total number of characteristic species per site tend to increase with the time elapsed after rewetting, but this increase is slow. The number of characteristic species appeared to be not clearly related to the presence of a characteristic raised bog vegetation. Until now rewetting measures, taken in different starting conditions and having attained different success regarding the vegetation, have resulted in a fairly similar species assemblage, including only a part of the species spectrum of an intact raised bog. Remnant water bodies -remnants of the former use of raised bogs, like peat cutting pits, and not influenced by restoration measures- were inhabited by relatively high numbers of characteristic macroinvertebrate species, even when the vegetation is not very characteristic (Van Duinen et al. 2002 and 2003). Thus, the environmental key-factors in the restoration of the aquatic macroinvertebrate fauna seem to be different from those for the vegetation.

Contrary to our results on aquatic macroinvertebrates Buttler et al. (1996) showed that the testate amoebae fauna of raised bogs can recover rapidly and fully, regardless of the initial condition of the cutover surface. The testate amoebae species assemblage is mainly structured by wetness, pH and nutrient availability. Probably different fauna groups respond to rewetting and *Sphagnum*-recovery in a different way as they make different demands to their environment. Microinvertebrates may respond more rapid to restoration of the abiotic environment and vegetation than macroinvertebrates. Next to the study on macroinvertebrates, we started a comparative study on aquatic zooplankton (Rotifera, Copepoda and Cladocera) in several raised bog areas in the Netherlands. The present paper addresses the questions whether the numbers of characteristic species differ between remnant water bodies and water bodies created by restoration measures and whether these numbers are related to 1) the presence of a characteristic vegetation and 2) the time that had elapsed since restoration measures were taken. Do these micro-invertebrates react in the same way as vegetation or as macroinvertebrates to the restoration measures?

## Material and Methods

Aquatic microinvertebrates were sampled at 21 sites in 7 raised bog areas in the Netherlands. Sampling sites were chosen to include most of the various types of water body present. The water bodies sampled differed in age, size, water and substrate quality, vegetation composition and structure. Ten of the water bodies sampled were created by rewetting measures, 11 were remnants of former peat cutting pits, which had been in existence for more than 50 years and had not been subject to bog restoration measures. These sites were in different stages of secondary succession. All samples were taken between April 1 and May 6, 2002, using two plankton nets with different mesh size. Rotifers were captured with a 35µm mesh net and Cladocera and Copepoda with a 115µm mesh net. Macroinvertebrates were sampled in 20 remnant sites and 27 restoration sites both in spring 1999 and autumn 1998 or 1999. For more details on the sampling of macroinvertebrates see Van Duinen et al. (2003). Invertebrate species were considered to be characteristic of natural raised bogs if they were listed in literature as acidophilous, acidobiontic, tyrphophilous, tyrphobiontic or typical of raised bogs. For each sampling site a Vegetation Quality Score (VQS) was calculated as described by Van Duinen et al. (2003), based on rareness, trend and desirability from the point of view of raised bog restoration. Thus, a site with a high score had a vegetation dominated by *Sphagnum* spp., preferably hummock-building species, accompanied by other plants charactersitic to natural raised bogs.

**Table 1.** Total numbers of species and characteristic species found at all sampling sites together, remnant sites and restoration sites. n= number of sampling sites.

| | All sites | | Remnant sites | | Restoration sites | |
|---|---|---|---|---|---|---|
| Microinvertebrates | n=21 | | n=11 | | n=10 | |
| Macroinvertebrates | n=47 | | n=20 | | n=27 | |
| | Total | Charact. | Total | Charact. | Total | Charact. |
| Microinvertebrates | 137 | 46 | 123 | 43 | 95 | 33 |
| Rotifera | 114 | 40 | 103 | 37 | 78 | 29 |
| Cladocera | 17 | 3 | 14 | 3 | 12 | 2 |
| Copepoda | 6 | 3 | 5 | 3 | 6 | 2 |
| Macroinvertebrates | 149 | 36 | 133 | 34 | 100 | 24 |

## Results

At 21 sampling sites a total of 137 microinvertebrate species were found. Of these, 123 species were found at the 11 remnant sites and 95 at the 10 restoration sites (Table 1). 95 species were found both at restoration and remnant sites. 46 species were characteristic to acid water. 43 of them were found at the 11 remnant sites and 33 at the restoration sites. Regarding macroinvertebrates, a total of 149 species were sampled at the 47 sites. Of these, 133 species were found at the 20 remnant sites, versus 100 species at the 27 restoration sites. 84 species were found at both remnant and restoration sites. 36 of the 149 species collected are more or less characteristic of water bodies in raised bog systems. 34 of them were found at the remnant sites and 24 at the restoration sites.

The number of characteristic microinvertebrate species per site was not significantly correlated with the Vegetation Quality Score of both the 11 remnant and the 10 restoration sites ($r$=0.21 and $r$=-0.16, respectively; Figure 1a). The number of characteristic macroinvertebrate species per site was significantly correlated with VQS of the 20 remnant sites ($r$=0.49, $P$=0.030; Figure 1b). For the 27 restoration sites no significant correlation was found between VQS and the number of characteristic macroinvertebrate species ($r$=0.20). No significant correlations were found between the number of years elapsed after rewetting measures were taken and the numbers of characteristic micro- and macroinvertebrate species at the restoration sites ($r$=0.46 and $r$=0.25, respectively), although positive trends were found (Figure 2).

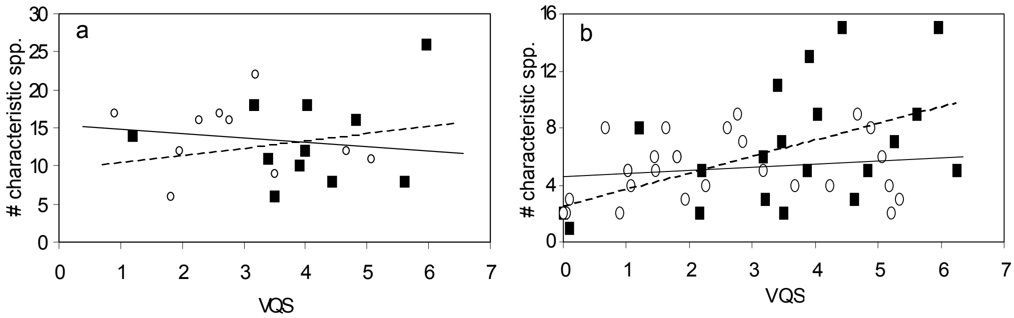


**Figure 1.** Relation between the numbers of characteristic a) microinvertebrate and b) macroinvertebrate species and the Vegetation Quality Scores (VQS) for remnant and restoration sites. Uninterrupted trend lines and open circles are used for restoration sites, dotted lines and filled squares for remnant sites.

## Discussion

For micro- as well as macroinvertebrates the total number of species and of characteristic species found at the remnant sites was higher than at the restoration sites and about a quarter of the characteristic species was only found at the remnant sites for both species groups (Table 1). However, microfauna was sampled at 11 remnant sites versus 10 restoration sites and thus species richness seems to be fairly comparable between restoration and remnant sites. The opposite was the case for macroinvertebrates, as only 20 remnant sites were sampled versus 27 restoration sites. Earlier data analysis showed that aquatic macroinvertebrate species assemblages of restoration sites are very similar, compared to remnant sites as well as an intact raised bog system. Until now the restoration measures have resulted in restoration of only a limited part of the macroinvertebrate species spectrum of pristine raised bogs, including only a part of the characteristic species (Van Duinen et al. 2002 and 2003). For microinvertebrate species assemblages this seems to be not the case (Zhuge and Van Duinen, unpublished data).

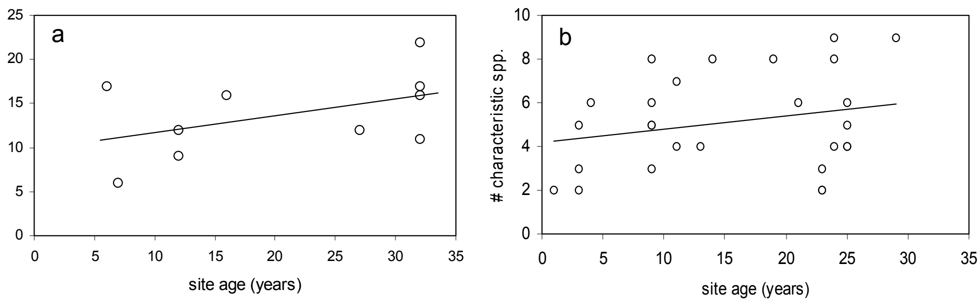


**Figure 2.** Relation between the numbers of characteristic a) microinvertebrate and b) macroinvertebrate species and the site age of restoration sites.

Numbers of characteristic species of micro- and macroinvertebrates were not significantly correlated to the number of years elapsed after rewetting, although a positive trend was found (Figure 2). This result can be explained by the fact that the age of the oldest restoration site sampled was just about 30 years. Restoration sites might be expected to become colonized by larger numbers of characteristic species after a longer time period. As raised bogs have become rare and the Western European landscape is highly fragmented, colonization of rewetted sites may be difficult. Therefore, during the restoration process remnant sites should be conserved in the area as they are valuable refugia and potential sources for colonization of rewetted sites. As rewetting measures may be unfavourable to still present invertebrates, especially macroinvertebrates, assessment of the species assemblages before any measures are taken is very profitable. If necessary measures can be phased in time and space to safeguard habitat diversity and species diversity.
As microinvertebrates like Rotifera and Cladocera are easily spread (Cáceres et al. 2002), have a short life cycle and parthenogenetic reproduction (Nogrady et al. 1993), they can colonize water bodies quickly after rewetting measures are taken. This may explain the absence of a significant correlation between numbers of characteristic species and site age as well as absence of clear differences in species richness between remnant and restoration sites. Thus, the effects of restoration measures on microinvertebrates might be different from that on macroinvertebrates that have a more complex life cycle and make higher demands to their environment.

The number of characteristic species was only significantly correlated with the Vegetation Quality Score in the case of macroinvertebrates in remnant sites. The highest numbers of rare characteristic macroinvertebrate species were, however, found in remnant sites with a moderate VQS (Van Duinen et al. 2003). These data do not support the assumption that restoration of characteristic fauna will generally follow restoration of characteristic vegetation. Indeed, restoration measures are necessary to restore hydrological and biogeochemical processes of raised bog systems in order to restore a characteristic hummock-hollow vegetation. Nutrient enrichment is indeed likely to hamper restoration of the fauna species assemblages of nutrient-poor bog pools (Van Duinen et al. 2002), like it hampers recovery of a characteristic raised bog vegetation (Limpens et al. 2003; Tomassen et al. 2003). However, this appears to be not the whole story of bog restoration.
To conserve and restore the fauna species diversity of raised bog systems, restoration should not focus everywhere on creating suitable conditions only for the hummock-hollow vegetation type. In a relatively pristine raised bog system characteristic species do not all occur in ombrotrophic raised bog centres. Raised bogs are not uniform in fauna species assemblages as they are not uniform in environmental conditions (Smits et al. 2002). Raised bog systems are characterised not only by *Sphagnum* spp. and peat production, but also include sites with a relatively high rate of decomposition of organic matter. Although several characteristic species might only depend on e.g. large, open pools or shallow pools with dense *Sphagnum* vegetation in bog centres, other species need other elements of the raised bog system as well, like transitional habitats or raised bog slopes with some water flow or the influence of minerotrophic water. The bog system as a whole has to meet the various demands of the different species to complete their life cycles (Verberk et al. 2001). Therefore, conservation and restoration of habitat diversity within the system is an important 'chapter' in the restoration of the characteristic invertebrate fauna of raised bogs.

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