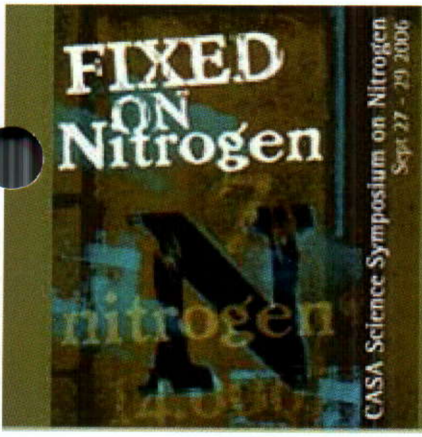


FIXED ON NITROGEN
CASA Science Symposium on Nitrogen
September 27 – 29, 2006
Fairmont Chateau Lake Louise
Lake Louise, Alberta

Abstract

Overview on Nitrogen: Effects, fate and impact and issues for research and management

Dr. Bridget Emmett

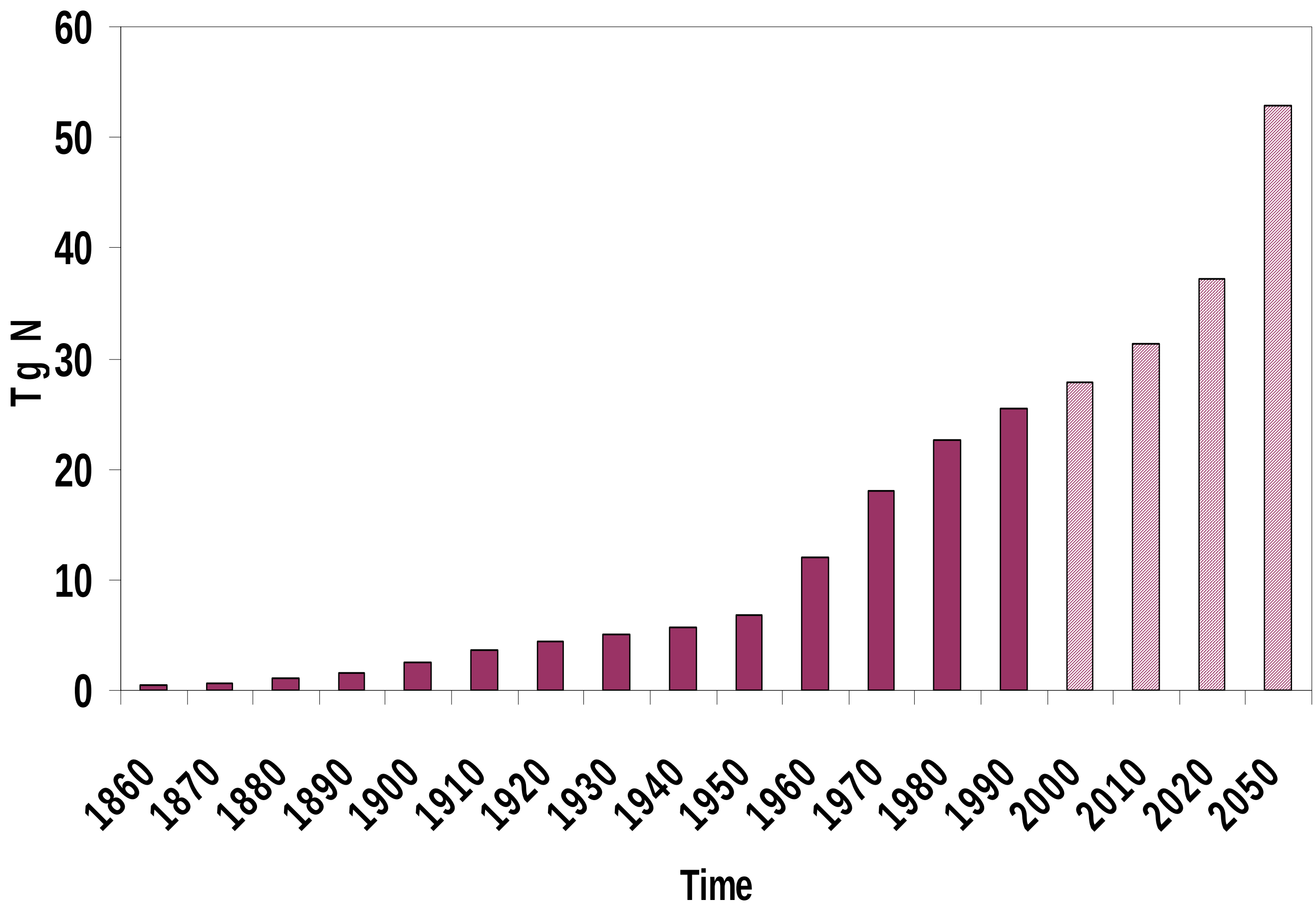
Through international agreements there has been some success in reducing emissions of nitrogen in Europe and N America. However, within specific regions such as Alberta, and in many other parts of the world, trends are increasing. Sources of this nitrogen are varied and include both dry and wet forms of oxidised and reduced nitrogen. Contributing sectors responsible for nitrogen oxide emissions include transport, energy industries and fertilizer applications and ammonia from animal husbandry activities and fertiliser applications. Impacts are also complex and varied and depend on the nitrogen species present. Areas of concern include species change of terrestrial systems, impacts on soil quality and tree growth, changes in water quality and species diversity of marine systems, adverse effects on human health both through water and air quality, and impacts on greenhouse gas fluxes. Significant advances have been made in our scientific understanding in many of these areas, which has helped inform policy development, but areas of uncertainty remain. These include accurate modelling of deposition, controls on soil nitrogen storage and links to above and below-ground species change, appropriate indicators/thresholds for ecosystem responses, relative importance of phosphorus and nitrogen enrichment in aquatic systems and appropriate air quality guidelines for nitrogen dioxide and ammonia due to their role in formation of particles ($PM_{2.5}$), to name but a few. Management approaches in Europe, whilst having some success, has perhaps not been as great as we could have been hoped for. Reasons for this are varied but include lack of scientific understanding and the complexity of the nitrogen cycle, lack of technologies to reduce emissions, conflicting policies (e.g. agricultural policy and emissions control), a focus on the wrong industries (industry instead of agriculture and omitting shipping) and cost.

Nitrogen overview

Bridget Emmett

with input, ideas,slides from Peringe Grennfelt, Gina Mills, Chris Evans, Roland Bobbink, David Fowler, Neil Cape, Wim de Vries and many others

Global Emissions of N



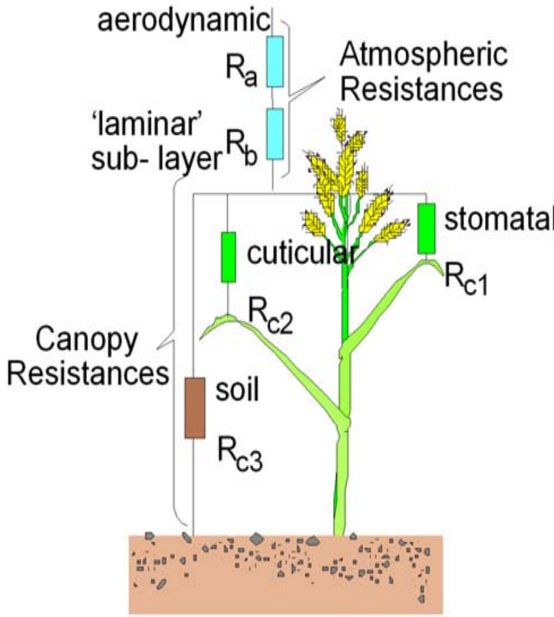
Sources of Nitrogen

Transport

Agriculture

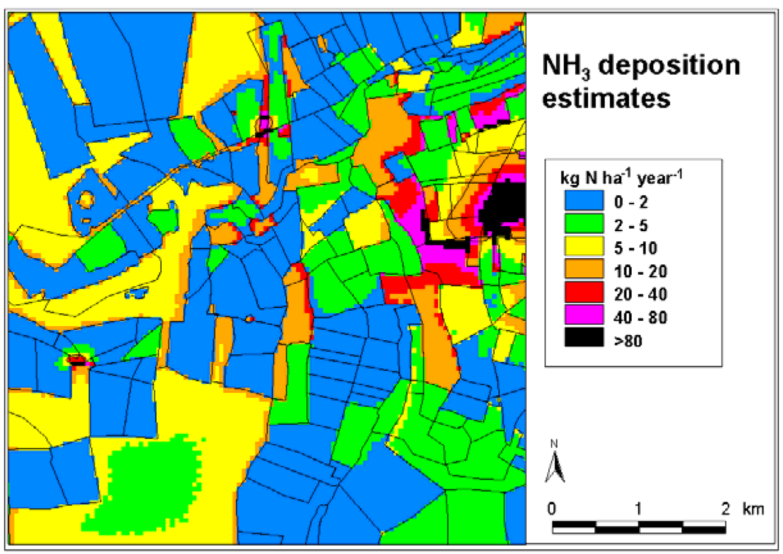
Energy and
Fertilizer production

Monitoring, understanding and mapping deposition complexities



$$v_d = \frac{\text{flux}}{\text{concentration}} = \frac{1}{R_t}$$

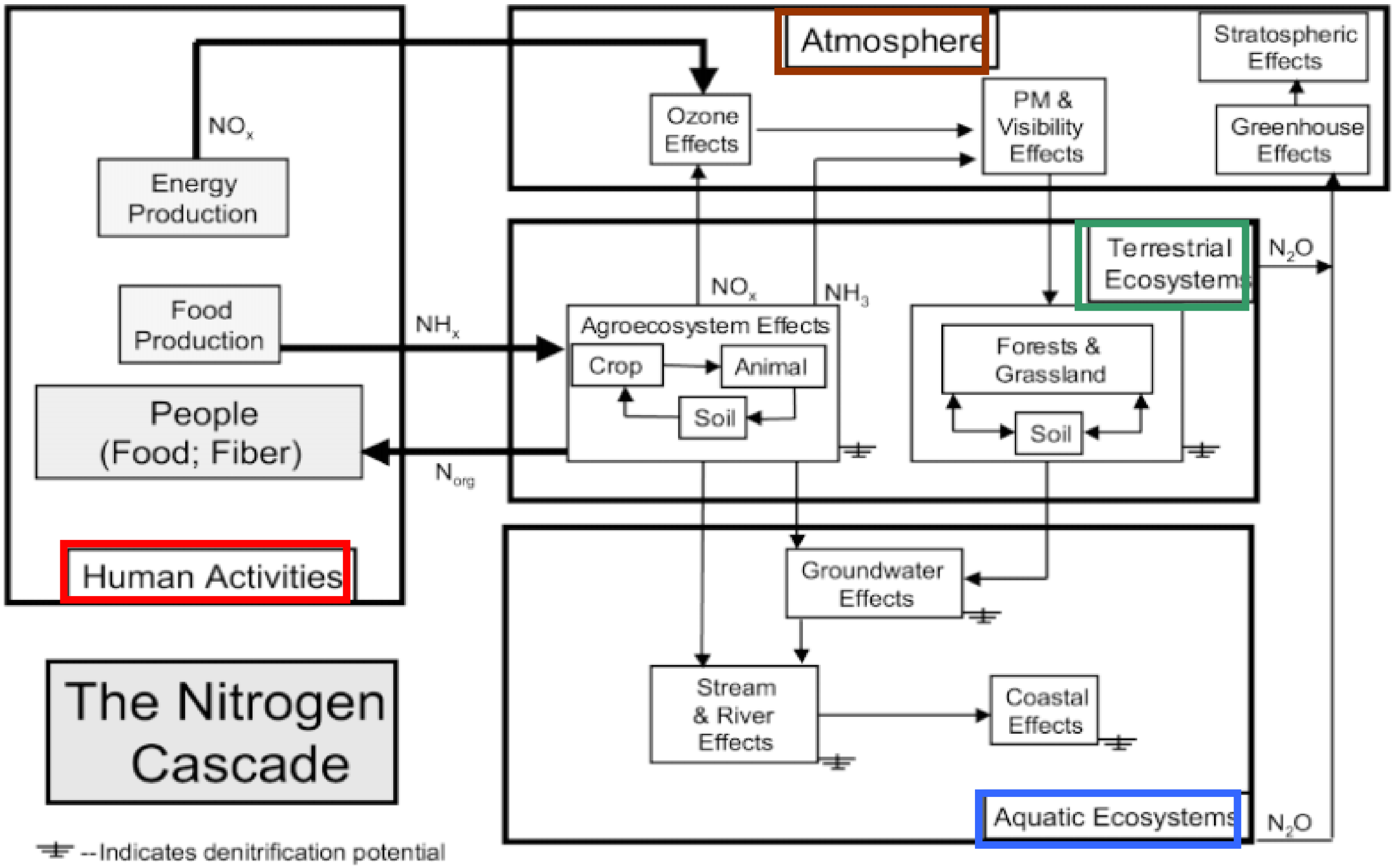
$$R_t = R_a + R_b + (1/R_{c1} + 1/R_{c2} + 1/R_{c3})^{-1}$$



Neil Cape's talk tomorrow

Dragosits et al. (Environ. Pollution 2002)

The Nitrogen cycle



Galloway (2002) Ambio

Balance sheet for nitrogen

- Positive effects of N use
  - Increased production and dietary nutrition
  - Benefits from fossil fuel use
- Unintended positive effects
  - Reduced greenhouse gas concentrations (CO_2 & CH_4)

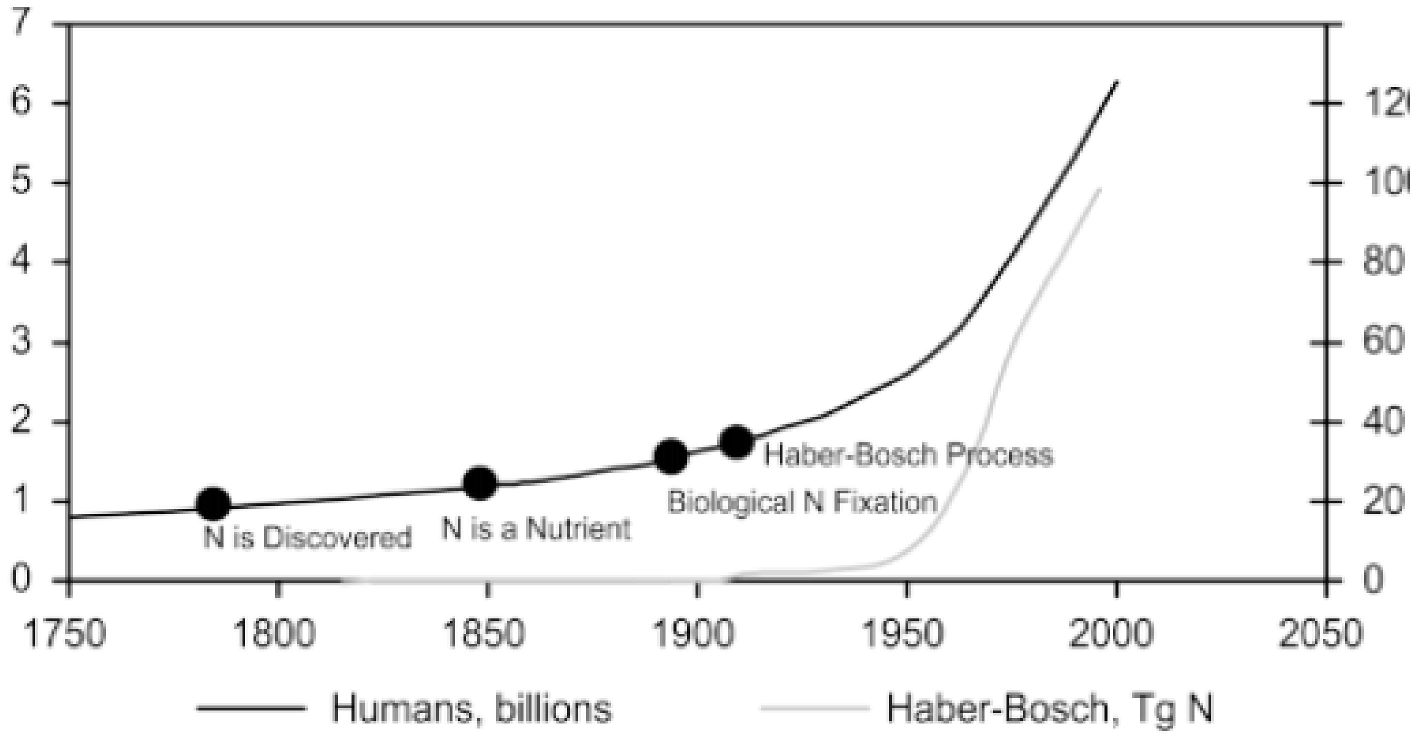
- Unintended negative effects
  - Health effects
  - Odour problems
  - Undesirable increase in production leading to species change
  - Acidification and eutrophication of waters
  - Increased greenhouse gas fluxes (e.g. N_2O)

Outline of talk

- Health effects
  - direct and indirect effects
- Unintended changes in production and carbon sequestration
- Biodiversity loss
  - evidence, importance of N form & when does it happen?
- Controls on N storage and release
- Research focus and policy outcomes in the EU

Health effects

Positive effects of nitrogen



Galloway and Cowling (2002) Ambio

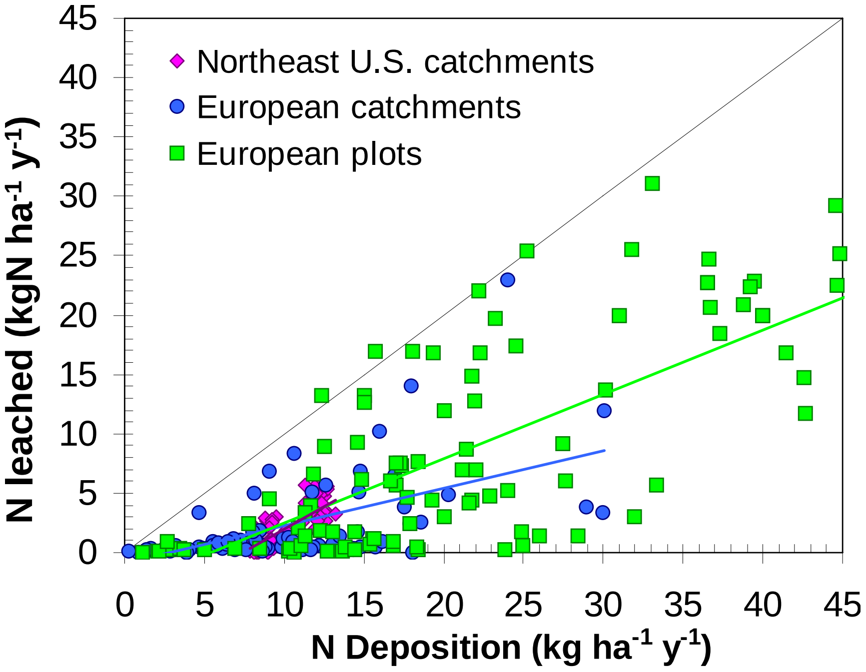
Unintended negative effects

- Direct factors
  - e.g. NOx concentrations indoors and outdoors
  - sensitivity factors e.g. asthma
- Indirect
  - change in vectors of disease
  - water pollution including nitrate concentrations and algal blooms
  - tropospheric ozone
  - particles
  - stratospheric ozone

Townsend et al. (2003) Frontiers in Ecology

Eutrophication of waters

- Eutrophication of waters a major problem in some areas
- Impacts on human health due to high concentrations of nitrate-N, risk of harmful algal blooms and vectors of some diseases
- Even forests and natural systems now leaching N in parts of N America and Europe due to N deposition



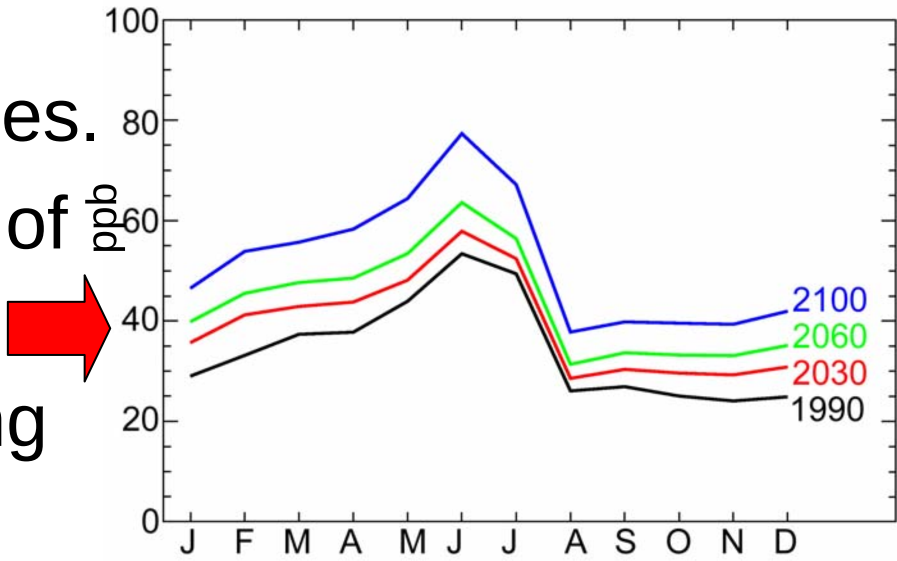
European (IFEF) data from Nancy Dise et al.

Particles

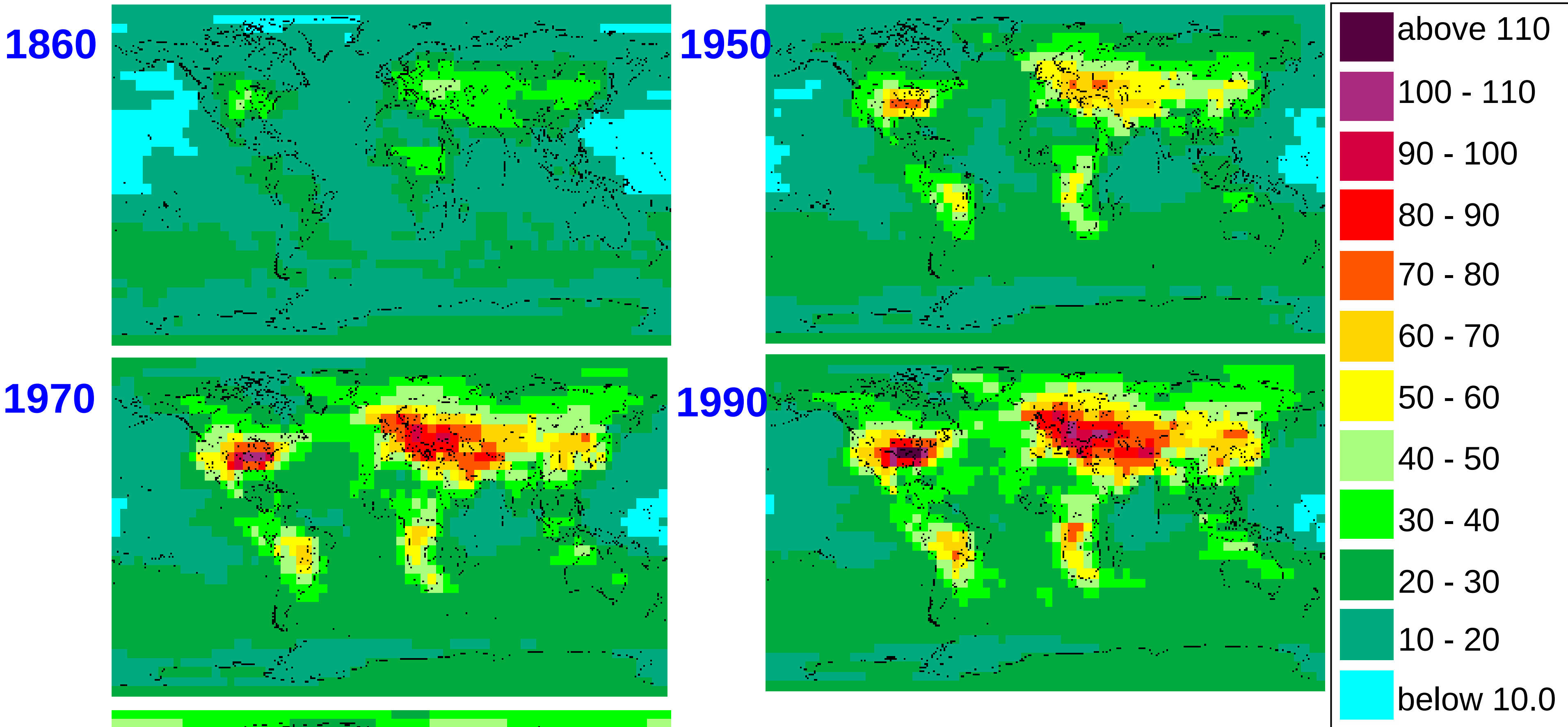
- What are particles?
  - a mixture of particles consisting of solid, liquid or both and suspended in the air and represent a complex mixture of organic and inorganic substances
- How is nitrogen involved?
  - Major role for nitrogen oxides and ammonia in production of secondary particles (PM2.5) which are most damaging to human health
- Why worry?
  - Estimated loss of 38 million life years annually in EU
  - Monetary benefit of reducing emissions by 20-25% estimated as 5 - 24 times higher than costs

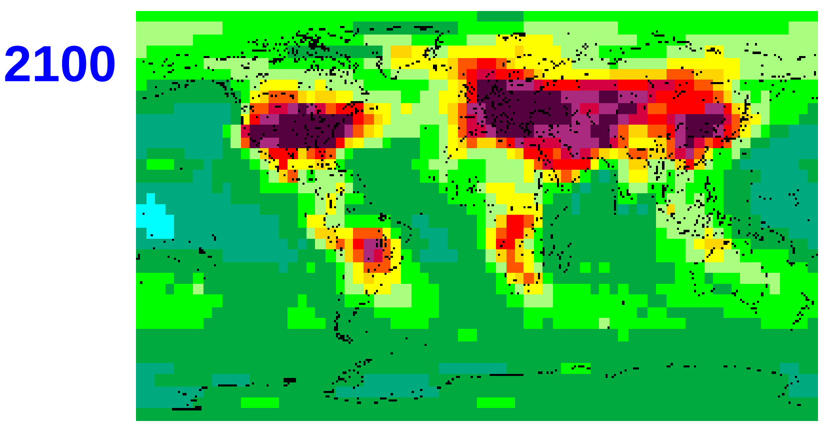
Tropospheric ozone

- Ozone is produced by photochemical and temperature reactions of NOx and VOCs
- NOx comes mainly from transport and electricity utilities.
- Vehicles are a major source of VOCs
- Baseline levels are increasing globally
- Ozone can aggravate a range of respiratory problems



Tropospheric ozone – a pollutant on the increase





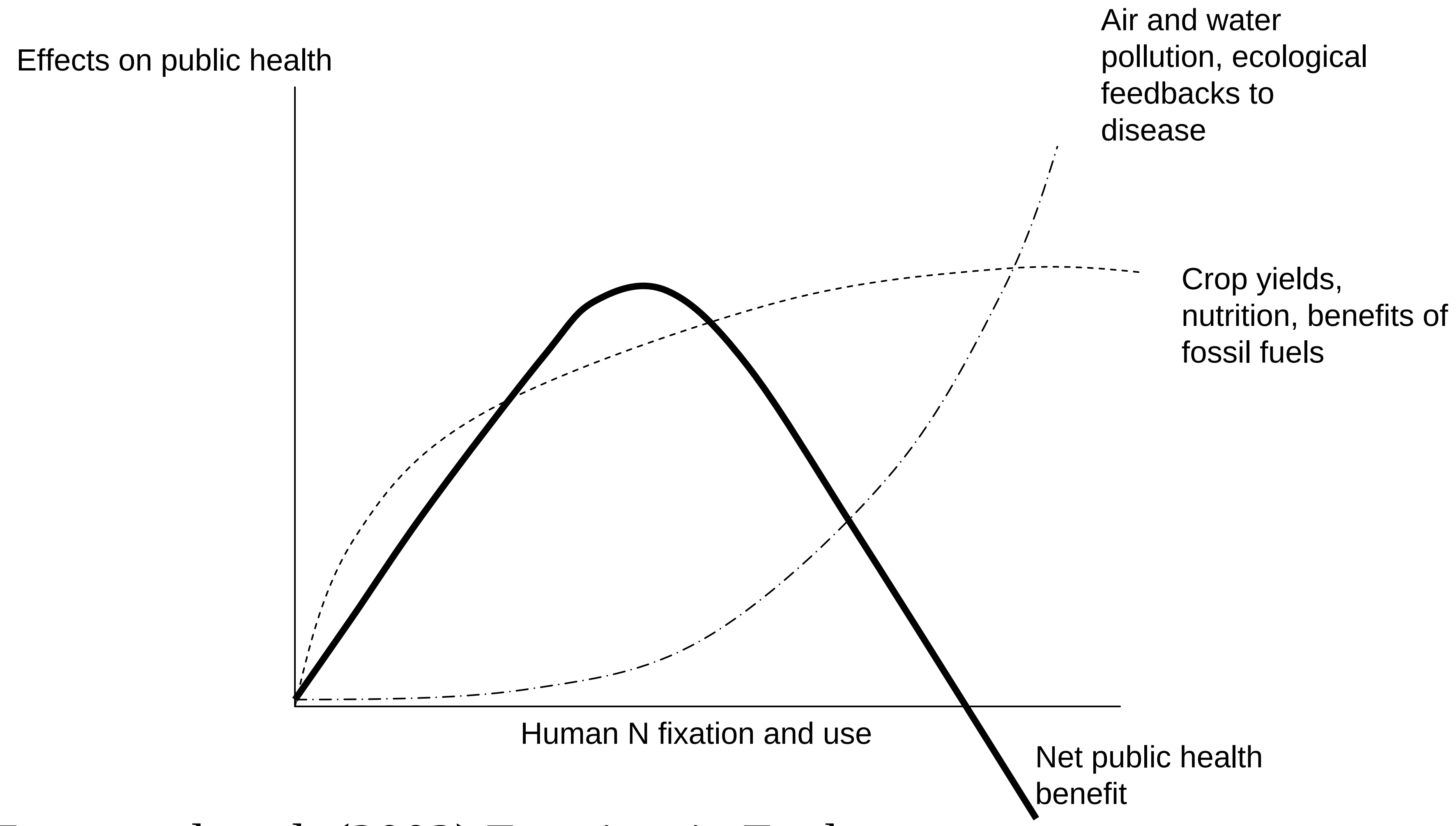
July data supplied by the UK Meteorological Office from the STOCHEM model.

Stratospheric ozone

- Nitrous oxide (N_2O) is the 4th greatest contributor to climate change (after water, CO_2 and methane) and increases with N fertiliser use
- It contributes estimated 6% of climate change and remains in the atmosphere for 120 years
- As it decomposes, nitric acid is formed which acts as a catalyst for reactions in which chlorine and bromine destroy stratospheric ozone
- Higher levels of ultraviolet radiation increasing risk of skin cancer, eye damage etc

Wolfe and Patz (2002)

Conceptual model of impact on public health due to either use or emissions of N



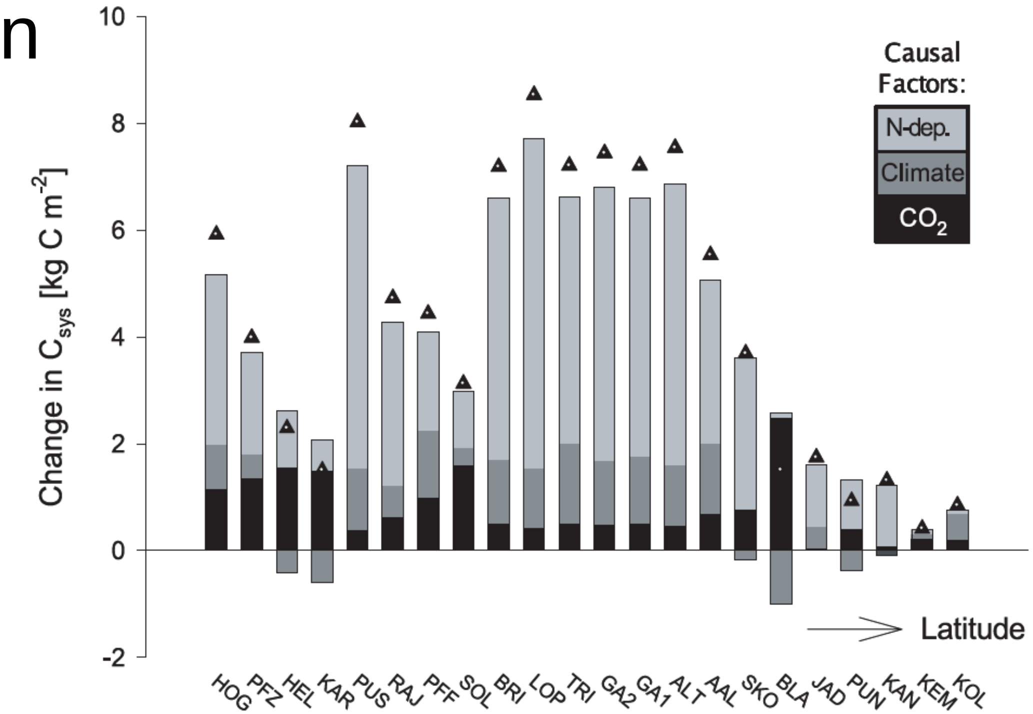
Townsend et al. (2003) Frontiers in Ecology

Change in production and C sequestration

Free fertiliser which will sequester carbon?

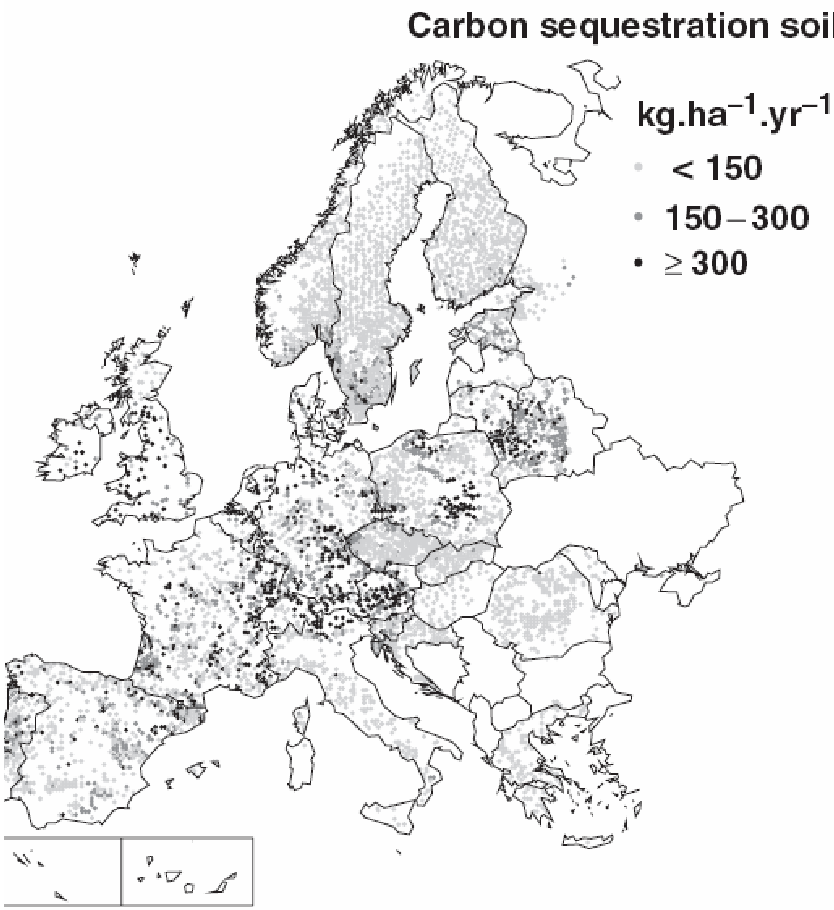
Direct effects of N can be positive for some industries

- Modelling work suggests N deposition has been the major factor which has increased forest growth across EU
- More important than climate and elevated CO2 effects



R. Milne and M. van Oijen, Annals Forest Sci. (2005)
See Chris Evans talk tomorrow

…which locks up carbon in vegetation and soil (20 - 35kgC/kgN)

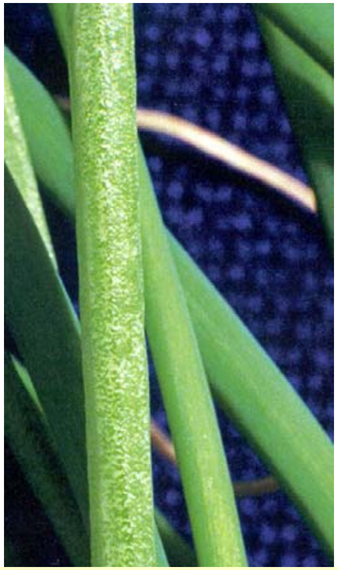


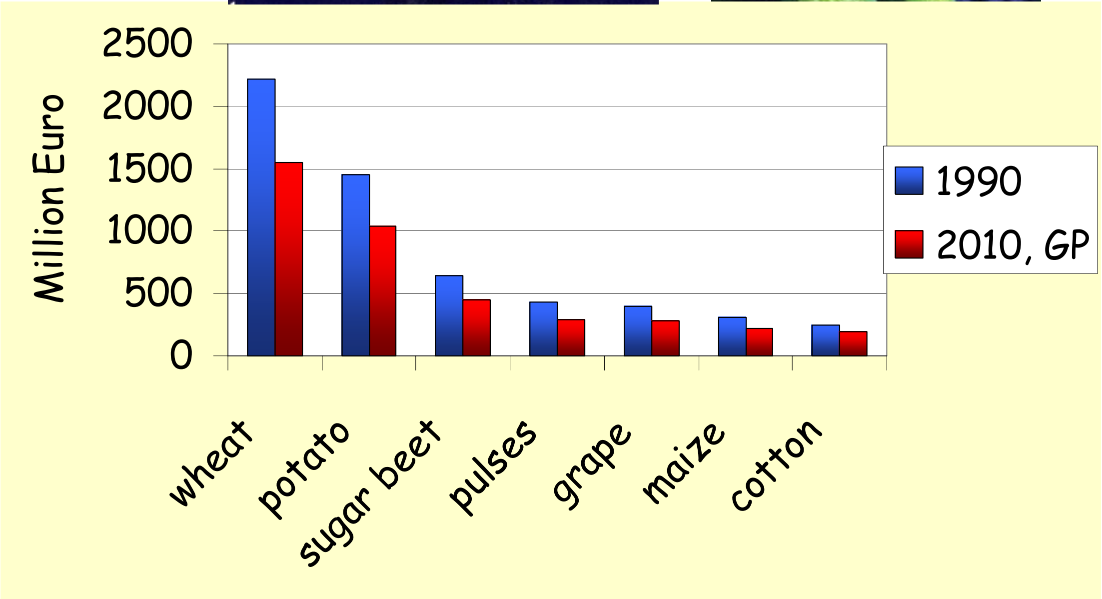
De Vries et al. (2006) Global Change Biology

See Chris Evans talk tomorrow

…but there are indirect negative effects

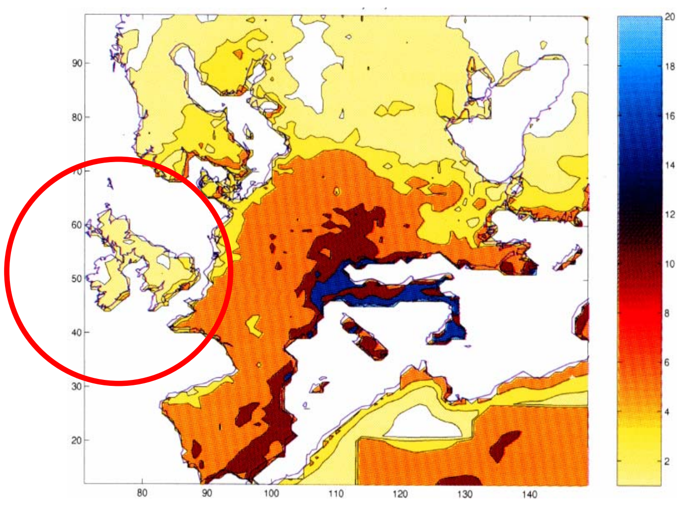
- Ozone damage to crops and forests which decreases production
- Large economic implications
- Impacts on carbon sequestration poorly quantified



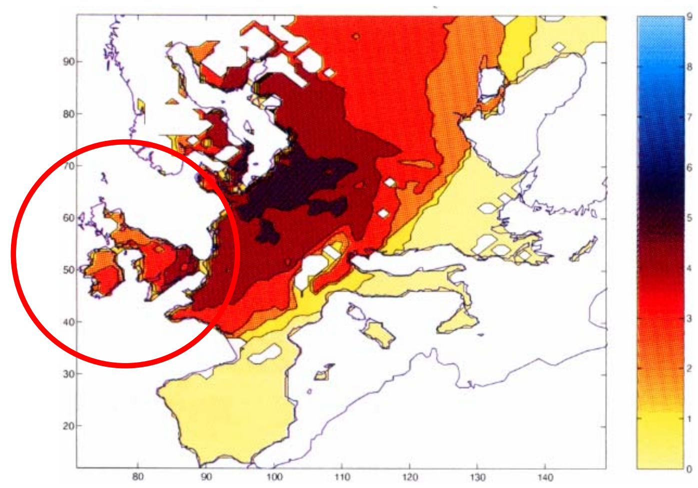


Concentration versus flux effects of ozone

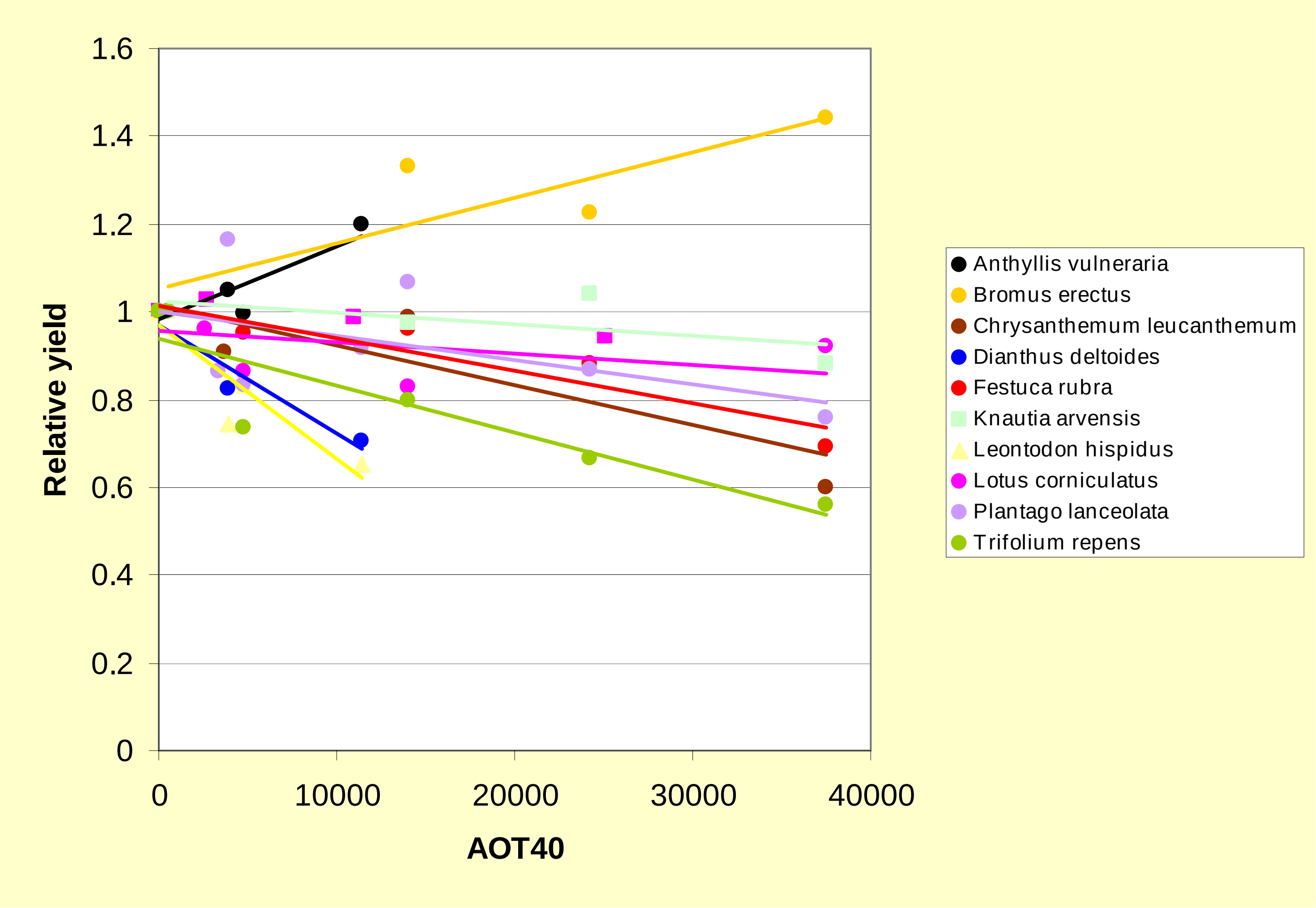
AOT40 for crops



Stomatal fluxes to wheat (nmol O3 m-2 s-1 (June)



Additional effects of ozone likely due to species change in natural systems

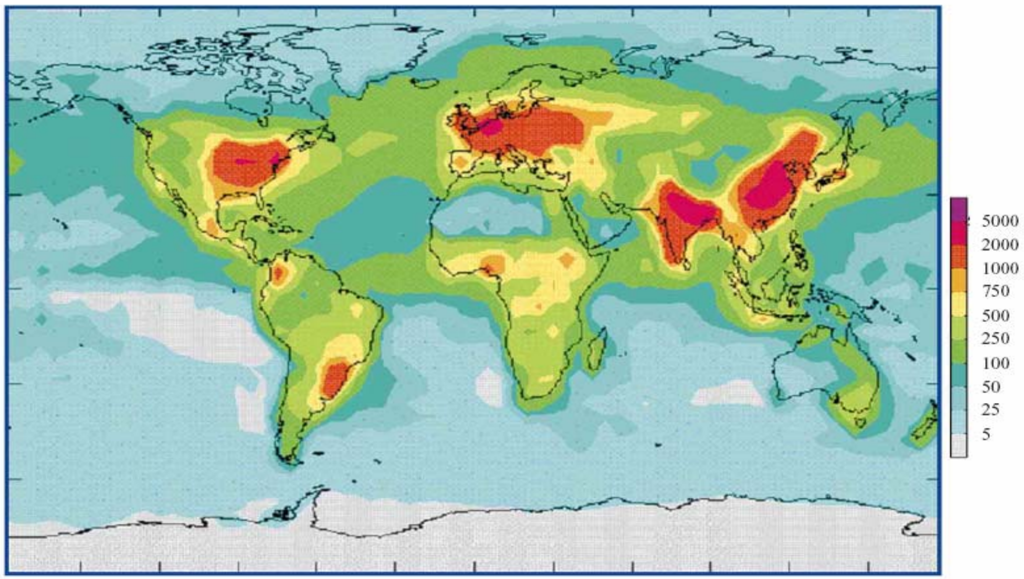


Mills et al. (2006) Environ Pollut

Biodiversity loss and species change

Global patterns in N deposition

- Hotspots of nitrogen deposition
- Future suggests significant increases in regions important as biodiversity reservoirs

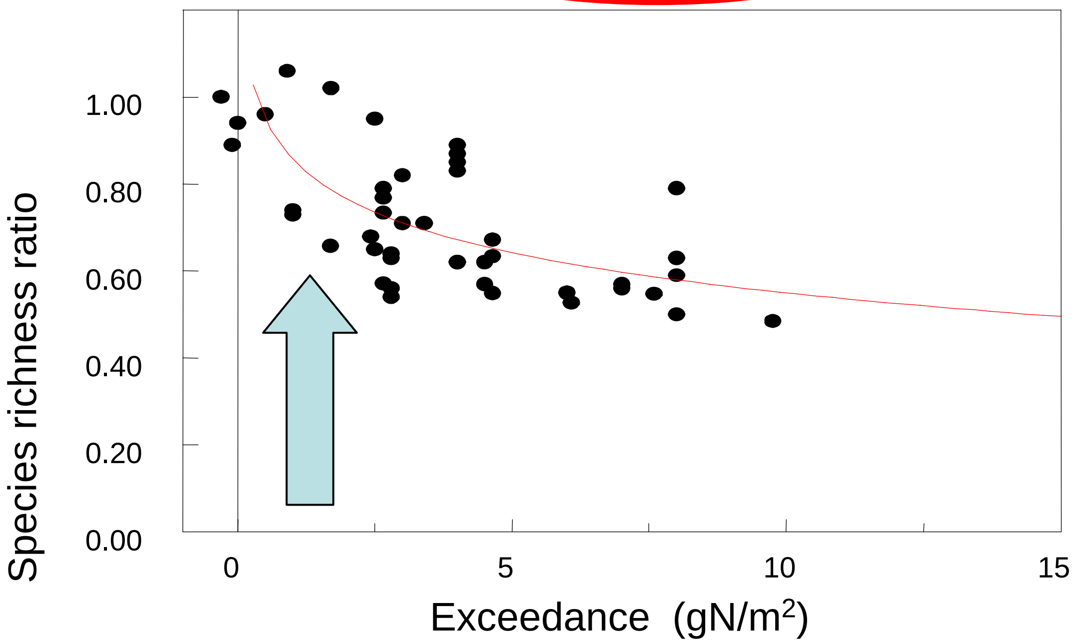


Galloway et al. 2002 Ambio 31:64-71

Pheonix et al. (2006) Global Change Biology 12 : 1-7

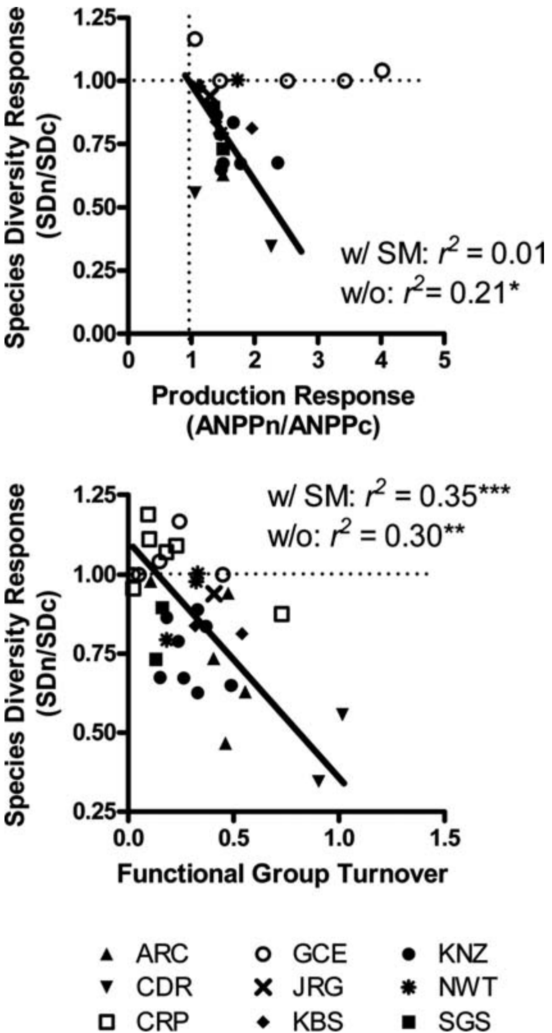
(1) Synthesis of experimental evidence (Europe)

Roland Bobbink, U. Utrecht, In Prep. Synthesis of 44 studies (excl boreal forests)



(2) Synthesis of experimental evidence (USA)

- Losses in biodiversity directly related to increase in plant production
- Changes also related to traits of species and abundance



Suding et al. (2005)

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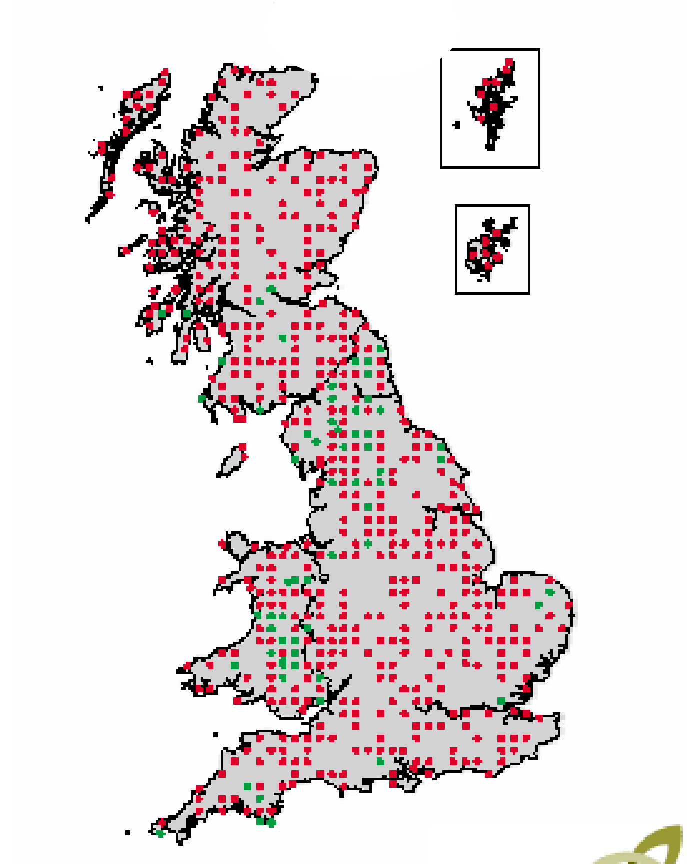
(3) Evidence from national monitoring scheme (UK)

Countryside Survey
www.CS2000.org.uk



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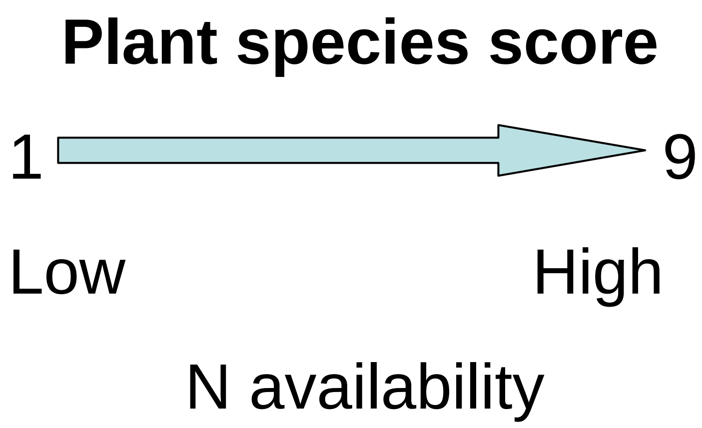
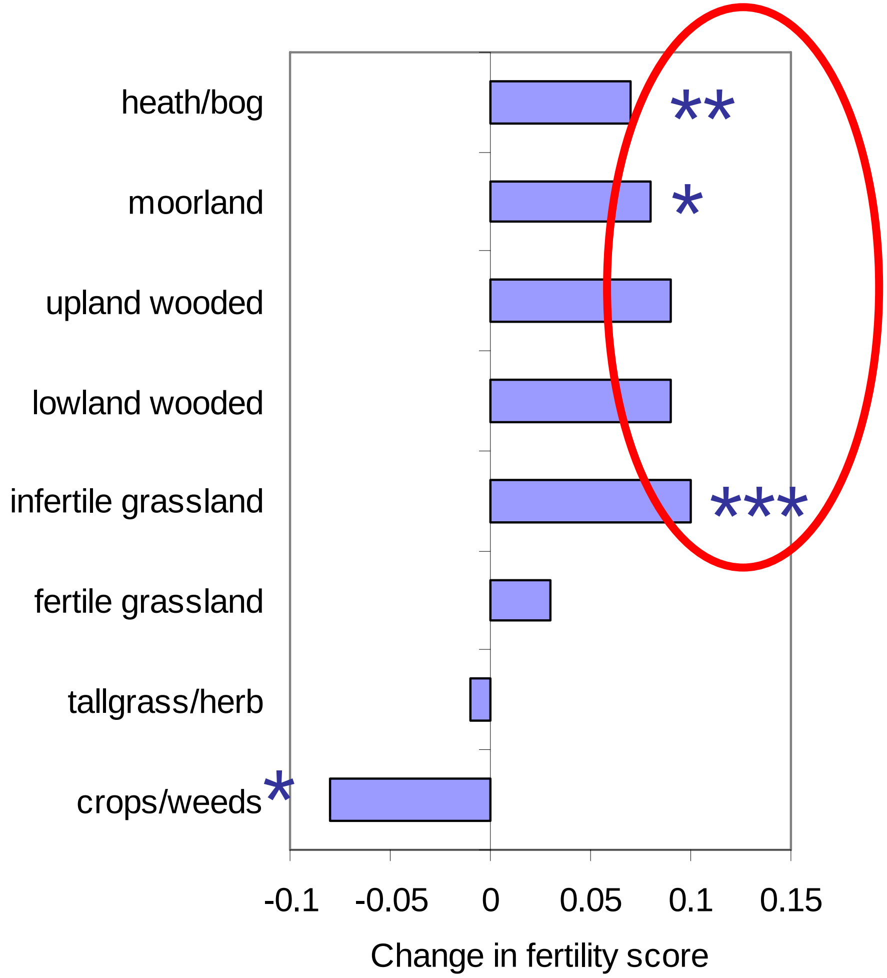
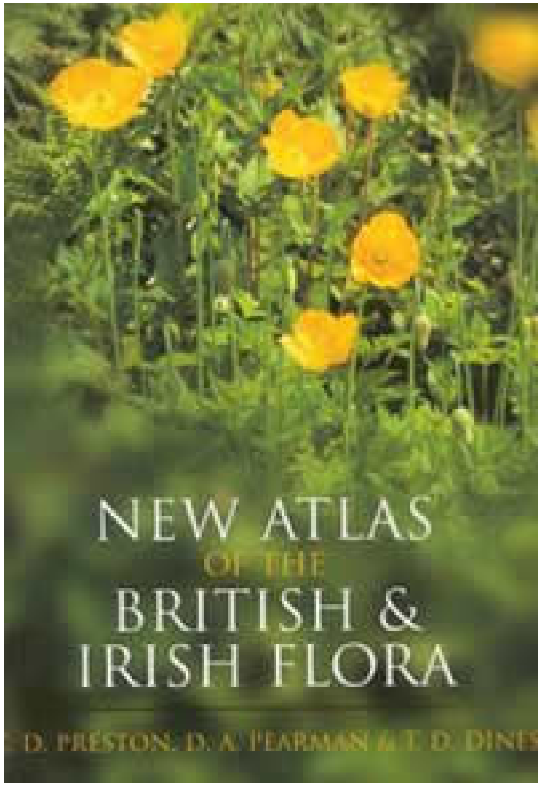
defra

Change in species indicates increased N availability in many habitats



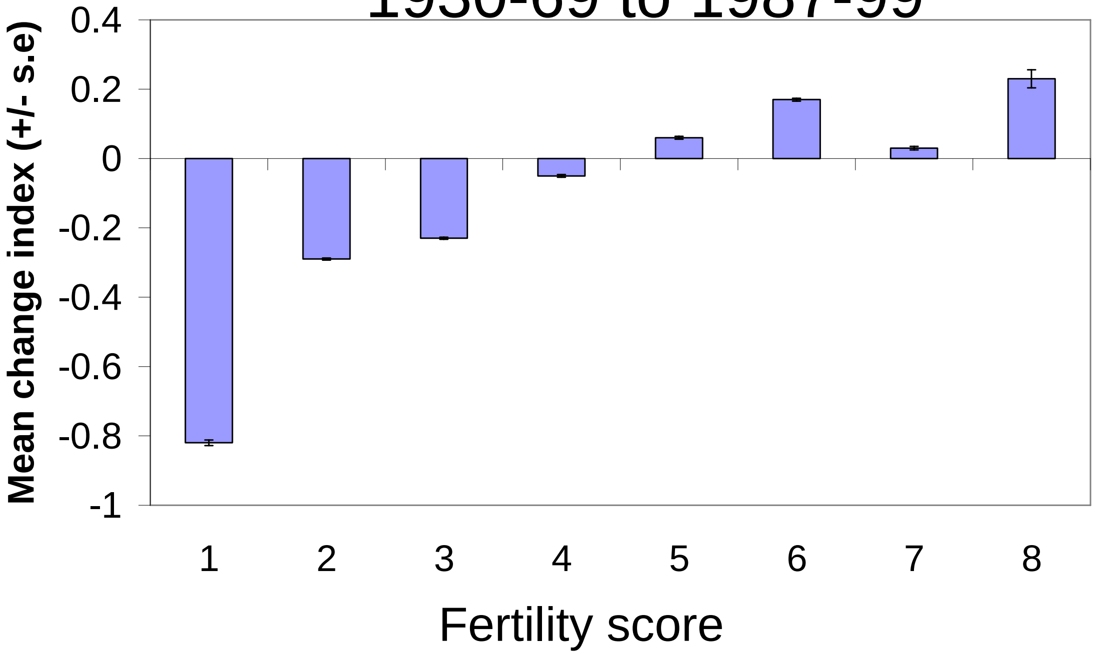


(4) Evidence from plant distribution long-term records (UK)



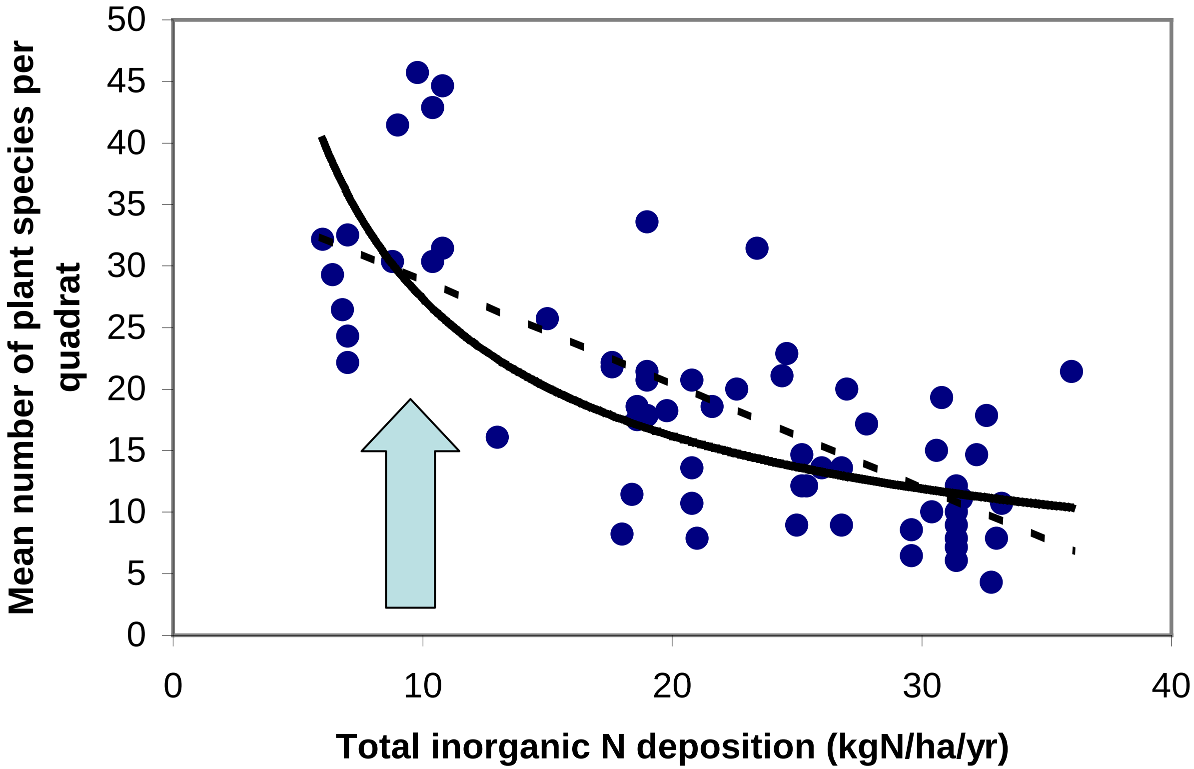
Preston et al. 2002

Species with most change
1930-69 to 1987-99



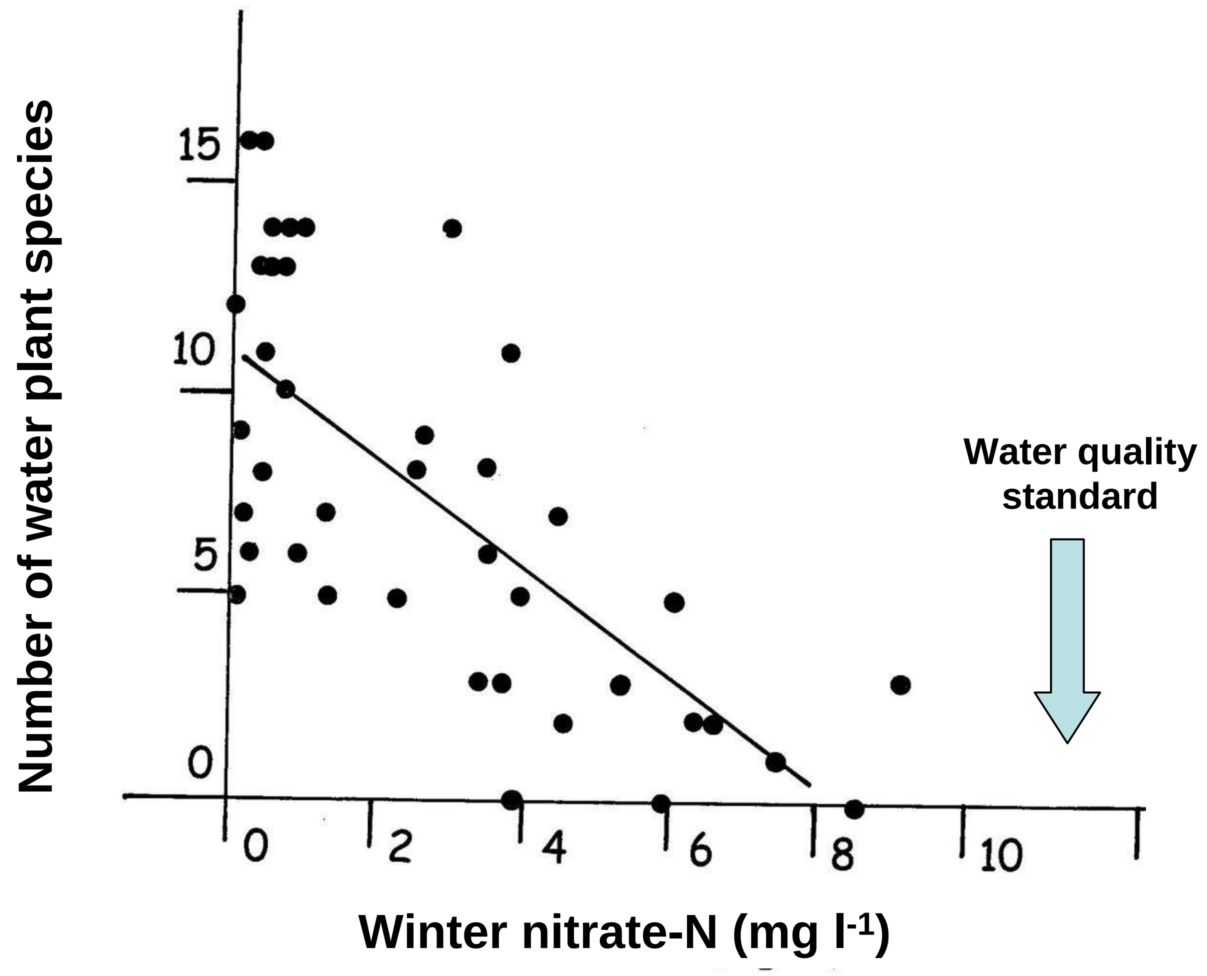
1600 recent recorders. Relative change in comparison to 'average' species for 100 species which shown the greatest change analysed for trends
Changes summarised for 10km square to reduce local sources of variability
2788 10km squares. 1524 taxa

(5) Reduction in species diversity across a N deposition gradient study in acid grassland (UK)



Stevens et al. (2004)

(6) Loss of freshwater macrophyte diversity (Europe)

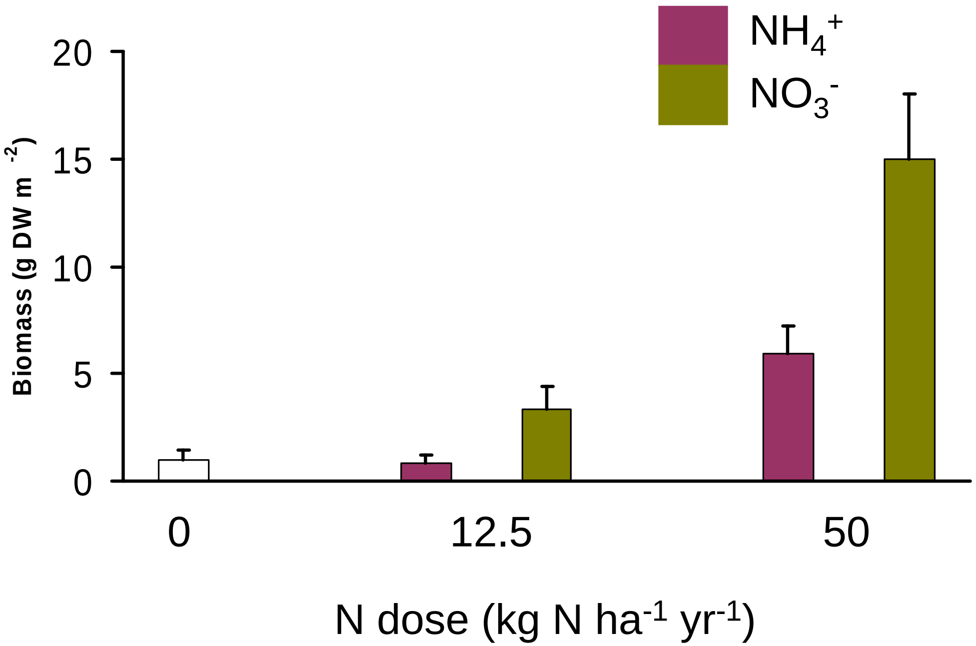


Moss et al. 2004

Does N form matter?

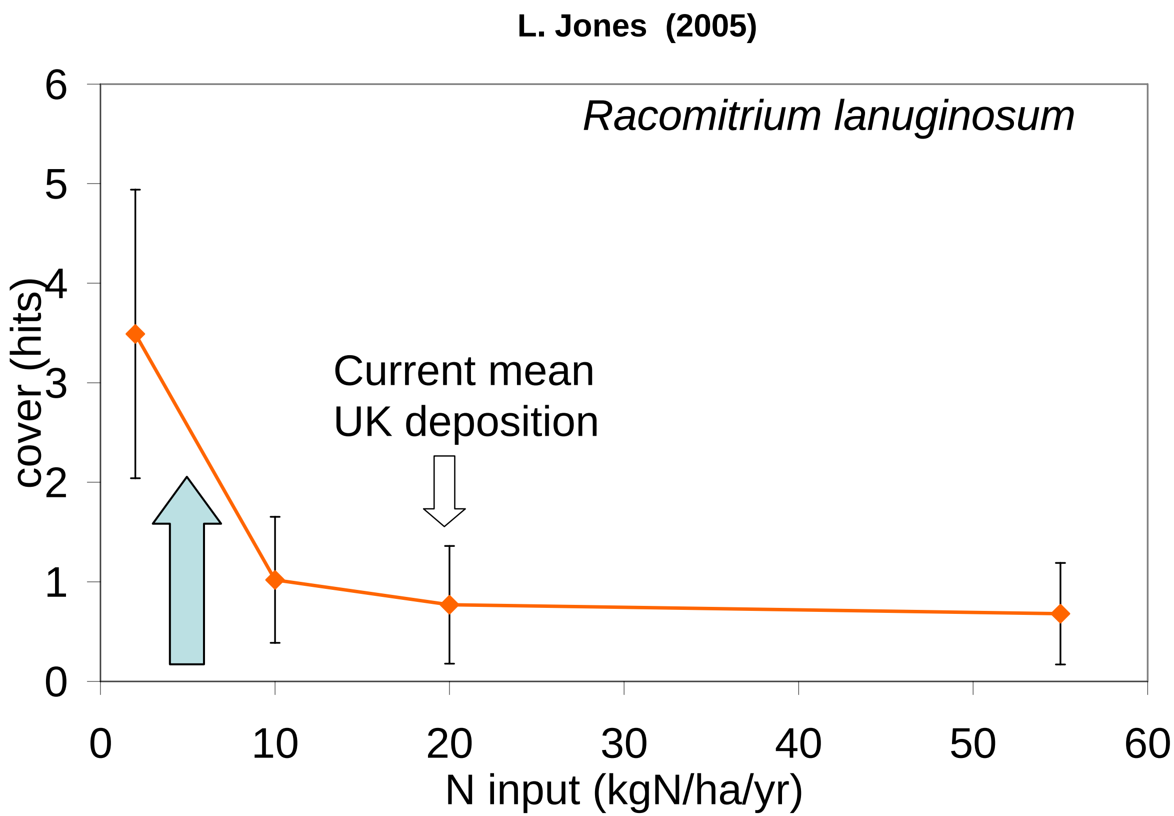
- Reduced N is usually considered more damaging
- However, experimental data suggests not so clear cut
- Oxidised nitrogen can favour some invasive species
- Dry deposition more damaging than wet

Biomass of invasive grass with N addition in boreal forest system



Nordin et al. (2004)

When does change happen?

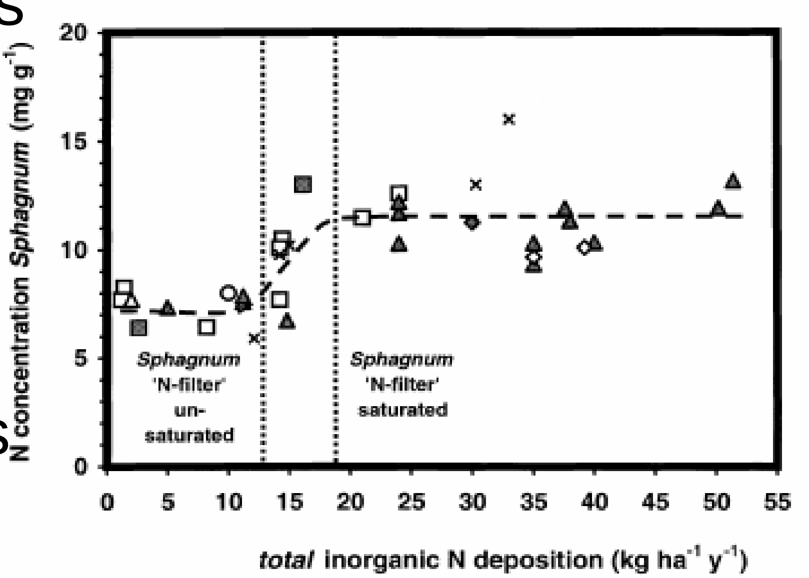


L. Jones et al (2005)

Controls on N storage and release

Controls by vegetation

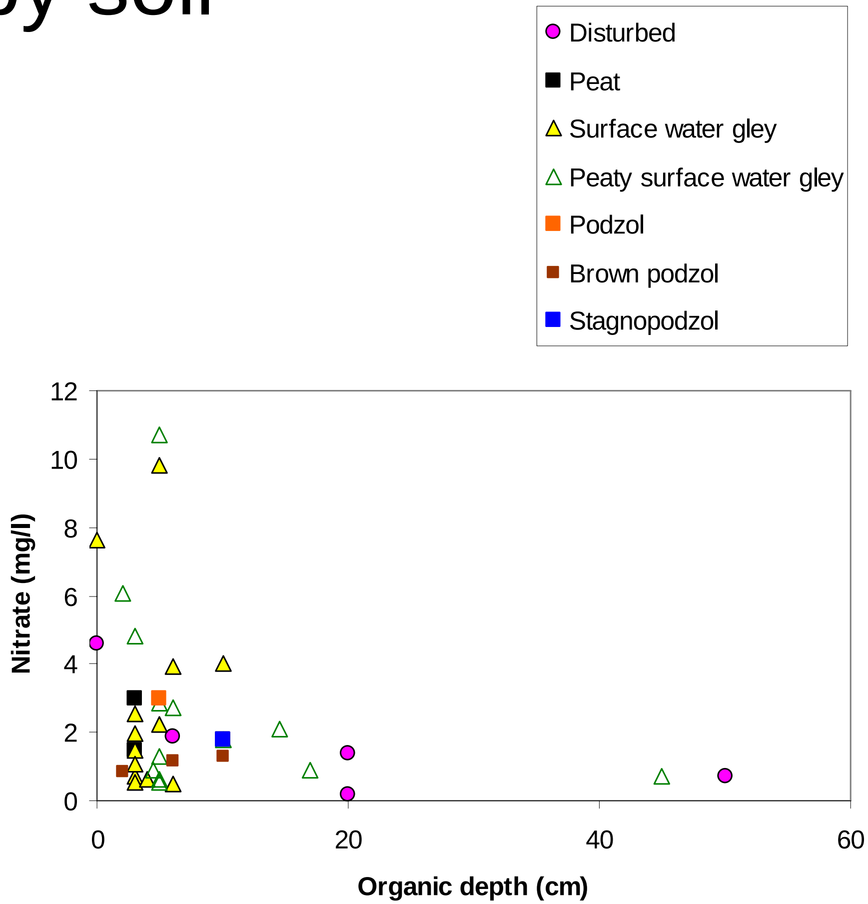
- Production
  - productive or aggrading systems can moderate N release
- Litter quality
  - Evidence that N deposition increases loss of soil C and decreases N storage in systems with high litter quality and reduces C loss and increases N storage with low litter quality
- Species change
  - Loss of N-efficient species causes a loss of a ‘N filter’



Lamers et al. 2000 Global Change Bio

Controls by soil

- Key factors for N retention are size of soil C store, how much nitrogen is already associated with that carbon and rate of N deposition
- but poor modelling predictive capability at present for dynamics of change



Z Frogbrook et al. Unpubl.

Research focus and policy outcomes

Research has focussed on:

- Monitoring for evidence of change
- Search for indicators (cheap and linked to something that matters)
- Quantification of thresholds (critical loads and levels)
- Development of models
  - Stage 1 - where will damage happen
  - Stage 2 - when will damage happen

Scientific basis to policy

- Major effort to agree on criteria and methodologies
- Involved critical reviews of survey and experimental data
- Published in refereed literature
- Scientific basis of Gothenburg protocol

Critical load concept

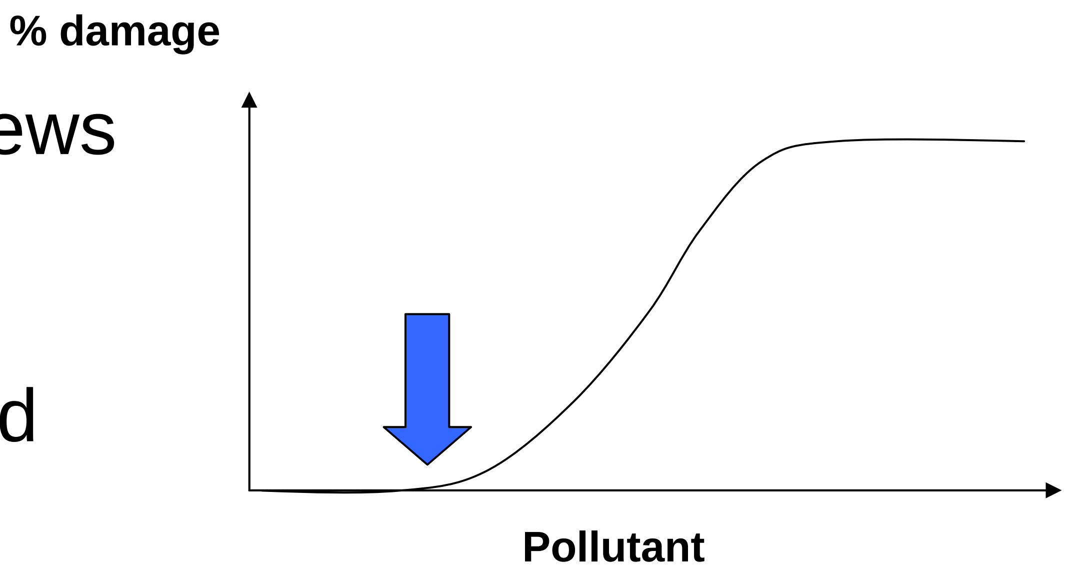


Table 1 Indicators for the effects of elevated N deposition and related empirical critical loads (kgN.ha^{-1}.yr^{-1}) for major ecosystem types (according to the EUNIS classification) occurring in Europe (from Achermann and Bobbink (2003).

Ecosystem type (EUNIS class)	EUNIS-code	Effect indicators	Empirical critical load
Forest habitats (G)			
Mycorrhizae	-	Reduced sporocarp production, reduced belowground species composition	10-20
Ground vegetation	-	Changed species composition, increased nitrophilous species; increased susceptibility to parasites (insects, fungi, virus)	10-15
Lichens and algae	-	Increase of algae; decrease of lichens	10-15
Grasslands and tall forb habitats (E)			
Sub-atlantic semi-dry calcareous grassland	E1.26	Increased mineralization, nitrification and N leaching Increased tall grasses, decreased diversity	15-25
Non-mediterranean dry acid and neutral closed grassland	E1.7	Increase in nitrophilous graminoids, decline of typical species	10-20
Inland dune grasslands	E1.94, E1.95	Decrease in lichens, increase in biomass, increased succession	10-20
Low and medium altitude hay meadows	E2.2	Increased tall grasses, decreased diversity	20-30
Mountain hay meadows	E2.3	Increase in nitrophilous graminoids, changes in diversity	10-20
Moist and wet oligotrophc grasslands	E3.5	Increase in tall graminoids, decreased diversity, decrease of bryophytes	10-25
Alpine and subalpine grasslands	E4.3 and E4.4	Increase in nitrophilous graminoids, changes in diversity	10-15
Moss and lichen dominated mountain summits	E4.2	Effects on bryophytes and lichens	5-10
Heathland habitats (F)			

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Heathland habitats (F)			

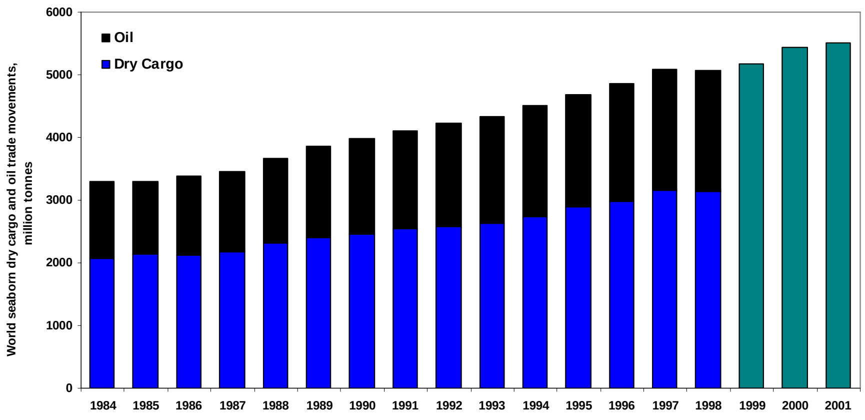
Remaining uncertainties

- Deposition
  - uncertainties in deposition can be greater than critical loads themselves
- Importance of N form
  - dry vs wet and reduced vs oxidised
- Controls on soil N storage and links to species change (incl. fauna)
- Appropriate thresholds for effects
  - $PM_{2.5}$, ammonia and in range of habitats)
- Timing of changes - ecosystem models

What has been achieved?

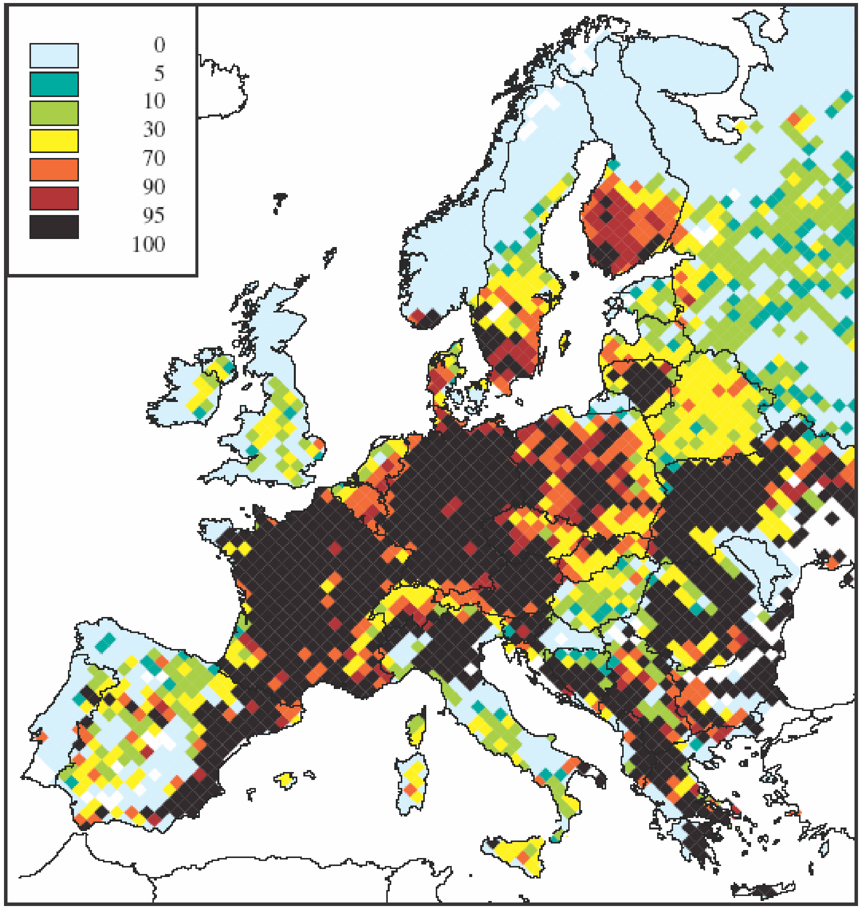
- Some successes
  - In general land-based NOx have been reduced by 20 - 40% since 1980
  - Further 40% reduction expected by 2020
- Problems
  - No reductions in NHy expected by 2020
  - Shipping is on the increase and is a major contributor of NOx

The trend in the global seaborne trade movement of dry cargo and oil since 1984 in million tonnes per year (OECD)



Modified from Peringe Grennfelt (IV

This results in many parts of Europe still at risk from N enrichment in 2020



Percentage of ecosystems area with nitrogen deposition above critical loads, using grid-average deposition. Average of calculations for 1997, 1999, 2000 & 2003 meteorologies

Modified from Peringe Grennfelt (IV

Why will so much of EU still be exceeded for N eutrophication by 2020?

- Lack of knowledge about contribution from some sources (e.g. shipping)
- Conflict with other policy goals (e.g. agriculture)
- Complexity (and sensitivity) of some industries (e.g. agriculture)
- Lack of alternative technologies
- Lack of priority on biodiversity
- Cost

Modified from Peringe Grennfelt (

Thank you