Nutrient enrichment changes the nature of invertebrate food webs in raised bog pools

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Summary

Drainage and increased atmospheric nitrogen and sulphur deposition results in increased nutrient availability in naturally nutrient-poor bogs. To study if increased nutrient availability changes the bog food web, stable isotope ratios of carbon and nitrogen of basal food sources (living plants and dead organic matter) and invertebrates were compared between bog pools, differing in nutrient availability, in Estonia and the Netherlands. For part of the invertebrate community, trophic relations could not be inferred from measured basal food sources. One or more basal carbon sources with a low stable isotope ratio for carbon still need to be identified. This unidentified carbon source becomes less important with increasing nutrient availability.

Key index words: eutrophication, nutrients, fauna, invertebrates, food web

Introduction

Intact raised bogs are extremely nutrient-poor and bog plants have correspondingly low nutritional value. Due to atmospheric nitrogen and sulphur deposition nutrient availability has increased in Western European raised bog pools and a simultaneous change in the invertebrate species composition has been documented (Desrocher and Van Duinen, 2006; Van Duinen *et al.,* 2006). SO_4 can lead to an increased release of NH_4 and PO_4 from the peat substrate in bog pools (Lamers *et al.,* 1998). Increased nutrient availability in raised bogs leads to a higher cover of vascular plants such as *Molinia caerulea* and *Betula* spp. and an elevated N-content of *Sphagnum* mosses (Lamers *et al.,* 2000). As a result, both the input and nutritional value of dead organic material in bog pools increase. Additionally, algal growth rate and nutrient content are increased. These changes in quantity and quality of food sources at the start of the aquatic food web may underlie the observed changes in invertebrate species composition. This paper addresses the question whether the increased nutrient availability has caused changes in the importance of basal food sources that may have led to cascading effects through the invertebrate food web in bog pools.

Material and methods

Stable isotope ratios of carbon and nitrogen of basal food sources and aquatic invertebrates were compared between nine bog pools differing in nutrient availability. Three bog pools were sampled in Nigula bog, Southwest Estonia, between 9 and 23 September 2002. In the Netherlands, six peat cuttings and inundated peat extraction fields were sampled in five raised bog remnants in total between 7 October and 15 November 2002. At each site surface water and sediment pore water samples were collected for analysis of nutrient availability (Table 1). For further details about water quality analyses see Van Duinen *et al.* (2006).

At all sampling sites plants (filamentous algae, mosses and vascular plants) and aquatic macroinvertebrates were collected. Settled dead organic matter was collected from the peat bottom by means of a plankton net with mesh size 45 µm. Zooplankton was collected from the open water by means of this plankton net and light traps. Gut contents were not removed from invertebrates. The collected material was sorted, washed with demineralised water and kept in a fridge until identification. Identified material was dried for 24 hours at 70°C and subsequently ground, using liquid nitrogen. Carbon and nitrogen isotopic composition was determined. Average reproducibilities of duplo and triplo measurements were <0.2‰. Stable isotope data are presented as the relative difference between the ratios of the sample and the standards, using the following formula:

$$\delta R = [(R_{sample} / R_{standard}) - 1] \times 1000$$

where $R = {}^{13}C/{}^{12}C$ or ${}^{15}N/{}^{14}N$. $\delta^{13}C$ or $\delta^{15}N$ is the per mille (‰) deviation of the sample from their isotope standards, that are PeeDee belemnite for $\delta^{13}C$ and atmospheric N_2 for $\delta^{15}N$.

Table 1. Average (± sd) pH and concentrations of o-PO_4 and NO_3+NH_4 (µmol/l) of surface water and sediment pore water at the nine sampling sites.

Site	Surface water pH	Surface water o-PO_4	Surface water NO_3+NH_4	Sediment pore water pH	Sediment pore water o-PO_4	Sediment pore water NO_3+NH_4
Estonia						
Nigula 1	4.2±0.3	0.2±0.1	13±14	4.9±0.2	0.2±0.1	5.4±4.0
Nigula 2	4.0±0.0	0.1±0.1	12±5.6	4.8±0.7	0.2±0.1	15±16
Nigula 3	3.9±0.1	0.3±0.0	11±9.0	4.5±0.2	0.2±0.1	21±14
The Netherlands						
Haaksbergerveen 1	4.2±0.2	0.8±0.4	14±12	4.8±0.5	1.3±1.2	46±21
Haaksbergerveen 2	4.2±0.1	2.2±2.8	13±7.4	5.5±0.5	1.7±0.5	40±14
Korenburgerveen	3.7±0.1	0.9±0.2	11±4.1	5.1±0.9	0.8±0.1	21±11
Reigerplas	4.2±0.5	0.4±0.3	8.3±2.8	5.0±0.0	3.2±2.3	110±131
Mariapeel	4.0±0.1	3.4±17	23±21	5.0±0.4	18±19	201±117
Bargerveen	3.8±0.1	5.6±8.2	20±16	4.5±0.5	82±102	213±219

Results and Discussion

Different invertebrate species collected within the same bog pool differ in their $\delta^{13}C$, indicating differential use of carbon sources, and in their $\delta^{15}N$, indicating the presence of various trophic levels in the invertebrate community (Figure 1). For dead organic matter and plants, as well as most invertebrate species trophic levels in the food web inferred from their $\delta^{15}N$ corresponded with common ecological knowledge.

In food web studies generally an enrichment of 0 to 1‰ (less negative) for $\delta^{13}C$ between trophic levels is found (McCutchan *et al.*, 2003). Only for the two most nutrient rich sites (Bargerveen and Mariapeel) all collected invertebrate species appeared to be similar or enriched in $\delta^{13}C$ compared to basal food sources (dead organic matter and living plants). In the three Estonian sites and the less nutrient-rich Dutch sites many invertebrates were depleted (more negative) in $\delta^{13}C$ compared to the analysed basal food sources. For example, in pool Nigula 1, $\delta^{13}C$ of dead organic matter and living plants ranged from -28.3 to -24.3‰, whereas $\delta^{13}C$ of invertebrates ranged from -34.8 to -24.2‰ (Fig. 1). Although consumers can be depleted in $\delta^{13}C$ relative to their food sources by more than 2‰ (McCutchan *et al.*, 2003), the depletion was not consistent for all sampling sites. The difference between the average $\delta^{13}C$ of all basal food sources and the average $\delta^{13}C$ of all invertebrates (=average trophic shift) correlated strongly and positively to nutrient concentrations of surface water ($p < 0.025$) and sediment pore water ($p < 0.001$; Fig. 2).

For the nutrient poor bog pools still one or more important basal carbon sources with $\delta^{13}C < -30‰$ need to be identified. The still unidentified basal carbon sources become less important with increasing nutrient availability. In a study on lake zooplankton, Grey *et al.* (2000) concluded that the relative importance of allochthonous sources of organic carbon decreases with increasing lake

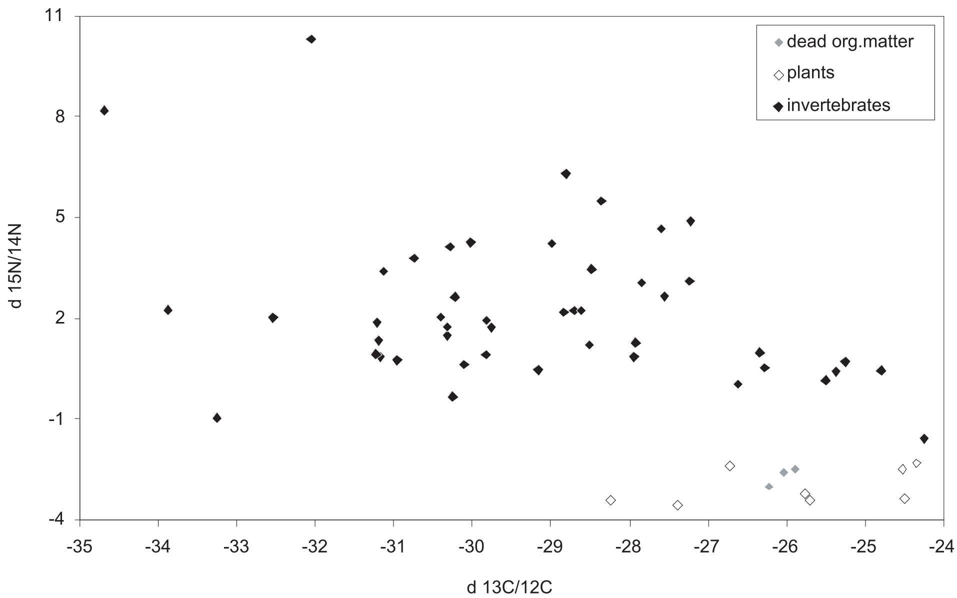

Figure 1. Scatter plot of δ15N against δ13C of dead organic matter, plants (vascular plants, mosses and filamentous algae) and aquatic invertebrates of the intact raised bog pool Nigula 1.

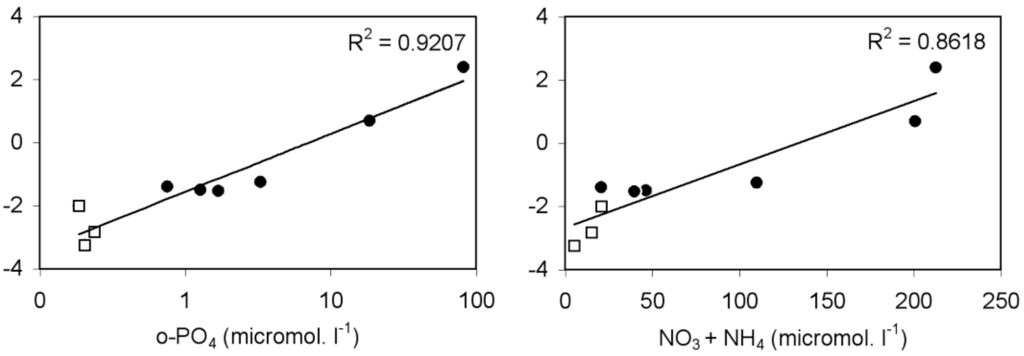

Figure 2. Relationship between the o-PO_4 and NO_3+NH_4 concentrations in sediment pore water and the average trophic shift for the nine sampling sites. Open squares for Estonian sites and filled circles for Dutch sites.

trophy. In the case of the pools sampled in Nigula bog, these allochthonous food sources could be pollen, seeds or leaves of *Betula* and *Pinus* trees, that are scattered in the surrounding bog, and terrestrial insects, for example ants and butterflies, falling and drowning in the pool. The $\delta^{13}C$ of *Betula* leaves and terrestrial invertebrates collected here was > -29,6‰. Alternatively, in oligotrophic lakes in which phytoplankton production is limited, zooplankton diets are supported by planktonic heterotrophs and detritus via the microbial pathway (Hessen *et al.*, 1990; Jones, 1992). Methanotrophic or chemoautotrophic bacteria are known to have a $\delta^{13}C$ < -40‰ and are assimilated by invertebrates such as chironomid larvae (Kiyashko, 2004; Grey and Deines, 2006) and zooplankton (Taipale *et al.,* 2007).

We suggest that only in the most nutrient enriched raised bog pools the quality of dead organic matter and/or the abundance and quality of algae are sufficient to support the whole invertebrate community. In the pristine or less nutrient enriched pools one or more basal carbon sources with $\delta^{13}C$ < -30‰ are more important. Thus, nutrient enrichment in bog pools changes the importance of basal carbon sources in the invertebrate food webs.

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