

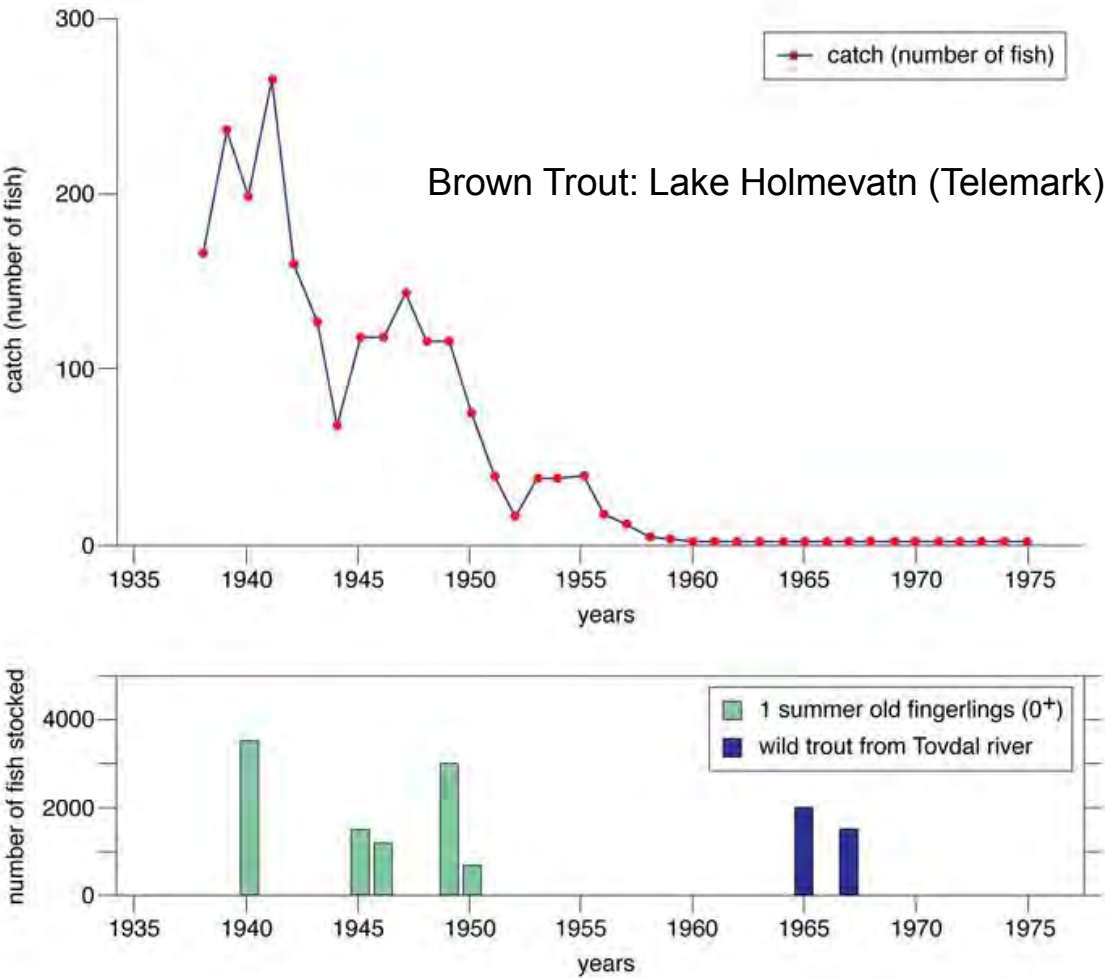
# The UK Upland Waters Monitoring Network: from acid rain to climate change

Rick Battarbee

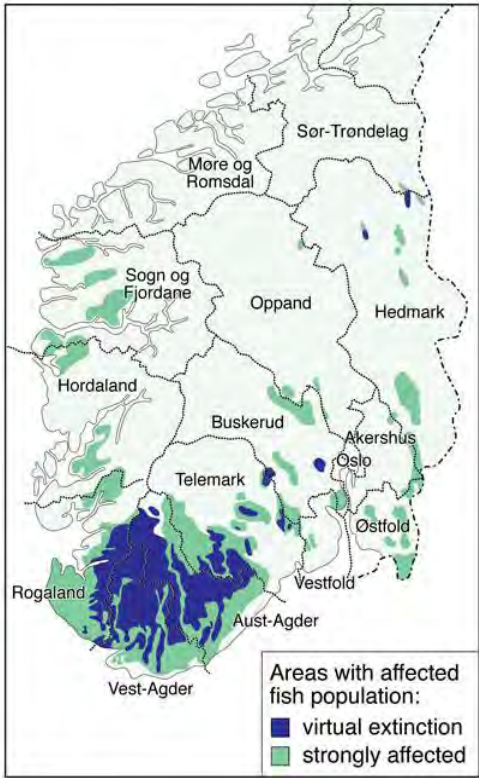
Environmental Change Research Centre  
University College London

SFG, Stirling, March 27th, 2014

The international concern over acid rain was first raised in Sweden and Norway



Overrein et al. 1980 SNSF Project FR 19/80



Sevaldrud & Muniz 1980, SNSF Project IR 77/80

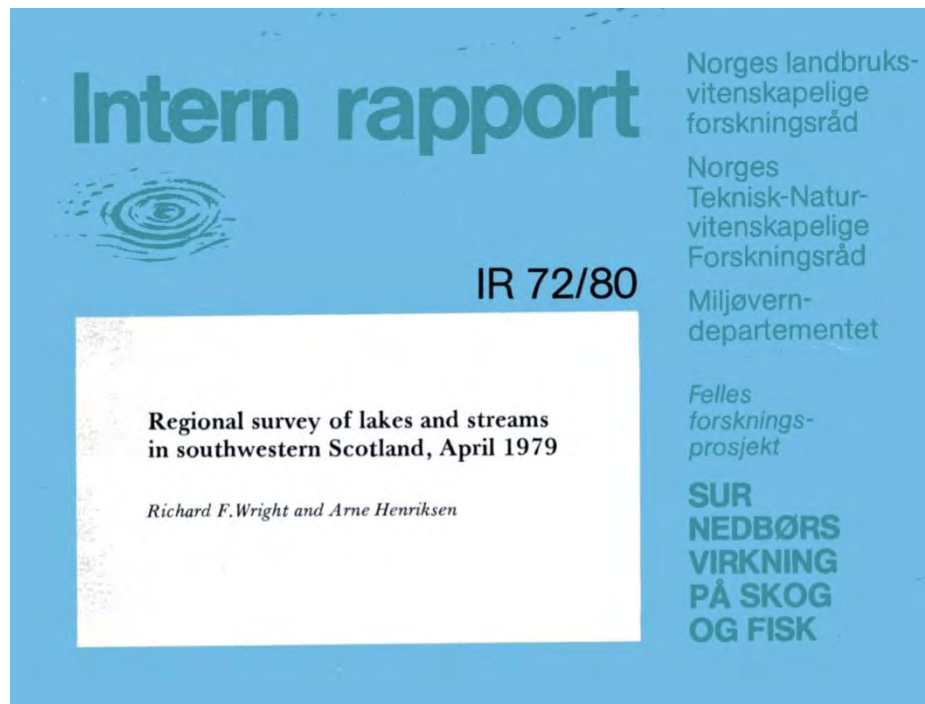
The UK denied responsibility, and was condemned in Scandinavia as  
“still the dirty old man of Europe”



*Great Britain - Still the dirty old man of Europe*

*Drawing: Nils Forshed*

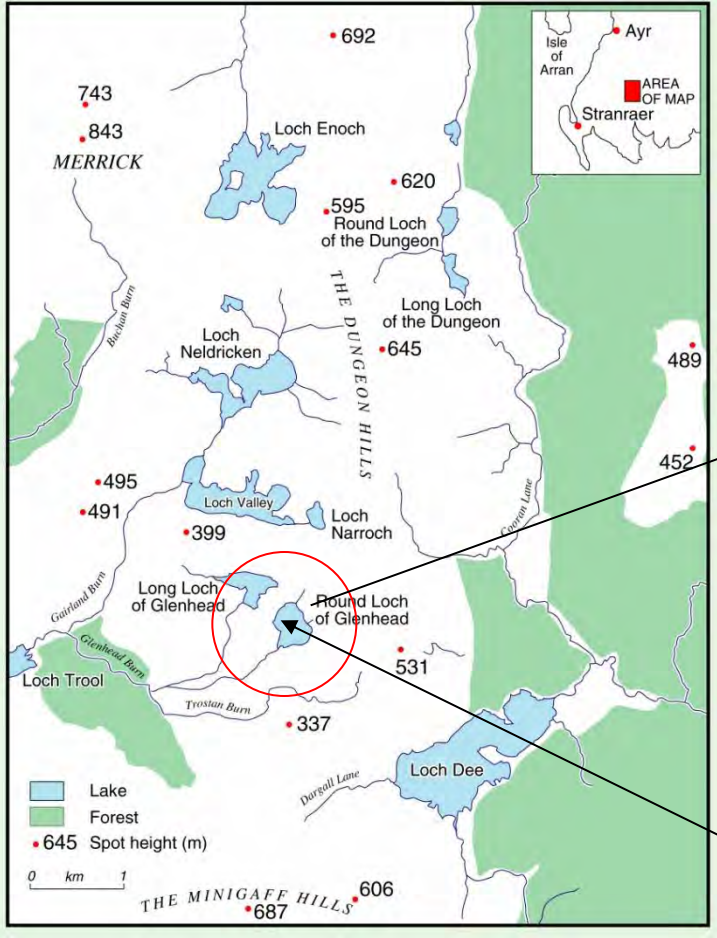
## 1980 Richard F. Wright and Arne Henriksen (in collaboration with Ron Harriman and Brian Morrison from the FFL, Pitlochry)



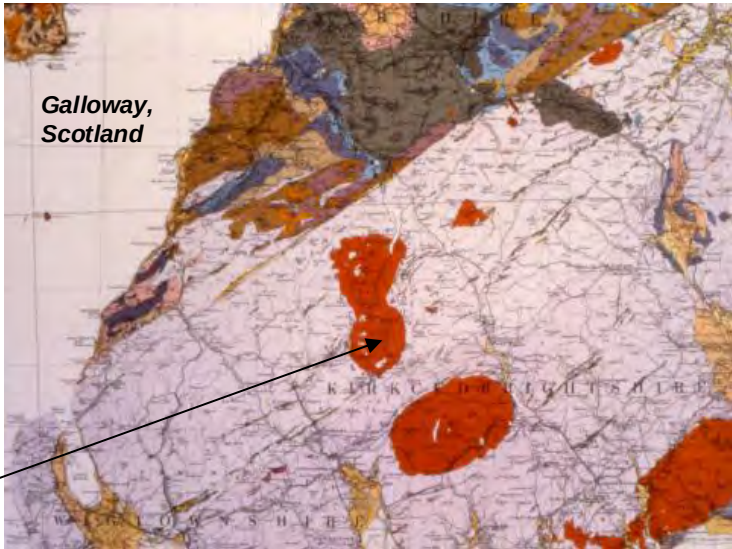
Dick Wright

“....The Galloway area thus appears to be yet another region in which acidification of freshwaters has occurred because of deposition of strong acids from the atmosphere.”

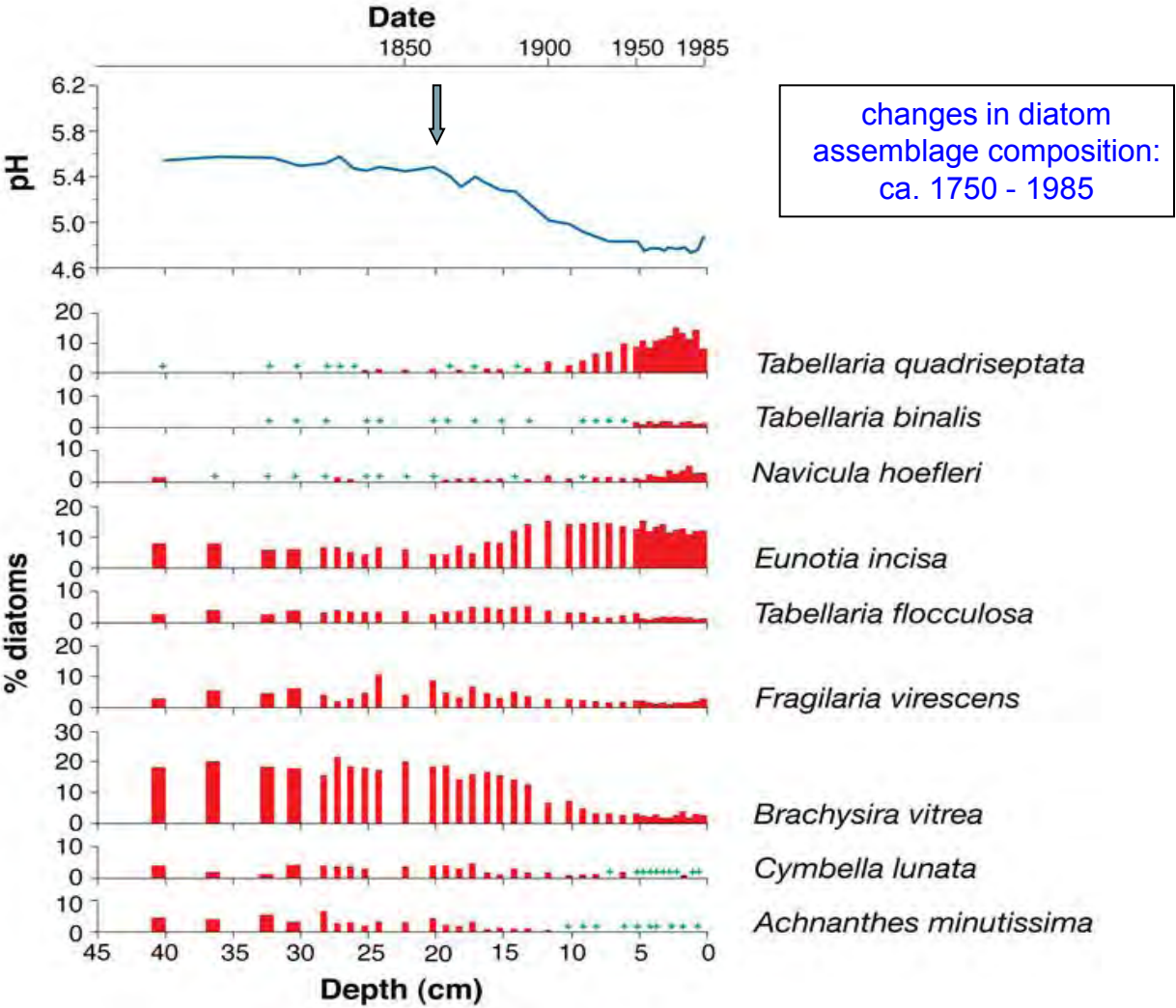
Galloway, S.W. Scotland



The Round Loch of Glenhead



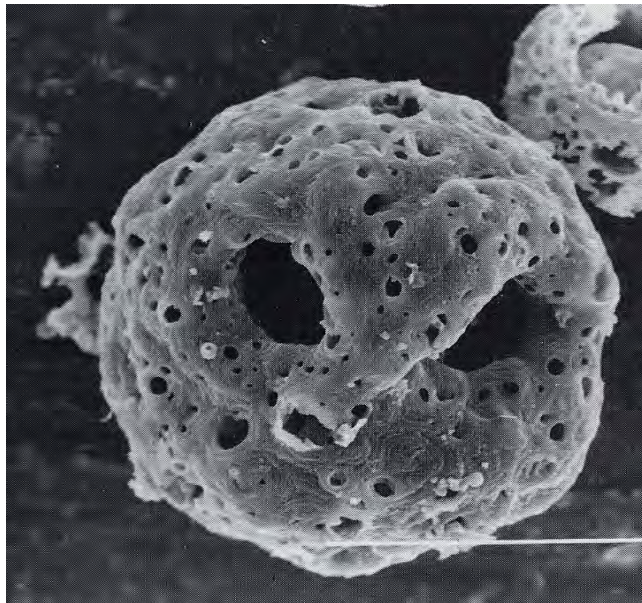
The definitive evidence came from diatom data from lake sediment cores



The Round Loch of Glenhead



## The clincher: fly ash



Fly ash particles that include **spheroidal carbonaceous particles (SCPs)**, produced by high temperature combustion of coal and oil, are found in high concentrations in the upper sediments of acidified lakes

# UNECE Protocols and EU Directives

## Current legislation

- UNECE Oslo Protocol on Further Reduction of Sulphur Emissions (second sulphur protocol) 1994
- UNECE Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, 1999
- EU Proposal for a National Emission Ceilings Directive (NECD) (1999)
- EU Water Framework Directive (WFD) (2000)



# The Acid Waters Monitoring Network 1988 onwards (now the UWMN)

*a science partnership of UCL, CEH, QMUL and MSS*

supported by

Defra, WAG, SNH, SEPA, SG, NRW, EA, Forestry Commission, SNH,  
CEH and ENSIS Ltd

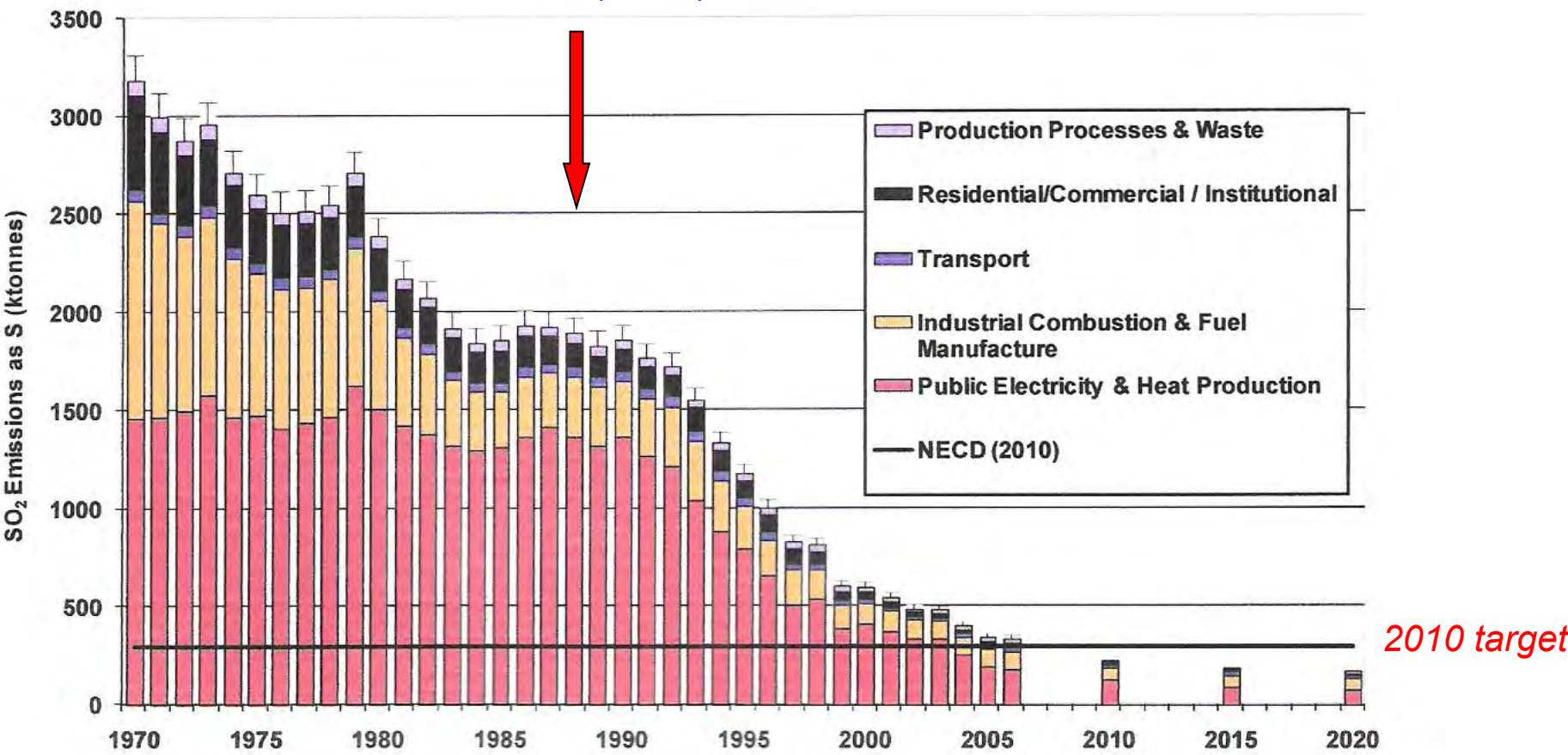


<http://awmn.defra.gov.uk/>



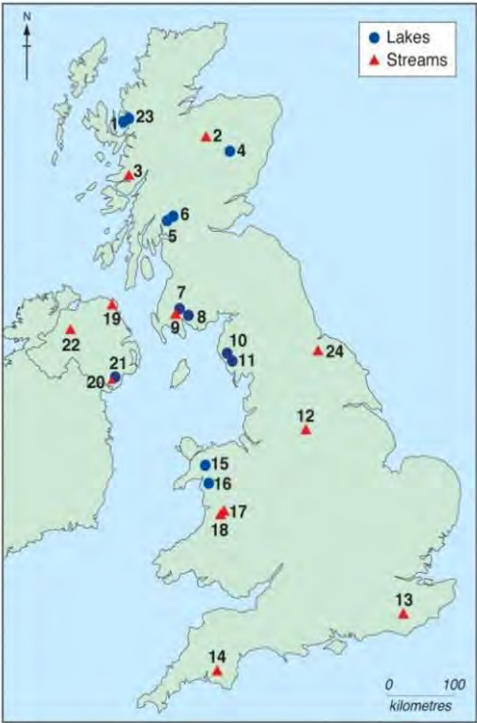
UK SO<sub>2</sub> emissions: 1970 - 2006

AWMN (1988)

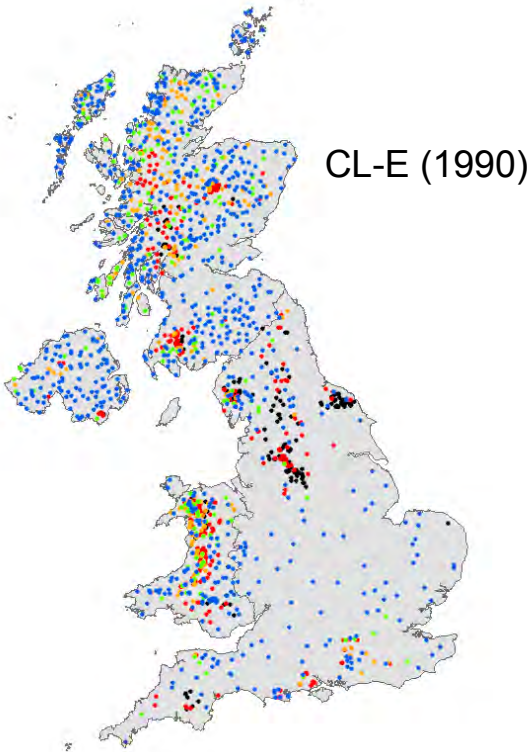


# The Acid Waters Monitoring Network (from 1988)

22 low alkalinity lakes and streams in high and low acid deposition areas

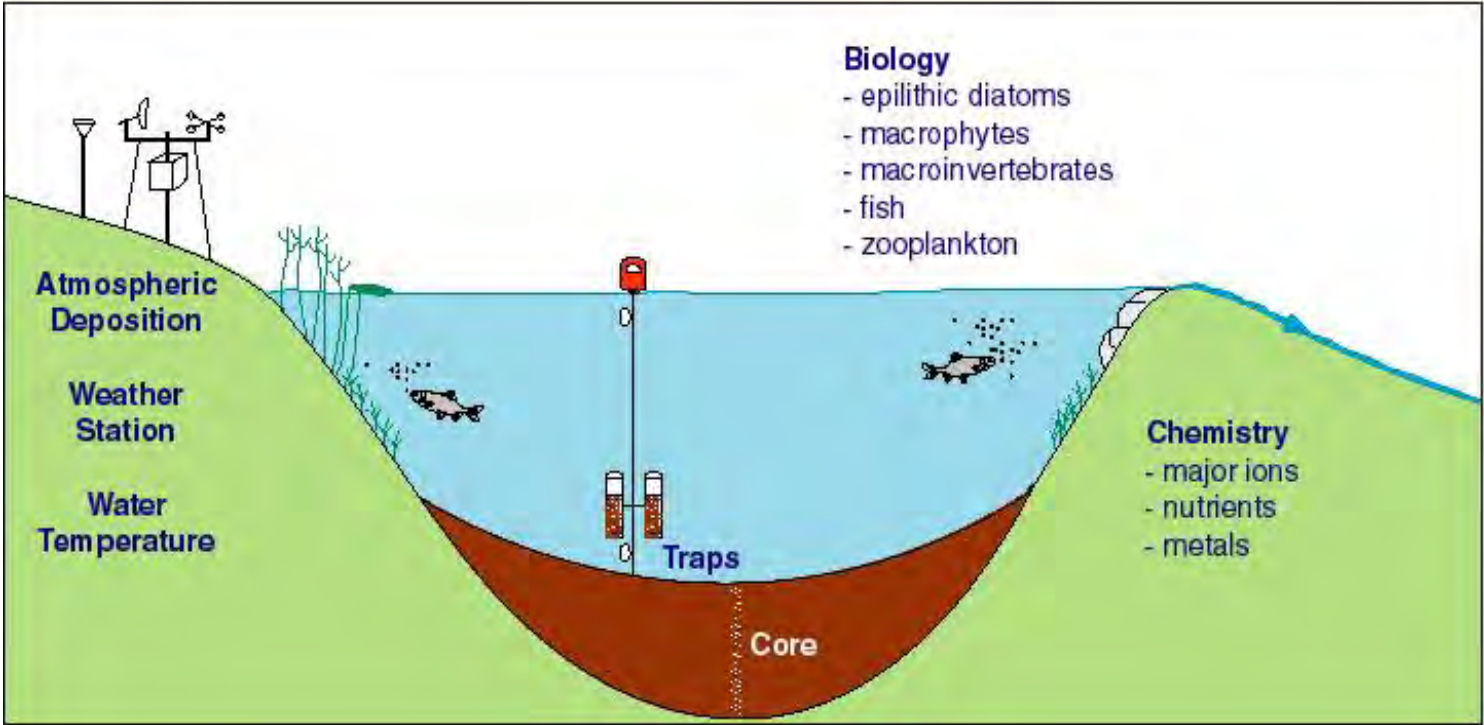
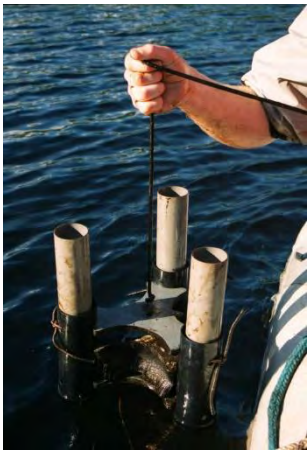
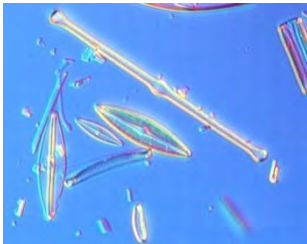


- 1. Loch Coire nan Arr
- 2. Allt a'Mharcaidh
- 3. Allt na Coire nan Con
- 4. Lochnagar
- 5. Loch Chon
- 6. Loch Tinker
- 7. Round Loch of Glenhead
- 8. Loch Grannoch
- 9. Dargall Lane
- 10. Scoat Tarn
- 11. Burnmoor Tarn
- 12. River Etherow
- 13. Old Lodge
- 14. Narrator Brook
- 15. Llyn Llgi
- 16. Llyn Cwm Mynach
- 17. Afon Hafren
- 18. Afon Gwy
- 19. Beagh's Burn
- 20. Bencrom River
- 21. Blue Lough
- 22. Coneyglen Burn
- 23. Loch Coire Fionnaraich
- 24. Danby Beck

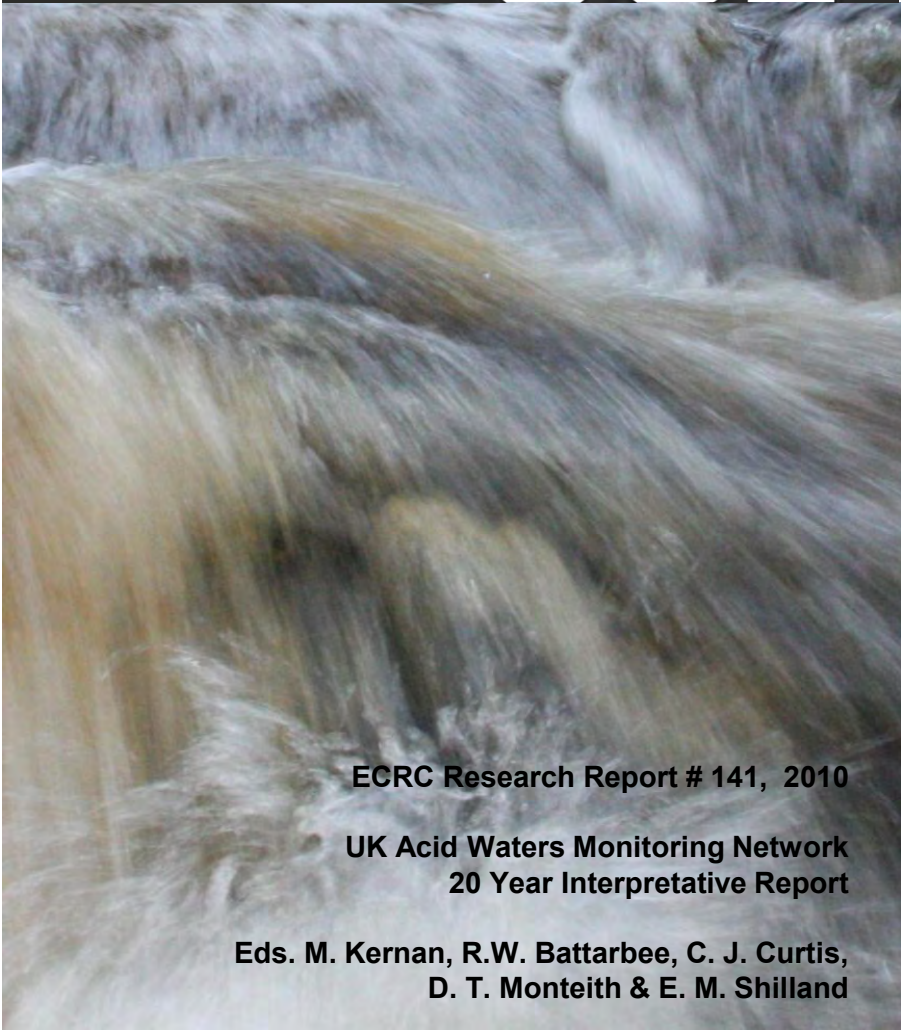


Photos: E Shilland

# The Acid Waters Monitoring Network: chemistry and biology



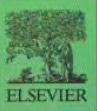
 **UCL**



**ECRC Research Report # 141, 2010**

**UK Acid Waters Monitoring Network  
20 Year Interpretative Report**

**Eds. M. Kernan, R.W. Battarbee, C. J. Curtis,  
D. T. Monteith & E. M. Shilland**



Volume 37, Part B, February 2014    ISSN 1470-160X

# ECOLOGICAL INDICATORS

INTEGRATING, MONITORING, ASSESSMENT  
AND MANAGEMENT



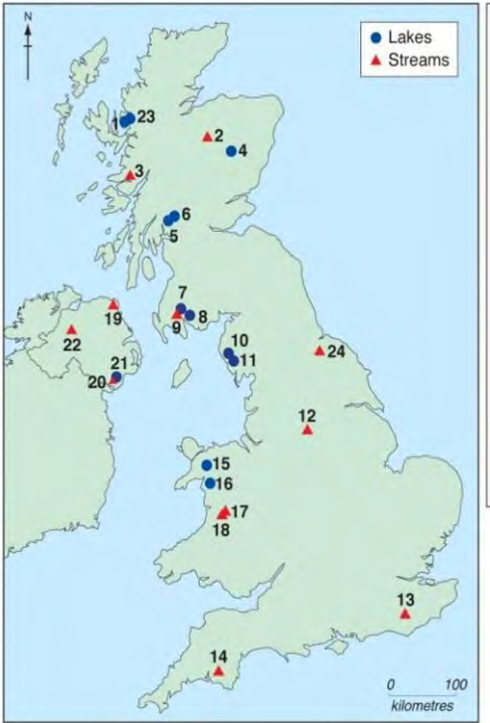
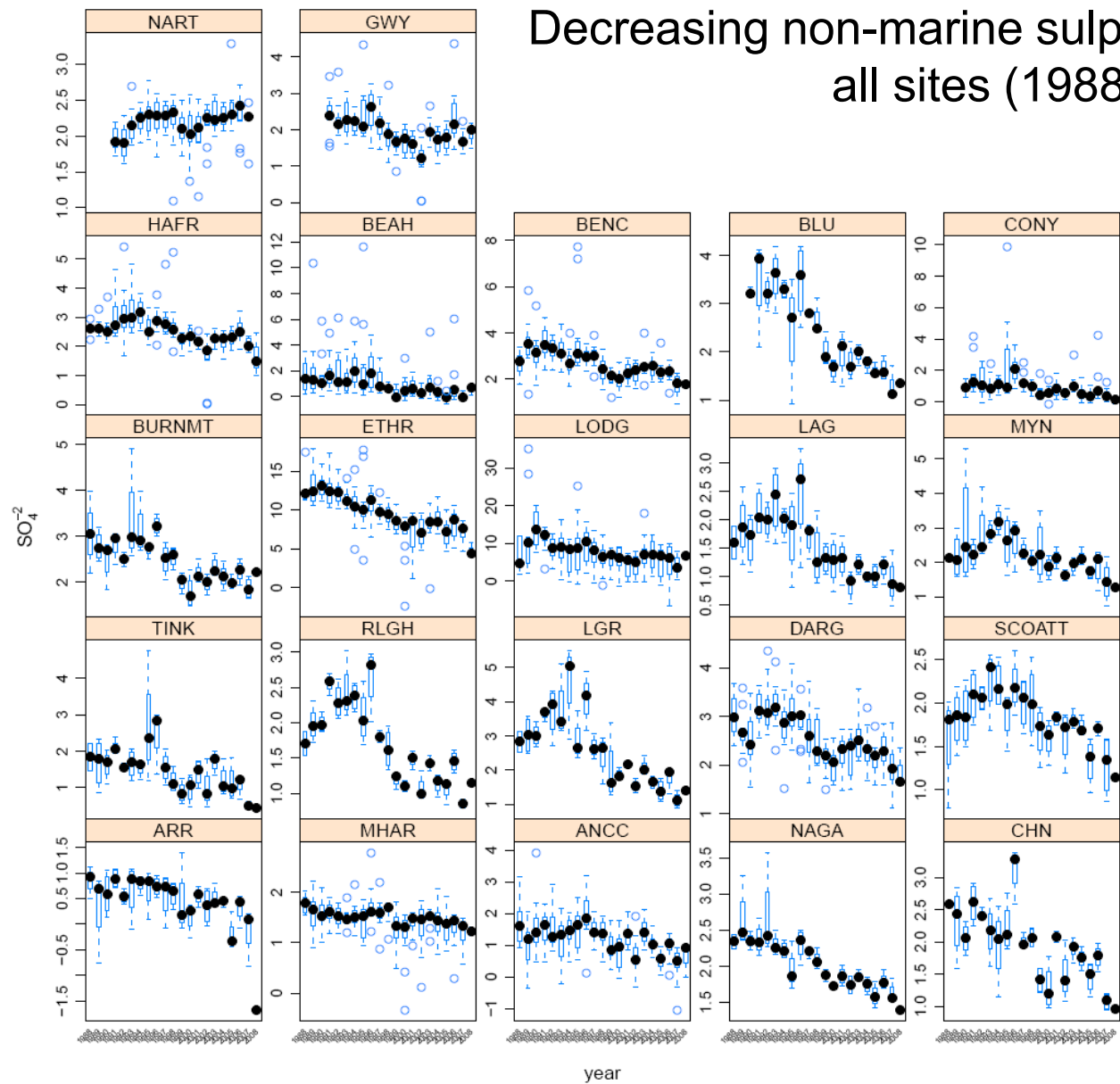
**Editor-in-chief**  
**Felix Müller**

**Special Issue:**  
Threats to upland waters

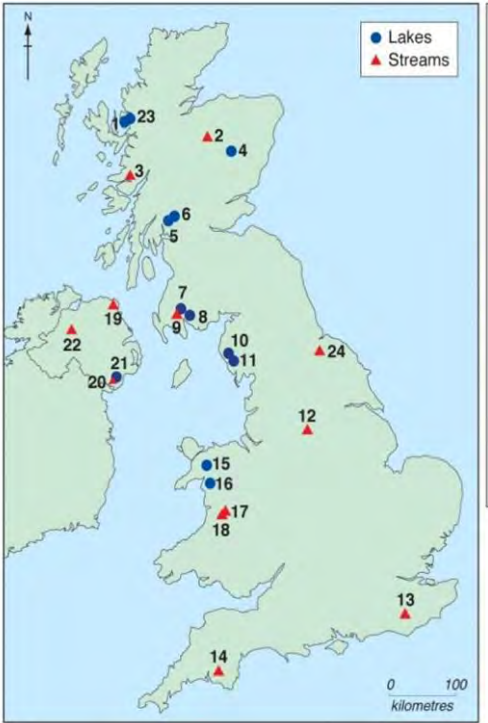
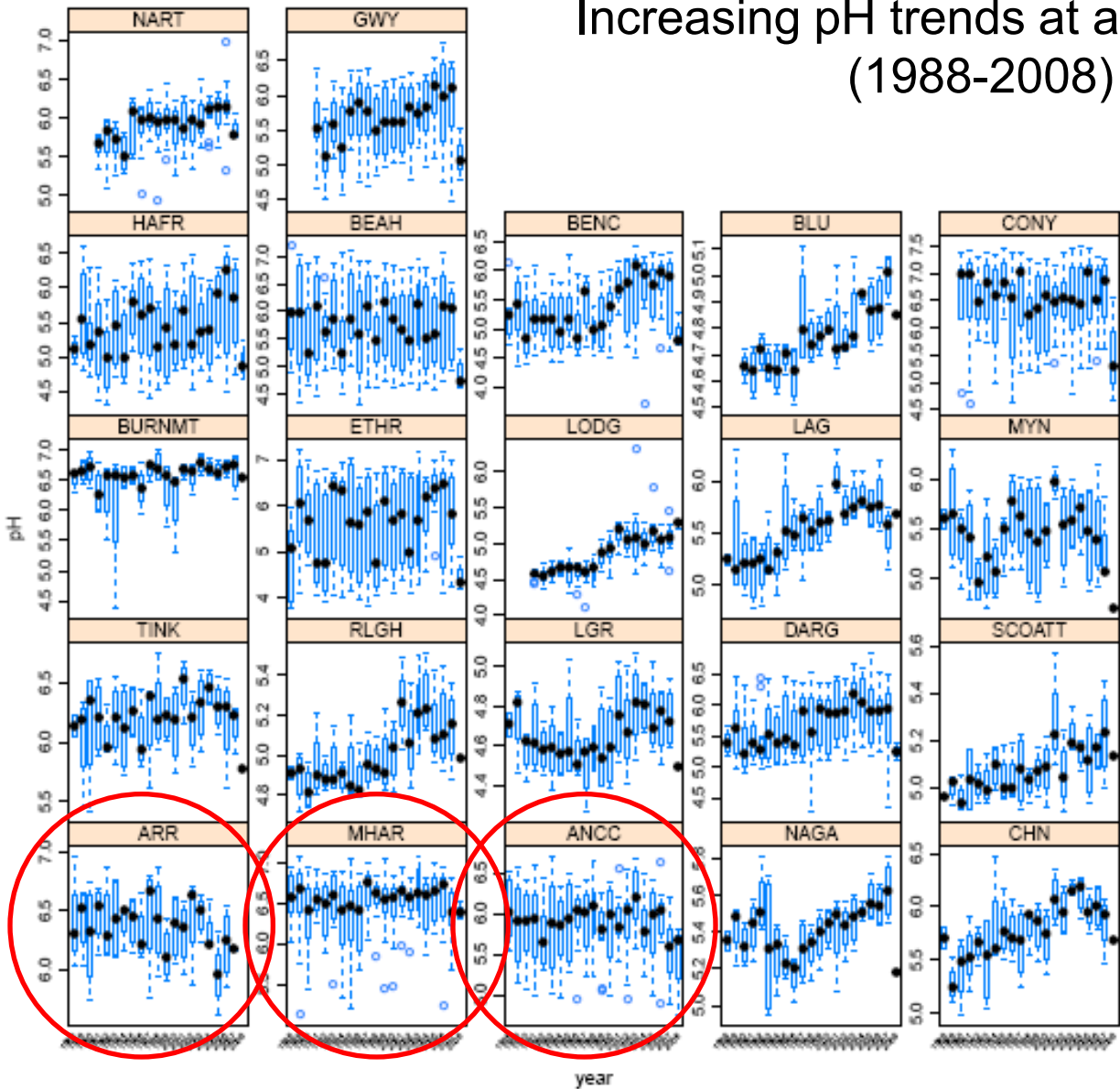
**Guest Editors:** Christopher J. Curtis, Richard W. Battarbee,  
Donald T. Monteith, Ewan M. Shilland

**Curtis et al. (Eds) Threats to Upland Waters  
*Ecological Indicators* 2014**

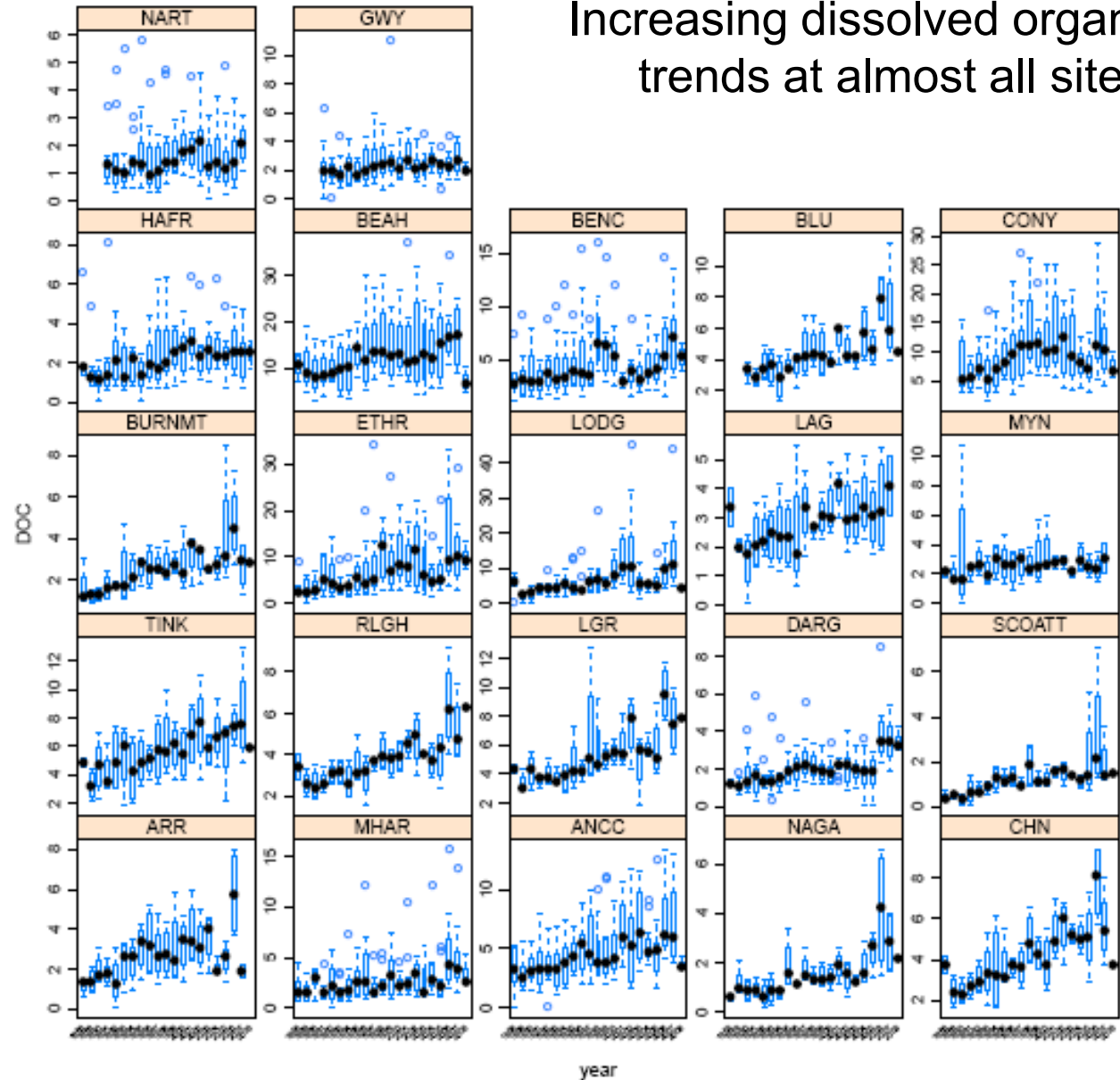
Decreasing non-marine sulphate trends at almost all sites (1988-2008)



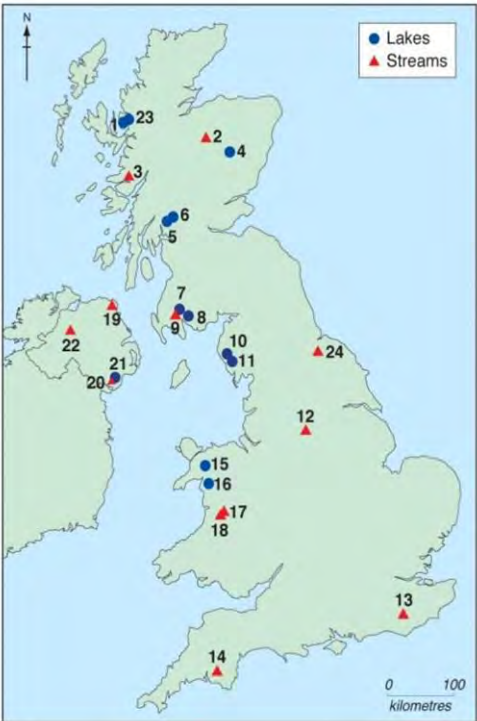
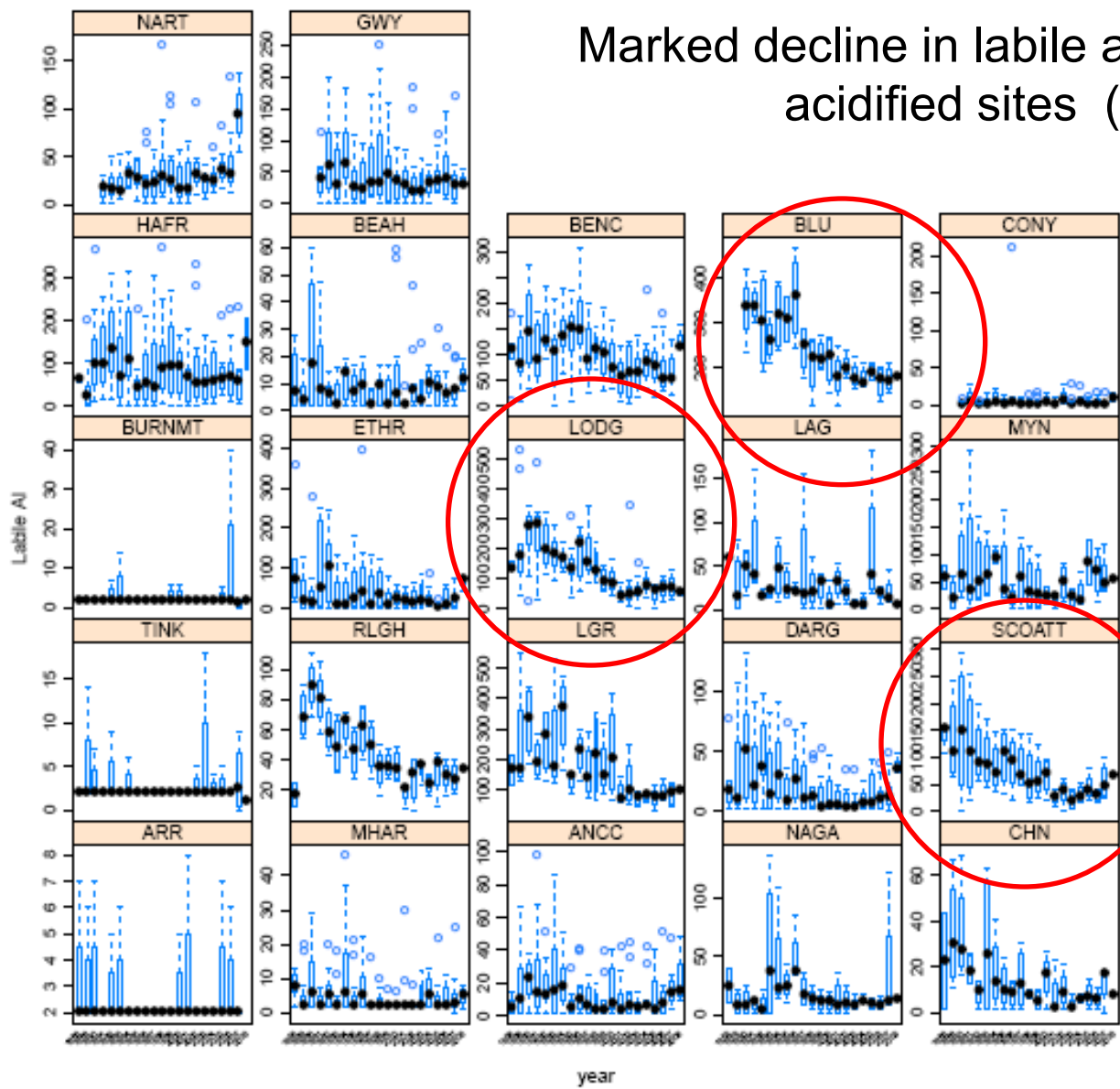
Increasing pH trends at acidified sites  
(1988-2008)



Increasing dissolved organic carbon (DOC) trends at almost all sites (1988-2008)

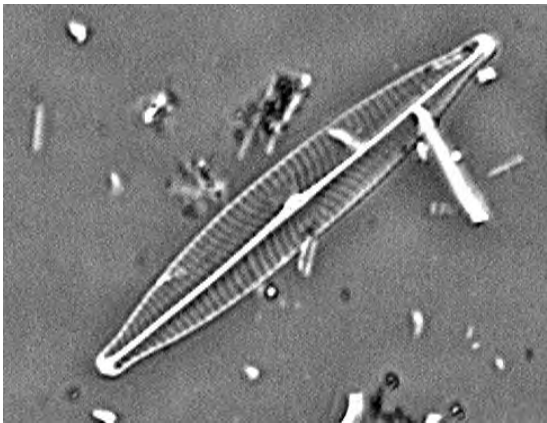
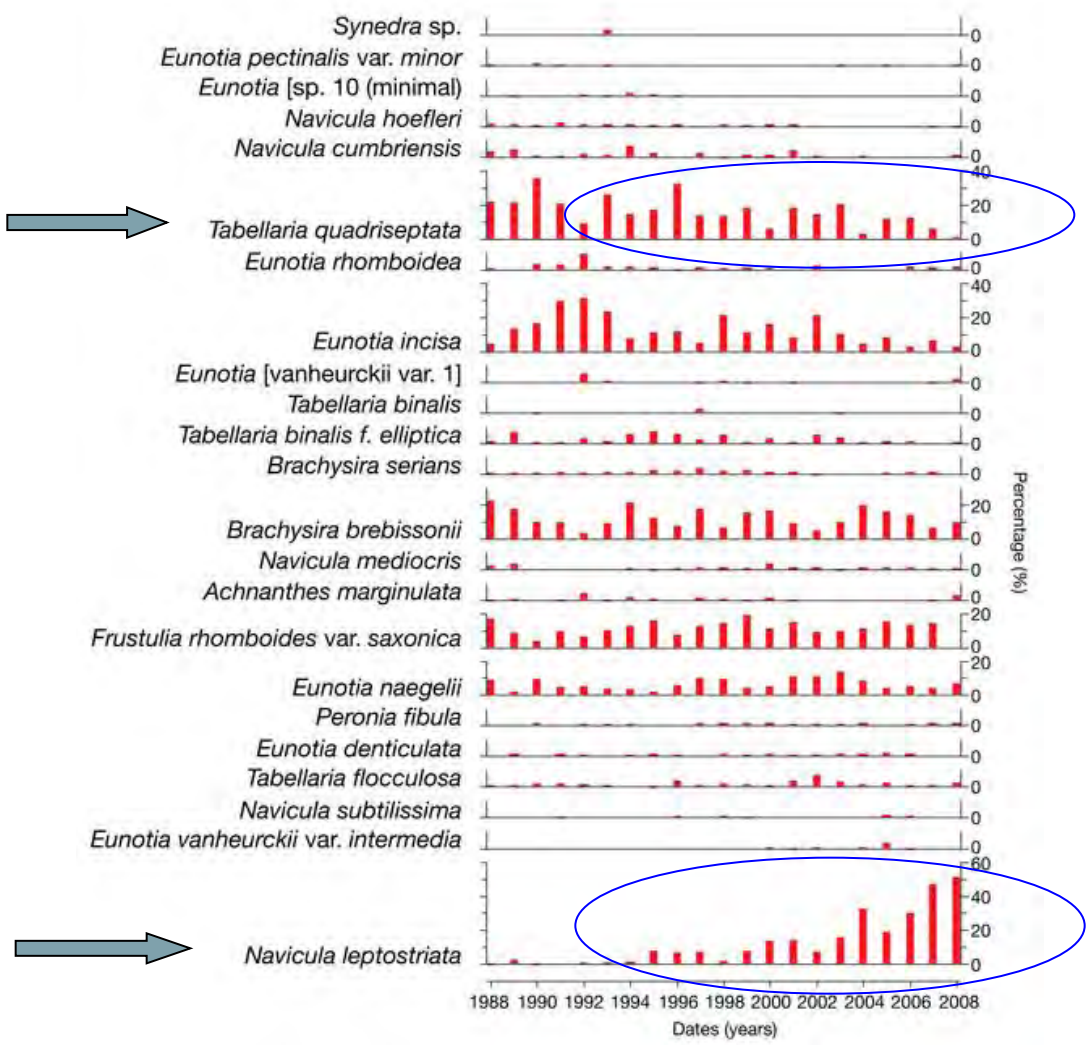


Marked decline in labile aluminium at the most acidified sites (1988-2008)



# Diatoms floras significantly shifting away from acid-tolerant taxa at all sites

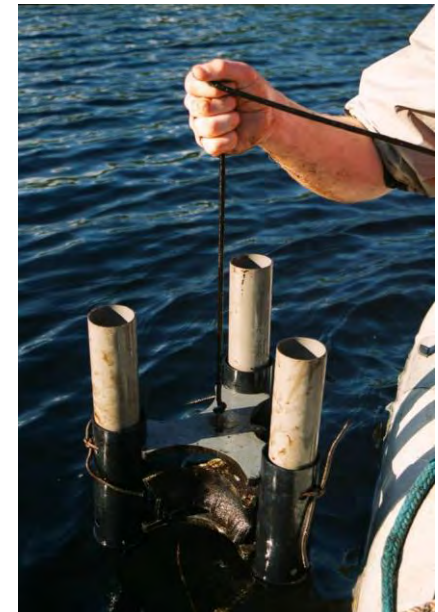
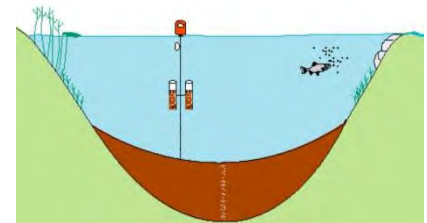
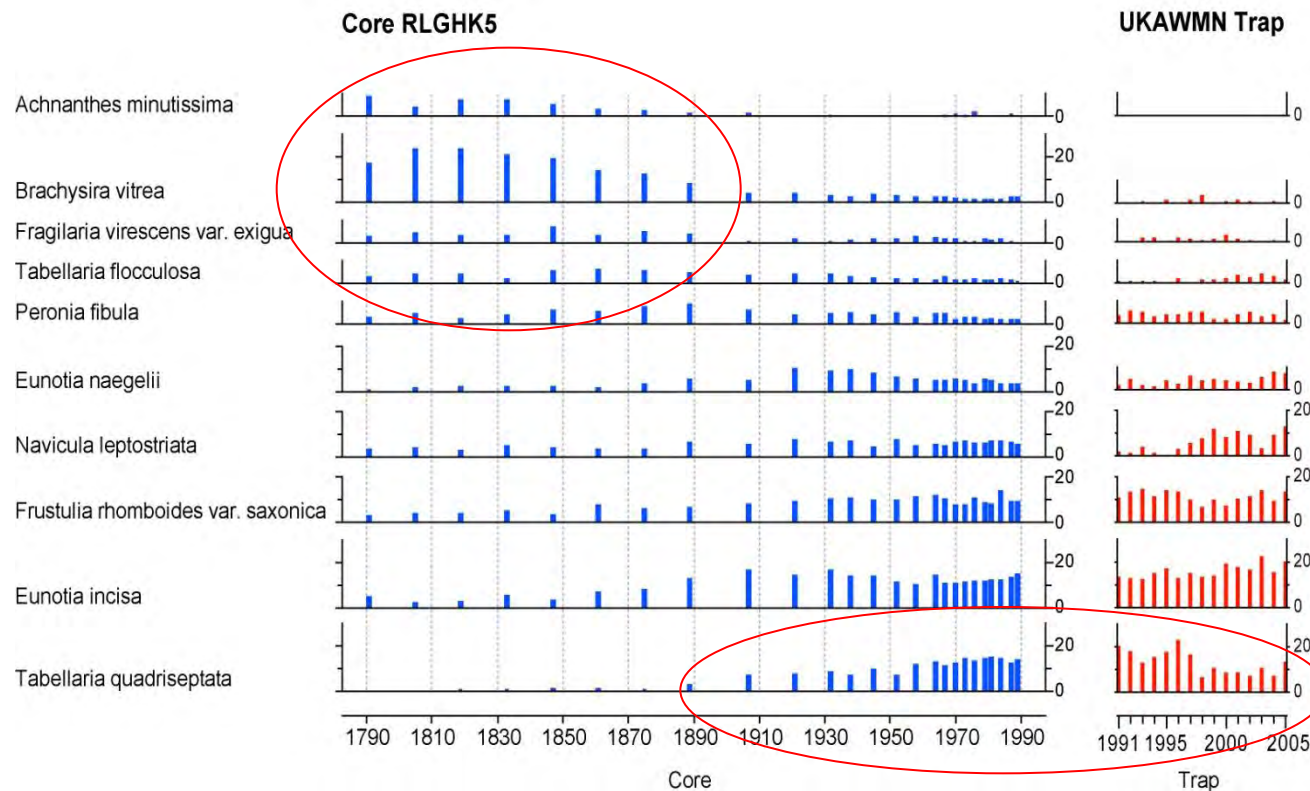
Diatom epilithon: The Round Loch of Glenhead 1988-2008



*Navicula leptostriata*

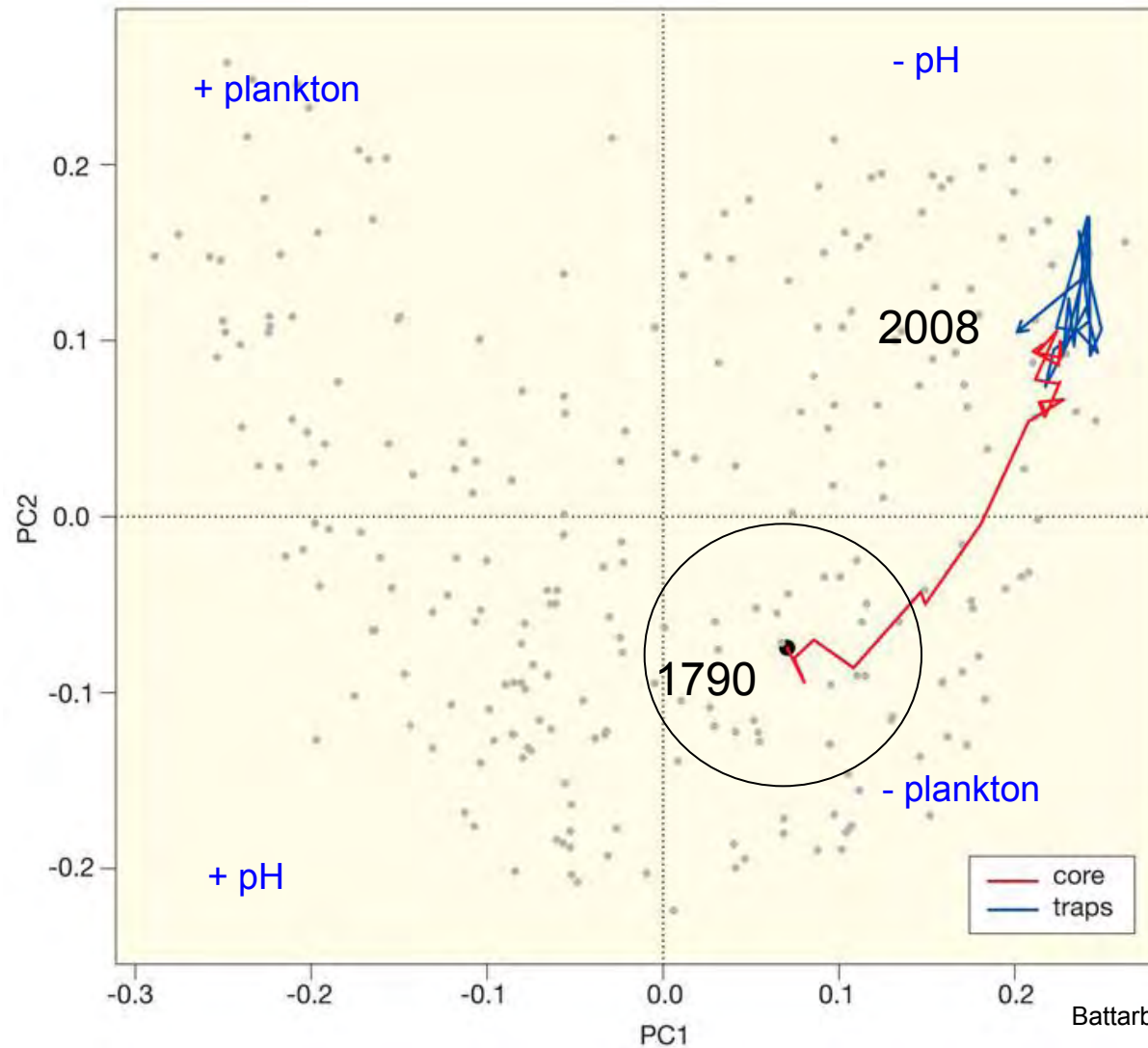
But recovery has a long way to go to reach pre-acidification conditions

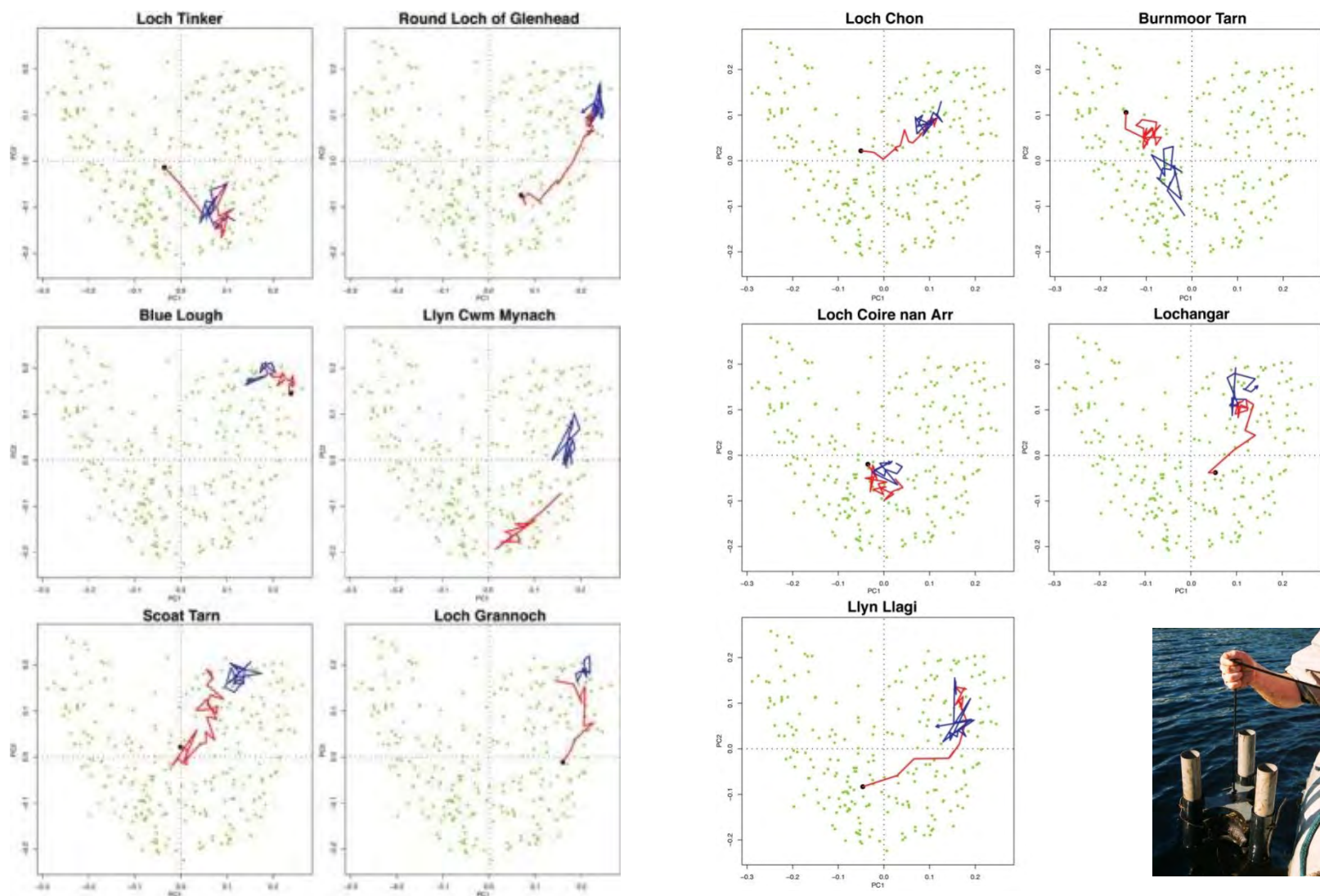
Sediment **core** (1790 – 1990) + sediment **trap** (1991- 2005)



## None of the AWMN lakes has yet reached “good ecological status”

Diatom assemblage trajectory for the Round Loch of Glenhead: 1790 – 2008 AD

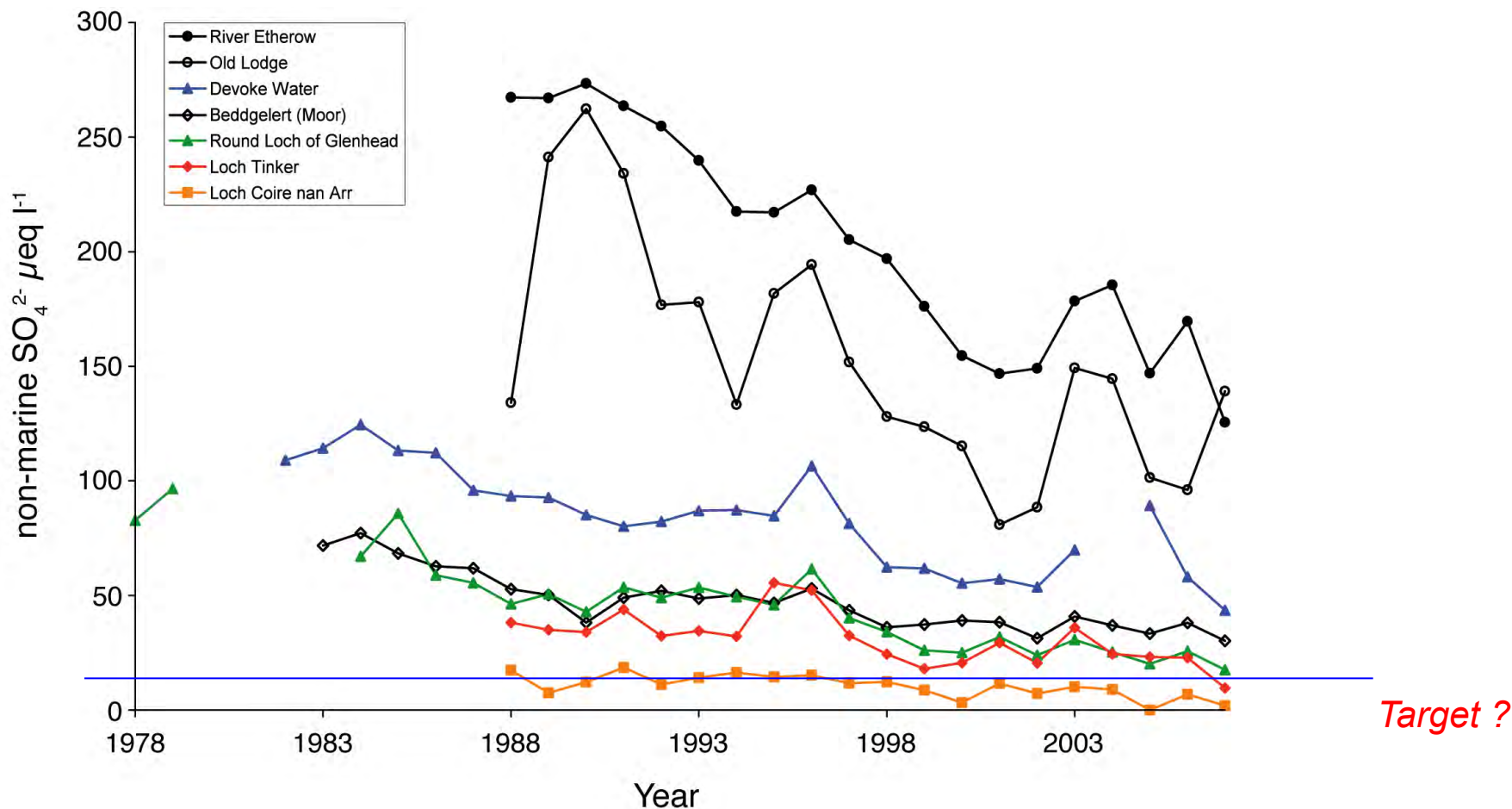




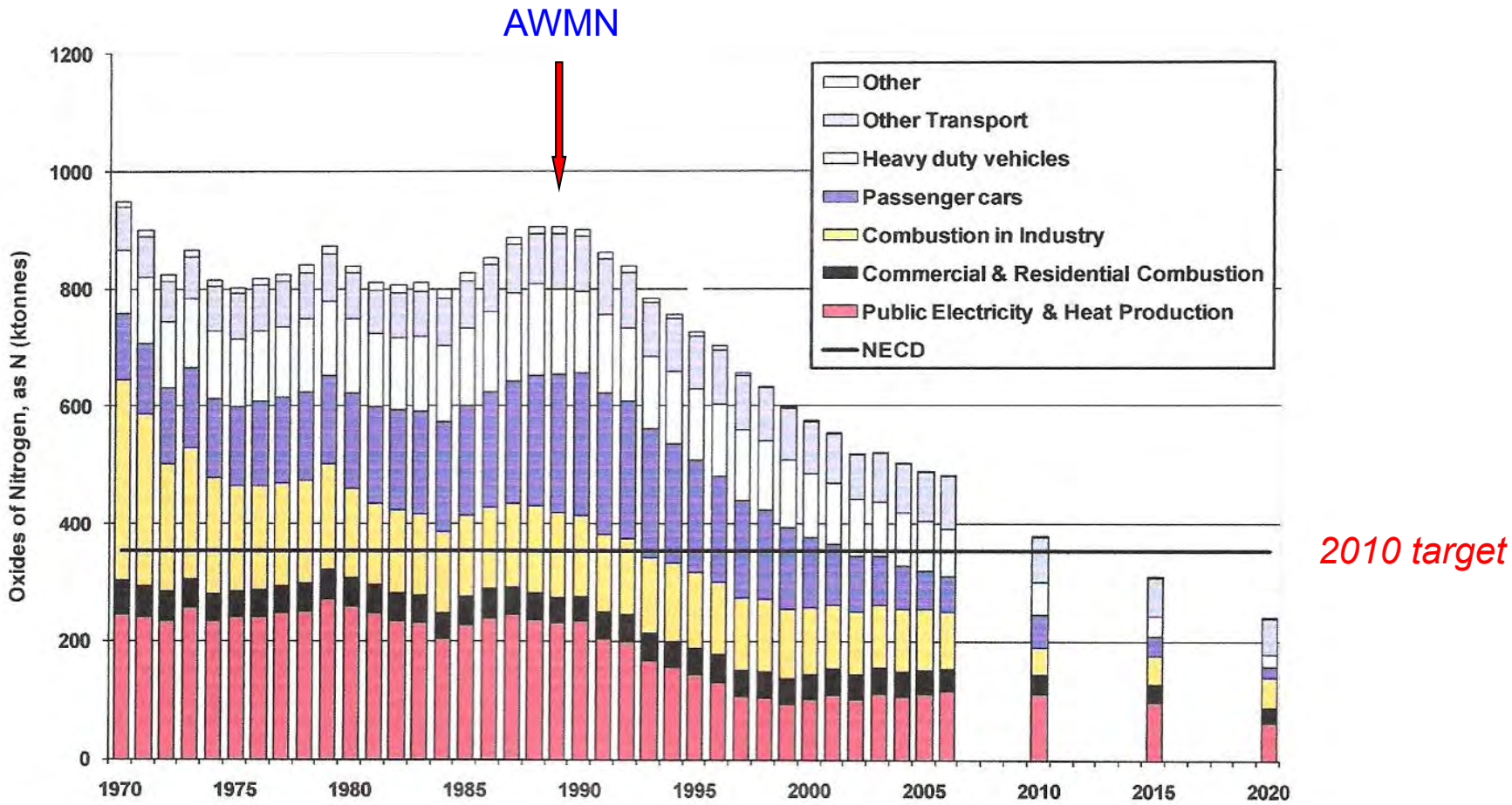
AWMN lakes: 1800 – 2008 (red: cores; blue: traps)

Why is recovery limited?

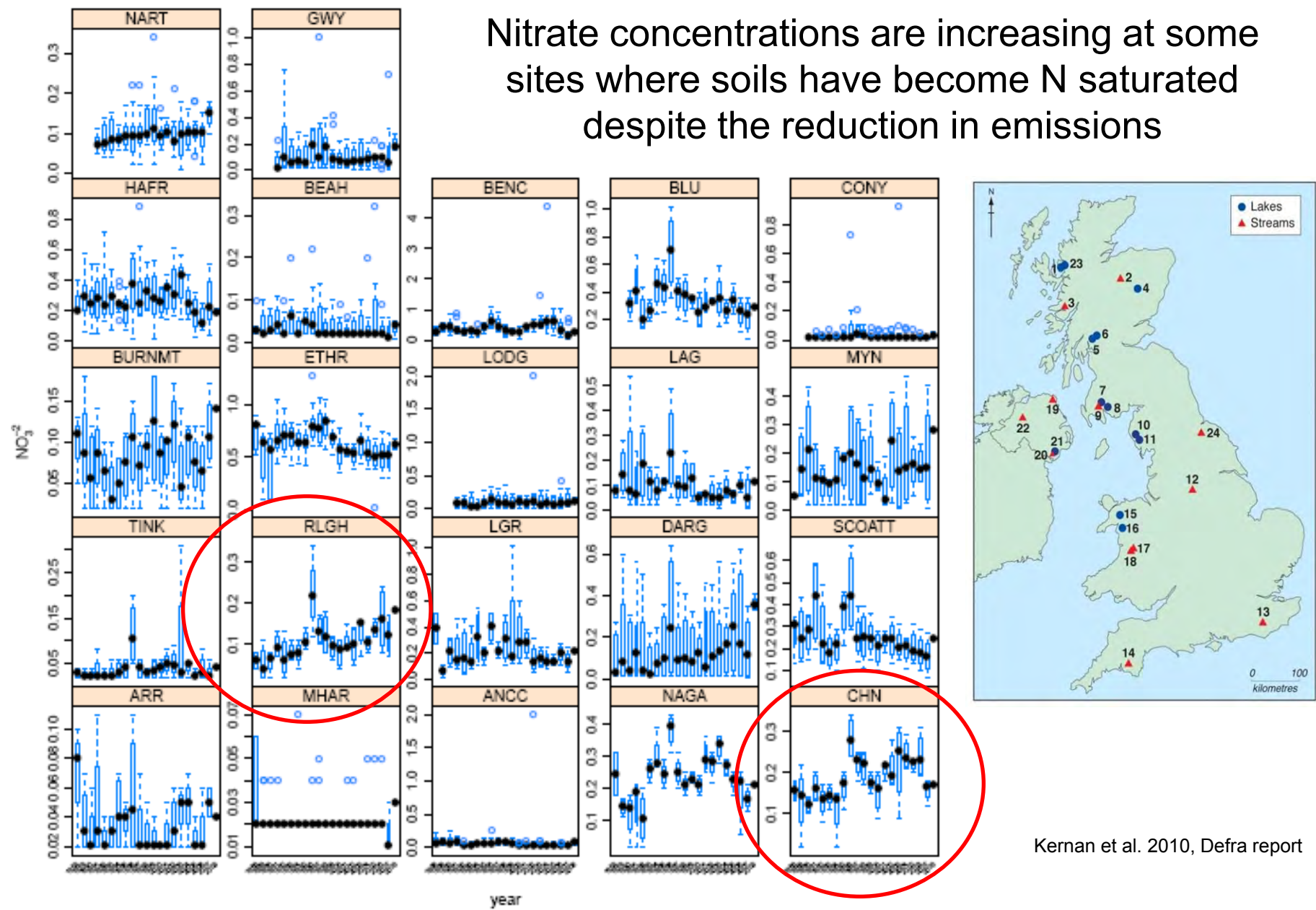
# Non-marine sulphate concentrations are still high at many sites



NO<sub>x</sub> emissions are going down but are still quite high



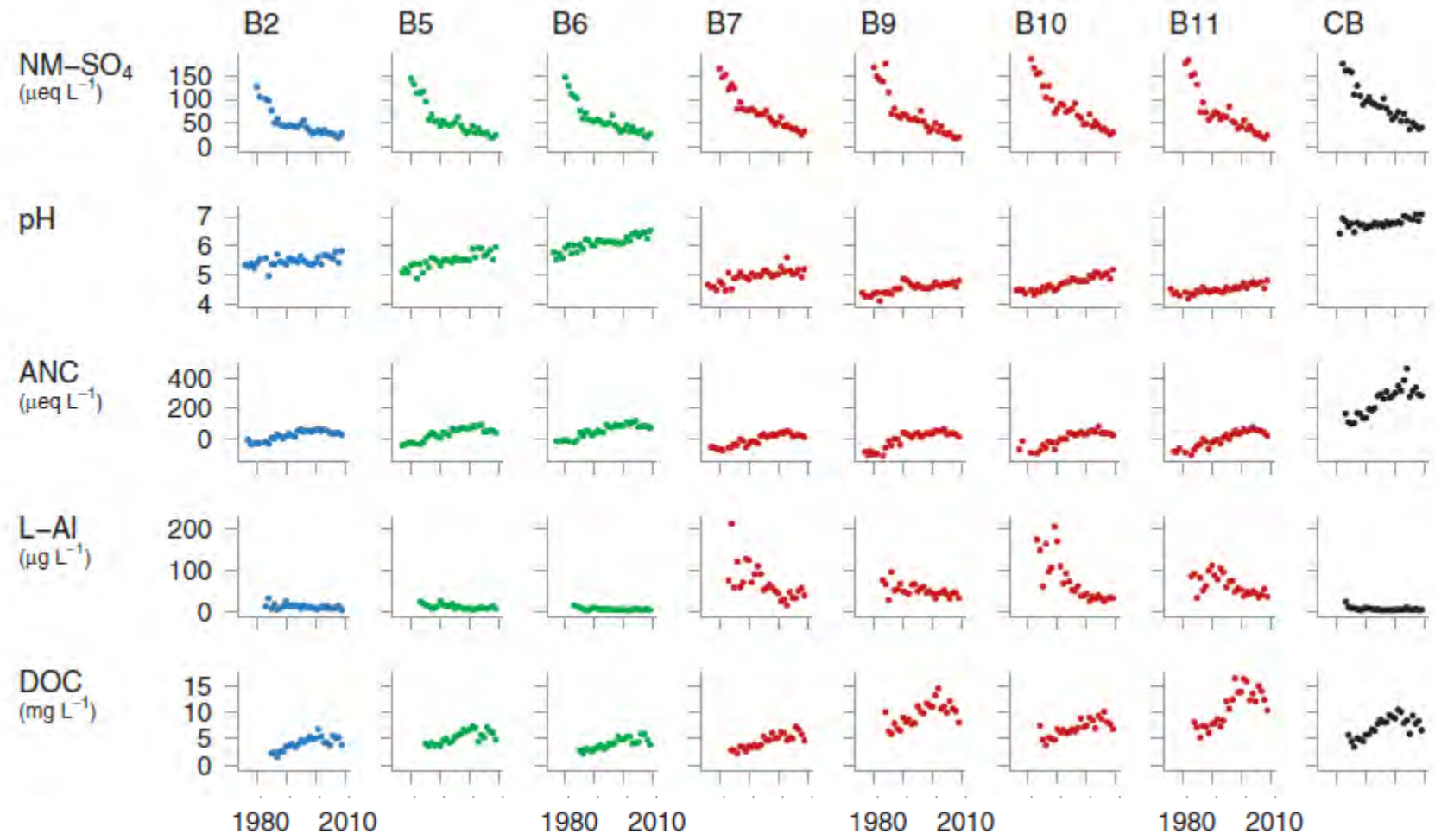
Nitrate concentrations are increasing at some sites where soils have become N saturated despite the reduction in emissions



Afforested sites are recovering but remain more acidic than moorland sites

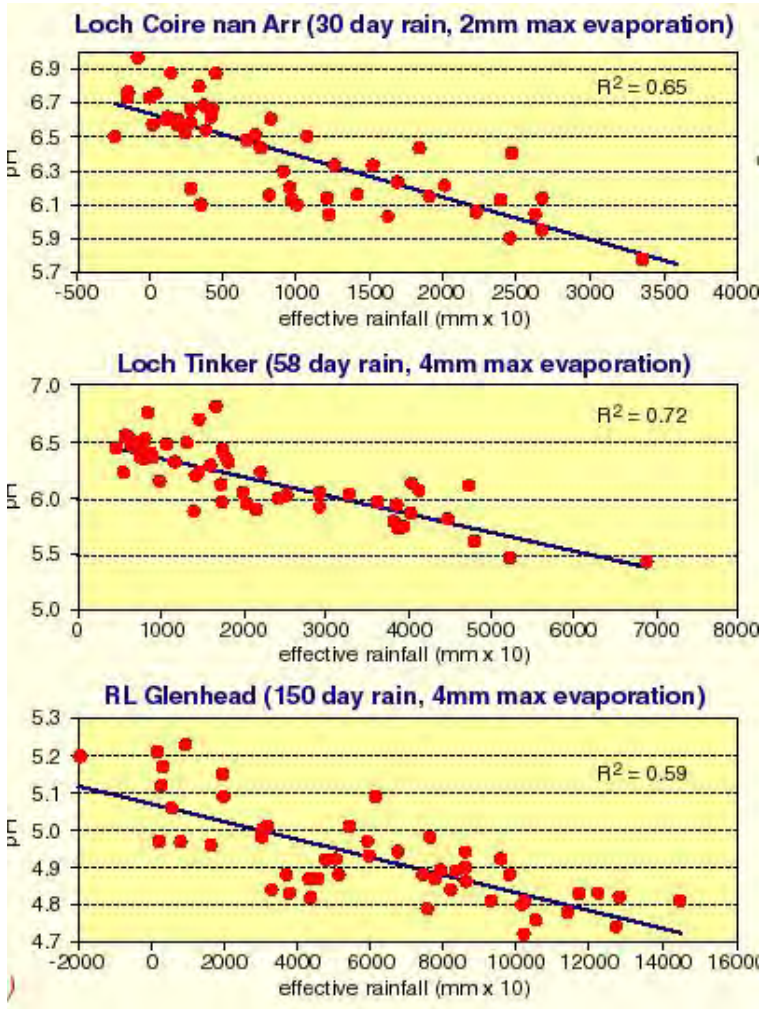
Moorland  
Limited forestry  
Extensive forestry  
Basic geology

Loch Ard streams



Increased winter precipitation exacerbated by sea-salt events may be offsetting reductions in acid emissions

Increased winter precipitation is predicted to increase the natural acidity of upland lakes as a result of increased surface runoff and the dilution of more alkaline base-flow in inflow streams



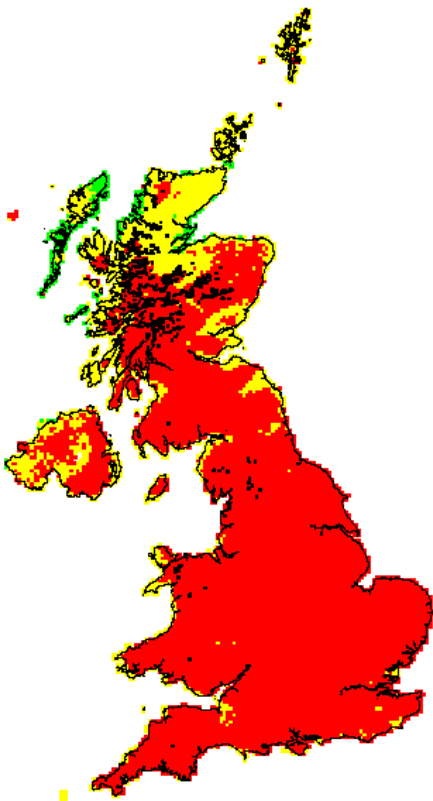
Other pressures not related to acidification

# Eutrophication may become a problem at N-limited sites

Almost all upland lakes in the UK received N deposition exceeding the theoretical critical load of 10 kgN ha<sup>-1</sup> yr<sup>-1</sup>

kg N m<sup>-2</sup> yr<sup>-1</sup>

- 0-3
- 3-5
- 5-10
- >10

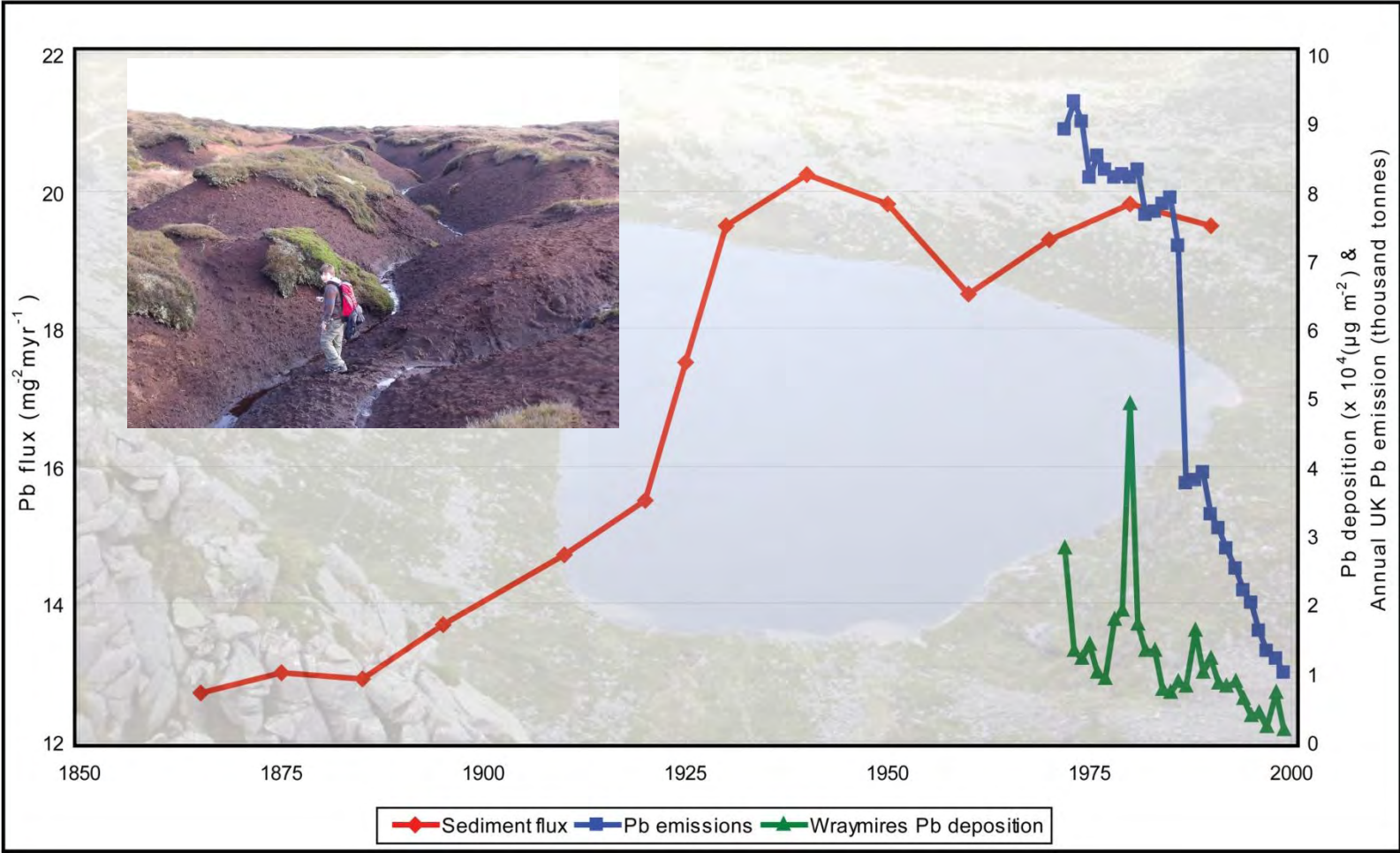


| Site                       | June | July | September |
|----------------------------|------|------|-----------|
| Scoat Tarn                 | P    | P    | P         |
| Small Water                | Co   | Co   | Co        |
| Burnmoor Tarn              | Co   | N    | Co        |
| Llyn Edno                  | Co   | P    | P         |
| Llyn Gamallt Fawr          | Co   | Co   | N         |
| Llyn Hiraethlyn            | N    | N    | Co        |
| Llyn Mair                  | Co   | P    | Co        |
| Hammer Pond                | N    | Co   | N         |
| Loch Beanie                | Co   | P    | P         |
| Lochnagar                  | Co   | P    | P         |
| Loch Coire nan Eion        | Co   | Co   | P         |
| Loch Coire Fhionnaraich    | Co   | N    | Co        |
| Loch Coire Mhic Fhearchair | Co   | P    | P         |

Phytoplankton N and P limitation bioassays

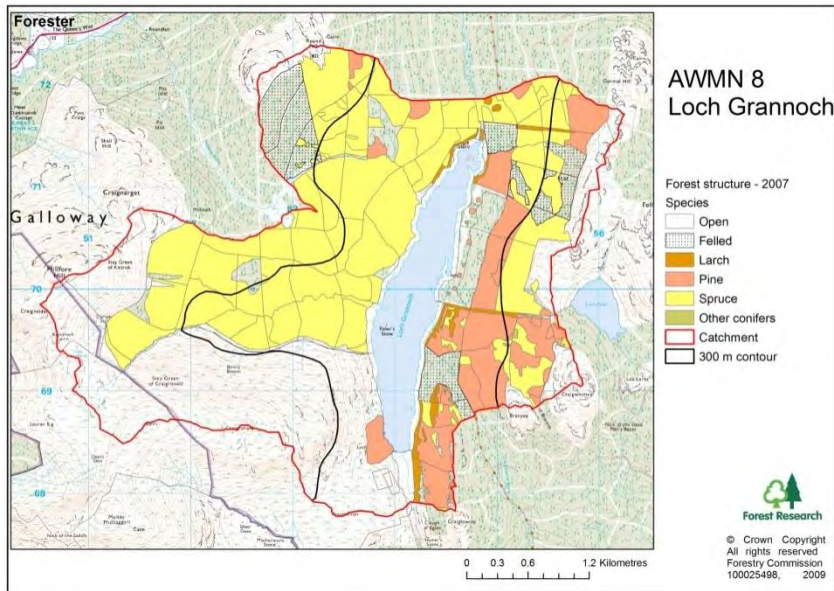
Accelerated soil erosion may lead to the further remobilisation of toxic substances from catchment soils and their accumulation in lake food chains

Pb in Lochnagar sediments from 1850 vs. emission trends

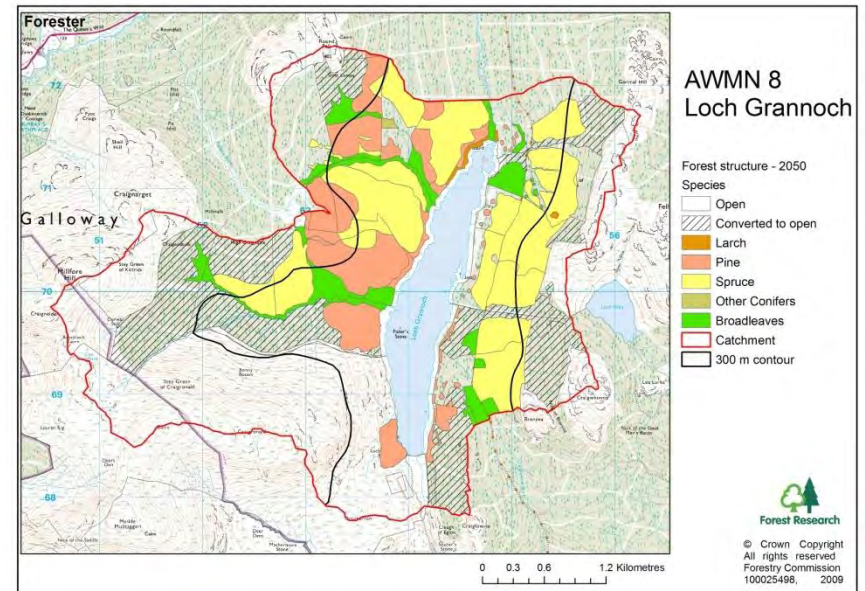


## Future change in commercial forestry planting may influence water quality and biodiversity in the uplands

2007



2050

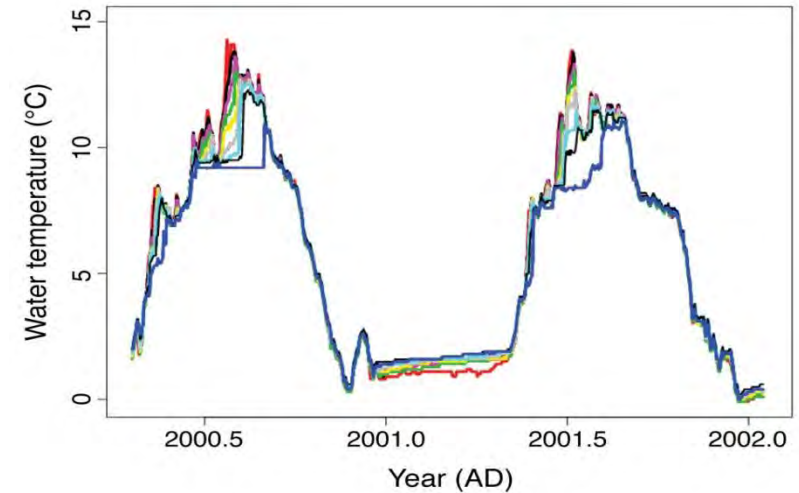
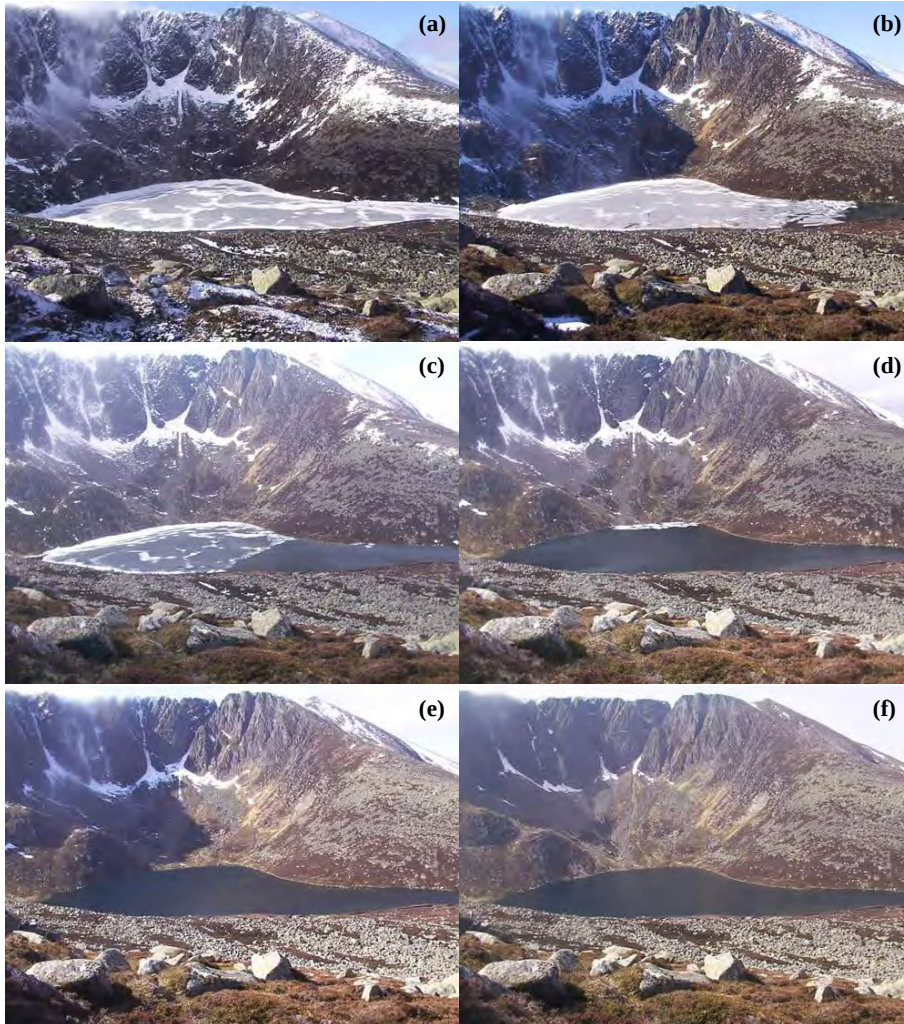


e.g. Loch Grannoch

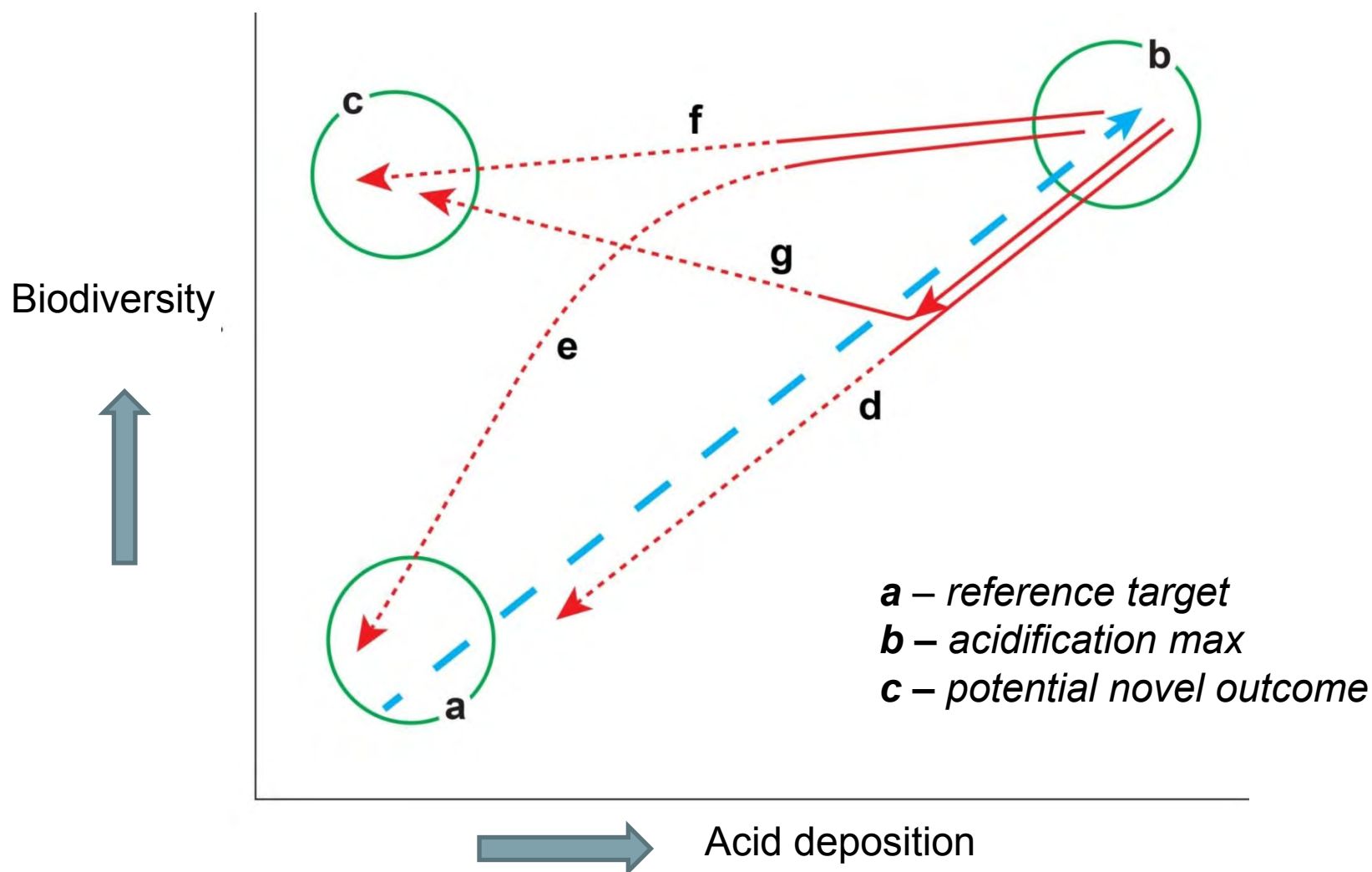
Monitoring is needed over the forest life-cycle

From Forestry Commission

# Increasing temperature may modify the thermal structure and biodiversity of upland lakes and streams



Current and future pressures, especially from climate change may lead to the creation of “novel” upland freshwater ecosystems and not necessarily to the restoration of pre-acidification “reference conditions”





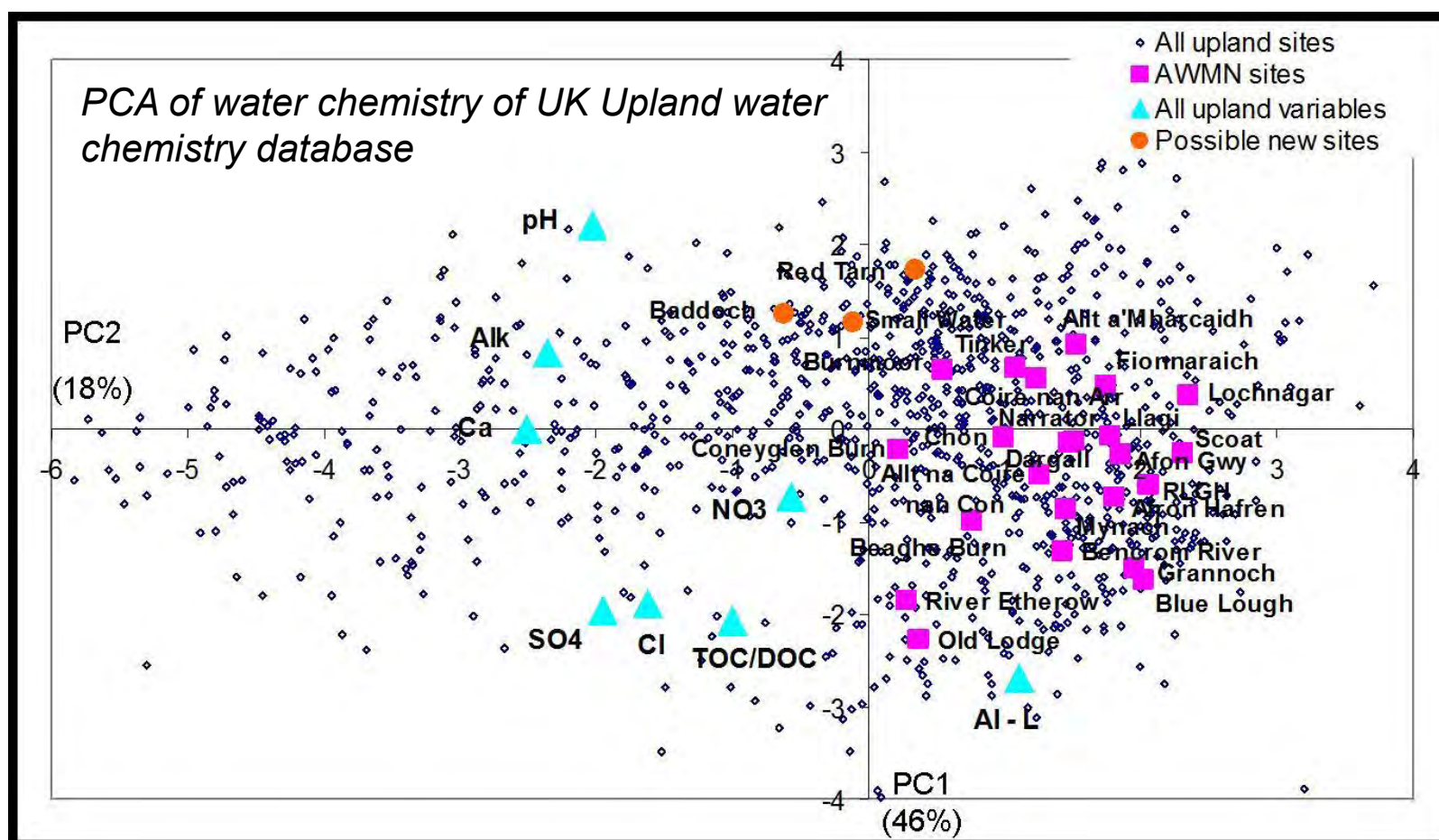
## An Upland Waters Monitoring Network for the UK

*(based on a science partnership of UCL, CEH, QMUL and MSS; supported by Defra, DOENI, WG, SNH, SEPA, SG, CCW, EA, Forestry Commission, CEH and ENSIS Ltd)*



## Upland waters in the UK

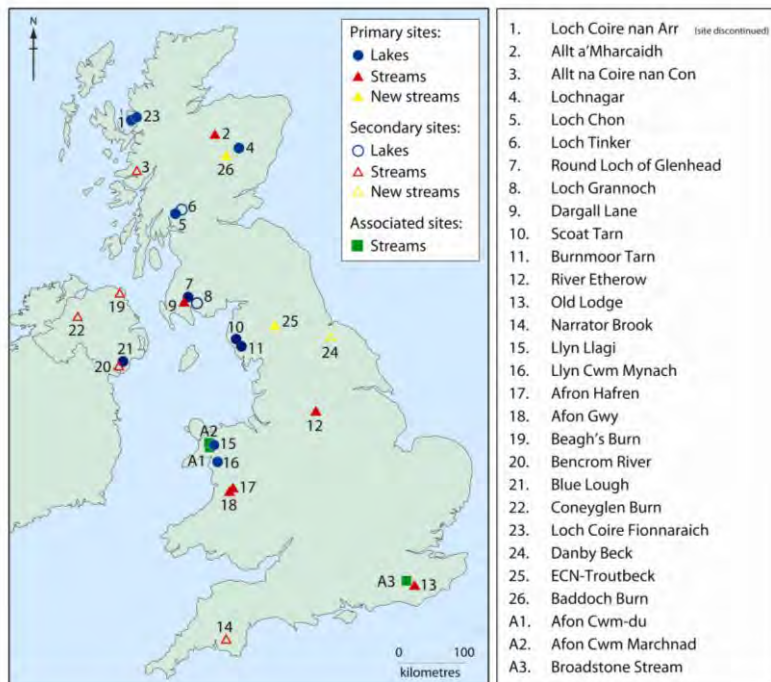
We define upland waters in the UK as headwaters situated beyond the limit of enclosed agricultural land in catchments occupying moorland or afforested catchments. This corresponds to land-use categories “mountain, moorland and heathland” (MMH) in the **UK National Ecosystem Assessment**. Afforestation has a separate classification



Troutbeck

## The UK UWMN: gradually adding more sites

- Baddoch Burn (Cairngorms)
- ECN-Troutbeck (Pennines)
- Danby Beck (North York Moors)
- Plus Associated sites
- Primary and secondary sites



Baddoch Burn



Danby Beck





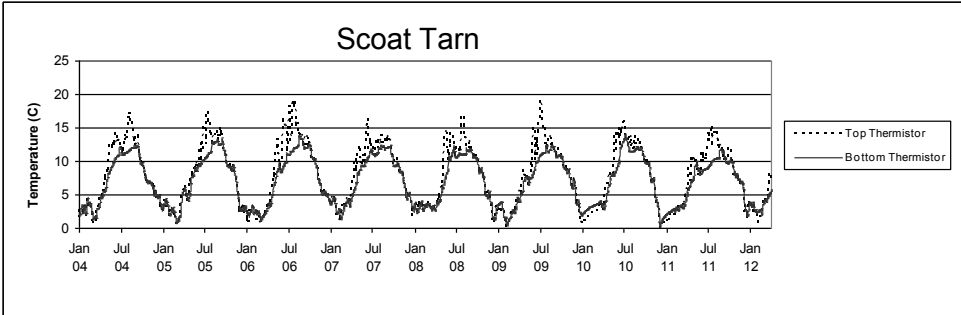
# Adding thermistors at (almost) all sites (from 1999) and thermistor chains at lake sites (from 2013)

| SITE                   | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |     |
|------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|
| Loch Coire nan Arr     |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS   |      |      |      |      |      | MS   | MS   | MS   | MS   | MS   | MS  |
| Allt a Mharcaidh       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS   | MS   | MS   | MS  |
| Allt na Coire nan Con  |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS   | MS   | MS   | MS  |
| Lochnagar              |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Loch Chon              |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Loch Tinker            |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Round Loch of Glenhead |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Loch Grannoch          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Dargall Lane           |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS  |
| Scoat Tarn             |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Burnmoor Tarn          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| River Etherow          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS  |
| Old Lodge              |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS  |
| Narrator Brook         |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS   | MS  |
| Llyn Llgi              |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Llyn Cwm Mynach        |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Afon Hafren            |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | CEH  | CEH  | CEH  | CEH |
| Afon Gwy               |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS   | MS  |
| Beaghs Burn            |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Bencrom River          |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Blue Loch              |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Coneyglen Burn         |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
| Loch Coire Fionnaraich |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | *    | *    | *    | *    | *    | *   |
| Danby Beck             |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | MS   | MS  |

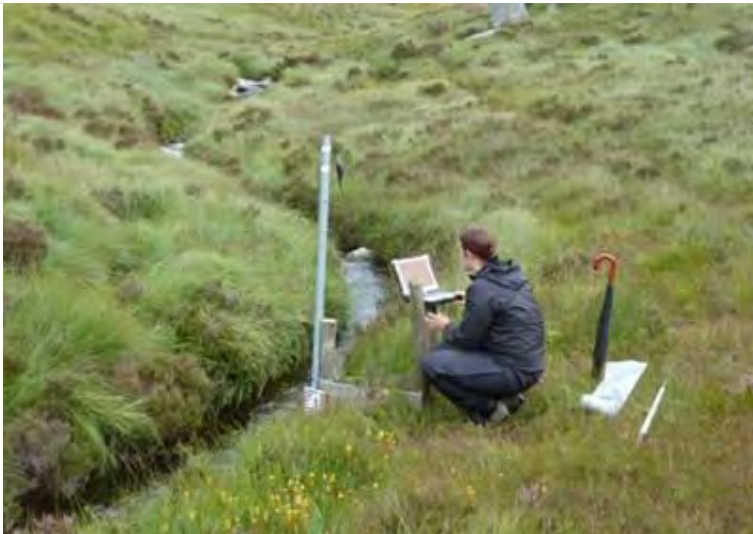
- No planned sampling
- Funded, sampled and analysed
- Funded but unsampled
- Unfunded, sampled and analysed

\* MS also have outflow data for all Scottish loch outflows 2008-2013

Temperature network coordinated by MSS



## Automatic water quality monitoring station, lake level recorders and outflow loggers at the Round Loch of Glenhead and Llyn Llgi



Funded by NERC, SNH and NRW

When funds allow, we need to:

- Continue to add new sites, especially those with higher alkalinity
- Extend the water level logging to all primary sites
- Introduce protocols for chl a and low concentration TP measurements
- Re-introduce measurements of toxic substances at Lochnagar and roll out to other sites (possibility of help from SEPA)
- Introduce a programme of systematic vegetation and land-use mapping for all catchments



**And most of all we need to find new funds – but thanks to all current funders and collaborators!**

*(based on a science partnership of UCL, CEH, QMUL and MSS; supported by Defra, DOENI, WAG, SNH, SEPA, SG, NRW, EA, Forestry Commission, CEH and ENSIS Ltd)*

