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Can on-site management mitigate nitrogen deposition impacts in non-wooded habitats?

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ABSTRACT

Nitrogen (N) deposition is a major cause of plant biodiversity loss, with serious implications for appropriate management of protected sites. Reducing N emissions is the only long-term solution. However, on-site management has the potential to mitigate some of the adverse effects of N deposition. In this paper we review how management activities such as grazing, cutting, burning, hydrological management and soil disturbance measures can mitigate the negative impacts of N across a range of temperate habitats (acid, calcareous and neutral grasslands, sand dunes and other coastal habitats, heathlands, bogs and fens). The review focuses mainly on European habitats, which have a long history of N deposition, and it excludes forested systems. For each management type we distinguish between actions that improve habitat suitability for plant species of conservation importance, and actions that immobilize N or remove it from the system. For grasslands and heathlands we collate data on the quantity of N removal by each management type. Our findings show that while most activities improve habitat suitability, the majority do little to slow or to reduce the amount of N accumulating in soil pools at current deposition rates. Only heavy cutting/mowing with removal in grasslands, high intensity burns in heathlands and sod cutting remove more N than comes in from deposition under typical management cycles. We conclude by discussing some of the unintended consequences of managing specifically for N impacts, which can include damage to non-target species, alteration of soil processes, loss of the seedbank and loss of soil carbon.

1. Introduction

The deposition of reactive nitrogen (N) has more than doubled over the last 100 years as a result of agricultural intensification and increased burning of fossil fuels by traffic and industry (Galloway et al., 2008). Globally, deposition of nitrogen is set to increase in the future while in Europe only small declines in N deposition are predicted in the next 10 years (Dentener et al., 2006). Therefore it remains a pressing problem. Atmospheric N deposition affects semi-natural habitats through three main mechanisms: eutrophication, acidification and direct toxicity (Bobbink et al., 1998; Jones et al., 2014).

Many studies have reported negative consequences of N deposition on species diversity and ecosystem function in different habitats (e.g. Aber et al., 1989; Bowman et al., 2008; Jones et al., 2004; Stevens et al., 2004) and severe impacts have been observed in some regions of the world. Amongst the most widely recognised examples has been the reduction of heather (*Calluna vulgaris*) cover in Dutch heathlands (Heil and Diemont, 1983). Reductions in plant species richness at high levels of N deposition have been observed across a broad suite of habitats (e.g. Clark and Tilman, 2008; Field et al., 2014; Maskell et al., 2010) together with changes in the composition of plant communities (Bai et al., 2010; Phoenix et al., 2012; Stevens et al., 2011). Nitrogen accumulates in the soil, augmenting soil N pools and altering soil processes. Experimental and gradient studies across the world have shown changes in the concentrations and processing of nitrogen in the soil (e.g. Aber et al., 2003; Gundersen et al., 1998), nutrient stoichiometry (e.g. Rowe et al., 2008), and leaching to surface waters (e.g. Boxman et al., 1998). Changes in above- and below-ground production and carbon cycling have also been widely observed (e.g. Lee et al., 2010; Reay et al., 2008). These changes affect the provision of a range of ecosystem services such as water quality regulation and greenhouse gas emissions with an associated economic cost (Compton et al., 2011; Jones et al., 2014; Sobota et al., 2015; van Grinsven et al., 2013).

As a result of such widespread impacts on biodiversity, soil processes and ecosystem services there is increasing recognition of the need to manage habitats, and particularly those of a high conservation value, in order to mitigate the effects of N deposition. In the extensive

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literature on N deposition impacts, there is relatively little focus on how on-site management activities might mitigate N impacts, and few experimental manipulations examining the interaction between N deposition and management. The primary studies that have been conducted (e.g. Britton et al., 2000; Pilkington et al., 2007; Plassmann et al., 2009; Power et al., 2001) have tended to focus on a single habitat and one or a few management options.

The aim of this paper is to draw together much of this disparate evidence to synthesise how on-site habitat management can reduce some of the direct impacts of N on biodiversity, and indirect effects mediated by altered soil N processes and pools of accumulated soil N. In doing so, we review evidence across a wide range of habitats (grasslands, heathlands, coastal habitats, fens and bogs) and management techniques (cutting, grazing, burning, disturbance and other measures). We exclude forested systems, where there is an extensive literature and where management, and therefore removal of N, is more complex. We separately explore impacts on habitat suitability for plant species of conservation interest, and on N removal and cycling. We define habitat suitability as the conditions affecting light, competition and regeneration, while N cycling and removal are separately considered as the conditions affecting biogeochemical cycling of N. We also collate N budget data to quantify N removal by management and we discuss the optimum management measures in the context of managing N deposition impacts. The focus is primarily on semi-natural habitats in the temperate zone, as this is where N deposition has historically been greatest, and where the greatest need for management responses currently lies. However, the findings have implications for other areas around the world where N deposition is increasingly a problem (e.g. Bobbink et al., 2010; Fenn et al., 2010).

2. Methods

The review searched literature databases using web of knowledge and Google Scholar. Keywords for searches were based on habitat and the management techniques using synonyms for both habitats and management techniques (e.g. moorland, heathland; sod cutting, turf cutting, turf stripping). We also searched for grey literature using web searches and databases available on websites of relevant charities and conservation organisations. From the studies identified through literature searches we selected those where nitrogen had been applied in combination with management and which reported management trials that had measured impact on nitrogen pools and/or on habitat suitability.

3. Impacts of pollutant N on ecosystem processes and biodiversity

Understanding the cycle of reactive N within ecosystems (Fig. 1) provides insights into appropriate management for reducing effects on biodiversity. Although N is an essential macronutrient needed for plants and animals to grow, natural systems typically have a low rate of N input, from N fixation and the effects of lightning, of the order of 3–5 kg N ha^{-1} yr^{-1} (DeLuca et al., 2008).

Nitrogen pollution can have rapid effects (Hendriks et al., 2014), and in particular gaseous ammonia is toxic for many lichens even at low concentrations of 1 μg m^{-3} (Cape et al., 2009). However, most impacts result from increasing N fluxes into soil and vegetation. In systems that are not N-saturated, the N leaching and other losses are lower than N input rates (Phoenix et al., 2012), so the majority of pollutant N deposited on semi-natural habitats since the onset of industrialization and agricultural intensification has accumulated in the soil. This causes a sustained increase in N mineralization, and the increased availability of N is likely to increase plant growth. Faster growth and greater litterfall rates make conditions difficult for short-growing plants, and these plant species tend to be the more threatened (Hodgson et al., 2014). The same processes also threaten animal species that require warm microclimates (WallisDeVries and Van Swaay, 2006). Increased N availability also tends to increase N concentrations in plant tissue, which can increase susceptibility to insect pests (Lee and Caporn, 1998), and change the structure of foliar invertebrate communities (Rowe et al., 2006).

In systems receiving large and/or prolonged N inputs, eventually the capacity for plant uptake and immobilization is saturated, and N leaching increases. This removes cations such as calcium from the soil, leading to acidification and species loss in poorly buffered habitats, although it should be noted that the dominant cause of soil acidification historically has been sulphur (S) rather than N deposition (Curtis et al., 2005).

4. Overview of management options and how they can mitigate N impacts

A range of management activities are routinely used to manage semi-natural habitats. These may be continuation of traditional management practices such as grazing, or may be implemented as a response to perceived problems affecting conservation status such as scrub encroachment, or loss of forb diversity (e.g. Backshall et al., 2001). Some of these conservation problems may in fact have been caused by, or exacerbated by, N deposition (Dise et al., 2011). Therefore,

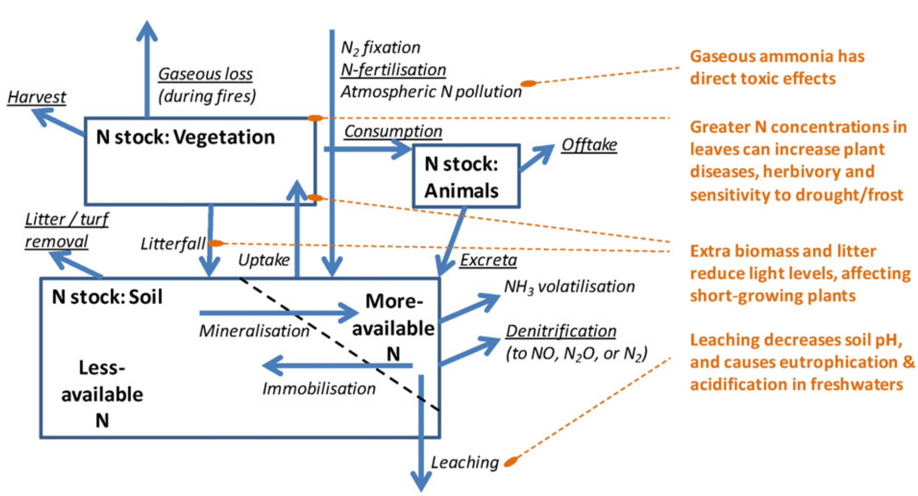

Fig. 1. Simplified summary of the nitrogen cycle in terrestrial ecosystems, indicating major effects on species and biodiversity. The arrows represent nitrogen flows. Underlined flows are those that are most readily influenced by on-site management.

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