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Upwind impacts of ammonia from an intensive poultry unit

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ABSTRACT

This study investigated potential ammonia impacts on a sand dune nature reserve 600 m upwind of an intensive poultry unit. Ammonia concentrations and total nitrogen deposition were measured over a calendar year. A series of ammonia and nitrogen exposure experiments using dune grassland species were conducted in controlled manipulations and in the field. Ammonia emissions from the intensive poultry unit were detected up to 2.8 km upwind, contributing to exceedance of critical levels of ammonia 800 m upwind and exceedance of critical loads of nitrogen 2.8 km upwind. Emissions contributed 30% of the total N load in parts of the upwind conservation site. In the nitrogen exposure experiments, plants showed elevated tissue nitrogen contents, and responded to ammonia concentrations and nitrogen deposition loads observed in the conservation site by increasing biomass. Estimated long-term impacts suggest an increase in the soil carbon pool of 9% over a 50-year timescale.

1. Introduction

Ammonia (NH_3) is a major source of atmospheric nitrogen (N) pollution which has negative consequences for ecosystems adapted to low levels of nitrogen. In Europe, while oxidised nitrogen emissions and deposition have declined since around the 1990s (Erisman et al., 2001; Vestreng et al., 2008), emissions of ammonia have remained virtually the same, with the result that ammonia is increasingly the dominant source of atmospheric nitrogen pollution (Fowler et al., 2004; RoTAP, 2012).

Both dry gaseous ammonia and wet deposited ammonium are damaging to natural systems. Experimental field-release of ammonia to a bog system has shown that ammonia is toxic to both vascular plants such as *Calluna vulgaris* and particularly lower plants such as *Cladonia* lichens (Sheppard et al., 2008, 2009). Lichen photosynthetic capacity is reduced at high ammonia concentrations (Paoli et al., 2010). Critical levels represent the thresholds defined for gaseous pollutant concentrations above which harmful effects are likely to occur, and critical levels for ammonia have been reduced to 3 $\mu g\ m^{-3}$ for vascular plants and to the lower level of 1 $\mu g\ m^{-3}$ to protect lichens and bryophytes (Cape et al., 2009). Ammonia is also damaging as a component of the total nitrogen deposition load, where the input of nitrogen causes both acidification and eutrophication effects. Ammonia effects on vegetation are documented in a number of reviews (e.g. Bobbink et al., 2010; Krupa, 2003) while nitrogen deposition as a whole causes declines in higher plant diversity (Sala et al., 2000; Stevens et al., 2004), increased susceptibility to secondary stresses (e.g. Power et al., 1998; Strengbom et al., 2002), and altered soil processes (Phoenix et al., 2012).

Sand dunes are a highly biodiverse habitat (Grootjans et al., 2004; Howe et al., 2010) providing many ecosystem services to society (Everard et al., 2010; Ford et al., 2012; Jones et al., 2011). They are also sensitive to N deposition, showing loss of plant species diversity, altered soil processes and accumulated N in plant and soil pools under enhanced deposition (Jones et al., 2004, 2008; Plassmann et al., 2009). As in other habitats, many of these changes are driven by increased biomass of nitrophilous species, particularly graminoids (Remke et al., 2009a; van den Berg et al., 2005). The current critical load for 'Fixed dunes with herbaceous vegetation' ("grey dunes") is 8–15 kg N $ha^{-1}\ yr^{-1}$ (Bobbink and Hettelingh, 2011), and bryophytes and lichens comprise a major component of the vegetation cover (Plassmann et al., 2009).

Ammonia gas is primarily a local pollutant, it is highly reactive and deposits readily to vegetation and other surfaces close to its source (Heij and Schneider, 1991) although, in its wet or aerosol NH_4^+ form, it can be transported much greater distances. Intensive animal husbandry units such as poultry farms are major point sources of ammonia. Downwind impacts can be substantial, completely

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altering vegetation communities close to the farm, causing declines in moss abundance and replacement of sensitive lower plant species by more nitrophilous species at distances of up to 200 m from the farm (Pitcairn et al., 2002, 2009). It is estimated that roughly 4% of the total ammonia emissions from a farm are deposited within 250 m and are largely responsible for the observed downwind effects (NEGTAP, 2001). The remaining 96% is assumed to contribute to short and medium range transport of N. Previous impact studies on ammonia point sources have concentrated on downwind effects with the assumption that concentrations upwind of the prevailing wind direction represent a clean background. Upwind effects are assumed to be insignificant and remain unquantified.

The influence of less prevalent wind directions on the pollutant deposition upwind of point sources is a major knowledge gap. Therefore, this study aimed to quantify the upwind influence of a poultry unit on a Natura 2000 designated sand dune system in an area with low background nitrogen deposition, and explore the implications for exceedance of the relevant critical levels and loads. This was conducted by measuring ammonia concentrations and resulting N deposition at varying distances upwind of the poultry unit, and by using experimental exposure in a range of controlled environment and in situ studies to test the sensitivity of dune vegetation to gaseous ammonia and to N deposition. The following hypotheses were tested: 1) Can ammonia emissions from a poultry unit be detected upwind of the prevailing wind direction, and to what distance? 2) If so, are critical levels of ammonia and critical loads of N exceeded upwind? 3) Is ammonia from the local point source likely to be affecting plant species composition upwind?

2. Methods

2.1. Site description and history

Newborough Warren is one of the largest UK sand dune systems, located on the island of Anglesey, North Wales, UK (53:08N 4:21W). It is a Natura 2000 designated site, up to 2 km wide and approximately 1300 ha in area. The site contains the full succession of habitats from strandline and mobile dunes to dune grassland and scrub, and includes wet and dry slacks. The dominant habitat at the site is Fixed dunes with herbaceous vegetation (Natura code 2130), the older parts of which show succession towards a de-calcified dune grassland containing acidophile species including *Cladonia* species and other lichens, which comprise special interest features of the site (Plassmann et al., 2010). Annual rainfall is 850 mm (Curreli et al., 2013) and the prevailing wind direction is from the south west.

The intensive poultry unit is located approximately 600 m north east of the Natura site. It comprises twelve barns with roof-top ventilation, with capacity for 160,000–180,000 birds. There are approximately six rearing cycles per year. Growing cycles run for 56 days, with a clearout period of 1 week in between growing cycles. Ammonia emissions are strongly cyclic, reflecting the birds' growth pattern and management cycle. Continuous ammonia sampler data from other monitoring studies at the poultry unit (NETCEN, 2006; Sheppard, 2003) showed that emission peaks increase through the 56 day growing cycle, and are highest in the last two-thirds of the growing cycle and during the clearing period between cycles when the sheds are emptied and manure removed. The poultry unit was established in 1972 with eight buildings, with a further four buildings constructed in 1978.

This study reports on a twelve-month monitoring campaign of dry and wet N deposition upwind and around the poultry unit, combined with three experiments to test the sensitivity of sand dune species to N. Gaseous ammonia concentrations were measured over a twelve-month period, sampled at eight locations (Fig. 1) using a combination of passive diffusion samplers (badge samplers) well suited to monitoring low ammonia concentrations (Tang et al., 2001) at locations upwind of the prevailing wind direction (i.e. to the south west of the poultry unit), and standard ammonia diffusion tubes (Gradko International Ltd, Winchester, UK) at the poultry unit and some additional locations experiencing high ammonia concentrations. Upwind sampling locations for gaseous ammonia were at sites labelled A–F (Fig. 1), ranging in distance from 0 to 2800 m to the south west, i.e. upwind from the poultry unit. Locations A–C were at the poultry unit itself and locations to 300 m upwind but outside the Natura 2000 site. Locations D–F were further upwind from 800 to 2800 m, within the Natura site boundary. The other monitoring sites were located near potential local ammonia sources: a sewage treatment works 520 m to the north–west and improved grazing land at a small livestock farm 1500 m to the south–east. Triplicate badge samplers and triplicate diffusion tubes were exposed in batches lasting one calendar month over a 12-month period, December to the following November. Field blanks and laboratory blanks were used to control for contamination. Missing data for sampling site B (months December and January) and site E (months December–April) were recreated using ratios of the mean ammonia concentrations of each site with means at the immediately adjacent monitoring locations for all periods without missing data. The gap filling was necessary in order to calculate annual means. Data from a separate study funded by the UK Environment Agency (NETCEN, 2006) are reported for comparison. In that study, gaseous ammonia concentrations were measured using triplicate diffusion

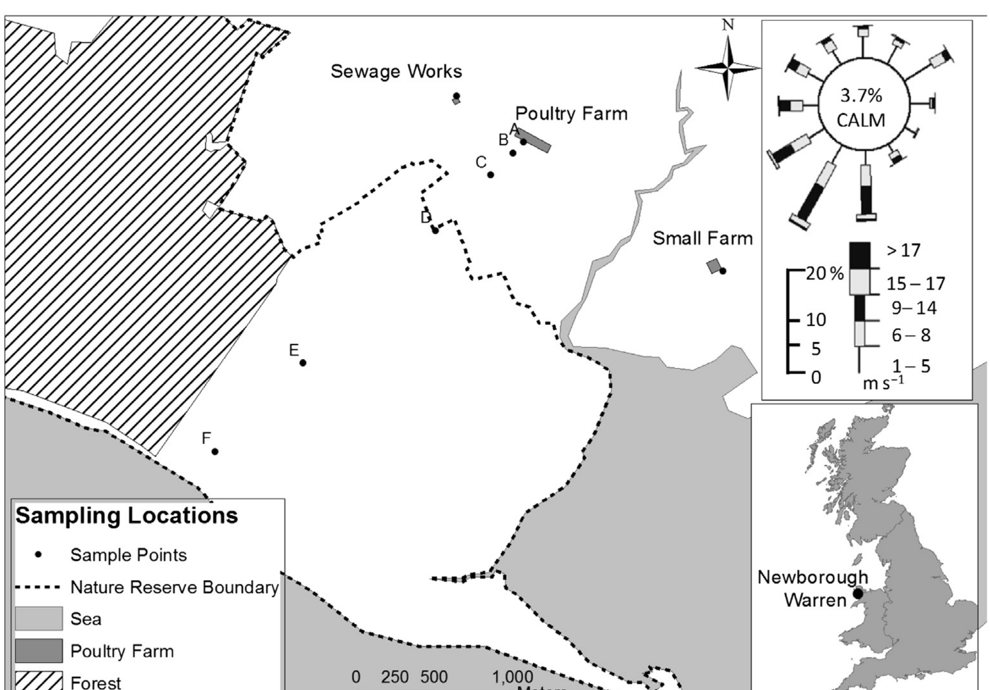

Fig. 1. Map showing study context, including sampling points for gaseous ammonia along upwind transect (A–F) and smaller point sources the sewage works (to the NW) and small livestock farm (to the SE). Annual wind rose shows 10-yr average wind direction and frequency (1994–2003) for RAF Valley, a nearby coastal meteorological station.