Environmental Pollution 195 (2014) 226–231

Contents lists available at ScienceDirect

Environmental Pollution

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

Short communication

Year-round grazing to counteract effects of atmospheric nitrogen deposition may aggravate these effects

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ARTICLE INFO

Article history:
Received 24 April 2014
Received in revised form
25 August 2014
Accepted 28 August 2014
Available online 23 September 2014

Keywords:
Vegetation management
Manure
Nitrogen
Eutrophication
Natura 2000
Grey dune

ABSTRACT

Excessive nitrogen input in natural ecosystems is a major threat to biodiversity. A coastal dune area near Amsterdam in the Netherlands suffers from high atmospheric nitrogen deposition affecting sensitive habitats such as fixed coastal dunes with herbaceous vegetation (‘grey dunes’). To mitigate its effect year round grazing was applied from 2007 until 2012. In winter, when natural food supply is low, the cattle received supplementary hay that caused additional inputs of nitrogen. Estimates based on nitrogen contents of hay, as well as of manure, showed the input through winter feeding (c. 3–14 kg N $ha^{-1}.y^{-1}$) is in the same order of magnitude as both the actual deposition (c. 17 kg N $ha^{-1}.y^{-1}$) and the critical load for a number of herbaceous habitat types (10–15 kg N $ha^{-1}.y^{-1}$). Locally, the effect of winter feeding adds to the effect of nitrogen redistribution within the area caused by the cattle's terrain usage. We conclude that winter feeding may aggravate effects of atmospheric nitrogen deposition.

1. Introduction

Excessive nitrogen input may change ecosystem composition and functioning (Galloway et al., 2003; Stevens et al., 2011). Most of the additional nitrogen that is received by ecosystems nowadays is due to atmospheric ammonia and nitrogen oxide, originating from agriculture, transport and industrial activities (Tilman, 1993; Thomas et al., 1999; Reich et al., 2001; Galloway et al., 2008). In general, atmospheric deposition of nitrogen leads to increased productivity and thereby to a decrease in species number by the exclusion of less competitive species (De Schrijver et al., 2011), and to an acceleration of the succession from grassland to woodland. As a result, species-rich dune grassland becomes increasingly rare in areas like The Netherlands that suffer from high nitrogen deposition (Provoost et al., 2011). Mitigating measures are applied to limit effects of nitrogen on the vegetation, both at the source of the pollutants (e.g. filters, catalysts) and at the polluted sites (e.g. sod cutting, mowing, grazing; Kelly et al., 2002; Tarason et al., 2003). Grazing is standard management in many semi-natural grasslands to keep vegetation open and short. When grazing is applied year round, additional feeding may be necessary during winter. However, this results in additional input of nitrogen, which is not desired in natural areas that already suffer from nitrogen overload. To investigate the magnitude of this effect we set up a simple nitrogen budget for a grazed coastal dune area in the Netherlands, which has been shown to be extremely sensitive to atmospheric deposition of nitrogen (Kooijman et al., 1998; Van Dobben et al., 2014). We attempted to make this budget spatially explicit by tracing the redistribution of nitrogen via the cows' excrements.

2. Material and method

2.1. Study area

We selected the Amsterdam Water Supply Dunes (Amsterdamse Waterleidingduinen; 52°20′ N, 4°32′ E, West of Amsterdam; Fig. 1) for a pilot study. This area is an EU protected ‘Natura 2000’ site (Council of the European Communities, 1992) hosting several rare vegetation types, typical for nutrient-poor conditions (Fig. 2). In this paper we use the habitat typology (as in Annex I of Council of the European Communities, 1992) refined by subtypes defined for the Dutch situation (as in Annex I of Van Dobben et al., 2014). The area is grazed by cattle to prevent succession of open dune to shrub and forest. The area is also used for water infiltration for the production of drinking water for the Amsterdam area.

Since the 1990s the species-rich, open and low-productive vegetation has been in a process of succession towards a species-poor and more productive tall grass vegetation. The succession is partly ascribed to nitrogen deposition and partly to the near extinction of the rabbit by myxomatosis (Sumption and Flowerdew, 1985) and later by rabbit haemorrhagic disease (Van de Bildt et al., 2006). Also the increasing

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http://dx.doi.org/10.1016/j.envpol.2014.08.029
0269-7491/

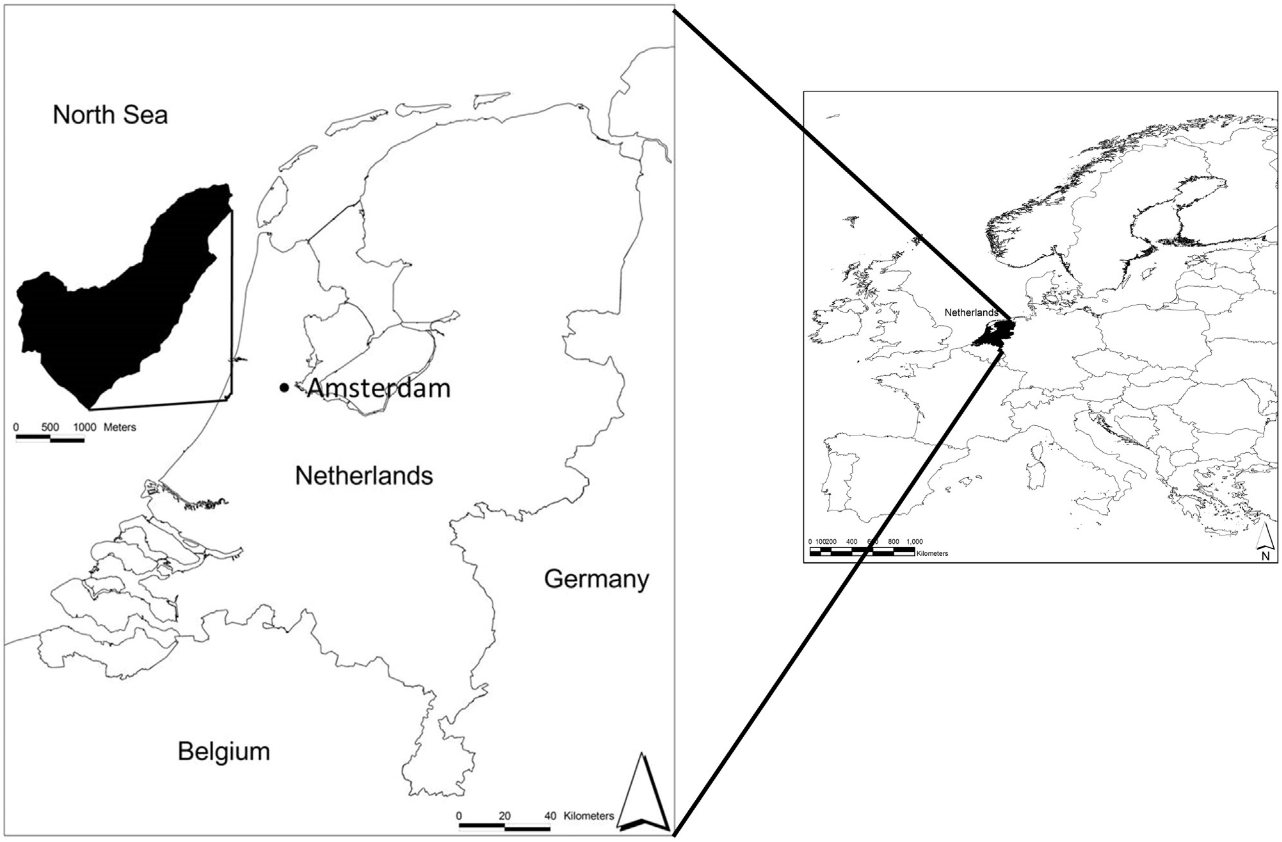

Fig. 1. Location of the study area.

dominance of the exotic invasive species *Prunus serotina* plays a role (Ehrenburg et al., 2008). To counteract these unwanted effects *P. serotina* was removed and year round grazing by cattle, including pregnant cows, was installed in 2007, in a relatively high density in order to tackle regrowth and rejuvenation of *P. serotina*. In winter the cattle received supplementary food in the form of hay harvested outside the area, to compensate for the temporary lack of food (see also Klimkowska et al., 2010).

Our study area is 439 ha, approximately half of which consists of fixed coastal dunes with herbaceous vegetation ('grey dune') which is highly sensitive to nitrogen input (critical load 10–15 kg N/ha/y) depending on the sub-type (Van Dobben et al., 2014) (Table 1, Fig. 2). Approximately 15% consists of oak-birch forest which is also highly sensitive. Less than one third is shrubland dominated by *Hippophae rhamnoides* but also containing *P. serotina*; this type is less sensitive to nitrogen deposition (note that H. *rhamnoides* is associated with the nitrogen-fixing actinomycete *Frankia*). Small parts of the area consist of relatively insensitive wet dune slack and wet forest.

2.2. Nitrogen deposition

We estimated nitrogen deposition on a 250*250 m grid by applying the regional model INITIATOR (De Vries et al., 2003). This model uses input from a geographical information system for agricultural companies (GIAB; Naeff, 2003), including location, animal type and number and farm details. Based on the emission, the deposition from local sources was calculated with the model OPS (Van Jaarsveld, 2004). The background deposition was taken from CPB/PBL (2006) and added to the local deposition. The total deposition in the area ranges between 15.7 and 20.9 kg N $ha^{-1}.j^{-1}$ (Fig. 3).

2.3. Dung heap counts

We counted dung heaps in 60 150 m^2 areas to estimate the manure input per habitat type (Fig. 3). These areas were randomly selected, stratified over the habitat types indicated in Fig. 2. The input was extrapolated over the whole area, assuming our counts to be representative for each habitat type. We thus assume that cattle uses every habitat patch in the same manner as in the sub-areas where dung heaps were counted. We performed a check to ascertain that the quantity of dung received by each Habitat type was not strongly influenced by the proximity of each Habitat type to the feeding station (Fig. 3) (Klimkowska et al., 2010).

2.4. Calculation of nitrogen input due to supplementary winter feeding

We estimated the additional nitrogen input through supplementary winter food in two ways, namely through hay and through manure.

2.5. Estimation of nitrogen input through hay

For this estimation we hypothesize that the net storage of nitrogen in the cattle's biomass is negligible over the considered period (20 weeks). Also, we hypothesize that all nitrogen excreted by the cattle becomes plant-available i.e. no nitrogen in stored in non-degradable soil organic matter. The cattle were fed with two types of hay: from semi-natural grassland and from agricultural grassland. The hay was presented to the cattle in the form of silage, i.e. after partial fermentation. For both types of hay, the nitrogen content was determined in 5 samples and averaged. The cattle received seven bales per week of semi-natural hay for thirteen weeks, seven bales per week of agricultural hay for five weeks and one bale per week of agricultural hay for two weeks (total feeding period: 20 weeks). We assumed that the cattle consumed all the hay supplied. The N input was calculated as:

$$\mathrm{Ninp} = \mathrm{Nbales}*\mathrm{Mbale}*(\%\mathrm{N}/100) \quad (1)$$

in which: Ninp: N input through winter feeding (kg N y^{-1}), Nbales: total number of bales (91 for the semi-natural hay and 37 for the agricultural hay), Mbale: average mass of a bale (400 kg), %N: N-content of fresh 'hay' (i.e., wet grass silage) (3.6 ± 0.12 and 3.8 ± 0.34% for the semi-natural and agricultural hay, respectively).

We calculated the total N input as the sum of the values for both types of hay.

2.6. Estimation of nitrogen input through manure

We assumed that cows and calves produce 40 kg and 10 kg of fresh manure per day, respectively (Klimkowska et al., 2010). We collected 15 dung heaps (11 from cows and 4 from calves) and determined their nitrogen content. Most of the N is returned to the system though urine and we also accounted for this by estimating that 30% of the total input is through manure, based on Bokdam (2003). We estimated the N input though manure for both cows and calves as:

$$\mathrm{Ninp} = \mathrm{Lp}*\mathrm{Nanim}*\mathrm{MP}*(\%\mathrm{N}/100)*(100/30) \quad (2)$$

in which: Ninp: N input through winter feeding (kg N y^{-1}), Lp: length of winter feeding period (day) (20 weeks = 140 days), Nanim: number animals (40 cows and