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Moorland pools as refugia for endangered species characteristic of raised bog gradients

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ABSTRACT

In intact raised bog landscapes transitions from ombrotrophic into minerotrophic conditions occur. These gradients are lost from many bogs due to peat harvesting and drainage, and are difficult to restore. To determine which endangered species are characteristic of pristine raised bog gradients and their current status in degraded bogs, plants and macroinvertebrates were surveyed in Estonian intact raised bogs and Dutch degraded bog remnants. Dutch national distribution data were used to determine whether communities with these species occurred outside bog habitats. Water chemistry data were used to describe associated environmental conditions. Intact bog gradients were the preferred habitat for six plant species and fifteen macroinvertebrate species, all of which are endangered. In degraded bogs these species were scarce or not recorded. In intact bogs these species lived at sites where runoff from the bog massif came into contact with regional ground water resulting in a gradient in pH, alkalinity, Ca, Fe and ionic ratio. Analysis of Dutch national distribution data revealed aggregations of these endangered species in moorland pools. These pools contained water chemistry gradients similar to those found in pristine bogs, which occurred at sites were groundwater seepage and stream water came in contact. In the past, stream water has been used to increase pH and trophic status of moorland pools facilitating fisheries. Today, this practice offers a conservation strategy for the protection of endangered species for which no short-term alternatives are available.

Introduction

Intact bog landscapes are characterised by a bog massif, which is formed by peat mosses (*Sphagnum* spp.) that may cover extensive areas (Couwenberg & Joosten 2005; Pons 1992). These mosses act as ecosystem engineers, creating their own optimal environment (i.e. permanently wet, acid and nutrient poor conditions) (Rochefort 2000; Van Breemen 1995). Such conditions offer an extreme environment for aquatic biota (Peus 1923; Van Duinen et al. 2006; Verberk et al. 2006). These harsh conditions are offset at places where mineral soils protrude through the peat and at the edge of the bog massif, giving rise to lagg zones and transitional mires (Wheeler & Proctor 2000). Here, the contact of acid, nutrient poor runoff from the bog massif and seepage of alkaline, mineral rich groundwater results in water chemistry gradients (Bragazza & Gerdol 2002). Contact zones between calcareous and acid water are known to harbour species rich communities (Palmer et al. 1992; Verberk et al. 2006). Despite their much smaller extent, these transitional zones contain similar numbers of species compared to the raised bog massif (Desrochers & Van Duinen 2006; Van Duinen et al. 2006). This habitat is protected by the European habitat directive as Transition Mire and Quaking Bog. The high diversity of the transitions can be attributed to a gradient of sequential different environmental conditions (niche partitioning), habitat complementation and mass effects, which can cause a high species richness locally by immigrating individuals from adjacent but dissimilar habitats (Shmida & Wilson 1985; Verberk et al. 2006). The diversity of the raised bog massif itself is limited by extreme environmental conditions such as acid and nutrient poor conditions.

The area covered by raised bogs has decreased considerably in many parts of the world and this decrease is still ongoing (Joosten & Clarke 2002). Exploitation of bogs in particular drainage, peat cutting and cultivation, started at the bogs' edges and gradually

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extended inwards (Verhoeven 1992). Consequently, the species rich gradients were lost first. Pressure on this element of the bog landscape further increased due to decreased groundwater quality and quantity as a result of agriculture, extraction of drinking water and drainage and peat cutting (Schouwenaars 1993). At present the conservation status of transitional mires is inadequate in many European countries (European Environment Agency 2011).

In many European bog remnants restoration measures are being taken to restore the environmental conditions and their populations of characteristic species. The primary target in most raised bog restoration projects is reformation of the bog massif by facilitation of *Sphagnum* growth. Consequently, restoration measures mainly focus on reducing nutrient availability and on raising the water tables by retaining rainwater (Wheeler & Shaw 1995). However, species rich gradients in bog landscapes also depend on base-rich ground water and therefore require a functional regional hydrology (Verberk et al. 2010). Yet groundwater systems are only occasionally being restored as this is difficult to achieve and often requires measure outside the bog remnants. Consequently, restoration of lagg zones, transitional mires and their characteristic communities is unlikely to be realised in the near future. Therefore, Van Duinen et al. (2003) emphasise the importance of conserving populations of these species in addition to bog ecosystem restoration by facilitating *Sphagnum* growth. This requires an overview of the endangered species belonging to these communities, insights to the prospects for these species in raised bog remnants and other habitats, knowledge of their environmental requirements as well as management tools to ensure the viability and expansion of populations. More specifically, the following questions are addressed:

(1) Which endangered species are characteristic of pristine raised bog gradients?
(2) Do these species still occur in raised bog remnants?
(3) Do communities with these species occur in other habitats?
(4) Under what environmental conditions do these species occur in intact bog landscapes?
(5) How are these conditions realised in other habitats?

Methods

Surveys of intact and degraded raised bogs

To establish which endangered species are characteristic of bog gradients (question 1) and whether these species occur in bog remnants (question 2), we used data on the distribution of plants and macroinvertebrates from field surveys in intact raised bogs in Estonia and Dutch raised bog remnants. The Estonian raised bog reserves Nigula, Soomaa and Endla were selected as reference sites for Dutch bog landscapes. These bogs are only marginally influenced by human activities and on the European main land are the closest intact bogs to the Netherlands. In spite of having a more continental climate, the Estonian species pool is comparable with that in the Netherlands.

To identify endangered species characteristic of raised bog gradients, vegetation relevés were made and aquatic macroinvertebrates were sampled from 26 sites in intact raised bogs in Estonia in spring 2001 and autumn 2005. These sites were selected from different parts of the raised bog landscape: 15 sites from the bog massif and 11 from transitional mire and lagg. Species with a higher presence (i.e. the percentage of samples in which a species was recorded) in transitional mire and lagg than in the bog massif were considered as endangered if they were listed in Red Data Books as vulnerable, endangered, critically endangered or extinct. In the Netherlands such lists are available for higher plants (Van der Meijden et al. 2000), dragonflies (Wasscher et al. 1998), caddisflies (Verdonschot et al. 2003) and aquatic beetles (Drost et al. 1992).

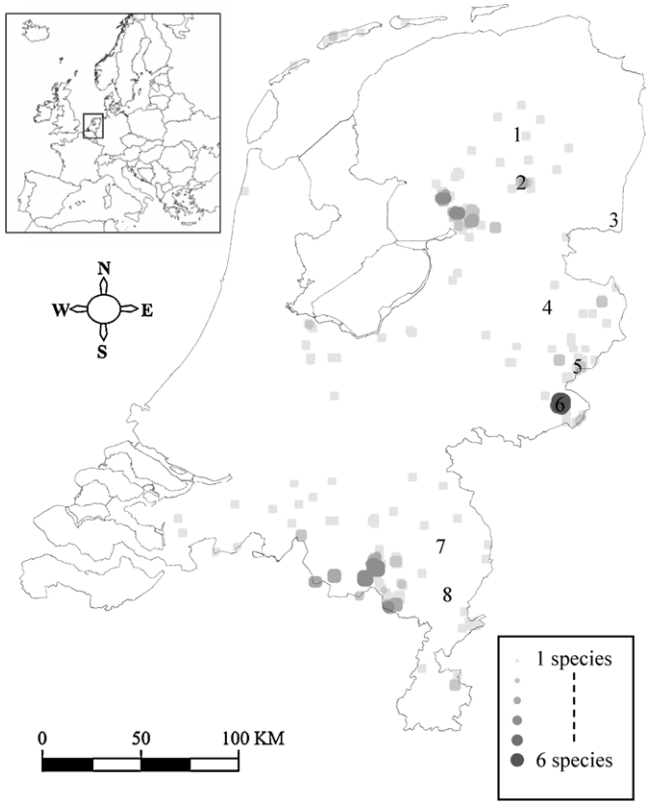

Fig. 1. Number of endangered bog-gradient species per km^2, based on Dutch national databases in the period 1991–2006. The number of species corresponds to the total number in that square and directly adjacent squares. Increasing dot size and darkness correspond to a higher number of species. Numbers correspond to studied raised bog remnants. (1) Fochteloërveen, (2) Dwingelderveld, (3) Bargerveen, (4) Wierdense Veld, (5) Haaksbergerveen, (6) Korenburgerveen, (7) Peel and (8) Tuspeel.

The formerly extensive raised bogs in the Netherlands are nowadays seriously degraded by peat harvesting, desiccation and N-deposition and no intact raised bogs remain. In order to determine the status of the selected endangered species in bog remnants in the Netherlands, data on plant and macroinvertebrate species occurrence for 198 sites in bog remnants was analysed. These data were previously collected in spring and autumn in the period 1998–2007 in different raised bog remnants (Fig. 1; Korenburgerveen 45; Dwingelderveld 8; Bargerveen 43; Haaksbergerveen 10; Fochteloërveen 4; Wierdense Veld 36; Peel 46 and Tuspeel 6 sites) (Van Duinen et al. 2003; Van Duinen 2008; Verberk et al. 2006, 2008). Sampling methods for aquatic macroinvertebrates at Estonian and Dutch sites have been described in detail by Van Duinen et al. (2003, 2006) and Verberk et al. (2008). Vascular plants were censused within a radius of 5 m of the area sampled for invertebrates.

Dutch distribution data of endangered species

To establish if communities with the identified endangered species occur in other habitats (question 3), we used Dutch distribution data that were available for a selection of plant and macroinvertebrate species. For vascular plants, dragonflies and caddisflies reliable data on their distribution in the Netherlands are available. These data were used to determine the status of endangered species outside bog remnants and identify areas where environmental gradients similar to those in raised bog lagg zones