

# The Global Nitrogen Enrichment (GANE) programme

## Programme description

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### **Summary**

More reactive nitrogen (N) is being released into the global environment by burning fossil fuels, applying fertilizers and growing legumes than by natural processes. Proportionately, the global nitrogen cycle is being perturbed much more than the carbon cycle. This N is accumulating and having major effects regionally and globally on the terrestrial, marine and atmospheric environments.

GANE addresses the UK interest in this global phenomenon, tackling some of the fundamental, modelling and scaling problems from UK and global perspectives. Issues have been identified which are unresolved and are of concern to the users of NERC science.

The programme covers three themes:

- transformation and pathways of reactive N from land to sea, focusing on organic N and the gaseous dissipation of N in rivers and coastal areas
- fluxes of reactive N at landscape and global scales, developing models of sources and sinks within landscapes/catchments and of the continental-scale spread of N, measuring N deposition in remote areas and reassessing global soil emissions of NO and N<sub>2</sub>O
- Impacts of reactive N on the global terrestrial carbon sink, UK N-sensitive semi-natural and Arctic ecosystems and UK shelf sea ecosystems.

GANE spans user interests in pollution, land use, global change and conservation; it will develop synergy between the terrestrial, freshwater, marine and atmospheric sciences; and it will stimulate advances and training in whole-system approaches and modelling.

### **Background**

It has only recently become widely appreciated that fossil fuel burning, fertilizer production, legume growing, livestock farming and biomass burning are now releasing more reactive N into the global environment than preindustrial natural processes (Vitousek, 1994; Galloway et al., 1995). Whereas the global carbon cycle is being perturbed by less than 10%, the global reactive N cycle is being perturbed by

over 80%. Furthermore, world energy and food demands make it inevitable that this N release will continue to increase proportionately much faster than the release of carbon. As a result, reactive N is accumulating in the biosphere, oceans and atmosphere and is having powerful interlinked effects - some positive (eg faster forest growth) others negative (eg pollution).

The UK clearly has major interests in this issue at the UK and global scales, encompassing policies on land, air and shelf sea pollution, land use, river and coastal zone management, farming practices, waste and sewage disposal, conservation of habitats and biodiversity, and also climate change, because global N enrichment is affecting the rate of increase of all major greenhouse gases (CO<sub>2</sub> - by altering the terrestrial and ocean carbon sinks, CH<sub>4</sub> and O<sub>3</sub> - by altering the oxidizing capacity of the atmosphere, and N<sub>2</sub>O directly).

These interests have been recognized in the N-related research completed or in progress on, for example, nitrate leaching, air pollution and critical loads, funded by NERC, BBSRC, government departments, the EU, Environment Agency, conservation agencies and others.

The rationale for this programme is to tackle some of the key questions concerning

- (i) the transformation and pathways of reactive N,
- (ii) the major problem of quantifying N fluxes at large temporal and spatial scales (from landscapes to the globe), and
- (iii) impacts on N-sensitive semi-natural ecosystems, coastal waters and the atmosphere, which are unresolved and are likely to cause heightened concern.

These questions have been identified in consultation with users and the scientific community.

The programme has a large whole-system modelling component, making full use of existing data and models wherever possible. It cuts across many policy issues and will develop synergy between NERC science areas (terrestrial, freshwater, marine, polar and atmospheric sciences).

## **Research themes and issues**

The programme will address nine issues in three major themes.

### **Theme 1. Transformation and pathways of reactive N from land to sea**

Significant amounts of N are leached from semi-natural land, woodland and grazed land as dissolved and particulate organic N (DON/PON) contributing to the pollution of groundwater, surface water and coastal seas. But we have a poor understanding of what controls the amount and stability of organic N in soils, the impact of N enrichment and other factors on DON/PON release, its contribution to inorganic N pools and the functional characterization and reactivity of DON in soil, river and coastal waters. GANE will advance our fundamental understanding in these areas.

Eutrophication of UK coastal waters by river discharge is a major environmental issue. But a substantial fraction (maybe 40% in the UK) of N entering rivers is dissipated as gases by bacterial denitrification and nitrification within the rivers themselves and in coastal mudflats/sediments. Some of it is lost as N<sub>2</sub>O. The issue, not covered in LOIS, is: what controls variation in rates of denitrification/ nitrification in sediments and overlying waters and how will changes in river management (eg straightening) water quality standards and coastal management (eg reclamation) nitrate loading and climate alter this 'cleansing' role of rivers and coastal areas, the amount of N<sub>2</sub>O emitted, and the amount of N reaching the sea?

## **Theme 2. Fluxes of reactive N at landscape and global scales**

Few attempts have yet been made to quantify and map the fluxes of reactive N from landscape to catchment scales, with varying point/diffuse sources/sinks and discontinuities, dependent on topography, soils, hydrology, climate, land use and human activities. GIS models which deal with processes at this scale are required by users. There is tremendous potential to develop risk assessment methodologies to explore the consequences of different land/river management options. The issue is: can the transfers and transformations of N within a landscape/catchment be modelled to guide users with specific environmental and conservation objectives?

Much of the reactive N that is emitted by man goes into the atmosphere and some is transported large distances. Terrestrial and oceanic areas enriched by N deposition may then re-emit a fraction of the N they receive as NO<sub>x</sub> or NH<sub>x</sub>. Thus, N enrichment may be 'rippling out from hotspots'. How much is reaching remote N-sensitive areas such as the Arctic, and also the northern North Sea and Irish Sea where riverine N inputs are proportionately less important?

Hitherto, it was assumed that NO emissions from soils were too small to have much impact on the oxidizing capacity of the atmosphere, and that NO<sub>y</sub> from fossil fuel combustion was the main reason for the doubling of tropospheric O<sub>3</sub> levels in the northern hemisphere this century. This assumption is now very insecure. To determine whether NO from soils is a major driver of increasing tropospheric O<sub>3</sub> levels we need a reassessment of global soil-NO emissions.

The global budget of N<sub>2</sub>O is the least well-understood of all the greenhouse gas budgets. The stratospheric lifetime of N<sub>2</sub>O seems to be shorter than previously thought (ie the sink is larger) indicating that the sources have been underestimated. Consequently, we need to reexamine relationships between N inputs to soils and N<sub>2</sub>O emissions, methods of scaling up (in time and space), sources in the tropics and possible 'new' sources such as N-enriched aquifers. Without a more secure global budget it will be impossible to predict the future rate of increase in this greenhouse gas.

## **Theme 3. Impacts of reactive N**

Globally, vegetation and soils provide a sink for about 25% of the carbon currently emitted to the atmosphere by man, because of the promotion of photosynthesis and net primary production by CO<sub>2</sub> enrichment and N-fertilization. This sink is lessening

the need for CO<sub>2</sub> emission control. Estimates of the magnitude and future operation of this sink depend on the development of models of global biomes which describe the coupling of carbon, N and water cycles in the soil-vegetation-atmosphere. Those couplings are not well enough understood to confidently predict the extent to which the terrestrial C sink is amplified by N enrichment.

We know too little about the N responses of many N-sensitive, semi-natural ecosystems of high conservation value in the UK to be able to evaluate the implications of N enrichment for policies such as the Habitats Directive and the management of Environmentally Sensitive Areas. This is especially true for high mountain ecosystems, lowland heaths, raised bogs and acidic grasslands. Also, very little work has been done on extremely N-deficient Arctic tundra ecosystems, which may respond to very small increases in N deposition by changing in species composition and groundcover. What are the dose-response relationships in these ecosystems, do reduced and oxidized N deposition have different effects, are responses limited by P and other factors, is the N-saturation concept applicable, are changes occurring and are they reversible? We have, at best, only partial answers to these important questions.

Primary production in UK shelf seas is N limited. Whereas it is suggested that nitrate inputs from the Rhine plume is increasing primary production and altering species composition, it is not known whether this is true more generally. If it is, then UK riverine inputs to the North Sea may be having an effect. The problem is to quantify N input dose-responses, when much of the N demand for production is met by internal cycling, and to quantify the impact of episodic N input events. The issue is: are riverine and atmospheric N inputs increasing primary production and altering species composition widely within UK shelf seas?

It is well-known that the concentrations and lifetimes of pollutant and greenhouse gases, including tropospheric O<sub>3</sub>, CH<sub>4</sub> and halocarbons, are being changed because increasing NO<sub>y</sub> emissions are altering the oxidizing capacity of the atmosphere. However, there is great uncertainty about the magnitude of change. Field observations in the ACSOE and other programmes are revealing weaknesses in model assumptions which need to be resolved. For instance, how can we explain the spring maximum in tropospheric O<sub>3</sub>, the extensive layers observed at 5-8km altitude over the remote ocean and the fact that levels of NO<sub>y</sub> are larger than the sum of component chemical species? The models need to be improved in the light of new observations to increase their ability to predict the effects of atmospheric N enrichment on tropospheric O<sub>3</sub>. Funding of this issue is to be deferred until such time as discussions have been held with other funding bodies.

## **Objectives**

### **Theme 1. Transformation and pathways of reactive N from land to sea**

- To improve understanding of the dynamics and role of dissolved and particulate organic N in soils and its fate in freshwaters and coastal areas.
- To develop models of denitrification/nitrification in rivers and coastal areas that can be used to assess the impact of management and environmental factors on N transfer to the sea.

### **Theme 2. Fluxes of reactive N at landscape and global scales**

- To develop a methodology to quantify N sources, fluxes and sinks within landscapes/ catchments that is capable of predicting effects of land use, climate and N inputs.
- To estimate the extent and timescale of N transfer from emission hot-spots to remote areas at a range of scales.
- To provide new measurements of NO and N<sub>2</sub>O emissions from soils in order to improve regional scale estimates of emission.

### **Theme 3. Impacts of reactive N**

- To improve estimates of the impact of global N enrichment on the present and future magnitude of the terrestrial carbon sink.
- To assess the responses of UK and Arctic ecosystems to inputs of reduced and oxidized N, the role of management, and limitations such as P supply in determining responses.
- To assess whether primary production and species composition associated with the UK shelf seas is being changed by atmospheric, riverine or marine N inputs.
- To determine the effects of reducing N inputs on processes and biota, and to identify the potential for restoration of N-impacted terrestrial, freshwater, estuarine and marine shelf ecosystems.

## **References**

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