IMPORTANT KEYS TO SUCCESSFUL RESTORATION OF CHARACTERISTIC AQUATIC MACROINVERTEBRATE FAUNA OF RAISED BOGS

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SUMMARY

To study whether restoration measures contribute to the conservation and restoration of the fauna species diversity and characteristic raised bog fauna species, macroinvertebrate species assemblages were compared between a variety of water bodies in raised bog remnants in the Netherlands in which either or not restoration measures have been taken and in the intact raised bog system Nigula, Estonia.

Previous data analyses showed that restoration of characteristic vegetations does not necessarily result in fauna restoration. The relationship between time elapsed after rewetting and the number of characteristic fauna species was not clear. A considerable number of characteristic and rare fauna species was only found in remnant sites, including sites without characteristic bog vegetation.

The present study shows that variation in species assemblage is low in restoration sites, compared to remnant sites and intact raised bog systems. Until now restoration measures result in restoration of a limited part of the species spectrum of pristine raised bogs. Nutrient enrichment may explain part of the differences in species assemblage. Important keys to a successful restoration of raised bog fauna are conservation and restoration of habitat diversity as well as conservation of remnant sites, being important sources for colonisation of rewetted sites, during the restoration process.

INTRODUCTION

Small- and large-scale drainage, peat cutting and cultivation have resulted in the degradation and disappearance of most of the Western European raised bog systems. Dehydration and mineralisation of peat, the inlet of minerotrophic or nutrient-rich water and increased nitrogen deposition have changed water and soil quality in bog areas (Lamers, 2001). As a result, a number of characteristic fauna species have declined or disappeared, whereas species poorly adapted to ombrotrophic (i.e., acid, nutrient-poor) conditions were able to establish in bog remnants (Göttlich, 1980; Wheeler & Shaw, 1995; Irmler *et al.*, 1998). For some of these species, the original habitats have been degraded or have disappeared as a result of cultivation, making bog areas nowadays a refugium for species which were originally not dependent on raised bogs (Akkermann, 1982; Schouwenaars *et al.*, 2002).

In attempts to regenerate *Sphagnum* growth, rewetting measures are taken in drained and cutover bog remnants by blocking drainage ditches and building bunds and weirs to retain rainwater (Wheeler & Shaw, 1995). In some cases, these measures have resulted in the recovery of a *Sphagnum* vegetation or the formation of floating rafts on which a characteristic hummock-hollow vegetation establishes (Lamers *et al.*, 1999). However, *Betula* sp. and *Molinia caerulea* have invaded most of these sites and large areas of inundated cutover peat still consist of open water with only *Sphagnum cuspidatum*.

The success of raised bog restoration measures is mainly evaluated on the basis of the development of a *Sphagnum*-dominated vegetation, as well as the presence of characteristic *Sphagnum* and vascular plant species. Evaluations of restoration measures including fauna diversity have been rare and have usually dealt with only one specific taxonomic group and one specific area (e.g. Utschick, 1990; König, 1992; Mossakowski & Främbs, 1993; Irmler *et al.*, 1998). Since most restoration projects do not include a 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. This is due to the large number of species of various taxonomic groups, necessitating specialised knowledge, as well as sampling with the help of different methods and at several times during the year. Taking fauna into account in nature management is also hampered by the lack of sufficient knowledge of the ecology of species and of the complex relationships between animals and their environment (Bink *et al.*, 1998).

To assess the effects of raised bog restoration measures on fauna and to identify the key factors in successful conservation and restoration of fauna in the Netherlands a study was started. Macroinvertebrate species assemblages were compared between (1) water bodies created by rewetting measures and (2) water bodies which have not been subject to restoration measures, but are remnants of the former use of raised bogs. These remnant sites are e.g. peat cuttings in different stages of secondary succession and trenches used for buckwheat culture. This comparative study showed that the restoration sites were inhabited by characteristic raised bog species and rare species, but their numbers were higher at the remnant sites not affected by restoration management. A considerable number of characteristic and rare fauna species were only found at the remnant sites. The number of characteristic species was not clearly related to the presence of a characteristic raised bog vegetation. Although numbers of rare and characteristic species per site tended to increase with the time elapsed after rewetting, it was concluded that restoration measures will not automatically result in restoration of a more or less complete macroinvertebrate species spectrum, as restoration measures have so far resulted in habitats for only a limited number of the characteristic raised bog species. The remnant sites included considerably more variation in macroinvertebrate species assemblages and had a higher cumulative species richness than restoration sites. Therefore, it was concluded that habitat diversity is an important key factor in the conservation and restoration of characteristic raised bog fauna and hence no overall restoration measures should be taken (Van Duinen *et al.*, subm.).

To collect reference data on macroinvertebrate species assemblages in intact raised bog systems a study was started in the fairly intact raised bog system Nigula in Southwest Estonia and a few other sites in Estonia. The present paper addresses the question whether species assemblage, variation in species assemblage, species richness and numbers of characteristic species differ between intact sites, remnant sites and restoration sites.

MATERIAL AND METHODS

Macroinvertebrate sampling

Aquatic macroinvertebrates were sampled at 47 sites in 7 raised bog areas in the Netherlands and 31 sites in fairly intact raised bog systems in Estonia. Of these, 27 sites were sampled in Nigula nature reserve, 2 in the transitional mire of Valgeraba (Soomaa national park) and 2 in the lagg of Punaraba (Endla nature reserve). Sampling sites were chosen to include most of the various types of water body present in Dutch and Estonian raised bogs, respectively. The water bodies sampled differed in age, size, water and substrate quality, vegetation composition and structure. Twenty-seven of the Dutch water bodies sampled were created by rewetting measures, 20 were remnants of former peat cutting or trenches used in buckwheat culture, which had been in existence for more than 50 years and had not been subject to bog restoration measures.

Macroinvertebrates were sampled using a 20x30 cm pond net with ½ mm mesh size. Most samples consisted of a 1 m sweep starting from the substrate and more or less open water into more dense vegetation near the shore. If the water body only included open water, one or more longer sweeps were taken. In very dense *Sphagnum* vegetation, shorter sweeps were made to avoid the pond net becoming clogged with *Sphagnum*. The intact sites were sampled in spring 2001. The remnant and restoration sites were sampled in spring 1999, except 1 temporary remnant water body, which could only be sampled in autumn. In the Netherlands the sites were also sampled in autumn 1998 or 1999, except 4 temporary remnant sites and 1 restoration site which could only be sampled in spring. For the restoration and remnant sites all macroinvertebrates were identified to species level if possible, except Coleoptera larvae and Oligochaetes. For the intact sites only Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera were identified.

Environmental variables

Environmental variables analysed for the Dutch sampling sites included the presence of open water, *Sphagnum*, floating leaves of higher plant species, trees and muddy sediment, as well as the mean *Sphagnum* density in numbers of capituli per dm^2, whether the water body was permanent or temporary, depth of the water body, surface area, electric conductivity and pH and samples of the surface and substrate water were taken. Samples were stored overnight at $4^{o}C$, and pH and alkalinity were measured the next day. After 1 mg citric acid per 5 ml of water had been added, samples were stored at $-20^{o}C$ until analysis. The analysis included determination of the concentrations of nitrate, ammonium, ortho-phosphate, calcium, magnesium, iron, phosphor, aluminium, sulphur, sodium, potassium, chloride, and total inorganic carbon. For those environmental variables that were measured more than once, average values were used in the data analysis.

Data analysis

As the intact sites were only sampled in spring, in the comparisons with intact sites only the spring data of 19 remnant and 27 restoration sites (Table 1) were used. In the comparisons between Dutch sites data on the presence of macroinvertebrate species in the spring and autumn samples were pooled for each of the 20 remnant and 27 restoration sites. In comparisons with intact sites only data of Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera were used. In comparisons between remnant and restoration sites also data of other Diptera families, Hydrachnidia, *Argyroneta aquatica*, Turbellaria, Megaloptera and Ephemeroptera were used.

Correspondence Analysis (CA) and Canonical Correspondence Analysis (CCA) of these data were performed in Canoco for Windows version 4.0 (Ter Braak & Smilauer, 1998). The significance of each environmental variable was tested with the Monte Carlo resampling procedure (500 permutations). Cumulative species richness curves were based on averages of 50 random sorts of the sampling sites using BioDiversityProfessional Beta 1 (McAleece, 1997). Similarity in macroinvertebrate species assemblages of site pairs was calculated using the Sorensen coefficient (Sorensen, 1948): S=2j/(a+b), with j being the number of species occurring in both sites and a and b the total species numbers of the two respective sites. Averages were calculated of all possible pairs of sites within the categories of sites compared. Species are considered to be characteristic for raised bogs when they are listed as typical of raised bogs or acid water bodies in literature.

RESULTS

Species assemblage and similarity

Figure 1 gives the CA plots of the intact, remnant and restoration sites, based on the data of Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera collected in spring. In this CA three intact lagg samples, a primary bog lake and one restoration site were left out, as their species composition was very different from all other sites. The most ombrotrophic pools in the intact central bog were plotted at the right side of the plot. Sites in the transitional mires and sites influenced by some water flow from bog brooklets were plotted near the origin. Sites in the bog brooklet, brooklet springs and in the transitional mire close to the lagg were plotted at the left side. Species assemblages of the remnant and restoration sites resembled the assemblages of the brooklet area and the transitional mires more than those of the central bog pools. Restoration sites were plotted near the origin of the plot.
Restoration sites were plotted close together compared to the intact sites (Figure 1c). This indicates that the degree of variation in species assemblages was lower at the restoration sites. The Sorensen similarity coefficients were significantly higher for the restoration sites (T-test: P=0.000; Table 1). When the primary bog lake and the 3 lagg sites were excluded from the analysis (Figure 1a) the total variation in species assemblage in the Dutch sites was fairly equal to the variation within the intact sites and the Sorensen similarity coefficients did not differ significantly. However, when these 4 sites were included the Sorensen similarity coefficients of the Dutch sites were significantly higher (T-test: P=0.000).
In Figure 1a remnant sites and restoration sites showed some overlap and the Sorensen similarity coefficients did not differ significantly. However, when all available data of the Dutch sites are used, remnant and restoration sites were clearly separated on the first and second CA-axis (Figure 2). Restoration sites were plotted very close together compared to remnant sites, indicating that the degree of variation in species assemblages was relatively low. The Sorensen similarity coefficients of the restoration sites were significantly higher (T-test: P=0.000; Table 1).
Concerning the environmental variables which may explain differences in species composition between remnant and restoration sites, 66.0% of the total variance in species data could be explained by the assessed environmental variables. Adding the variable restoration vs. remnant site resulted in an increase of total explained variation of 2.5%. Restoration vs. remnant alone explained 6.0% of the total species variation. This is equal to 8.8% of the variance explained by all environmental variables and to 81% of the variation explained by the first CA-axis. After the deletion of alkalinity, total P and Na from CCA – because of high correlations with pH, PO_4 and Cl respectively – the variables restoration vs. remnant site, pH, electric conductivity, Ca, Fe, PO_4, depth, presence of floating leaves and turbidity contributed significantly (P<0.05) to explaining the variation in fauna data. These significant variables together accounted for 34.5% of the variation in fauna data.

Species richness

In spring a total of 113 Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera species were found in at least one of the sites (Table 2). Of these, 75 species were found at the 31 intact sites, versus 89 species at 46 Dutch sites. 70 species were found in remnant sites and 65 in restoration sites. 51 of the species were collected in both the intact sites and the Dutch sites, 41 in the 19 remnant sites and 41 in the 27 restoration sites. Regarding all available data of the 47 Dutch sites, 149 macroinvertebrate species were found in the Dutch 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. Total numbers of characteristic species were not very different between intact, remnant and restoration sites, regarding the spring data. However, when all available data are used most characteristic species were found at the remnant sites.

Figure 3a shows cumulative species richness curves for intact, remnant and restoration sites. When all available data of the Dutch sites are used, the difference in cumulative species richness between remnant and restoration sites is much more clear (Figure 3b). Apart from the differences in total species richness, the differences in the shape of the curves is remarkable. All curves are still rising at their ends, but the slope of the remnant sites curve is steeper than that of the restoration sites curve, especially in Figure 3b. The cumulative species richness curve shows a sharper slow down for restoration sites and crosses the curve of intact sites. Species richness per site did not differ significantly between the remnant and restoration sites. Species richness at intact sites was significantly lower than at Dutch sites (T-test: P=0.021).

DISCUSSION

Aquatic macroinvertebrate species assemblages appear to differ between intact sites, restoration sites and remnant sites. Still 70% of the species found in the 31 intact sites were found in at least one of the 47 Dutch sites sampled and 57% of the species found in the Dutch sites were also found in at least one of the intact sites sampled. Only very few of the species collected have a distribution area that does not include either Estonia or the Netherlands (data not shown). Collecting data in more seasons and of more fauna groups will of course result in more species, which is also clear from the comparison of the species numbers of the spring data and all available data of the Dutch sites (Table 2). However, it is not possible to collect a more or less complete species spectrum of pristine raised bogs in the Dutch restoration sites. This is due to the high similarity between the restoration sites, which is also apparent from the low increase in cumulative species richness. So far, rewetting measures in raised bog areas have resulted in a habitat for a limited number of fauna species, including only a part of the characteristic species.

The remnant sites have a much higher cumulative species richness and harbour about 95% of the characteristic raised bog species found in the Dutch sites to about 60% in the restoration sites (Table 2). Currently, a considerable number of characteristic and rare species are dependent on remnant sites for their survival in raised bog areas and in the Netherlands as a whole. Therefore, remnant sites are valuable refugia until restoration sites have been colonized by the species. This was also found in the case of restoration of the river Cole (UK), where the upper reaches and stagnant water bodies along the river harboured many species, which were able to recolonize the river after restoration (Biggs *et al.*, 2001).

Species richness per site is low in intact sites, but similarity is also low, resulting in a relatively high species number on the level of the complete raised bog system. Dutch sites are enriched with nutrients by increased atmospheric nitrogen deposition, inlet of minerotrophic and nutrient-rich water and mineralisation of drained peat (Lamers, 2001). These disturbances made the raised bog habitats suitable for more species. This may explain why the species numbers in the Dutch sites were higher then in the intact sites as well as why the species assemblages of restoration sites showed highest resemblance with the intact sites with higher nutrient availability. None of the Dutch sampling sites resembled species assemblages of the most ombrotrophic bog pools. High nutrient availability can hinder recovery of some characteristic raised bog species (Van Duinen *et al*., 2000). Species assemblages of remnant sites were most similar to those of the intact bog brooklet and the transitional mire close to the lagg. Although remnant sites do not all look like these intact sites, they are still inhabited by a number of characteristic species.

Nutrient availability and other chemical or physical characteristics of the water bodies can not explain all observed differences in species assemblages. CCA of the Dutch sites (Figure 2) revealed that some of the environmental variables assessed significantly explained the variation in the species assemblages within the group of remnant sites as well as within the group of restoration sites, but not clearly between these two groups of sites. Time elapsed after rewetting may be an important factor (Painter, 1999; Fairchild *et al.*, 2000). Earlier data analyses showed that rare and characteristic species tend to increase with the time elapsed after rewetting (Van Duinen *et al.*, subm.). The age of the oldest restoration site sampled in the present study was 29 years. So, the restoration sites might be expected to become colonized by larger numbers of characteristic and rare species after a longer time period. As raised bogs have become rare and the Western European landscape is highly fragmented, colonisation of rewetted sites may be difficult. During the restoration process remnant sites, being potential sources for colonisation of rewetted sites, should be conserved. An assessment of the species assemblages before any measures are taken is very profitable. Next to that, the sites as well as the whole bog system have to meet the various demands of the different species (Verberk *et al*., 2001). Therefore, conservation and restoration of habitat diversity is another important key to a more successful restoration of the characteristic macroinvertebrate fauna.

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Table 1: Averages (± sd.) of the Sorensen similarity coefficients for all pairs of sites within the categories of sampling sites. The spring column concerns data on Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera collected in spring, whereas the spring & autumn column concerns all available data of Dutch sites. n=number of sampling sites.

	Spring			Spring & autumn		
Categories of sites	avg.	± sd.	n	avg.	± sd.	n
Intact sites	0.131	± 0.160	31	-	-	-
Intact sites without lake and lagg	0.166	± 0.168	27	-	-	-
Dutch sites	0.176	± 0.146	46	0.322	± 0.146	47
Remnant sites	0.235	± 0.157	19	0.276	± 0.139	20
Restoration sites	0.214	± 0.154	27	0.448	± 0.115	27

Table 2: Averages (±sd.) of the species richness per site and cumulative numbers of species (N) and characteristic species (C). The spring column concerns data on Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera collected in spring, whereas the spring & autumn column concerns all available data of Dutch sites. n=number of sampling sites.

	Spring					Spring & autumn				
Categories of sites	avg.	± sd.	N	C	n	avg.	± sd.	N	C	n
Intact sites	7.0	± 4.5	75	19	31	-	-	-	-	-
Dutch sites	10.5	± 5.3	89	25	46	23.3	± 11.0	149	36	47
Remnant sites	11.5	± 6.4	70	23	19	24.0	± 15.4	133	34	20
Restoration sites	9.7	± 4.3	65	17	27	22.7	± 5.8	100	24	27

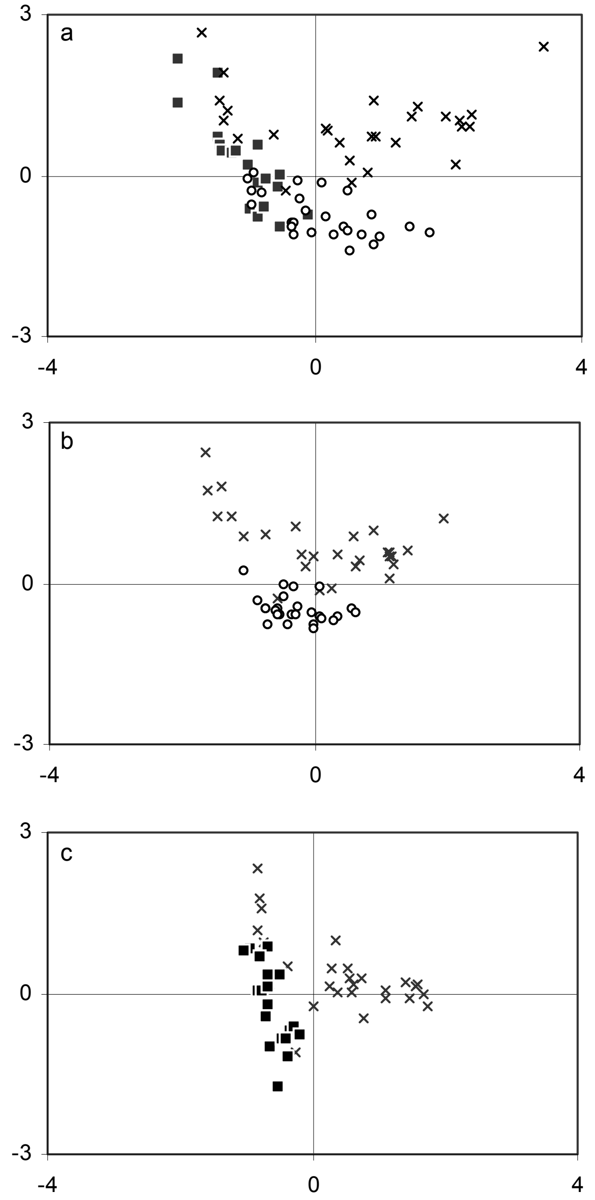

Figure 1: Plots of Correspondence Analyses of species presence data on Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera collected in spring of a) intact sites (x), remnant sites (■) and restoration sites (O) together, b) intact and restoration sites and c) intact and remnant sites.

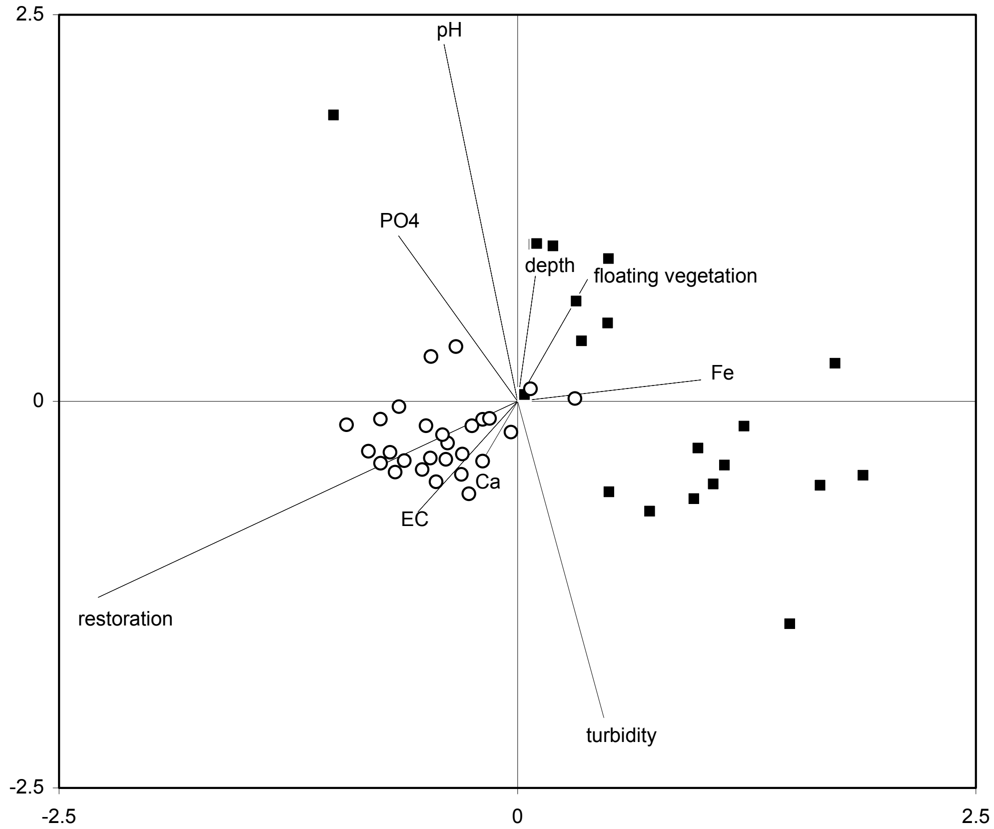

Figure 2: Correspondence Analysis plot of all available species presence data of remnant (■) and restoration sites (O). Significant environmental variables are shown as lines.

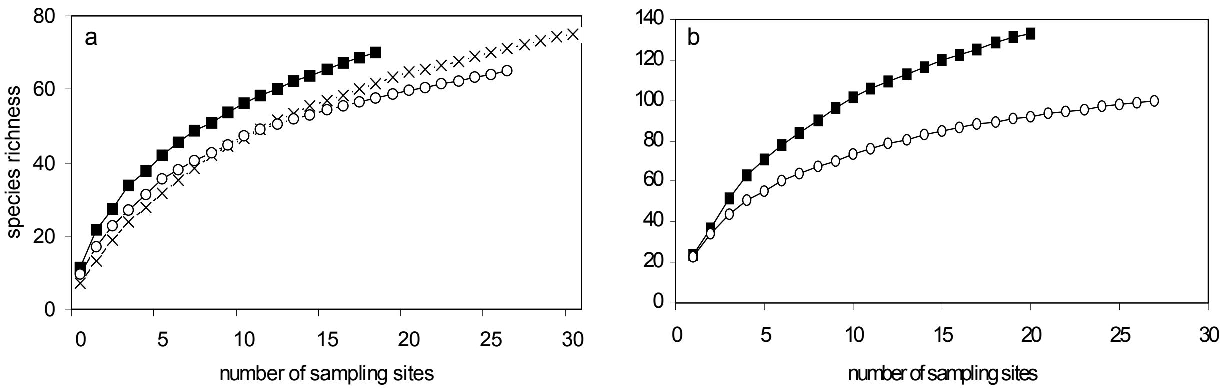

Figure 3. Cumulative macroinvertebrate species richness curves of a) spring data of intact sites (x), remnant sites (■) and restoration sites (O) and b) all available data of remnant and restoration sites. Curves are composed of averages of 50 random sorts of samples.