Science of the Total Environment 490 (2014) 106–113

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evidence for sensitivity of dune wetlands to groundwater nutrients

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HIGHLIGHTS

- We studied a dune system surrounded by fertilised agricultural land.
- Groundwater nutrients affected vegetation and soils in dune slack wetlands.
- Change in vegetation and soil were observed at 0.2mg/L of DIN within groundwater.

ARTICLE INFO

Article history:
Received 17 December 2013
Received in revised form 7 April 2014
Accepted 8 April 2014
Available online xxxx

Editor: Eddy Y. Zeng

Keywords:
Dune slacks
Nitrogen
Groundwater
Contamination
Sand dunes
Ecohydrology

ABSTRACT

Dune slacks are seasonal wetlands, high in biodiversity, which experience considerable within-year and between-year variations in water-table. They are subject to many pressures including climate change, land use change and eutrophication. Despite their biological importance and the threats facing them, the hydrological and nutrient parameters that influence their soil properties and biodiversity are poorly understood and there have been no empirical studies to date testing for biological effects in dune systems resulting from groundwater nutrients at low concentrations. In this study we examined the impact of groundwater nutrients on water chemistry, soil chemistry and vegetation composition of dune slacks at three distance classes (0–150 m, 150–300 m, 300–450 m) away from known (off-site) nutrient sources at Aberffraw dunes in North Wales, whilst accounting for differences in water-table regime. Groundwater nitrate and dissolved inorganic nitrogen (DIN) and soil nitrate and nitrite all had significantly higher concentrations closest to the nutrient source. Multivariate analysis showed that although plant species composition within this site was primarily controlled by water table depth and water table fluctuation, nitrogen from groundwater also influenced species composition, independently of water table and soil development. A model containing all hydrological parameters explained 17% of the total species variance; an additional 7% was explained following the addition of NO_3 to this model. Areas exposed to elevated, but still relatively low, groundwater nutrient concentrations (mean 0.204 mg/L +/− 0.091 of DIN) had greater abundance of nitrophilous species and fewer basipholous species than in areas with lower concentrations. This shows that clear biological impact occurs below previously suggested DIN thresholds of 0.20–0.40 (mg/L).

1. Introduction

Sand dune systems have a global distribution (Martinez et al., 2004) and support a high biodiversity, including many threatened plant, insect and animal species (Rhind and Jones, 2009; Howe et al., 2010). They contain seasonal wetlands, known as dune slacks, which support a particularly diverse flora in Europe (Grootjans et al., 2004), including red list species such as the fen orchid *Liparis loeselii* and the liverwort *Petalophyllum ralfsii*.

Sand dune systems have undergone considerable change globally in the last century (Martinez et al., 2004). In temperate European dune systems these drivers include: changes in land use, crashing rabbit populations, climate change and eutrophication (Provoost et al., 2011; Jones et al., 2011; Beaumont et al., 2014). With regard to the latter; nutrients from atmospheric deposition have increased dramatically from their pre-industrial levels of 2–6 kg N ha^{-1} yr^{-1} (Fowler et al., 2004). As a consequence, the critical load defined for dune slacks, 10–15 kg N ha^{-1} yr^{-1} (Bobbink and Hettelingh, 2011), is exceeded across much of Europe. Whilst the effects of atmospheric deposition have received recent attention in dry dune habitats (Plassmann et al., 2009; Remke et al., 2009; Jones et al., 2013), relatively little attention has been given to the impact of other sources of nutrients in dune

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http://dx.doi.org/10.1016/j.scitotenv.2014.04.029
0048-9697/

wetlands, indeed in wetlands in general, and the issue of groundwater or surface water-derived nutrients is not explicitly considered within atmospheric critical loads frameworks. In dune systems that are not isolated hydrologically from surrounding groundwater, there is the potential for nutrient inputs to these habitats from agricultural and other sources via groundwater to add to the nutrient load already received from atmospheric deposition. A collation of dune groundwater chemistry data (Davy et al., 2010) suggested that values >1 mg/L dissolved inorganic nitrogen (DIN) in dune groundwater indicated probable nutrient contamination of the groundwater within a site, whilst concentrations above 0.2 mg/L may also signify contamination. A global assessment of aquatic ecosystems concluded that concentrations above 0.5–1.0 mg/L of total nitrogen could lead to eutrophication (Camargo and Alonso, 2006). There have been studies in the Netherlands on impacts of highly eutrophic river water around drinking water infiltration ponds (Meltzer and van Dijk, 1986). However, there have been no empirical studies to date testing for biological effects in dune systems resulting from groundwater nutrients at low concentrations.

Species distribution within these ecosystems is governed primarily by water table depth, seasonal water table fluctuations and water chemistry (Curreli et al., 2012; Grootjans et al., 1996; Lammerts et al., 1992, 2001; Willis et al., 1959). Yet, there remains a major knowledge gap as to how groundwater nutrients may affect dune slack vegetation and at what concentrations (Jones et al., 2006). Studies of atmospheric nitrogen deposition impacts have been made in many habitats (e.g. Phoenix et al., 2012), with the potential for community shift in extreme cases such as conversion of heathlands into grasslands (Heil and Diemont, 1983). However, in dune slacks there is still relatively little empirical evidence of nutrient impacts either from atmospheric deposition or from other sources, especially at realistic N loads. One of the few studies, using high nutrient loads on dune vegetation at Braunton Burrows demonstrated that *Agrostis stolonifera* dominated a dune slack following surface additions of N and P (Willis, 1963).

Dune slack water tables tend to be at their highest in winter and fall in the summer months (Van Der Laan, 1979) as the water table is highly dependent on precipitation and evaporation. Water tables can also vary substantially from year to year (Ranwell, 1959; Stratford et al., 2013), causing periods of drought and flooding which affect the period in which the rooting zone is in contact with the water table. These fluctuations also play an important role in controlling nutrient composition within the soils. During periods of high water level, mineralisation of organic matter is reduced thus conserving the low nutrient status favoured by dune slack species (Berendse et al., 1998). Soil processes are important in regulating the impacts of N. Soil exchange sites may actively bind ammonium from the groundwater during periods of inundation, whilst denitrifying bacteria may release nitrogen back into the atmosphere (Myrold, 1998).

The aim of this investigation was to examine the impact of nutrients on dune groundwater chemistry, soil chemistry and botanical composition along gradients of nutrient input from known sources, and accounting for differences in water-table regime. We tested the following hypotheses: does nutrient contamination from off-site sources extend into the groundwater under the dune system? If nutrients are present in the groundwater, is there any evidence in the plant assemblages and soils of dune slacks that these nutrients are accessible to the vegetation in the dune slacks, and do they have an adverse ecological impact on the plant community composition?

2. Methods

2.1. Site description

Aberffraw dunes are located on the south west corner of the island of Anglesey in North Wales, UK (53°11′N, 4°27′W). The site extends for 1 km in width and 3 km inland (Fig. 1). A small lake, Llyn Coron bounds the north east edge of the system and feeds the river Afon Fraw, which

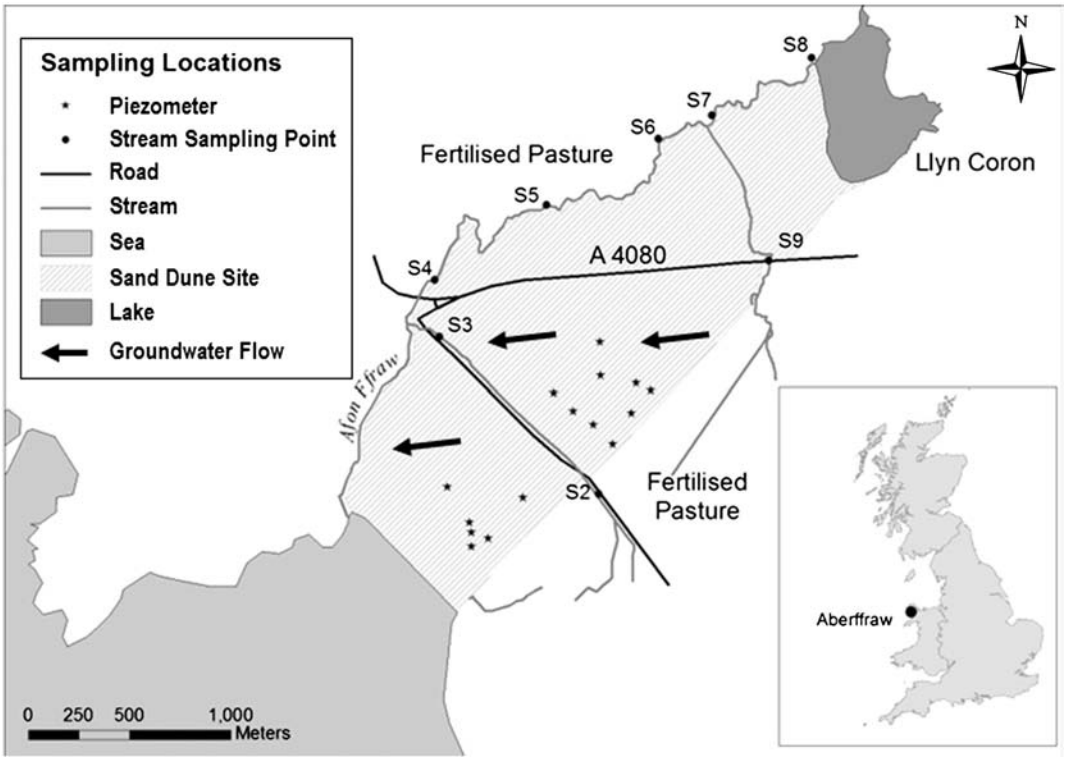

Fig. 1. Map of Aberffraw dune system, showing all piezometers and stream (S2–S9) sampling points. S1 (not shown) was an episodic stream and data were only collected from this sampling point for one month. Cross-hatched area represents designated site.
Redrawn from Ordnance Survey.