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Groundwater nitrogen and the distribution of groundwater-dependent vegetation in riparian areas in agricultural catchments

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ABSTRACT

Eutrophication is a major threat for several species-rich habitat types e.g. fens and meadows in riparian discharge areas throughout Europe, but few data are available to support the supposition that nutrient-contaminated groundwater from agricultural land is the direct cause for the continued decline of these formerly widespread habitat types. In the present study we investigated the role of nitrogen for the distribution of groundwater-dependent vegetation types in discharge areas in Denmark. Specifically we hypothesised (1) that the nitrogen availability in riparian discharge areas is linked to agricultural intensity in the topographic catchment and (2) that the spatial distribution of vegetation in riparian areas is influenced by nitrogen in the groundwater e.g. high productive reed beds dominate in areas with high levels of groundwater nitrogen, whereas species rich fens occur in areas with lower levels of groundwater nitrogen reflecting that incoming nutrients influence the productivity within the areas. We find evidence that the percentage of agriculture in the topographic catchment directly influenced the amount of nitrate in the discharging groundwater in the study areas and that groundwater nitrogen is closely coupled to the distribution of groundwater-dependent vegetation. Meadow and reed bed vegetation being highly productive were associated with higher levels of nitrate in the groundwater compared to low productive rich fen vegetation. From these findings we recommend that protected groundwater-dependent vegetation is mapped in groundwater discharge areas and that only those without presence of protected habitats are considered in rewetting plans to mitigate nutrient loss from agricultural production.

1. Introduction

Stream and river ecosystems worldwide have experienced long-term degradation from various anthropogenic pressures. In lowland regions these have mainly been related to agriculture, with significant pollution of groundwater and surface waters with nutrients and toxic compounds as well as by changes in hydro-morphological features (Brookes, 1987; Brookes and Long, 1990; Landwehr and Rhoads, 2003; Mattingly et al., 1993; Verdonschot and Nijboer, 2002) that affect not only in-stream habitats but also the distribution of habitats in the associated riparian areas (Baattrup-Pedersen et al., 2011). Additionally, groundwater abstraction and artificial drainage significantly interfere with groundwater discharge in stream and river ecosystems and even small changes in groundwater levels may affect the distribution of groundwater dependent ecosystems in the riparian areas (Bledsoe and Shear, 2000; Johansen et al., 2011).

The influence of anthropogenic pressures of both past and present land use has changed riparian habitat conditions dramatically. As a consequence, formerly widespread mesotrophic fen and meadow communities have declined (Middleton et al., 2006; Poschlod et al., 2005; van Diggelen et al., 2006), and many species that were formerly widespread are declining rapidly (Ewers and Didham, 2006). Today the common perception is that eutrophication is among the most important threats for several groundwater-dependent ecosystems e.g. species rich fens and fen-meadows. Reduced groundwater inflow and falling groundwater tables allow atmospheric oxygen to enter the soil invoking mineralisation of organic material and the release of large quantities of nutrients (Venterink et al., 2009). Additionally, atmospheric nitrogen deposition and inflow of nutrient contaminated groundwater may contribute to eutrophication of discharge areas (Koerselman

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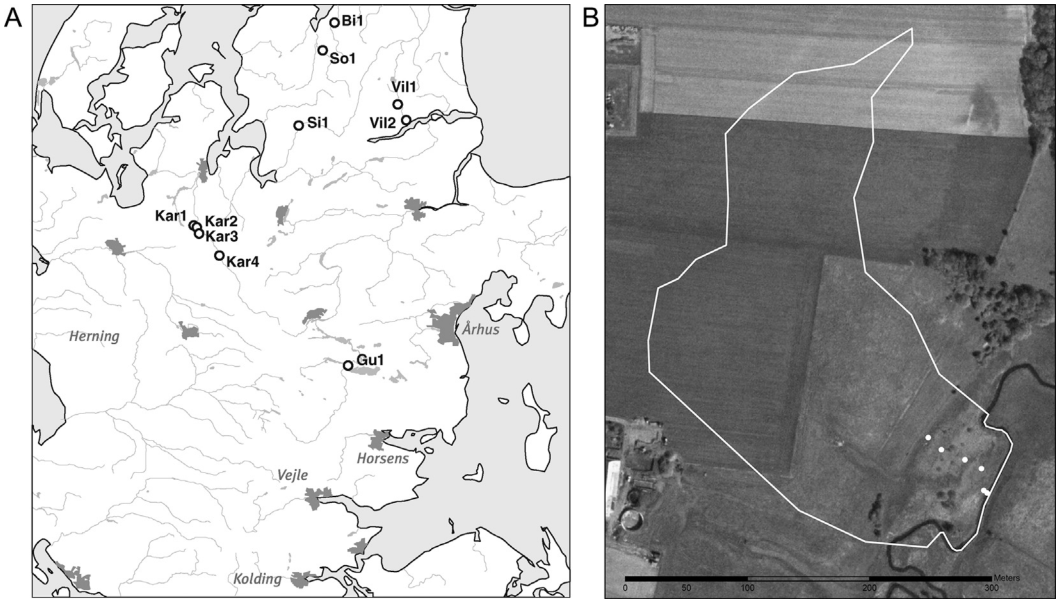

Fig. 1. (A) Map showing the location of the ten study sites situated along 6 middle-sized rivers in central Jutland. Denmark. More site specific details are given in Table 1. (B) The topographic catchment delineated on a map from one of the study sites, Binderup å, and the location of plots used for surveys of vegetation and groundwater nitrogen.

and Verhoeven, 1992; Pieterse et al., 2005). Over the last decade the influence from atmospheric nitrogen deposition has declined in many lowland regions due to the implementation of several mitigation measures in the agricultural production (Diacono et al., 2013; Hirt et al., 2012), whereas the influence from nutrient contaminated groundwater may persist or even increase as a consequence of climate change in many regions throughout Europe and Northern America (Refsgaard et al., 1999; Stuart et al., 2007, 2011).

In recent years there has been an increased use of riparian areas to mitigate nutrient loads and toxic compounds to freshwater ecosystems to comply with the Water Framework Directive (WFD; Council Directive 2000/60/EC; Hill, 1996; Kronvang et al., 2008; Venterink et al., 2006). These measures may involve cutting of tile drains that enter the riparian area leading directly to increased nutrient loads which can furthermore interfere with the hydrological and biogeochemical settings in the riparian areas (Hammersmark et al., 2009). Such measures may therefore directly threaten communities that are sensitive to eutrophication including several groundwater-dependent ecosystems e.g. alkaline fens, periodically inundated meadows and mires (Dybkjær et al., 2012; Grootjans et al., 2006). These ecosystems are embraced by international legal frameworks such as the Convention on Biological Diversity, the WFD, and the EU Habitats Directive (HD; Council Directive 92/43/EC) and measures should therefore be taken to protect them from further degradation.

The objective of this study was to examine the distribution of groundwater-dependent vegetation in discharge areas situated along middle-sized streams in Denmark in relation to dissolved inorganic nitrogen in the discharging groundwater. Specifically we hypothesised (1) that the nitrogen availability in riparian discharge areas is linked to agricultural intensity in the topographic catchment and (2) that the spatial distribution of vegetation in riparian areas is influenced by nitrogen in the groundwater e.g. high productive reed beds dominate in areas with high levels of groundwater nitrogen, whereas species rich fens occur in areas with lower levels of groundwater nitrogen reflecting that incoming nutrients influence the productivity within the areas (Bridgham and Richardson, 1993; Grootjans et al., 1985, 1986; Kotowski et al., 2006). All study sites were located in the central Jutland, Denmark, but significant differences existed in topographic catchment area, soil characteristics and percentage of agriculture in the topographic catchment varying from 0% to 99.8%. This variability in land use made our data suitable for testing the effect of agriculture in the topographic catchment for nitrogen concentrations in discharging groundwater in riparian areas and concomitant impacts on vegetation characteristics.

2. Methods

2.1. Study sites

Ten study areas were selected along six middle-sized naturally meandering streams that are among the least disturbed stream ecosystems in Denmark. Four sites were located at River Karup, two sites at River Villestrup, one site at River Soenderup, one site at River Gudenå, one site at River Simested and one site at river Binderup (Fig. 1A). The riparian areas were covered by semi-natural grassland vegetation with scattered occurrence of trees and shrubs. The geomorphology of the study sites differed: the River Karup and River Gudenå is situated on sandy outwash plains from the Weichsel glaciation, River Villestrup is situated on a small patch of marine foreland built up since the Atlantic marine regression (8000 B.P.) and River Soenderup, River Simested, and River Binderup are located on a younger sandy moraine from the Weichsel glaciation. The total catchment area varied greatly among study sites ranging from 1042 ha (Karup 2) to 162,081 ha (Gudenå; Table 1). The percentage of agriculture in the topographic catchments also varied greatly from 0% (Karup 3) to 99.8% (Binderup; Table 1) along with soil characteristics (Table 1). Generally the soils were wet and peaty in the study areas. There was, however, a high variability in groundwater levels and bulk density among plots as shown in Table 1.

2.2. Study design and water analysis

A total of 51 plots (app. 49 m^2) were delineated within the study areas (Table 1). The delineated plots covered contrasting vegetation characteristics. In particular we aimed at finding rich fen vegetation in all study sites to be sure to cover the variability in nitrate discharge associated with this vegetation type. The plots