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A review and application of the evidence for nitrogen impacts on ecosystem services

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ABSTRACT

Levels of reactive nitrogen (N) in the atmosphere have declined by around 25% in Europe since 1990. Ecosystem services provide a framework for valuing N impacts on the environment, and this study provides a synthesis of evidence for atmospheric N deposition effects on ecosystem services. We estimate the marginal economic value of the decline in N deposition on six ecosystem services in the UK. This decline resulted in a net benefit (Equivalent Annual Value) of £65 m (£5 m to £123 m, 95% CI). There was a cost (loss of value) for provisioning services: timber and livestock production of −£6.2 m (−£3.5 m to −£9.2 m, 95% CI). There was a cost for CO_2 sequestration and a benefit for N_2O emissions which combined amounted to a cost for greenhouse gas regulation of −£15.7 m (−£4.5 m to −£30.6 m). However, there were benefits for the cultural services of recreational fishing and appreciation of biodiversity, which amounted to £87.7 m (£13.1 m to £163.0 m), outweighing costs to provisioning and regulating services. Knowledge gaps in both the under-pinning science and in the value-transfer evidence prevent economic valuation of many services, particularly for cultural services, providing only a partial picture of N impacts which may underestimate the benefits of reducing N deposition.

Contents

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1. Introduction

Levels of reactive nitrogen (N) in the atmosphere have increased globally since the 1940s as a result of man's activities (Galloway et al., 2008). The main sources of oxidised N compounds are vehicle emissions, industry and domestic combustion, while reduced N compounds, primarily ammonia, derive from agriculture sources such as manure and fertiliser volatilisation. Nitrogen is a basic nutrient required for growth, and most semi-natural systems are N-limited (Vitousek et al., 1997). Increased N deposition in the last 70 years has caused widespread adverse impacts on biogeochemical cycling and biodiversity in semi-natural systems as a result of both eutrophication and acidification, which have been well studied (e.g. Duprè et al., 2010; Phoenix et al., 2012; Sutton et al., 2011a). However, since N stimulates plant growth, deposition of this nutrient may be seen as beneficial for human production systems, e.g. by increasing forest growth (De Vries et al., 2009).

Across Europe, emissions of N have now declined by 25% since around 1990 due to policy measures to reduce industrial and vehicular emissions of oxidised N, and to reduce ammonia emissions from agriculture (Oenema et al., 2011). However, the effect of this decline in emissions has not been systematically evaluated across a wide range of sectors.

Ecosystem Services frameworks are emerging as a way of capturing the wider effects of policy decisions or evaluating land use change in order to more comprehensively take into account the range of impacts on the environment, and on the benefits humans receive from it (Turner and Daily, 2008). However, although rapidly developing, much of the conceptualisation around ecosystem services, and the data required to quantify them, do not readily marry to existing experimental data, and the links to ecological processes are poorly defined. Applications to new situations are often largely qualitative, based on expert judgement or assumptions, and lack supporting evidence from the literature. When examined in more detail, the literature reveals far greater complexity to what are presented as simple relationships. There is a need to bridge this gap in scientific understanding between ecosystem processes and ecosystem service delivery.

Valuation of ecosystem services, monetary and non-monetary, increasingly feeds into decision making processes (Fisher et al., 2009). Assigning an economic value to N pollution impacts has been conducted in some studies e.g. valuation of ammonia (NH_3) impacts on human health (Holland et al., 2005; Watkiss, 2008), and for impacts of N from agriculture (Sutton et al., 2011b). Detailed cost-benefit approaches have been applied in The European Nitrogen Assessment for the impacts of nitrogen in Europe (Brink et al., 2011), and for the effects of water quality legislation in Chesapeake Bay, USA (Morgan and Owens, 2006). An ecosystem services framework has been proposed for ammonia pollution (Smart et al., 2011), but has not yet been applied in detail. A key challenge of applying an ecosystem services framework to the valuation of air pollution impacts is that it requires a full understanding and quantification of the impact pathway: from changes in emissions, to deposition and its consequent effects on ecosystem processes and how those changes affect ecosystem service provision and the goods and benefits arising from them.

Therefore, in this paper we aim to review the published evidence supporting N impacts on ecosystem services and show how improved understanding of those links can be used to guide valuation of impacts. Firstly, we describe the main mechanisms of N impacts on ecological systems, and then make explicit the conceptual links between N and supporting, provisioning, regulating and cultural ecosystem services. The study then conducts a marginal cost analysis using examples in a UK context, comparing the impact of a net reduction in N deposition from 1987 to 2005, using 1987 as the reference year. For this we use the typology of final ecosystem services (*sensu* Fisher et al., 2008) as developed in the UK National Ecosystem Assessment (UK NEA, 2012).

2. Mechanisms of N impacts on ecological processes

Nitrogen impacts are manifested through three principal mechanisms: eutrophication, acidification and direct toxicity (Bobbink et al., 2010). We briefly describe these mechanisms here, and show the conceptual links to ecosystem services for each mechanism (Figs. 1–3), based on the wide range of impacts on