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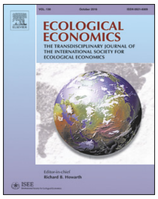

Analysis

Valuing Improvements in Biodiversity Due to Controls on Atmospheric Nitrogen Pollution

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ABSTRACT

Atmospheric nitrogen pollution has severe impacts on biodiversity, but approaches to value them are limited. This paper develops a spatially explicit methodology to value the benefits from improvements in biodiversity resulting from current policy initiatives to reduce nitrogen emissions. Using the UK as a case study, we quantify nitrogen impacts on plant diversity in four habitats: heathland, acid grassland, dunes and bogs, at fine spatial resolution. Focusing on non-use values for biodiversity we apply value-transfer based on household's willingness to pay to avoid changes in plant species richness, and calculate the benefit of projected emission declines of 37% for nitrogen dioxide (NO_2) and 6% for ammonia (NH_3) over the scenario period 2007–2020. The annualised benefit resulting from these pollutant declines is £32.7 m (£4.4 m to £109.7 m, 95% Confidence Interval), with the greatest benefit accruing from heathland and acid grassland due to their large area. We also calculate damage costs per unit of NO_2 and NH_3 emitted, to quantify some of the environmental impacts of air pollution for use alongside damage costs for human health in policy appraisal. The benefit is £103 (£33 to £237) per tonne of NO_2 saved, and £414 (£139 to £1022) per tonne of NH_3 saved.

1. Introduction

Air pollution is a global issue that has substantial adverse impacts on human health, but also on the environment (Galloway et al., 2008; Oenema et al., 2011). For example, plant diversity at sites receiving high atmospheric nitrogen deposition in Europe is typically 50% lower than sites receiving low levels of nitrogen (Maskell et al., 2010; Stevens et al., 2004). While decades of research have catalogued the impacts of nitrogen deposition on natural systems (e.g. Pardo et al., 2011; Phoenix et al., 2012), there is increasing interest in using an ecosystem services perspective to evaluate the wider impacts of nitrogen on flows of goods and services (Compton et al., 2011; Jones et al., 2014; Smart et al., 2011).

Nitrogen deposition has started to decline in Western Europe due to targeted policies on emissions, with emissions 25% lower than their peak in 1990 (Oenema et al., 2011). Applying an ecosystem services approach to evaluate the non-health impacts of this pollution decline has shown both negative and positive impacts (Jones et al., 2014). For example, there are some costs to society as a result of the decline in ‘free’ fertiliser from atmospheric deposition. These costs come in the form of lower productivity of agricultural grasslands, and reductions in tree growth and in carbon sequestration. However, there are also major benefits to society through reductions in emissions of the greenhouse gas N_2O, improvements in water quality, and there may be large benefits to biodiversity, although this is difficult to value.

For a pollutant like nitrogen, this leads to potential tensions in deriving a Total Economic Value of those impacts, because provisioning services generally increase with nitrogen, and are much easier to value than cultural services where nitrogen generally has an adverse impact. In many cases provisioning services can be linked to market values, providing the basis for a relatively straightforward economic assessment (e.g. agricultural crop productivity, livestock productivity, or timber productivity). By contrast cultural benefits, including non-use values for biodiversity conservation, are the domain of non-market valuation methods (Hanley and Barbier, 2009). Deriving a TEV which fails to account for impacts on biodiversity may lead to incomplete assessment of the net benefit arising from lower levels of nitrogen deposition. There is therefore a need to improve the robustness of valuation approaches focusing on biodiversity and the drivers which impact on it.

A key knowledge gap relates to economic valuation of changes to biodiversity. Biodiversity is important at all levels in ecosystem

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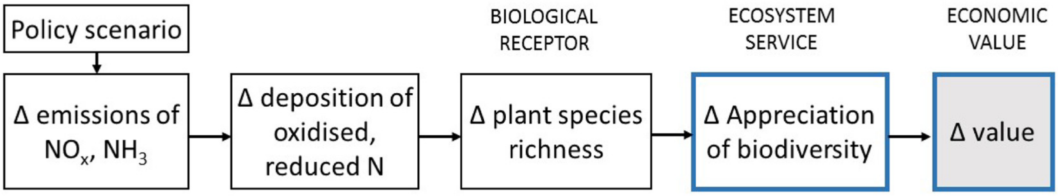

Fig. 1. Impact pathway for nitrogen impacts on the ecosystem service 'Appreciation of biodiversity'. Blue outlines represent quantified impact on the ecosystem service. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

services, playing a role in supporting, intermediate and final services (Mace et al., 2012). Both the level and the stability of ecosystem services tend to improve with increasing biodiversity (Isbell et al., 2011), while nitrogen decreases plant diversity (Field et al., 2014). Nitrogen alters the core processes, functions and biodiversity which underpin a wide range of supporting and intermediate services. It also influences final services directly through effects on environmental attributes such as plant and animal diversity and landscape aesthetics which people care about (Clark et al., 2017; Rhodes et al., 2017). Stated preference methods are the main approach to value the effect of changes in biodiversity on cultural services and non-use values (Champ et al., 2003; Christie et al., 2006), but studies need to be robust enough to satisfy value transfer requirements (Ninan, 2014).

A number of other issues present problems for valuing biodiversity impacts. These centre on spatial context and the relationships between nitrogen and biodiversity. Robust assessment of impacts requires information on the spatial location of both pressures (nitrogen) and receptors (biodiversity). Previous approaches have only been applied at national level (Smart et al., 2011). However, omitting spatial context may lead to considerable over- or under-estimation of impact depending on whether the changes in air pollution occur in the same location as the components of the ecosystem experiencing damage. Addressing this spatial disconnect is most important where the pattern of an air pollutant such as ammonia is heterogeneous at relatively fine scales (Loubet et al., 2009), and where the receptor plant communities have an uneven spatial distribution.

This approach requires sufficient understanding of the dose-response function between nitrogen and biodiversity. This can be a challenge because the evidence for nitrogen impacts on organisms covers a relatively small number of species (Dise et al., 2011), and relatively few of those studies provide the dose response functions required to model impacts across a range of nitrogen deposition. The most promising are studies that have evaluated statistical relationships between nitrogen and diversity but which also account for the effects of confounding factors like climate and other pollutants (Field et al., 2014; van den Berg et al., 2016).

Policy makers are increasingly required to utilise economic tools to evaluate the positive and negative impacts of policy measures (HM Treasury, 2003) in order to justify and to better target those policies. Therefore, there is a need to develop more sophisticated approaches to quantifying air pollution impacts on ecosystem services, which incorporate spatial context, and which value those impacts in ways that can be incorporated into policy appraisal (Dickens et al., 2013).

In this paper, we develop and apply new approaches to address these issues, using the UK as a case study. We i) outline a spatially-explicit methodology to quantify the impacts of N on biodiversity, ii) present a value-transfer approach to translate those impacts into economic values and iii) combine these techniques to answer the policy question: What is the economic impact to biodiversity of forecast reductions in nitrogen pollution? Lastly, we calculate the damage cost per unit of nitrogen dioxide (NO_x) or ammonia (NH_3) emitted, for use in policy appraisal. These forms of nitrogen are emitted from two main sources: nitrogen dioxide primarily from combustion processes, and ammonia primarily from agricultural practices. Therefore, the effect of policies which only address emissions in particular sectors will vary spatially, eliciting different economic values.

Thus, we calculate the marginal value associated with a decline in nitrogen pollution and its subsequent impacts on the 'cultural' service 'Appreciation of biodiversity'. This service was identified in Jones et al. (2014) as requiring considerable development, in particular an improved evidence base for quantifying the nitrogen impacts and the development of spatial analysis. The approach taken focuses on one aspect of biodiversity – the non-use value component associated with conservation of species and maintaining species abundance. We use plant species richness as a proxy for the wider impacts of N deposition on biodiversity because responses of plant communities to N deposition are the best characterised of all organism groups, and because impacts on plants cascade up to higher trophic levels (Clark et al., 2017). We quantify the impact on species richness spatially in four habitats (heathland, acid grassland, dunes and bogs), and calculate the marginal economic value of declining nitrogen deposition per 5x5km grid cell of the UK, applying a value transfer procedure developed using data from Christie and Rayment (2012). Data are presented by region of the UK, including the uncertainty bounds for these estimates.

2. Materials and Methods

2.1. Ecosystem Services Assessment: The Impact Pathway for Air (Nitrogen) Pollution

We use the impact pathway approach (Friedrich and Bickel, 2001) for assessing the ecosystem services impacts of atmospheric nitrogen pollution (Fig. 1). This shows how a policy initiative to curb air pollution results in a change in emissions of NO_x and NH_3 which leads, via changes in deposition, to an altered impact on biological receptors (plant species richness) and hence to the ecosystem service (Appreciation of biodiversity) they underpin. The steps are described in the following sections.

2.2. Policy Scenario, and Nitrogen Emissions and Deposition

The first stage of the impact pathway is to specify alternative policy scenarios on the likely changes to N deposition. In this study, we compare a projected decline in N deposition from 2007 to 2020, against a counterfactual. Our scenarios were based on the UEP43 energy scenario 3 for 2020 (Misra et al., 2012). This scenario was seen as the most likely outcome of planned initiatives to reduce pollutant emissions across a range of sectors. The scenario estimated that policies designed to reduce air pollution emissions from combustion sources lead to a projected 37% decline in oxidised N emissions (nitrogen dioxides, NO_x), while policies to reduce emissions from agriculture lead to a projected 6% decline in the forms of reduced N from agriculture (primarily ammonia, NH_3). The counterfactual assumes emissions continue at 2007 levels. Thus, our scenarios essentially ask: "What is the expected impact on ecosystem service values under forecast reductions in nitrogen deposition"?

Nitrogen emissions data were obtained from Murrells et al. (2010) and Misra et al. (2012), while nitrogen deposition data were available at 5 × 5 km resolution across the United Kingdom. Deposition for 2007 used Concentration-Based Estimated Deposition (CBED) data (Centre