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Temporal variation in atmospheric ammonia concentrations above seabird colonies

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ABSTRACT

Recent studies have shown that seabirds are an important source of ammonia (NH_3) emissions in remote coastal ecosystems. Nesting behaviour, which varies between seabird species, is likely to be a major factor in determining the proportion of excreted nitrogen (N) volatilised to the atmosphere as NH_3. A long-term NH_3 monitoring programme was implemented at a Scottish seabird colony with a range of species and associated nesting behaviours. The average monthly NH_3 concentration was measured at 12 locations over a 14-month period, to infer spatial (i.e. species-specific) and temporal (seasonal) changes in NH_3 emissions from different seabird species. An emissions model of seabird NH_3, based on species-specific bioenergetics and behaviour, was applied to produce spatial estimates for input to a dispersion model.

Atmospheric NH_3 concentrations demonstrated spatial variability as a result of differing local populations of breeding seabirds, with the highest concentrations measured above cliff nesting species such as Common guillemot *Uria aalge*, Razorbill *Alca torda* and Black-legged kittiwake *Rissa tridactyla*. NH_3 concentrations above a colony of burrow nesting Atlantic puffin *Fratercula arctica* were low, considering the high number of birds. Emission of NH_3 from excreted N exhibits a time lag of approximately a month. It is likely that all excreted N is lost from the colony by volatilisation as NH_3 or surface run-off between breeding seasons. Modelled NH_3 emissions and concentrations correlated with measured concentrations, but were much higher, reflecting uncertainties in the local turbulent characteristics. The results allow multi-species seabird population data to be used for the calculation of regional and global NH_3 emission inventories, whilst improving understanding of N budgets of remote coastal ecosystems.

1. Introduction

Ammonia (NH_3) is an important atmospheric gas that arises from both natural and anthropogenic sources. The major source of NH_3 is the breakdown of urea or uric acid excretions from animals. Non-biological emissions of NH_3 arise from sources such as fertiliser production and vehicle emissions (Sutton et al., 2000). NH_3 is an important component of the nitrogen (N) cycle, having the potential to cause both eutrophication and acidification (e.g. Van Breemen et al., 1982; Pearson and Stewart, 1993; Fangmeier et al., 1994; Bouwman et al., 2002). The determination of the magnitude and distribution of NH_3 emission sources allows the prediction of their environmental consequences, through the use of atmospheric transport and pollution

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deposition models (e.g. Sutton et al., 1993a–c; Singles et al., 1998; Fournier et al., 2002).

UK NH_3 emissions have been estimated at 366 Gg NH_3 yr^{-1}, with 81% of the emission arising from agriculture and 19% from non-agricultural sources such as wild animals, sewage treatment, industry and transport (Misselbrook et al., 2000; Sutton et al., 2000). The greater magnitude of agricultural emissions means that research has focused more on the quantification of emissions from this source, with less attention given to emissions from non-agricultural sources. Some studies (e.g. Lee and Dollard, 1994; Sutton et al., 1995, 2000) have addressed the issue of UK NH_3 emissions from non-agricultural sources. Of the non-agricultural emission sources identified by Sutton et al. (2000), seabird colonies were highlighted as a source that required further research into both the distribution and magnitude of NH_3 emissions. Wilson et al. (2004) estimated that UK seabirds emit ~2.7 Gg NH_3 yr^{-1}, which corresponds to ~1% of estimated total global seabirds emission of ~242 Gg NH_3 yr^{-1} (Blackall et al., 2007). On a regional scale, seabirds only contribute ~0.7% of UK NH_3 emissions, based on the estimates of Misselbrook et al. (2000) and Wilson et al. (2004). However, by mapping the distribution of UK seabird NH_3 emissions, Wilson et al. (2004) highlighted the potential for a significant local effect from seabird NH_3 emissions, as they tend to be most prominent in remote areas with few other sources of NH_3 emission (e.g. north and west of Scotland), thus representing major point sources.

There are a variety of reasons why seabird colonies have the potential to be point sources of NH_3 emissions. Seabirds consume a nitrogen-rich diet (e.g. fish and squid) and have high metabolic rates (Birt-Friesen et al., 1989; Bryant and Furness, 1995; Hilton et al., 1998), resulting in high N excretion rates (primarily as uric acid). Seabird colonies often comprise large numbers of individual birds breeding in a congested space. The crowded nature of seabird colonies creates favourable conditions for the volatilisation of NH_3 from seabird excreta, as the volatilisation of NH_3 increases with the intensity of emission source (Sutton et al., 1995).

There are a number of species-specific traits that are likely to affect the magnitude of NH_3 volatilization from excreted nitrogenous waste, such as bird mass, energy requirement, N and energy content of food and the assimilation efficiency of the food (Wilson et al., 2004). Other factors that may vary among seabird species include the proportion of time during the breeding season that an individual bird will spend ashore at the colony, nesting behaviour (e.g. bare rock, vegetative nest, burrow). Nesting behaviour is likely to affect the magnitude of volatilised NH_3 being dispersed in the atmosphere. It is known that overlying vegetation and absorption of NH_3 by soil can reduce NH_3 emissions (Nemitz et al., 2000; Misselbrook et al., 2000). As such, vegetation or burrow nesting species such as the Atlantic puffin *Fratercula arctica*, are likely to result in a lower proportion of N volatilisation than species which breed on bare ground/rock, such as the Common guillemot *Uria aalge*.

Here we present data from a 14-month atmospheric NH_3 monitoring campaign at a Scottish seabird colony. Data are presented to illustrate temporal patterns in NH_3 emissions from seabirds, differences in the magnitude of NH_3 concentrations near seabirds with varying nesting behaviour and compares measured NH_3 concentration data with outputs from a seabird NH_3 emission model for the Isle of May, Scotland.

2. Methodology

2.1. Study site

The Isle of May (latitude 56°11′N, longitude 02°33′W) is located ~8 km from the Fife coast in the Firth of Forth, Scotland. It is ~1.8 km long, ~0.5 km at the widest point and is composed of olivine-dolerite, a hard volcanic rock (Sobey, 1976). The western side of the island is dominated by cliffs of up to 45 m high, with the elevation of the island decreasing gradually eastwards towards sea level. The vegetation communities of the island are classified as being primarily NVC community MC6 (*Atriplex hastata agg.-Beta vulgaris sp. Maritima* seabird cliff community) at the north and south of the island, with NVC community MC8 (*Festuca rubra-Armeria maritima* maritime grassland) dominating across most of the inland areas (Bell, 1996). The Isle of May seabird population demonstrates a non-random distribution, with certain species forming colonies. Annual counts of breeding seabird numbers are undertaken by Scottish Natural Heritage. Estimated population numbers for breeding seabird species, based on recent detailed spatial counts by Scottish Natural Heritage (Wilson and Parkinson, 2000 – see Table 1), which are considered to be uncertain to ±5–10% (M.P. Harris, personal communication).

2.2. Atmospheric NH_3 monitoring

A monitoring programme for monthly average NH_3 concentration was implemented on the Isle of May in April 2000. The campaign measured the integrated monthly average NH_3 concentration at 0.5 m above ground level using the CEH ALPHA (Adapted Low-cost Passive High Absorption) sampler system (Tang et al., 2001). Three replicate samplers were exposed at each of 12 locations across the island for periods of approximately one-month duration, from inception to November 2001. The passive sampling stations were located in areas representing a range of different habitats across the island with

Table 1
Population estimates of Isle of May seabirds in 2000 (adapted from Wilson and Parkinson, 2000)

Seabird species	Count	Units
Puffin, *Fratercula arctica*	41,785	Breeding pairs
Guillemot, *Uria aalge*	17,384	Breeding pairs
Razorbill, *Alca torda*	3,126	Breeding pairs
Kittiwake, *Rissa tridactyla*	4,342	Nests
Shag, *Phalacrocorax aristotelis*	621	Nests
Fulmar, *Fulmarus glacialis*	373	Nests
Herring gull, *Larus argentatus*	2,729	Nests
Lesser black-backed gull, *Larus fuscus*	1,533	Nests
Great black-backed gull, *Larus marinus*	20	Occupied territories
Arctic tern, *Sterna paradisaea*	451	Breeding pairs
Common tern, *Sterna hirundo*	127	Breeding pairs