The general science of eutrophication

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Outline

- What is eutrophication?
- What controls sensitivity?
- How is it measured?
- How do we attribute to N deposition (not other drivers such as management or climate change)
- Sources of evidence
- Other factors which affect sensitivity
- Forecasting change
- Uncertainties

What is eutrophication?

- Nitrogen as a nutrient rather than an acidifying pollutant
- The ‘fertiliser’ effect
- Imagine spreading bags of fertiliser over mountain tops and wetlands all year-round
- On acid-sensitive soils, promoting plant growth when stripped soil of other nutrients

Nitrogen eutrophication can be considered as the unintended enrichment of terrestrial and aquatic systems by nitrogen such that changes are observed which are considered harmful or undesirable in the long term

What controls sensitivity?

Abiotic factors which affect sensitivity

Sensitivity	Temperature	Soil wetness	Duration of frost period	Base cation availability	Management intensity
High	*Cold*	*Dry*	*Long*	*Low*	*Low*
Medium	*Intermediate*	*Normal*	*Short*	*Intermediate*	*Intermediate*
Low	*hot*	*Wet*	*None*	*high*	*high*

e.g. mountain tops

- Cold
- dry
- Can be acid
- long frost/snow period
- thin soil and bare rock
- sensitive species (e.g. mosses and lichens)

Sensitivity is reflected in difference in critical loads for different habitats

- 5 - 10 kgN/ha/y
  - Moss and lichen dominated mountain tops
  - arctic alpine and sub-alpine scrub
  - raised and blanket bogs

- 20 - 30 kgN/ha/yr
  - rich fens
  - low and medium altitude hay meadows

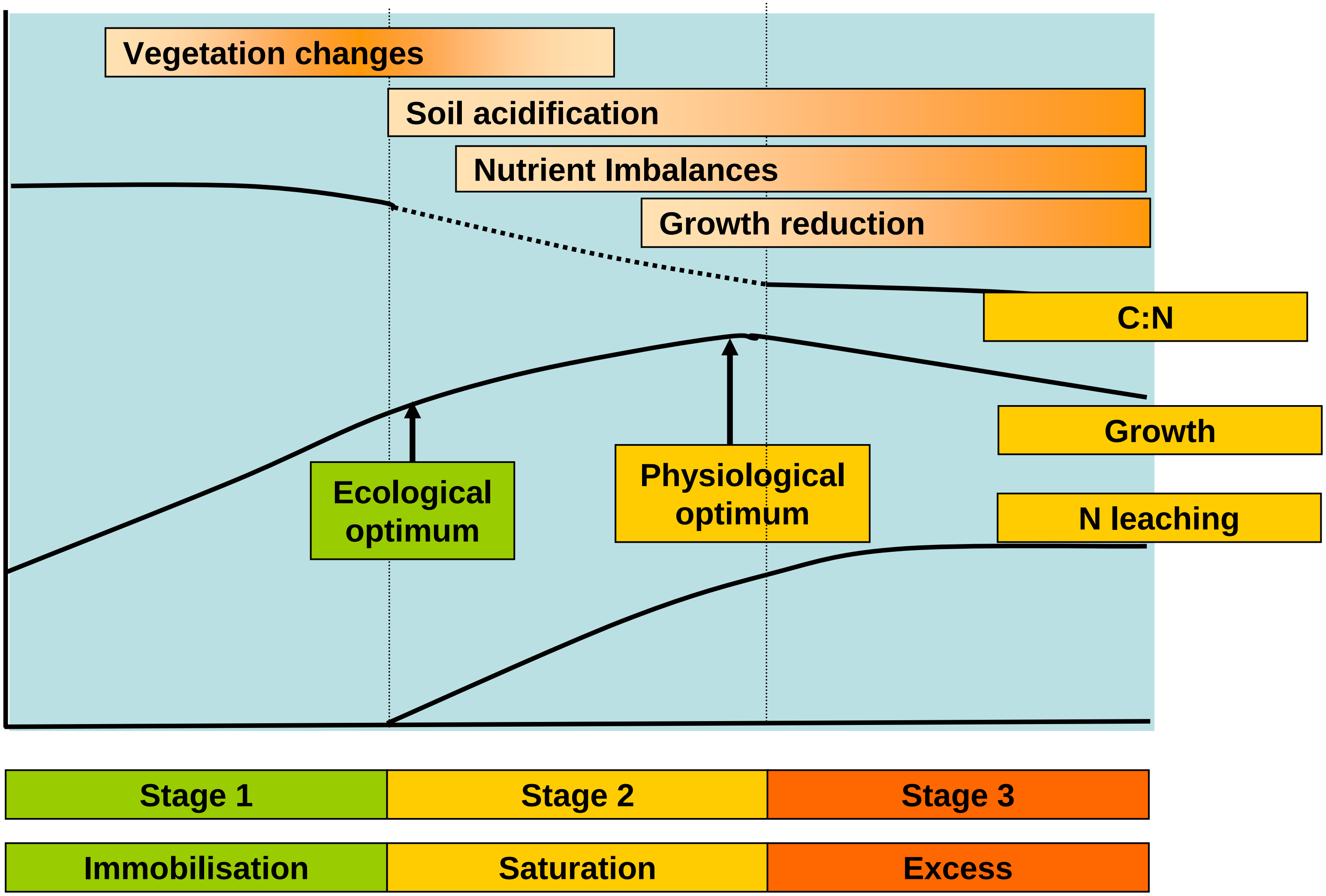
Table 1 Indicators for the effects of elevated N deposition and related empirical critical loads ($kgN.ha^{-1}.yr^{-1}$) for major ecosystem types (according to the EUNIS classification) occurring in Europe (from Achermann and Bobbink (2003).

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)			

How is nitrogen eutrophication measured?

i.e. what changes?

N saturation stage and effects on terrestrial ecosystems



Modified from Gundersen 1991

Indicators

- Vegetation
  - Increased foliar N
  - More nutritional imbalances
  - decreased mycorrhizal fruiting bodies
  - Increased pathogens
  - Increased grasses
  - Increased production (vegetation height)
  - Loss of mosses and lichens
  - Increased ‘N loving’ species
- Soils and waters
  - increased soil water N concentration or N leaching
  - increased N mineralisation / nitrification

Indicators that don’t work

- Tested but poor relationships
  - amino acid concentration
  - N_2O production
  - N:P concentrations
  - soil enzymes
- Too slow to be useful for early warning
  - soil C:N
  - N leaching in some systems

Attribution of change to N deposition

Some responses not unique to N deposition (1)

- N deposition
  - change production (+ then -ve)
  - change competitive balance in favour of grasses
  - increase N mineralisation
  - increase N leaching
  - can increase/decrease soil carbon stocks?
  - Acidification but only on acid-sensitive soils
- Grazing
  - change production (+ then -ve)
  - change competitive balance in favour of grasses
  - increase N mineralisation
  - variable effect on N leaching
  - can increase/decrease soil carbon stocks?

Some responses not unique to N deposition (2)

- N deposition
  - change production (+ then -ve)
  - change competitive balance to N loving species
  - increase N mineralisation
  - increase N leaching
  - can increase/decrease soil carbon stocks?
  - Acidification but only on acid-sensitive soils

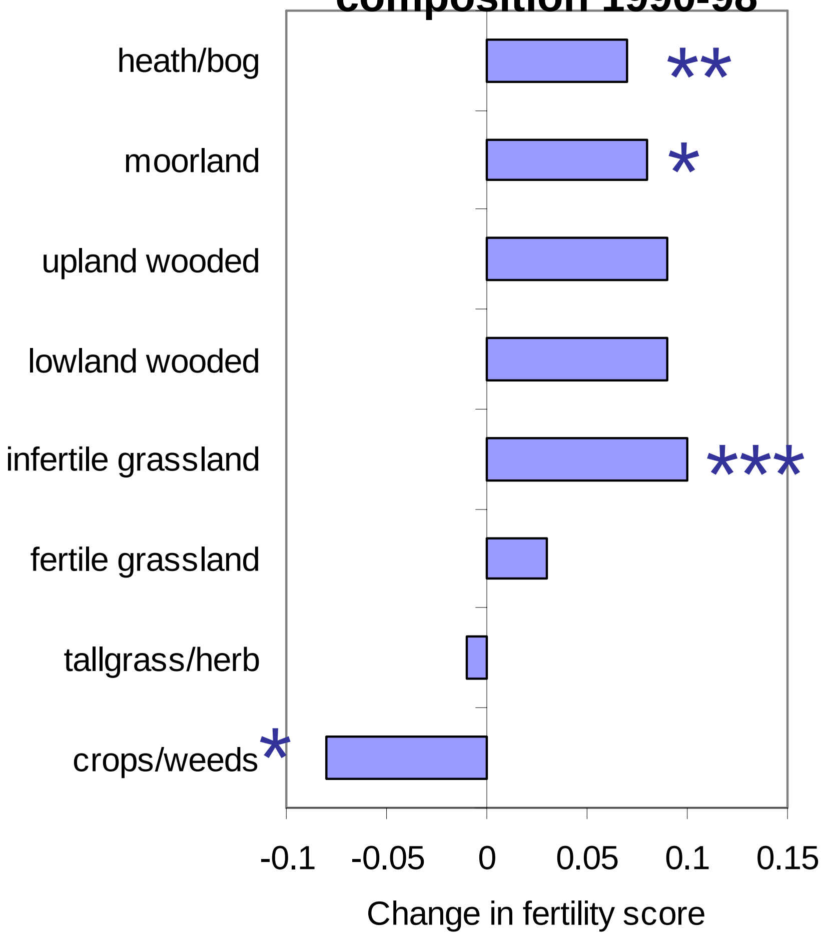
- Climate change
  - change production (both + and -ve)
  - change competitive balance to 'southern' species
  - increase N mineralisation
  - increase N leaching
  - decrease soil carbon stocks
  - acid pulses (drought/rewets)

Solution?

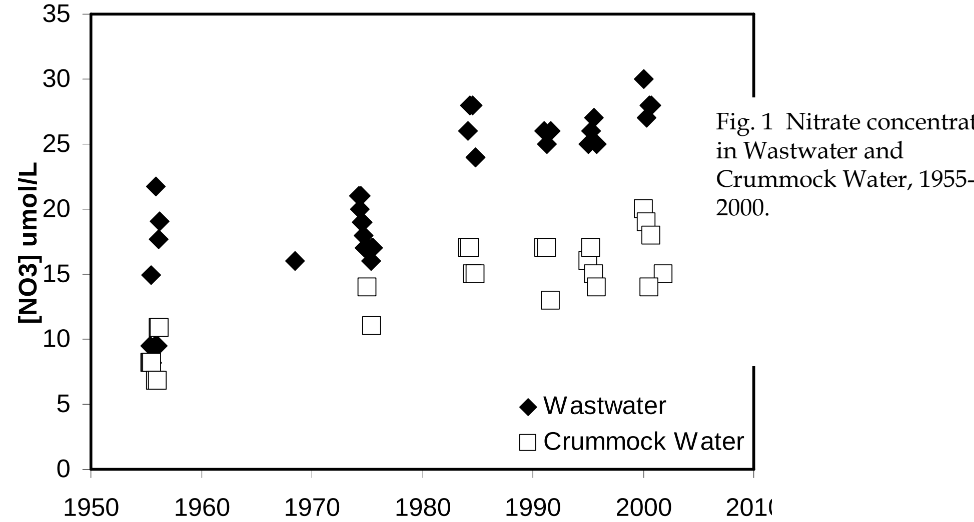
- Monitoring schemes which include several indicators
- Include vegetation and soil variables preferably in the same place
- Permanently mark plots/quadrats
- Monitor across current and predicted maximum future N gradient
- Measure other explanatory variables such as management, climate
- Find a good statistician who can do multi-variate analysis

In UK and EU this kind of evidence has been critical in pushing forward air quality controls

Change in species composition 1990-98



Change in lake water nitrate concentration

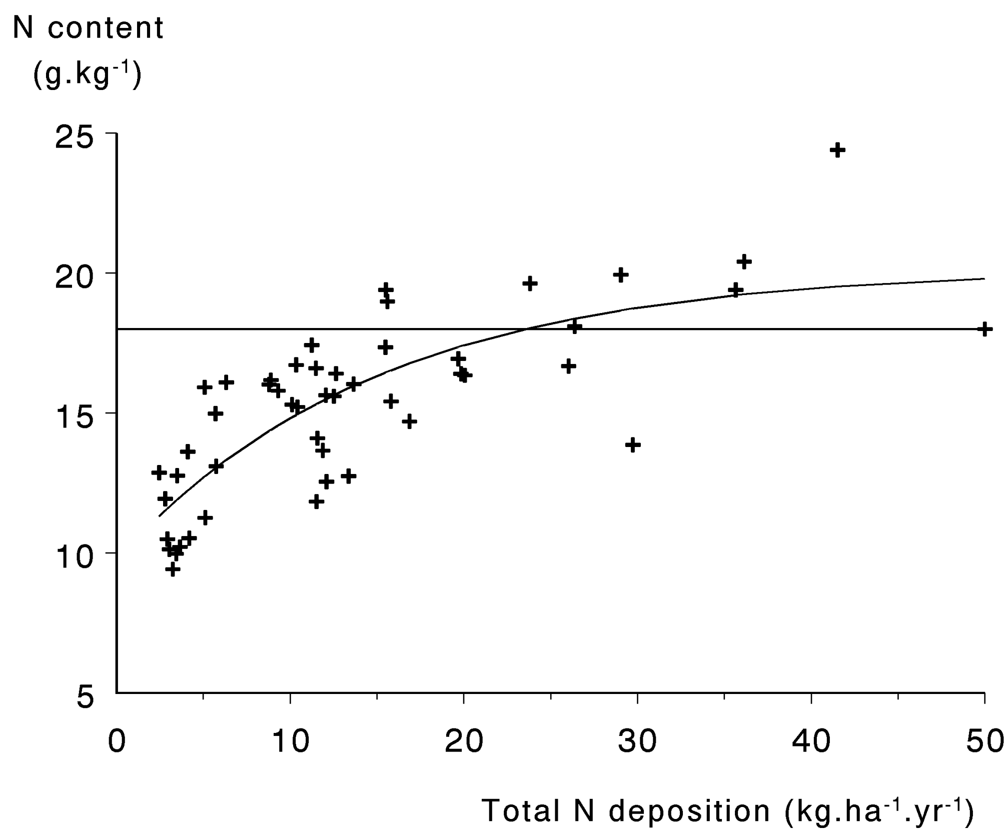


Sources of evidence

Sources of evidence of change and identification of indicators

- Monitoring schemes which allow attribution to different drivers
- One-off surveys across N deposition gradients
- Experiments
  - N addition experiments in low-N deposition areas (I.e. below the critical load and with range of N doses
  - N removal experiments in high deposition areas
- As a last resort for poorly studied ecosystems
  - ‘expert knowledge’

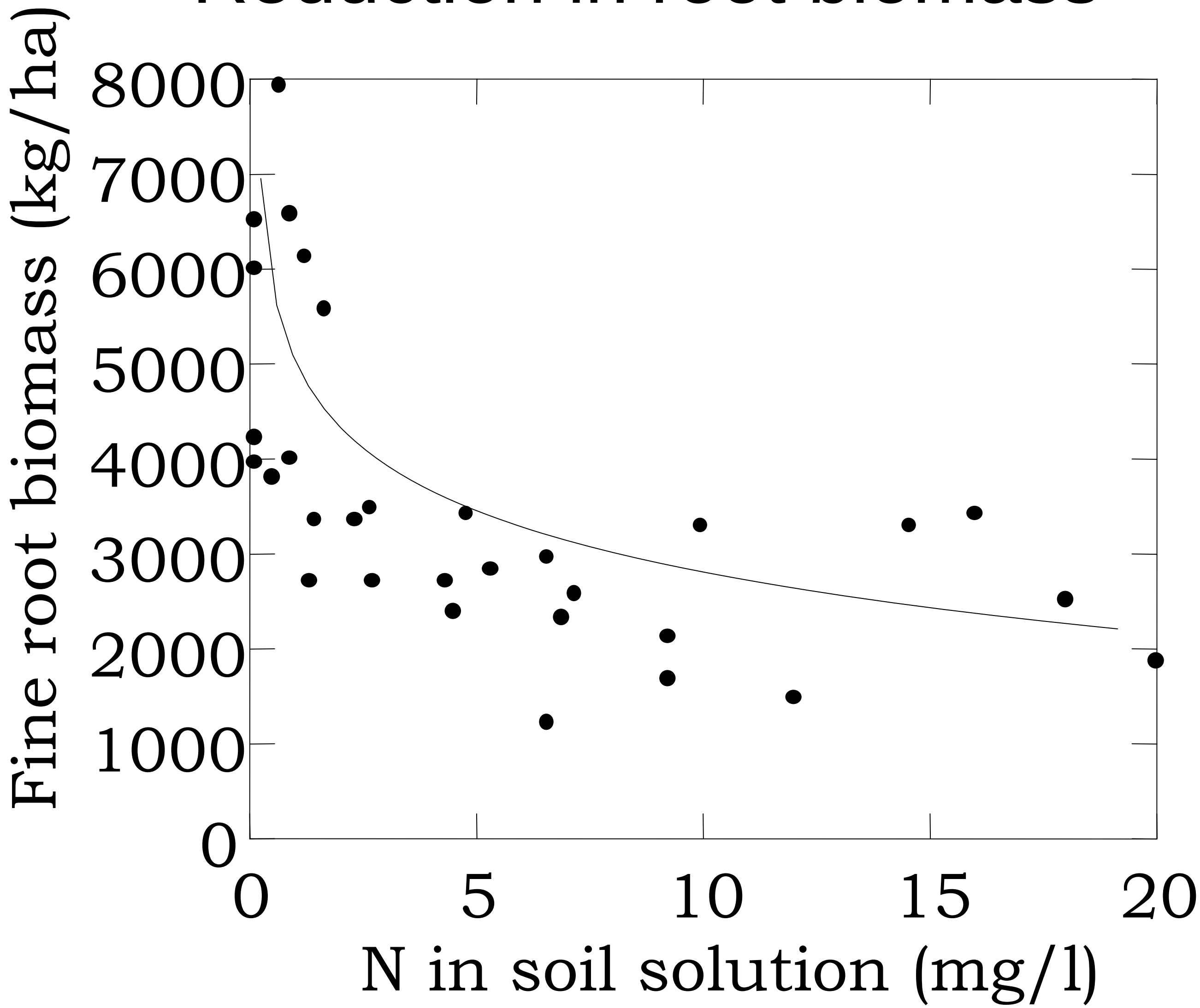
Foliar N increases



Relationship between N contents in first year needles of Scots pine and total N deposition at 68 plots in Europe.

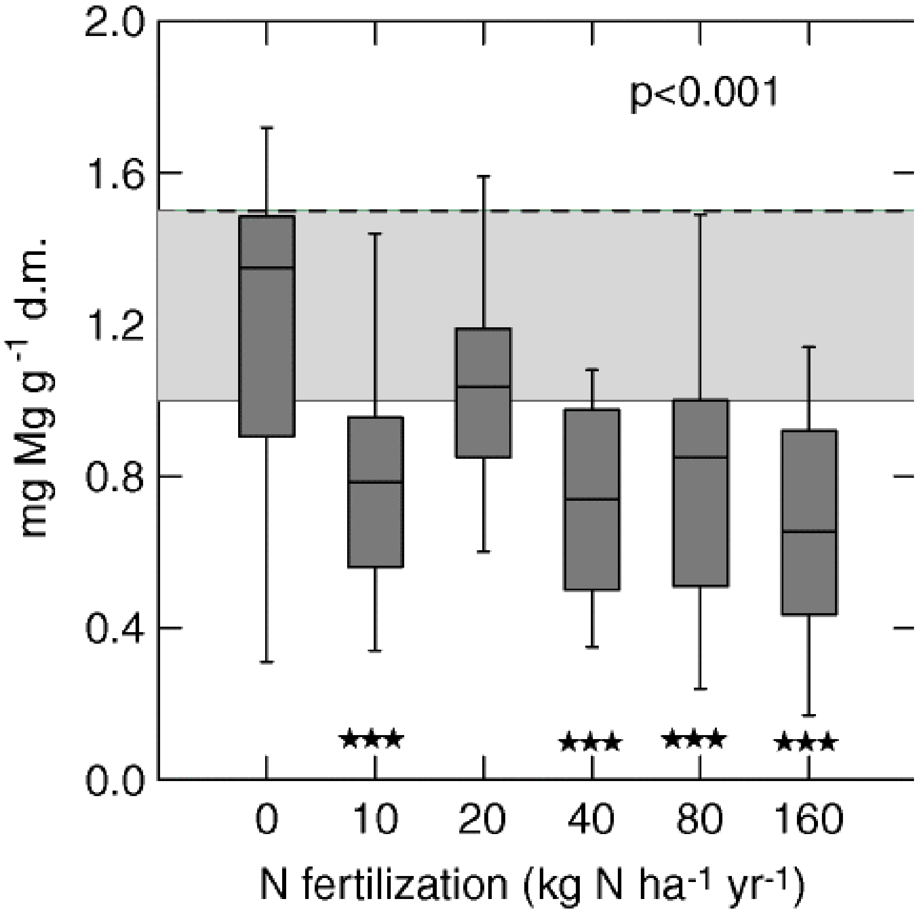
De Vries et al. 2003

Reduction in root biomass



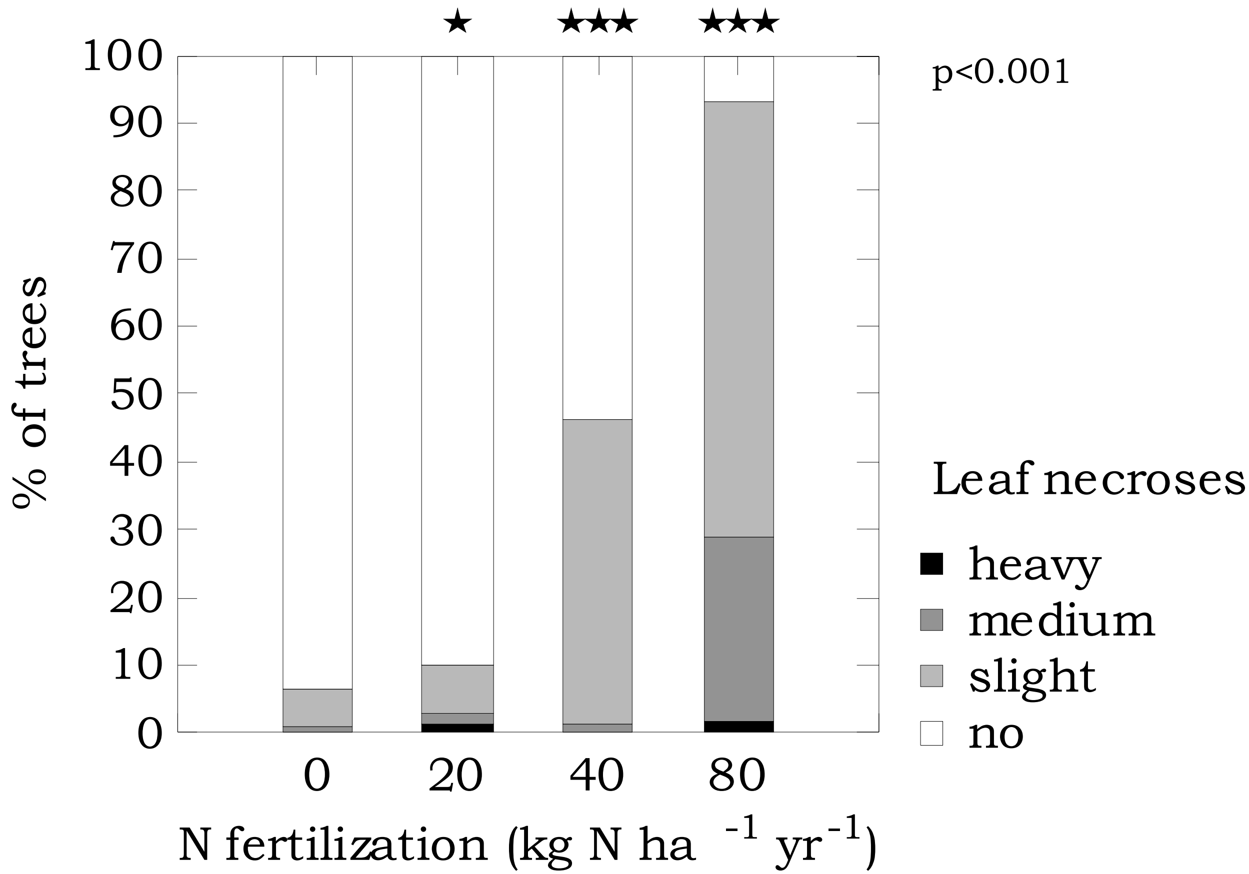
Matzner & Murach, 1995

Foliar nutrient imbalances



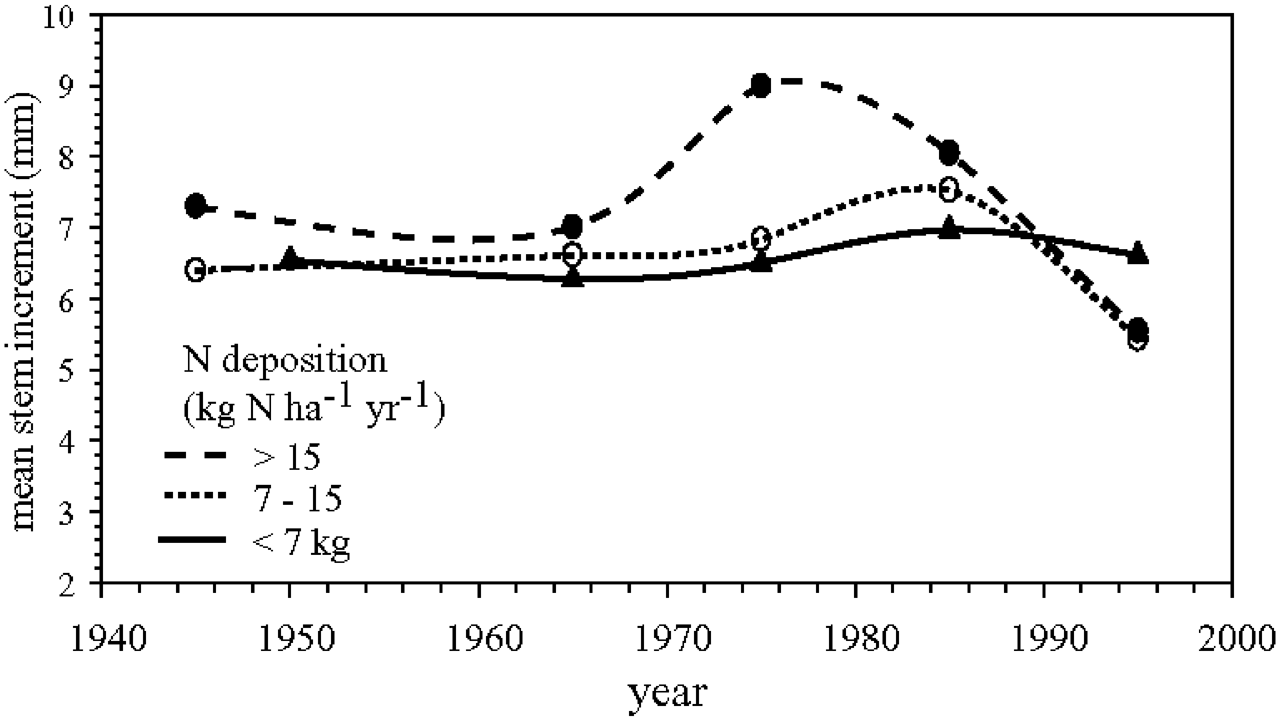
*Magnesium concentration in beech leaves in a nitrogen fertilization experiment on acid soil. Significant differences to control are indicated with *** p<0.001, overall linear regression p<0.001 (After Flückiger & Braun, 1999a) Grey field: range for optimum nutrient concentration after Stefan et al. (1997).*

Increased sensitivity to stresses



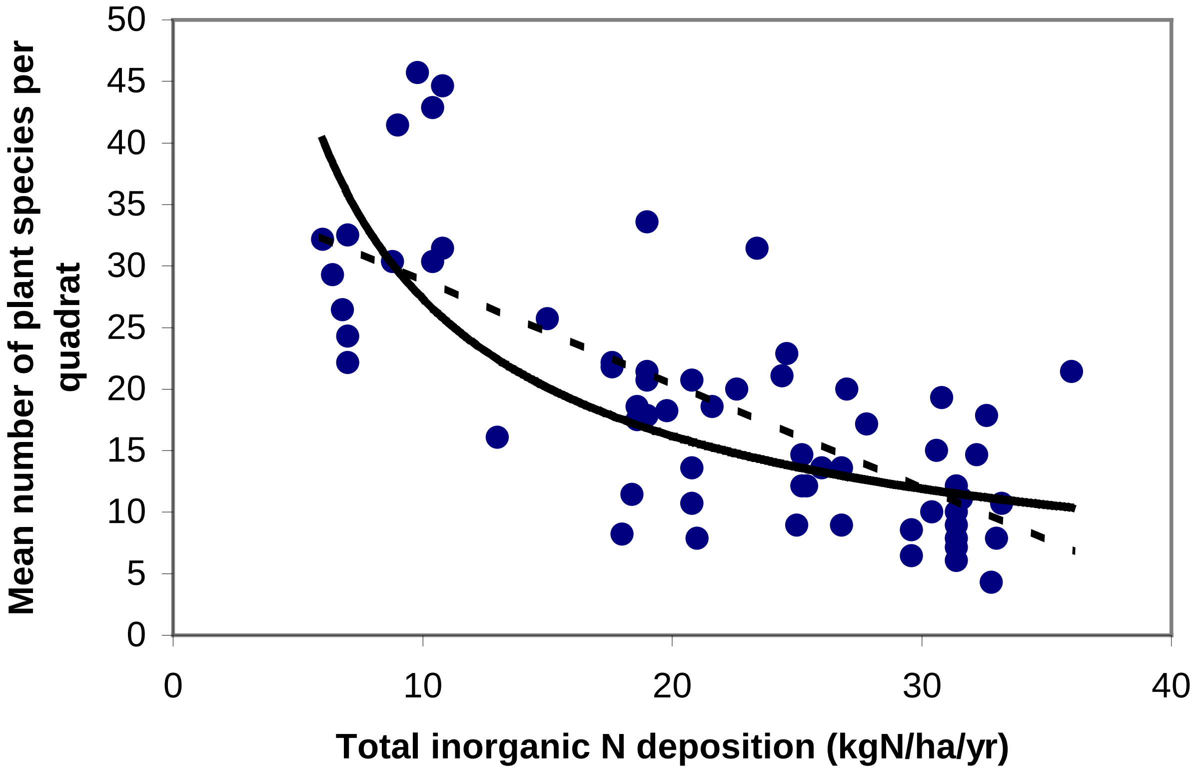
*Leaf necroses in beech caused by drought in a nitrogen addition experiment. Differences to control significant at *p<0.05, ***p<0.001, general linear trend p<0.001 (After Thomas et al., 2002).*

Production increase



Stem increment of spruce in Norway from 31,606 increment cores grouped according to modelled wet nitrogen deposition. Growth increase in the highest deposition class as well as the decrease in the two highest classes are significant at p<0.01 (After Nellemann & Thomsen, 2001).

Reduction in species richness

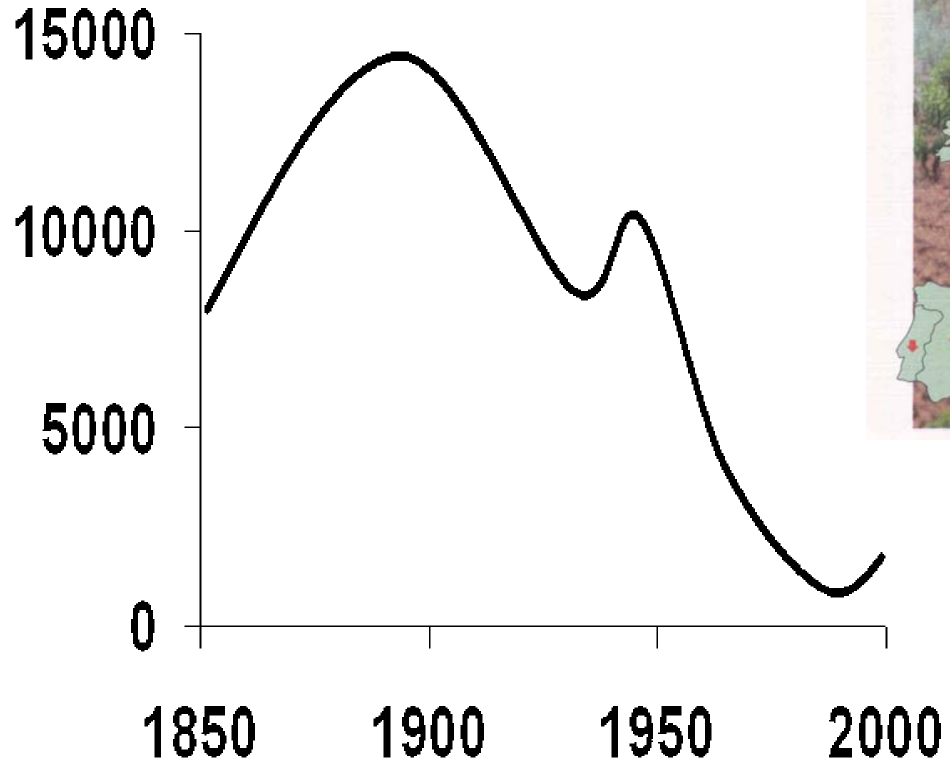


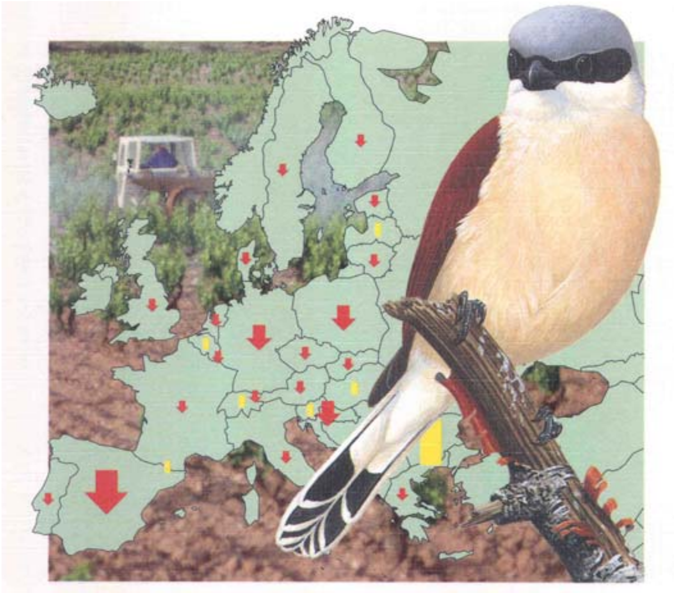
Stevens et al. (2004)

Vegetation change characteristic of N eutrophication

- Loss of mosses and lichens
- Increase in grasses (particularly tall species)
- Loss of ‘typical’ species for habitat
- Increase in ‘N loving’ plants
- Decline in species richness (can be increase in some habitats)
- Accelerated succession

Decline in some animal species





The change in the number of breeding pairs of red back shrike in the Netherlands due to loss of habitat heterogeneity in coastal habitats due to stabilisation of dunes

Beusink et al., 2003

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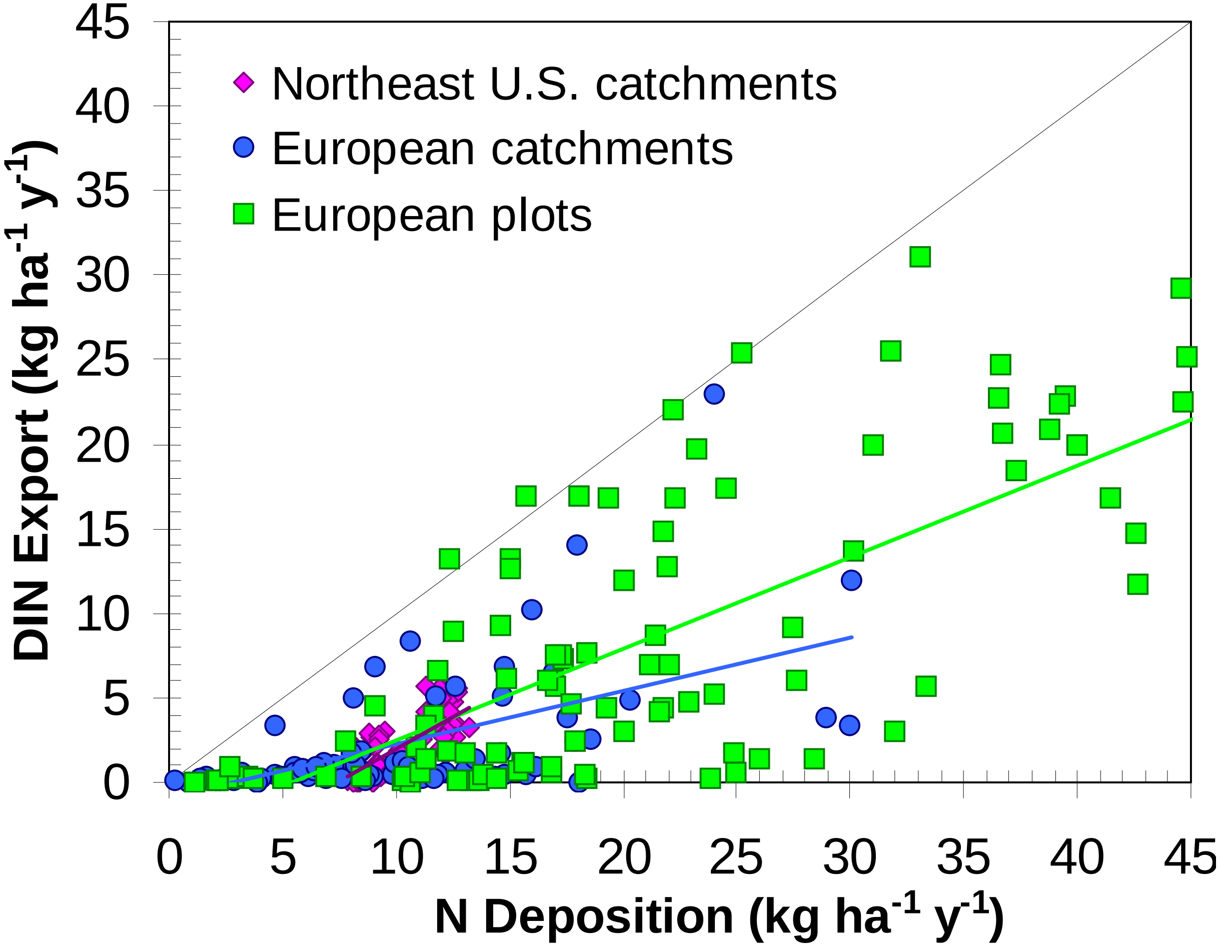
N leaching

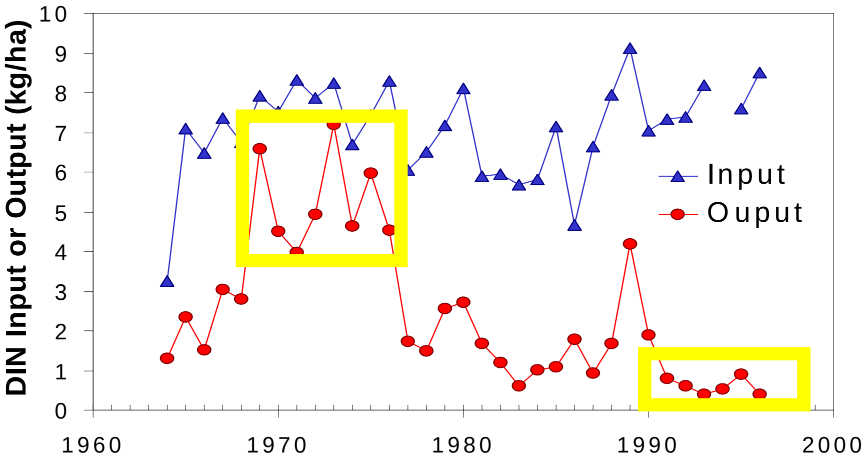
Good relation at large spatial scale but very variable



N leaching is very sensitive to many things

- Attribution of change in nitrate can be a problem as responds to:
  - climate
  - extremes (drought & frost)
  - pest outbreaks
  - management

Variation in N retention over time: Hubbard Brook, W6



Data from Likens & Bormann 1995; Campbell et al. 2000 obtained through 1995 on-line at: http://www.hbrook.sr.unh.edu/data/

Need long time trends, multiple sites and associated data to attribute changes to N deposition

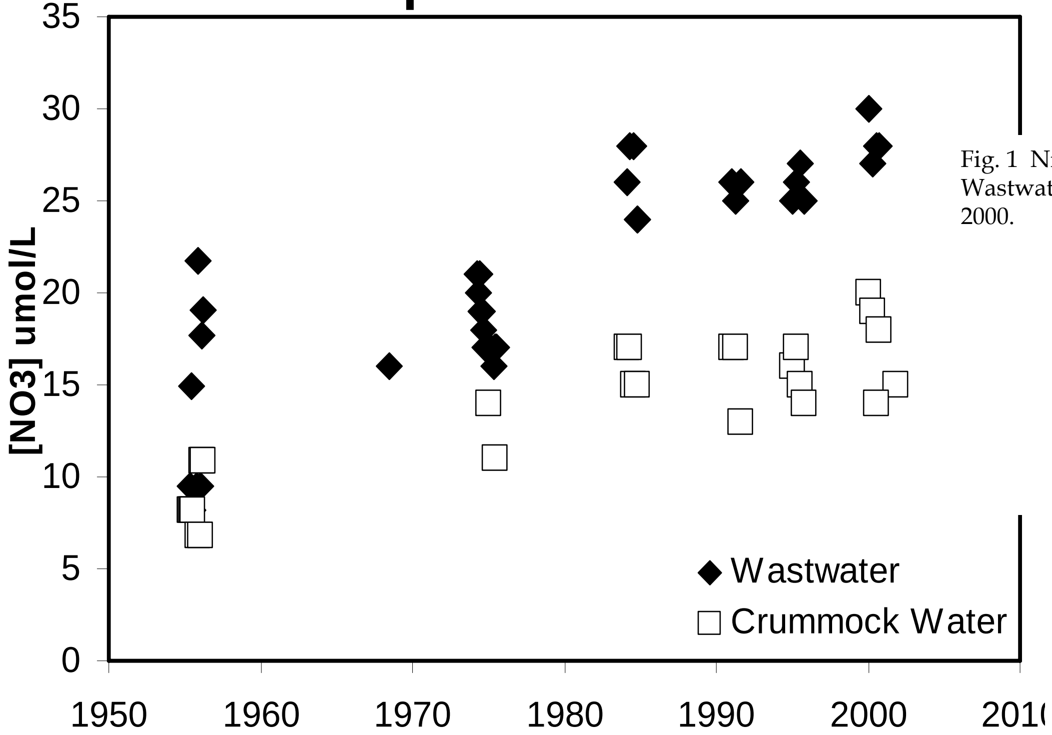


Fig. 1 Nitrate concentrations in Wastwater and Crummock Water, 1955-2000.

E. Tipping CEH Lancaster

Summary N-related effects

Effects	Evidence for effect[1]	Level of scientific understanding
Species diversity of terrestrial ecosystems		
– Plant species diversity		
Nature	++	+
Forests	?	+/ -
– Faunal species diversity	+	+/ -
Soil quality and forest nutrition		
– Nutritional imbalance	++	+
– Soil acidification	+	+
– Increased sensitivity to frost, drought and diseases	+	+/ -
Water quality and species diversity of aquatic ecosystems		
– Soft water ecosystems	++	+
– Coastal / marine ecosystems	++	+/ -
Human health		
– Nitrate in drinking water	+	+/ -
– Air pollution		
Ozone and NO_x pollution	++	+
Fine particulate air pollution	+	+
Pollen pollution	?	+/ -
Climate		
– Nitrous oxide emissions	++	+/ -
– Fine particulates	++	+/ -
Visibility	+	+
Materials	?	+/ -

Other factors which affect sensitivity

Dry vs wet deposition

- Wet deposition of NH4 and NO3 8 - 64 kgN/ha/yr

- Ammonia transect 5 - 25 kgN/ha/yr

L. Sheppard et al. CEH Edinburgh

Wet Dry

Cladonia (lichen)

Why?

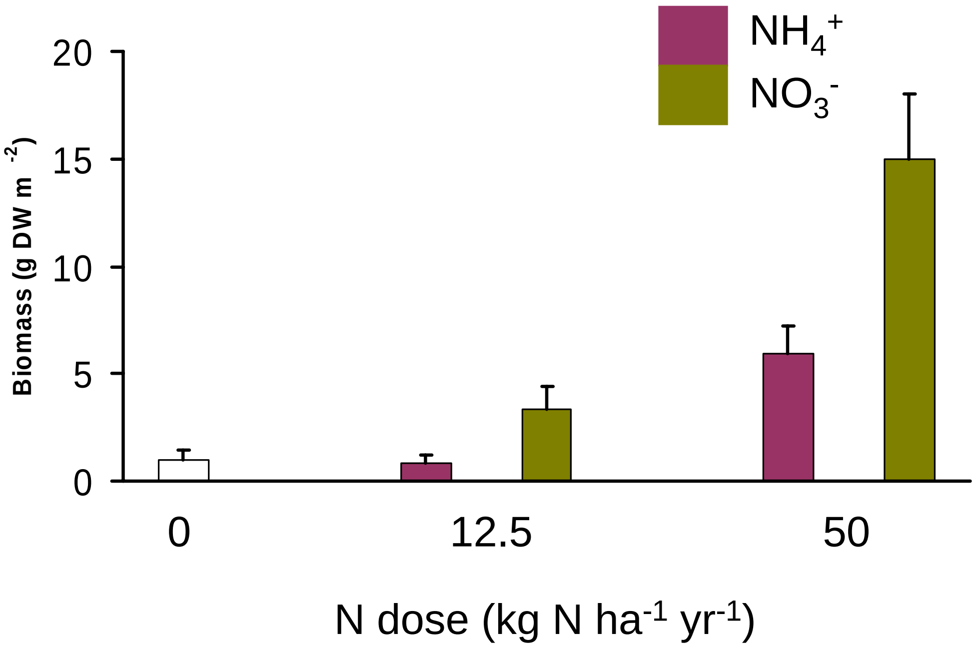
A few high concentration events of ammonia are very damaging to plants

Current critical levels for ammonia of 8ug/m3 probably too high to protect species

Reduced versus oxidised (habitat and species specific)

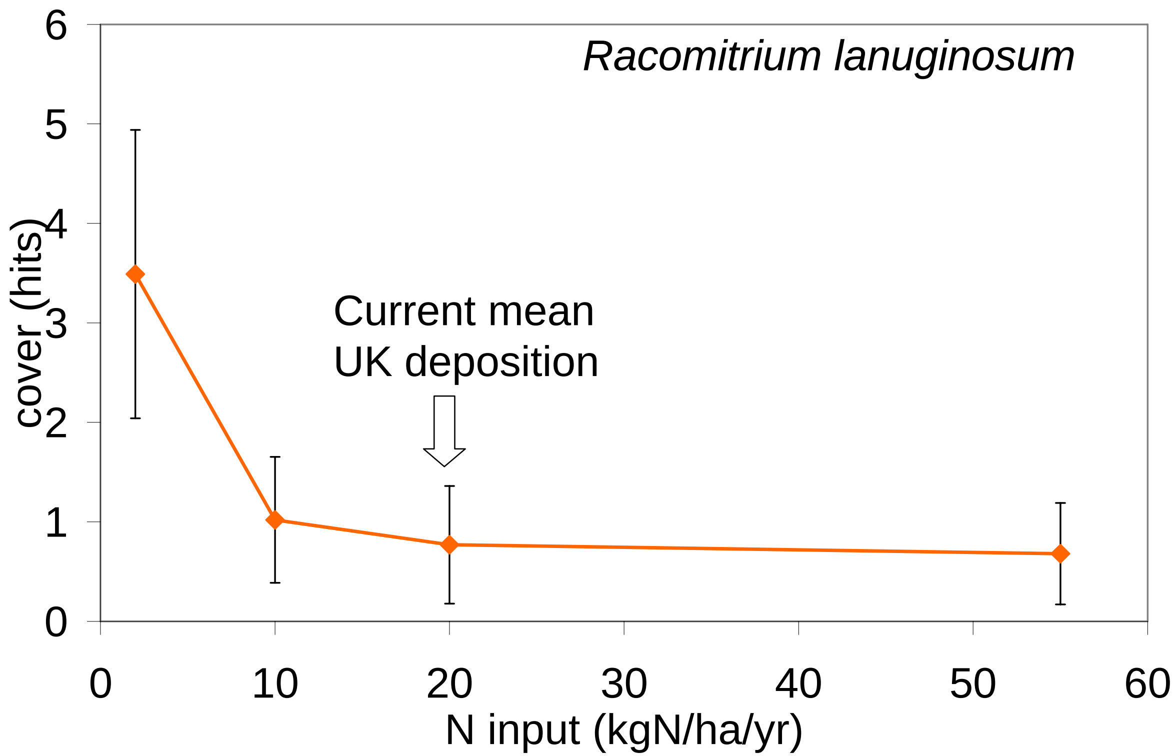
- Reduced N is usually considered more damaging
- However, experimental data suggests not so clear cut
- Oxidised nitrogen can favour some invasive species

Biomass of invasive grass with N addition in boreal forest system



Nordin et al. (2004)

Where you are on the N deposition gradient



L. Jones et al (2005)

Long term UK N addition experimental sites

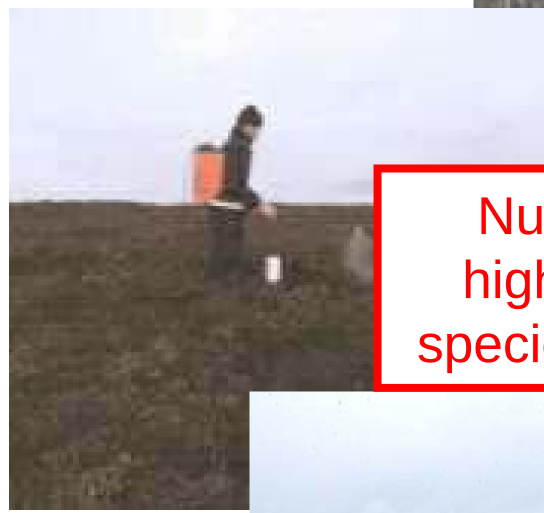
Ruabon - Simon Caporn/Jackie Carroll et al. Manchester Metropolitan University

Budworth - Simon Caporn/Jackie Caroll et al. Manchester Metropolitan University

Thursley - Sally Power, Imperial College

Wardlow HayCop - Jonathan Leake/John Lee, University of Sheffield

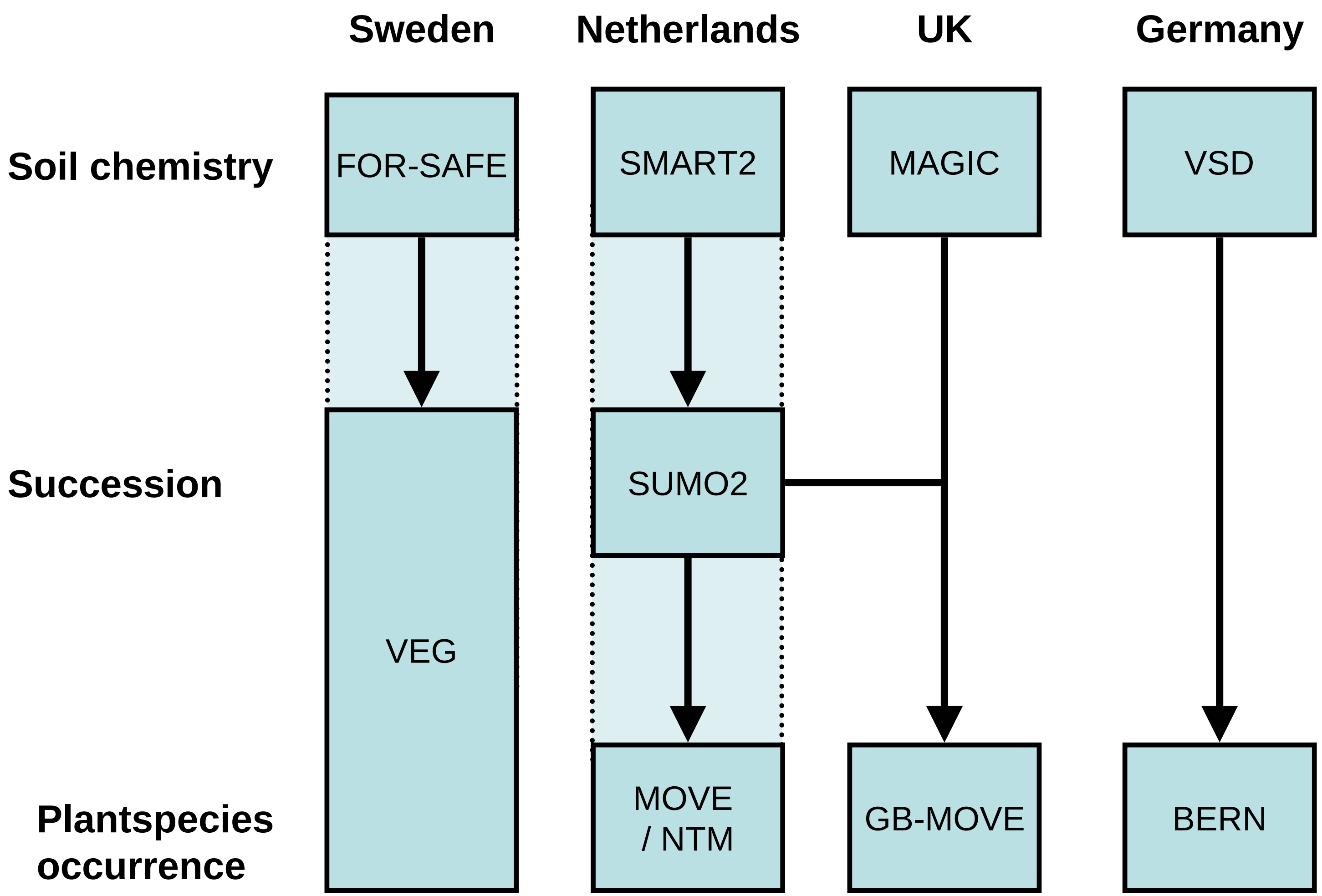
Pwllpeiran - Bridget Emmett/John Wildig, Centre for Ecology and Hydrology and ADAS



Number of higher plant species lost = 0

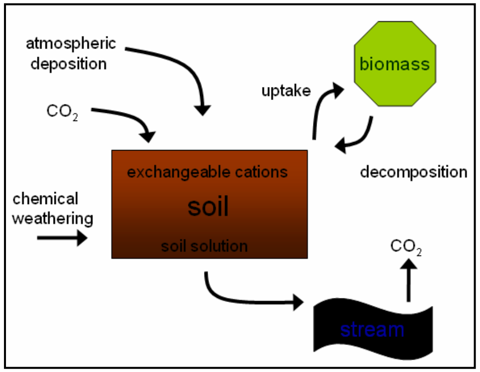
Forecasting where and when there will be soil, water and species change

Model chains for predicting N effects on biodiversity



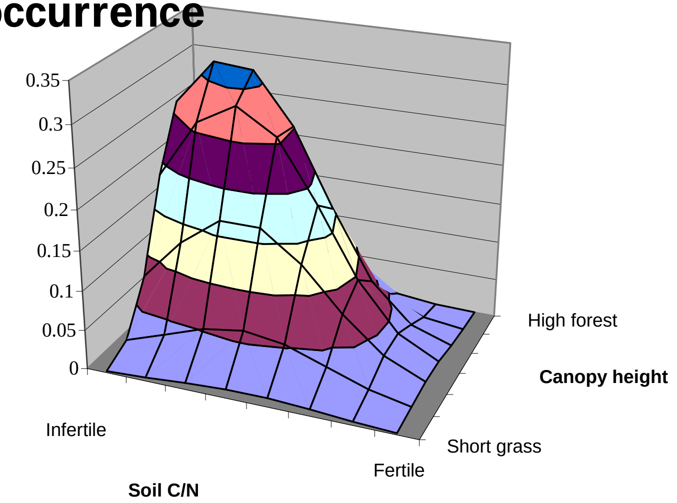
Approach

Dynamic models of soil and biomass change

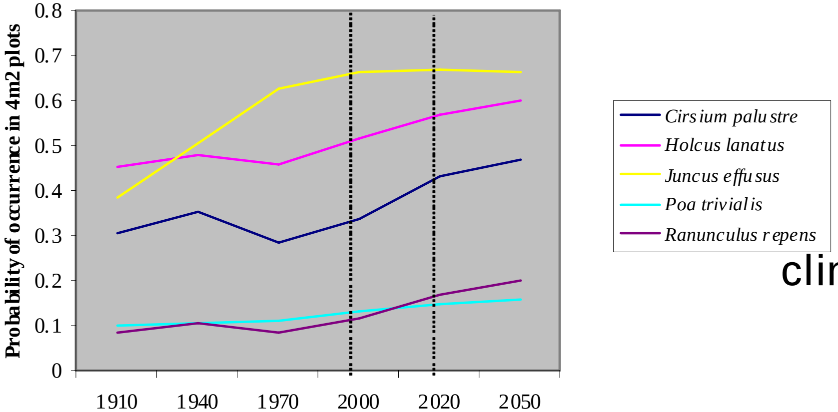


Key variables

Static models of species occurrence



Predicted species change



Key variables:
pH
C/N ratio
% soil moisture
canopy height
climate (min Jan, max July, precip

Smart et al,, CEH

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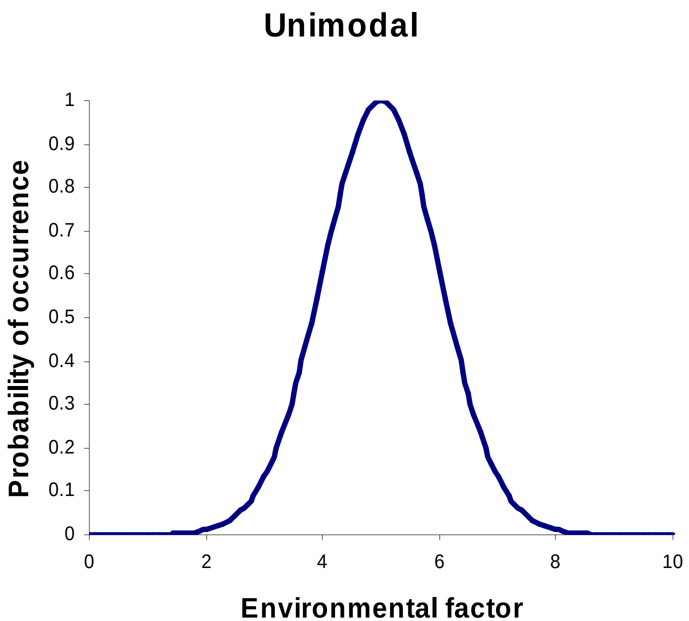
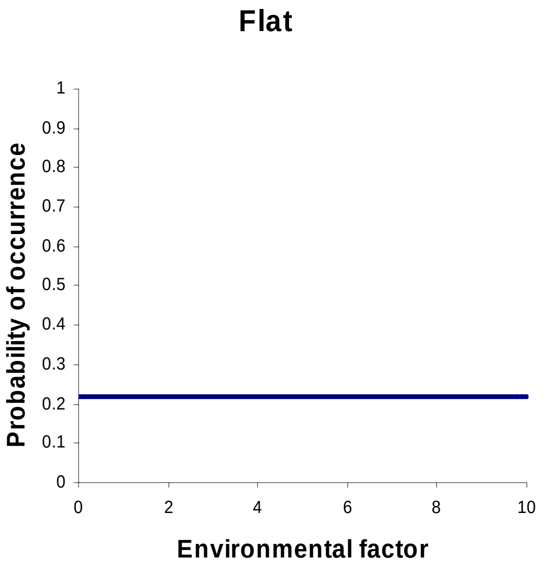
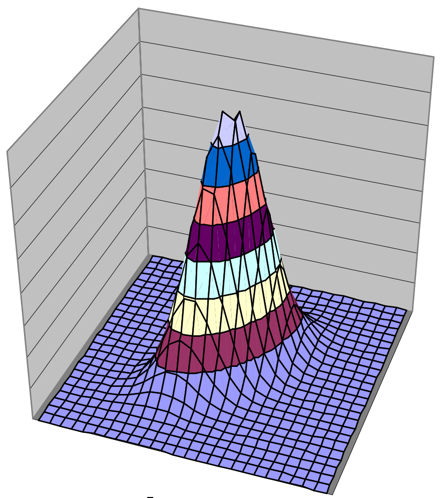
Calibrating occurrence - environment relationships





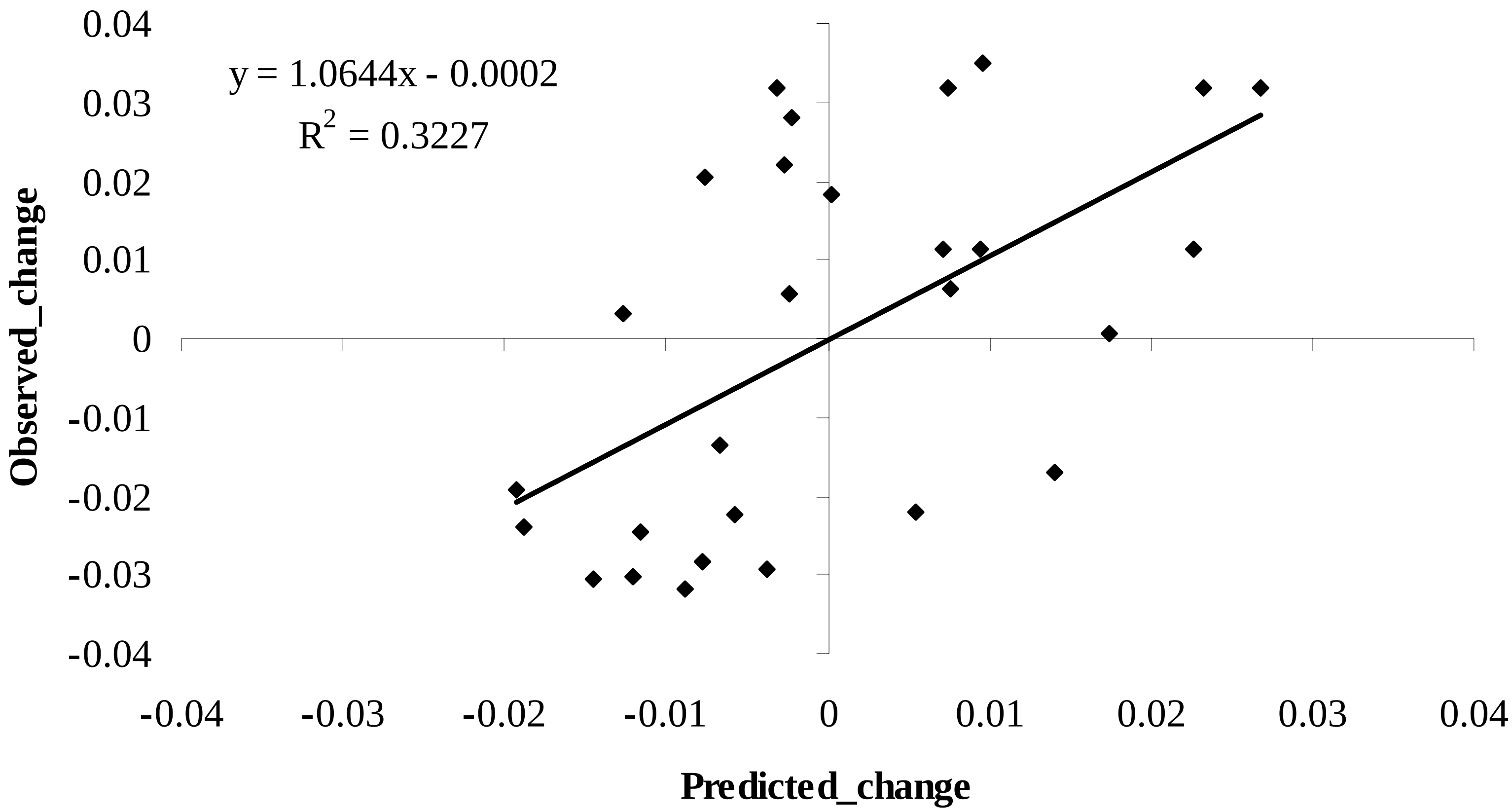


Species' optima (maximum probability of occurrence) are defined in relation to several factors

Smart et al,, CEH

Testing model output

Comparison of observed changes (1971-2001) in cover with predicted changes in suitability index for 28 species in English Blanket Bog (Moor House Hard Hills, Upper Teesdale NNR).



Smart et al,, CEH

Uncertainties

Uncertainties

- Applicability of indicators and critical loads to ‘new’ ecosystems
- Effect of N form (do we need separate critical loads?)
- Soil N storage, faunal responses, below-ground diversity
- Interactions with management and climate change
- Timing of changes = models

Thank you