UCL DEPARTMENT OF GEOGRAPHY
ENVIRONMENTAL CHANGE RESEARCH CENTRE

The Scottish Freshwater Group 100th Meeting, Stirling, April 2018

UCL

Environmental change in Scottish lochs revisited

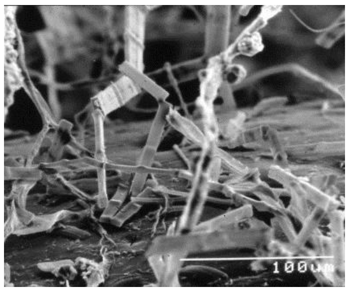
Helen Bennion & Rick Battarbee

In the ECRC we have been principally interested in the use of long-term records to understand how and why lake ecosystems change in time and space and in particular how they respond to pressures from human activity

Coring

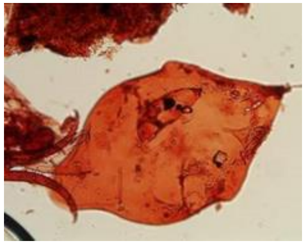
Indicators

Diatoms

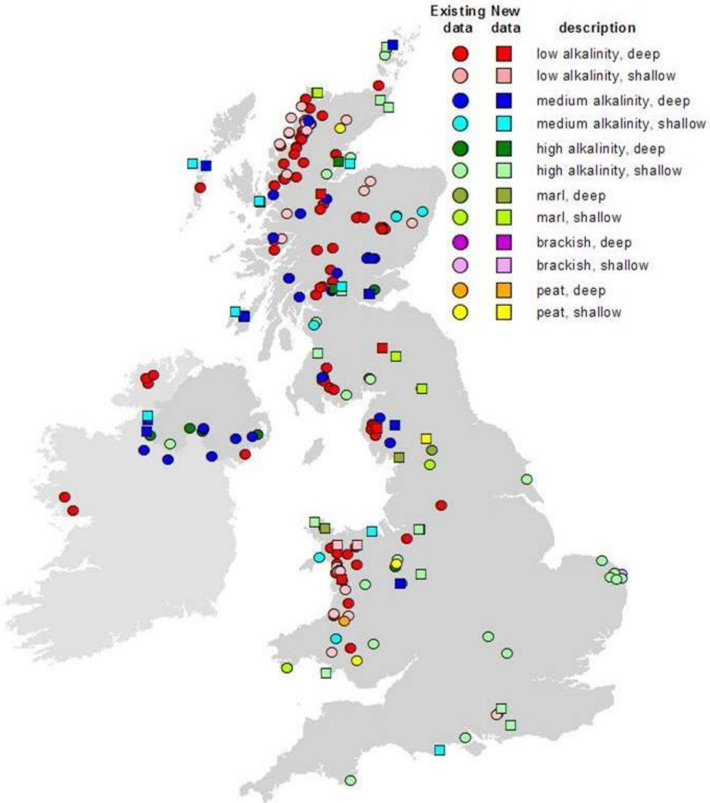


Plant macrofossils

Cladocera



Lakes with core data

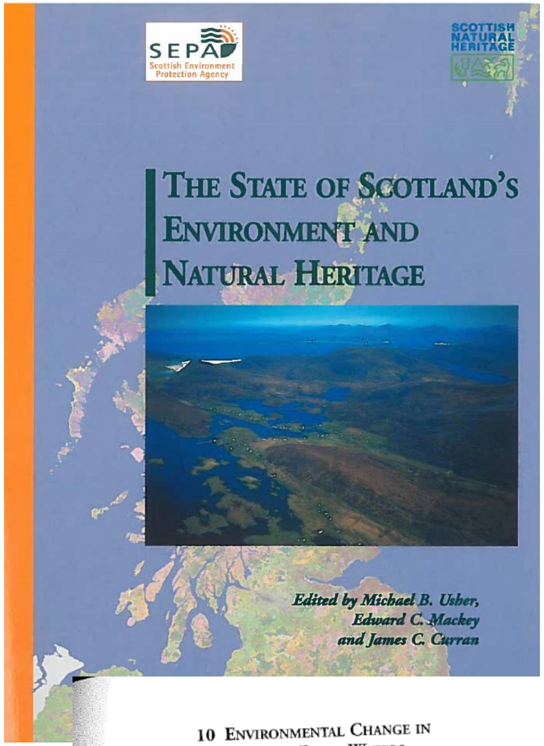


Upland waters - Rick

- Palaeolimnological evidence for the impact of acid deposition
- Evidence for recovery from the Upland Waters Monitoring Network
  (also see talk by Ewan Shilland)

Lowland waters – Helen

- Understanding of timing, rates and causes of eutrophication
- Determining baselines and degree of ecological change
- Ecological response to enrichment
- Insights into climate-nutrient interactions
- Assessing recovery from eutrophication
- Informing conservation of rare species
  (see talk by Isabel Bishop)



10 Environmental Change in Scottish Fresh Waters

H. Bennion, G. Simpson, R.W. Battarbee, N.G. Cameron, C. Curtis, R.J. Flower, M. Hughes, V.J. Jones, M. Kernan, D.T. Monteith, S.T. Patrick, N.L. Rose, C.D. Sayer and H. Yang

Summary

1. Recovery of Scottish inland waters from acidification has been patchy over the period 1988 to 1998 despite large UK sulphur emission reductions. Climate variability may confound the expected relationship between sulphur deposition and surface water acidity. Furthermore, nitrogen has been shown to be an important acidifier and continued high N deposition at some sites may contribute to the lack of chemical recovery.
2. Eutrophication has been identified in a number of lowland Scottish lochs across a broad range of loch types. Importantly, ecological change has been detected in large, deep lochs previously assumed to be relatively unimpacted.
3. Mountain lochs, despite their remote nature and lack of catchment disturbance, have received high levels of atmospheric contaminants, especially metals. The on-going release of these pollutants from catchment soils may delay reductions in loadings by decades.

10.1 Introduction

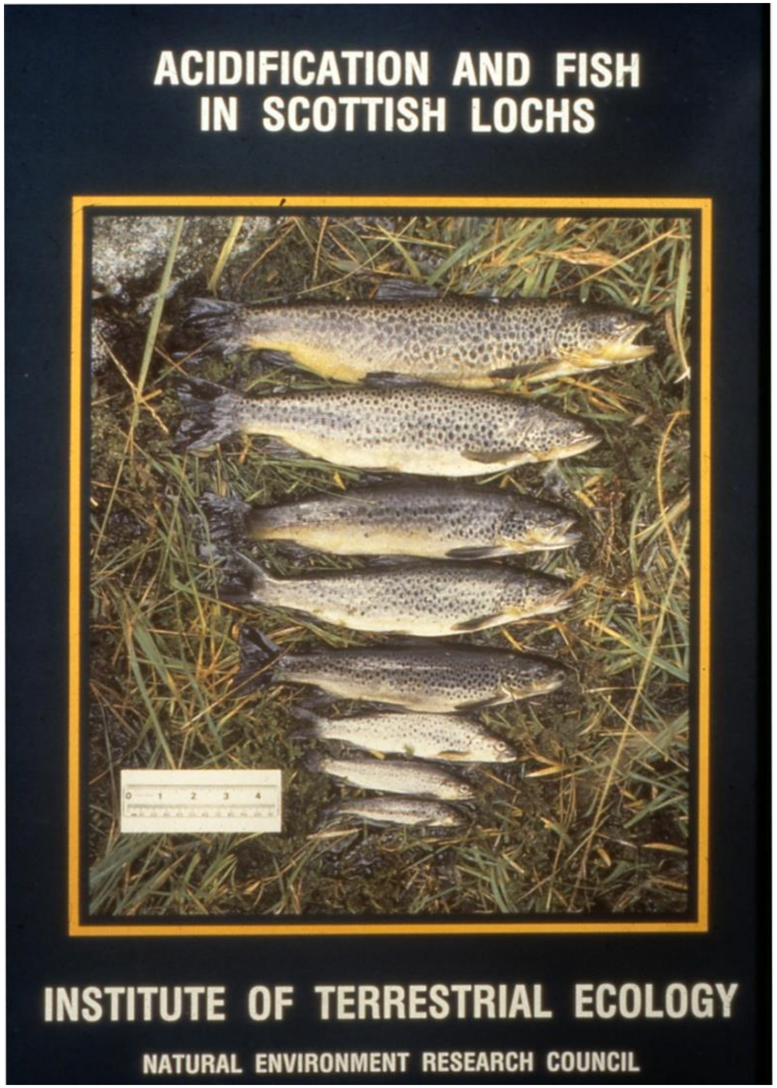
Over the last few hundred years, Scotland's fresh waters have been subject to increasing human pressures resulting in environmental problems such as acidification, eutrophication, increased catchment erosion, and atmospheric contamination from trace metals and persistent organic materials. The potential exacerbating effect of climate change now poses an additional challenge. The recent European Union Water Framework Directive (WFD) has highlighted the need to evaluate change in the ecological status of waters, requiring an assessment of how far present day conditions differ from those expected in the absence of significant anthropogenic influence ('reference conditions' in WFD terminology). However, the lack of background information on chemical and biological conditions prior to the onset of environmental problems makes this difficult. Palaeolimnology is a technique that employs the sediment record to determine past chemistry and biology of lochs before the onset of monitoring programmes (e.g. Battarbee, 1999). Here we summarise the findings of recent research that examines trends in surface water acidification, eutrophication, and contamination of Scottish fresh waters.

10.2 Surface water acidification

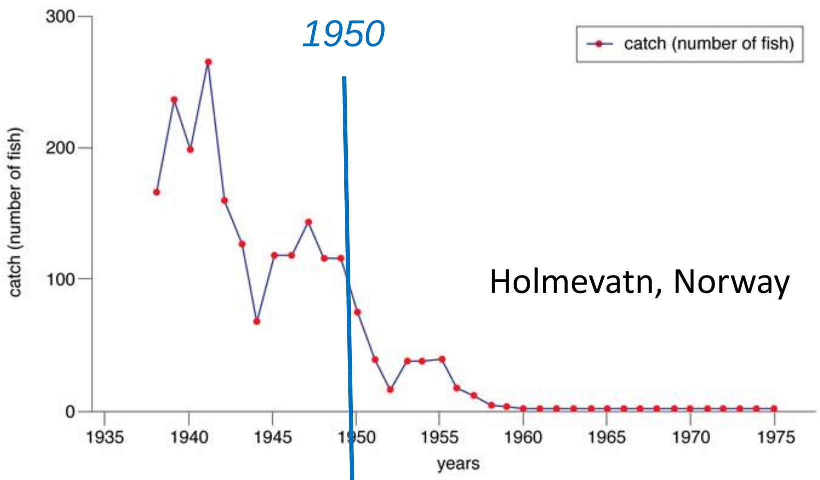
Early palaeolimnological work in the Galloway and Trossachs regions highlighted the primary

SNH, 2002

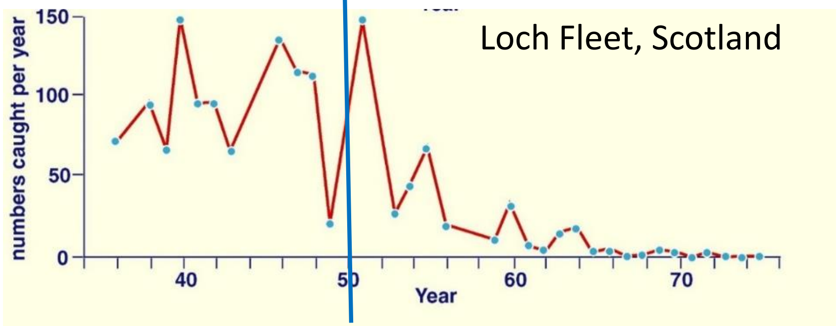
Loss of brown trout populations in Scandinavia and Scotland



Maitland et al. 1987, Natural Environment Research Council

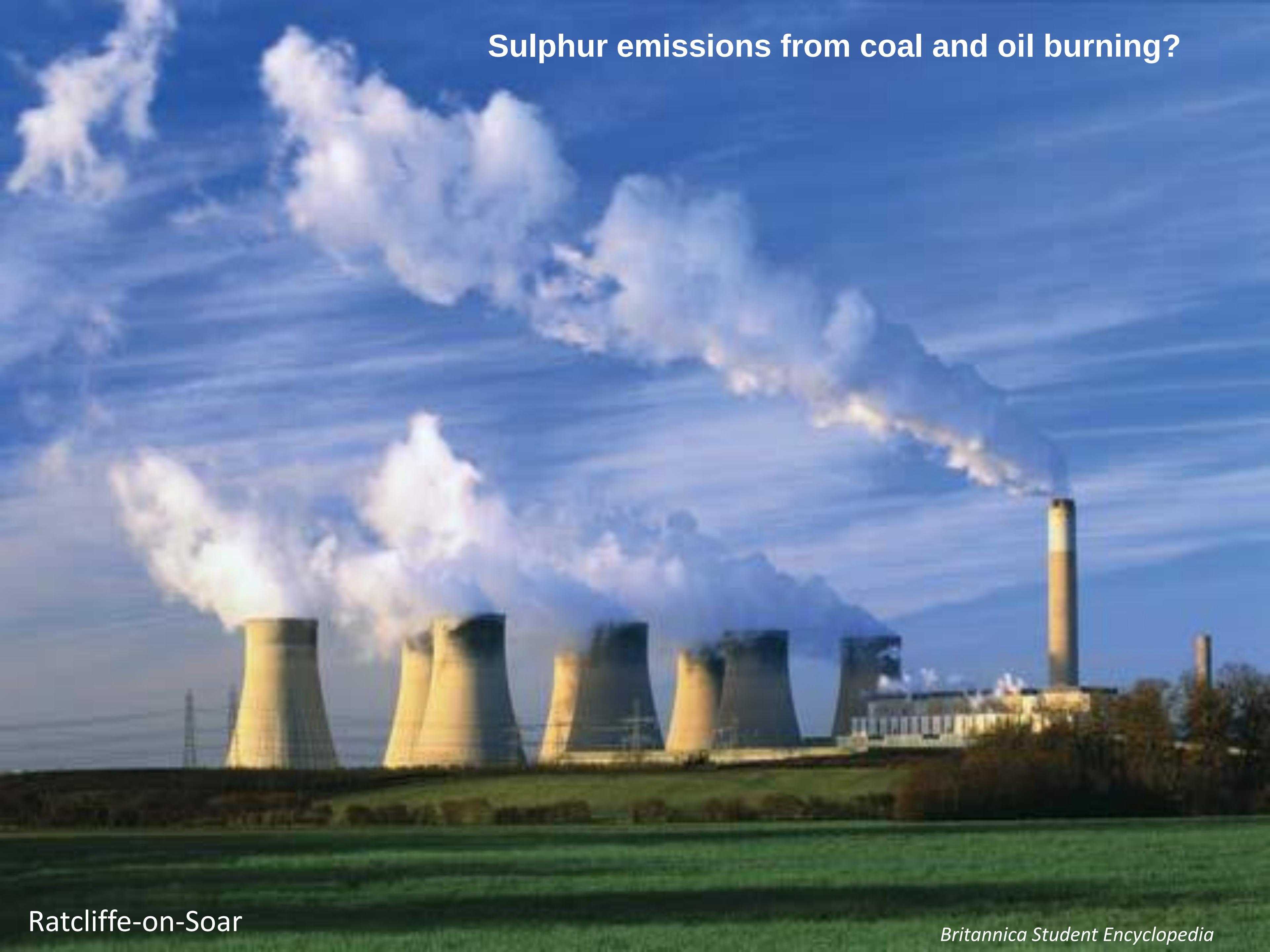


Overrein et al. 1980 SNSF Project FR 19/80

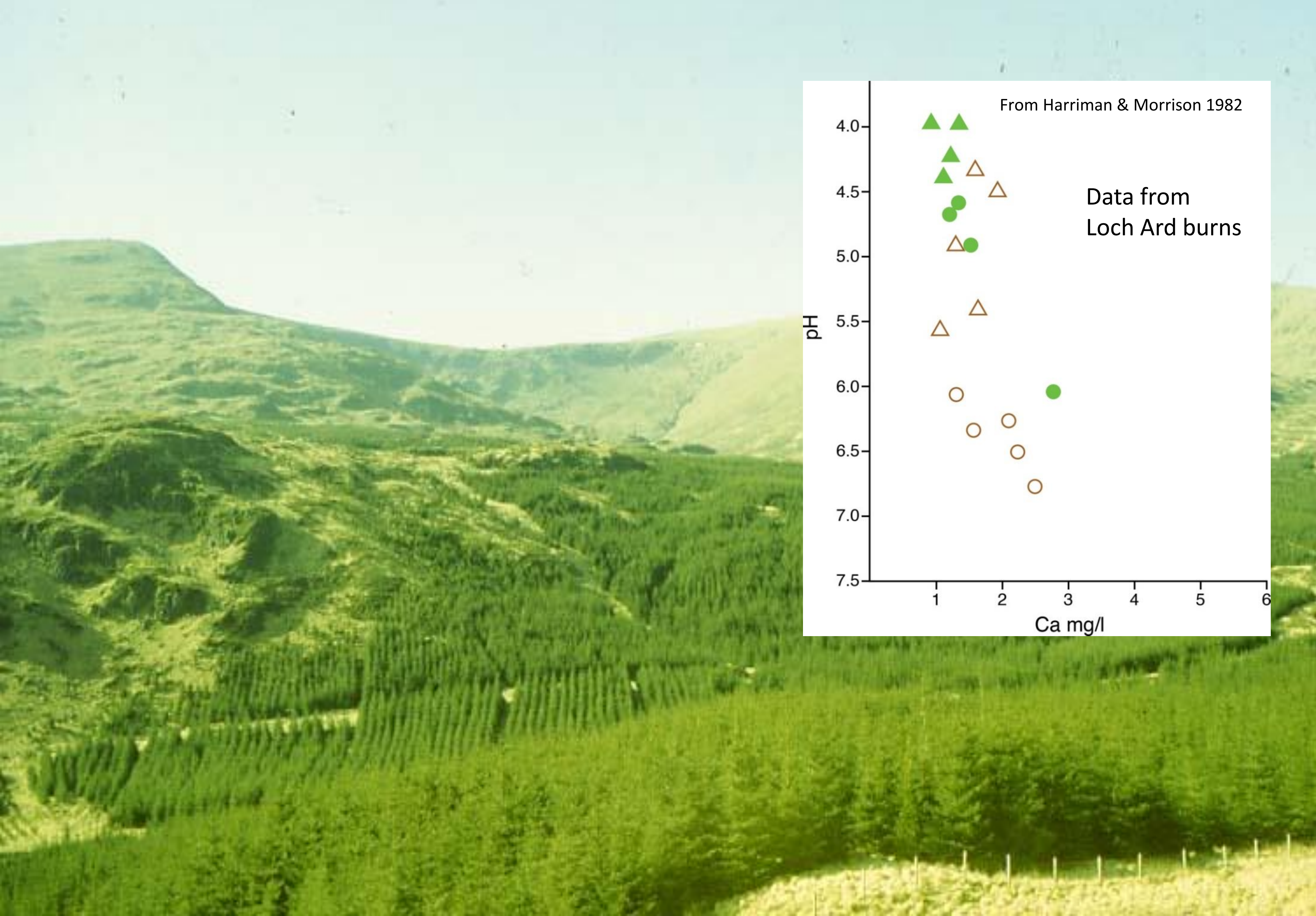


Turnpenny 1992 *Restoring Acid Waters*, Elsevier

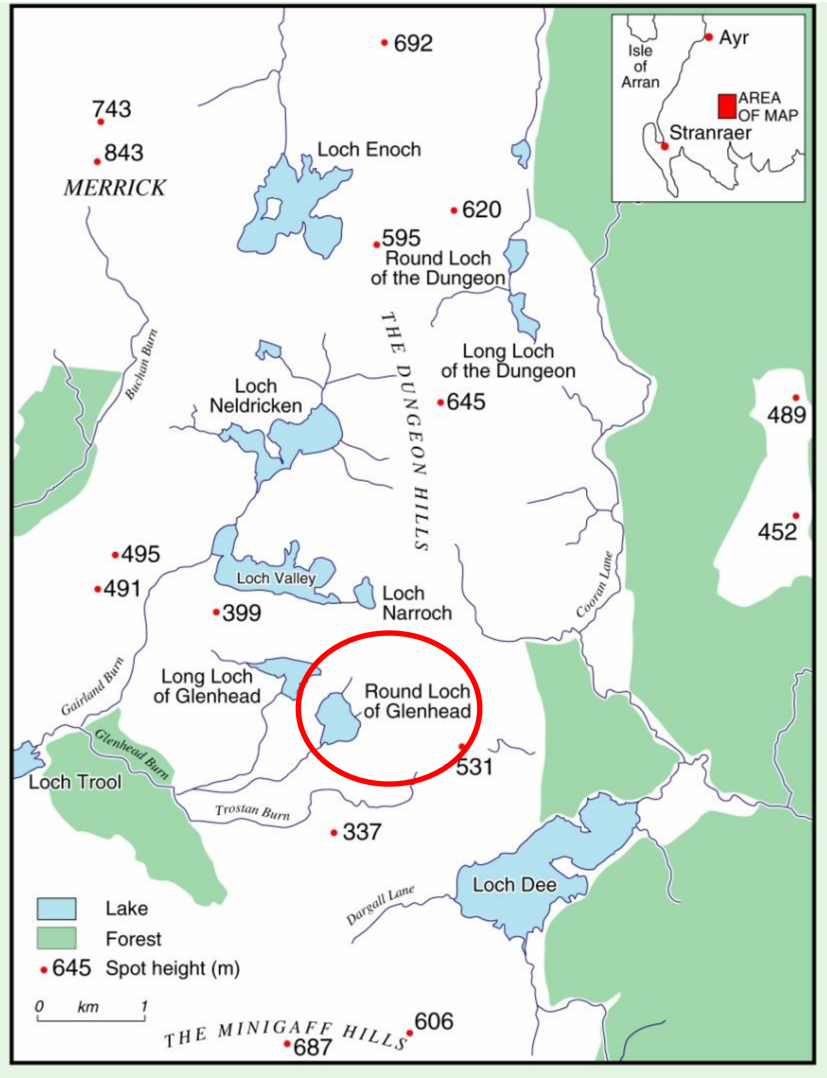
And many other countries in Europe
and North America


Sulphur emissions from coal and oil burning?
Ratcliffe-on-Soar
Britannica Student Encyclopedia

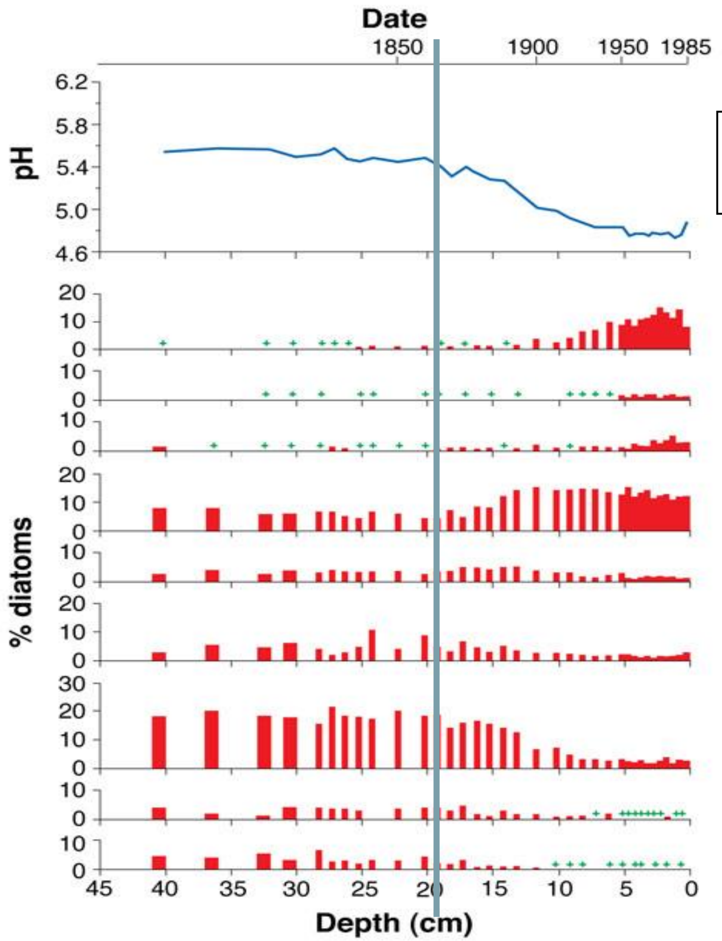
Or post-war afforestation of moorland?



Lochs on the granites in Galloway, with and without afforested catchments



At the Round Loch of Glenhead, with a moorland catchment, acidification began in the mid 19th century



changes in diatom assemblage composition: ca. 1750 - 1985

Flower & Battarbee 1983, *Nature*, 305, 130-133; Jones, et al. 1989, *J. Ecology* 77, 1-23

Palaeolimnology played its part in persuading Margaret Thatcher and the UK Government in 1987 to sign up to international protocols requiring S and N gas emissions to be reduced from UK power stations

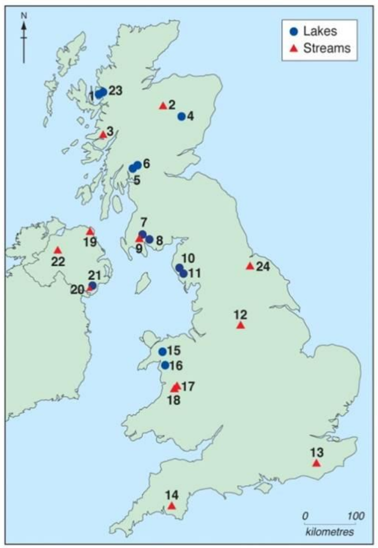
Current Directives and Protocols

- 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)

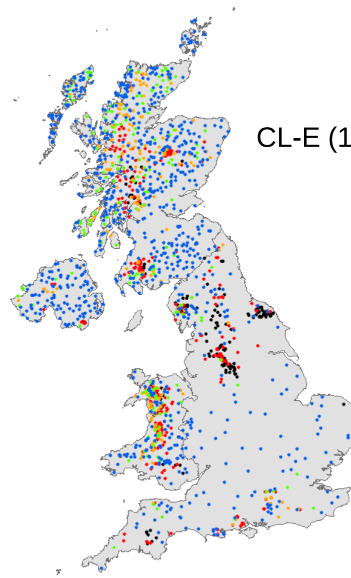
The Acid (now Upland) Waters Monitoring Network (from 1988)

Low alkalinity lakes and streams in high and low acid deposition areas, with and without forestry

Eight sites in Scotland



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 Llagi
16. Llyn Cwm Mynach
17. Afron Hafren
18. Afon Gwy
19. Beagh's Burn
20. Bencrom River
21. Blue Lough
22. Coneyglen Burn
23. Loch Coire Fionnaraich
24. Danby Beck

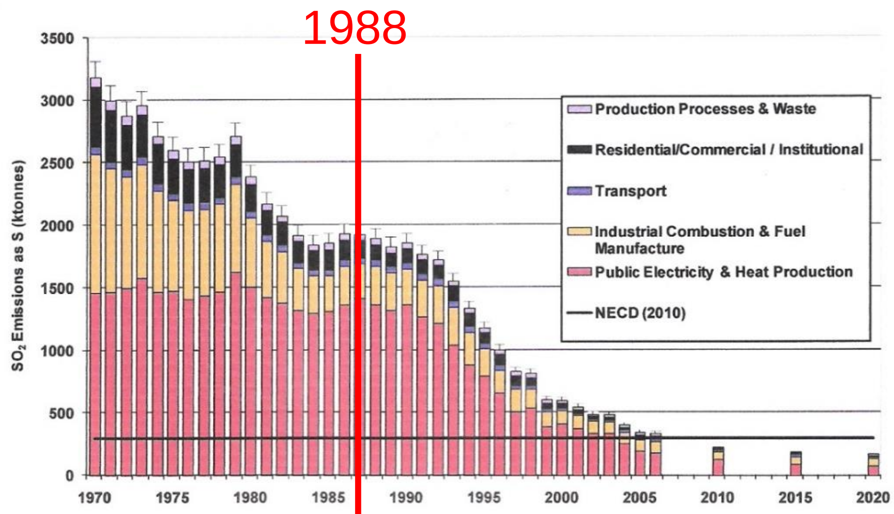


CL-E (1990)

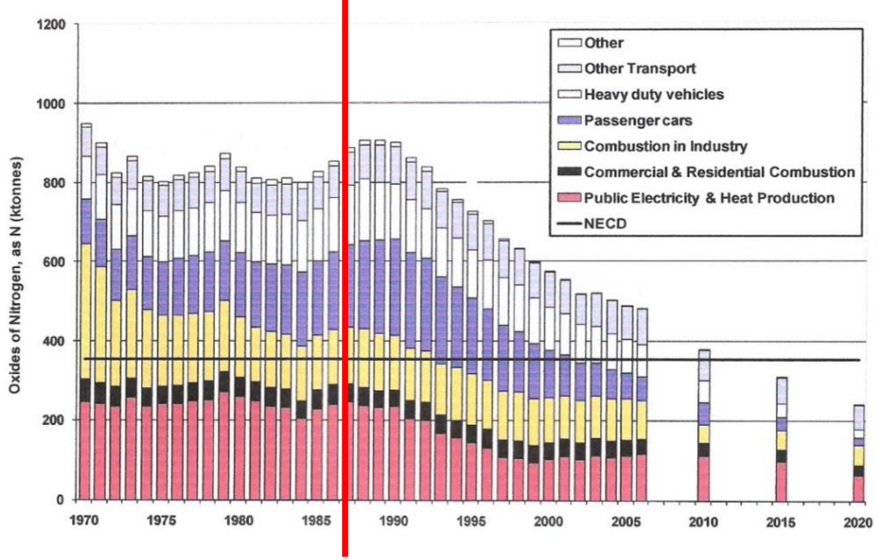
Photos: E Shilland

The UWMN is run by a research consortium including CEH, MSS, QMUL and UCL and it is now co-ordinated by CEH and funded by WAG, NRW, SNH, FC and NIEA.

UK Sulphur dioxide emissions 1970-2020

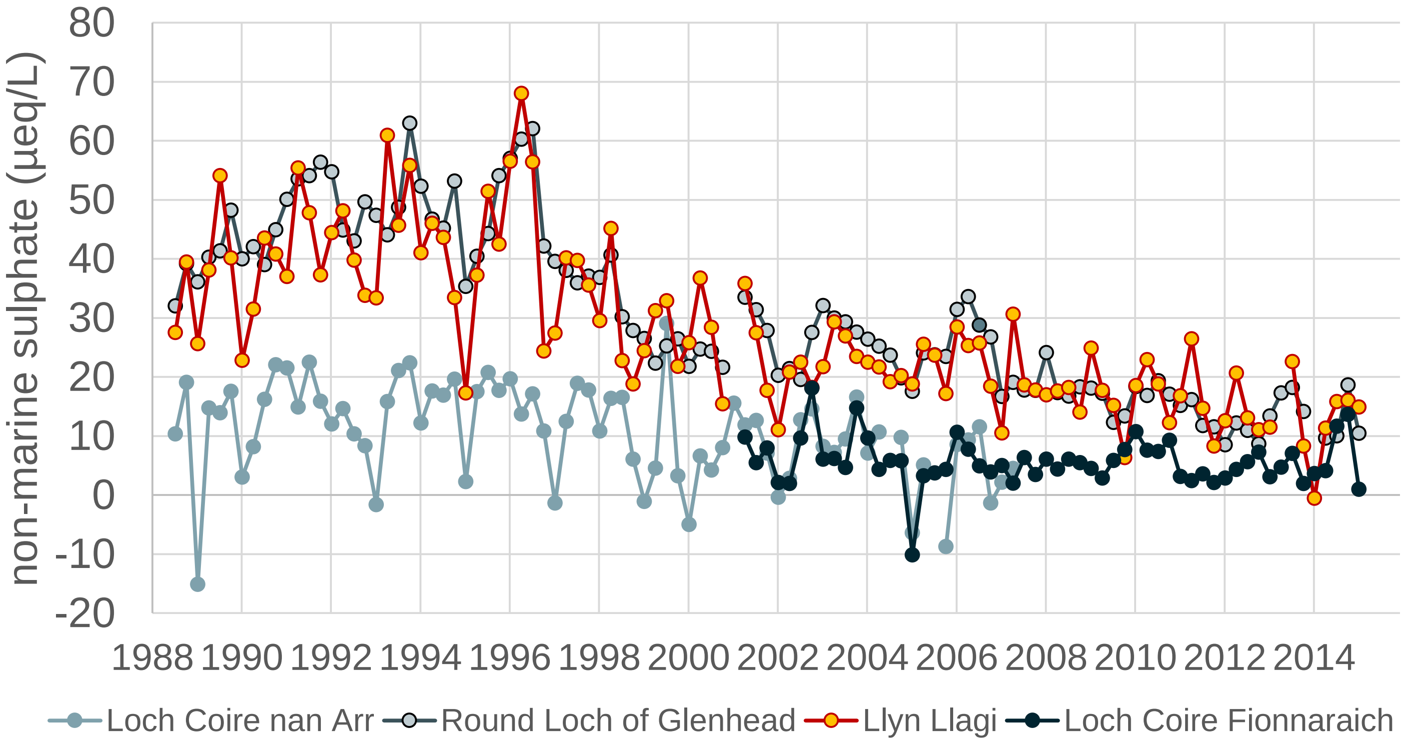


UK NO_x emissions 1970-2020

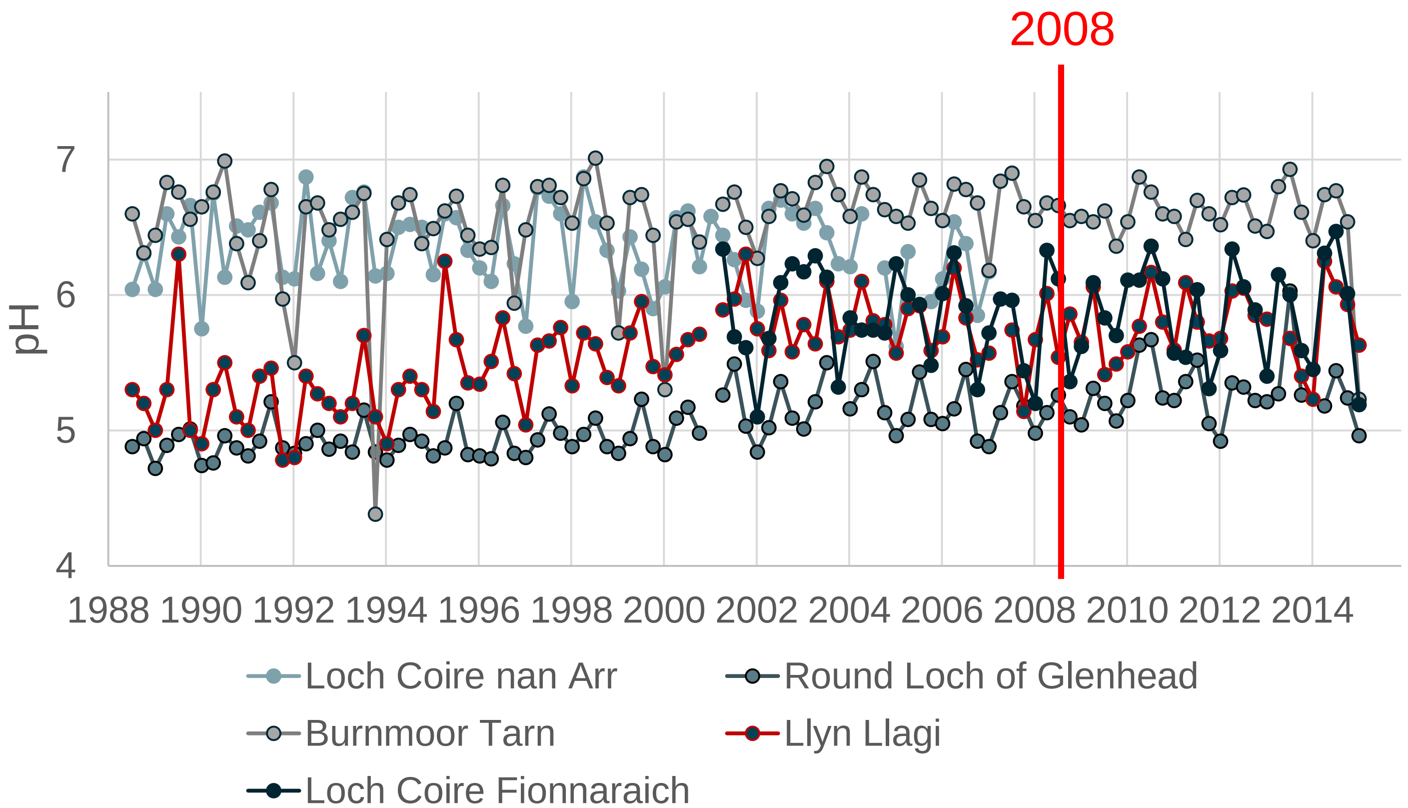


RoTAP, 2012, Defra, UK

Non-marine sulphate (1988 – 2015), comparing non-acidified sensitive “clean” control sites in north-west Scotland, with two acidified sites in SW Scotland (Round Loch of Glenhead) and N Wales (Llyn Llagi)



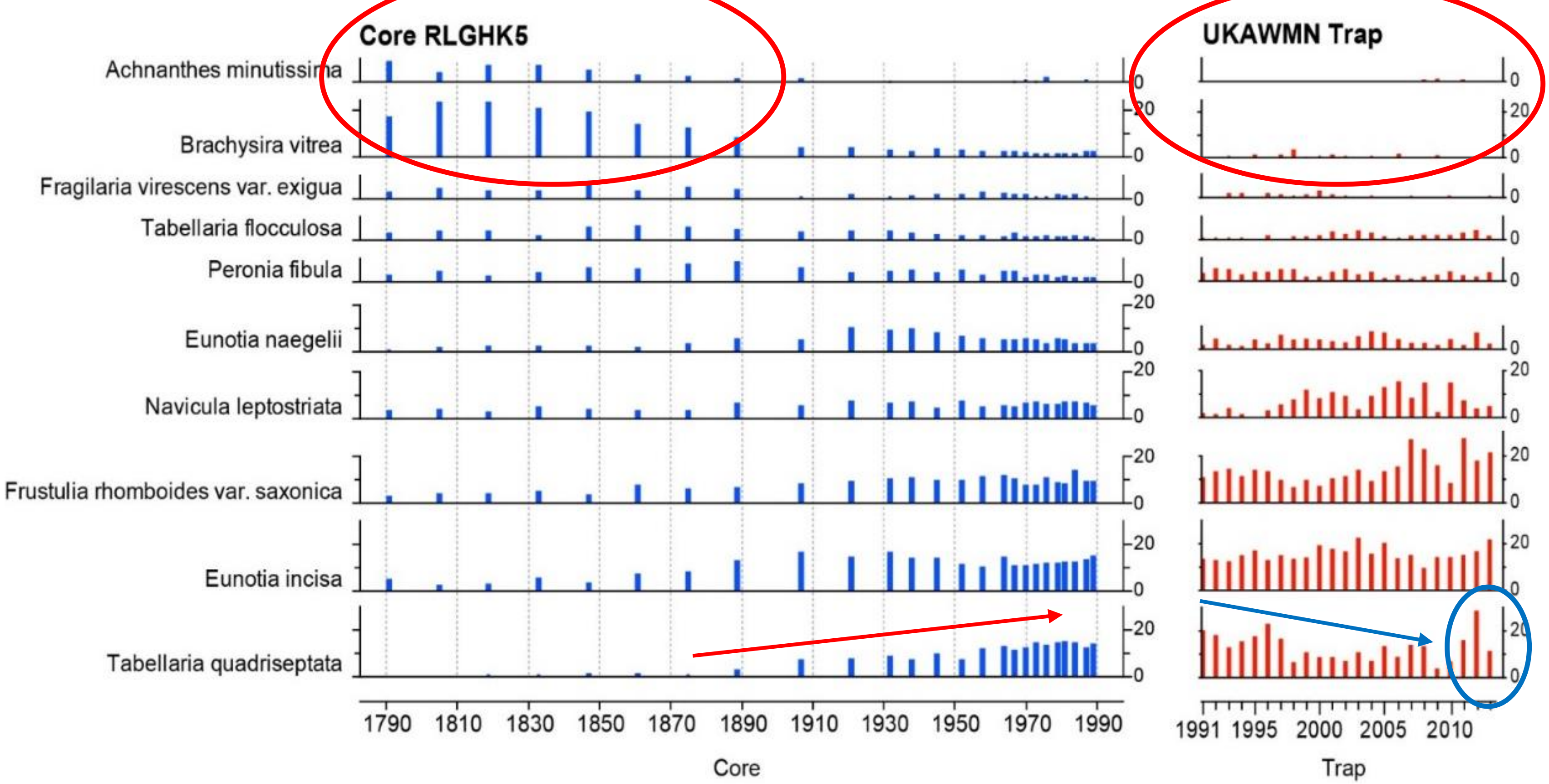
pH (1988-2015) comparing sensitive (Coire nan Arr, Coire Fionnaraich) and less sensitive (Burnmoor Tarn) “control” sites with two acidified sites (Llagi and RLGH)



Some recovery after 1995 , but return to more acid tolerant diatom assemblages after 2008

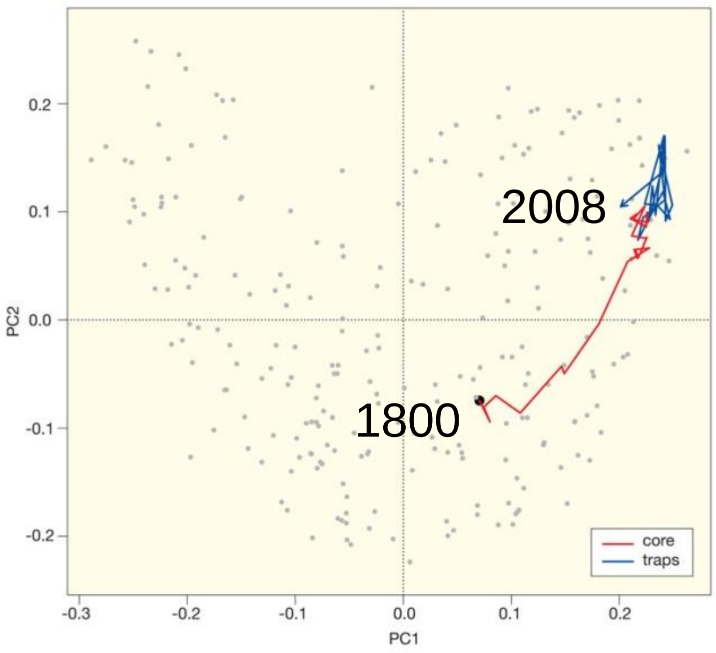
Round Loch of Glenhead

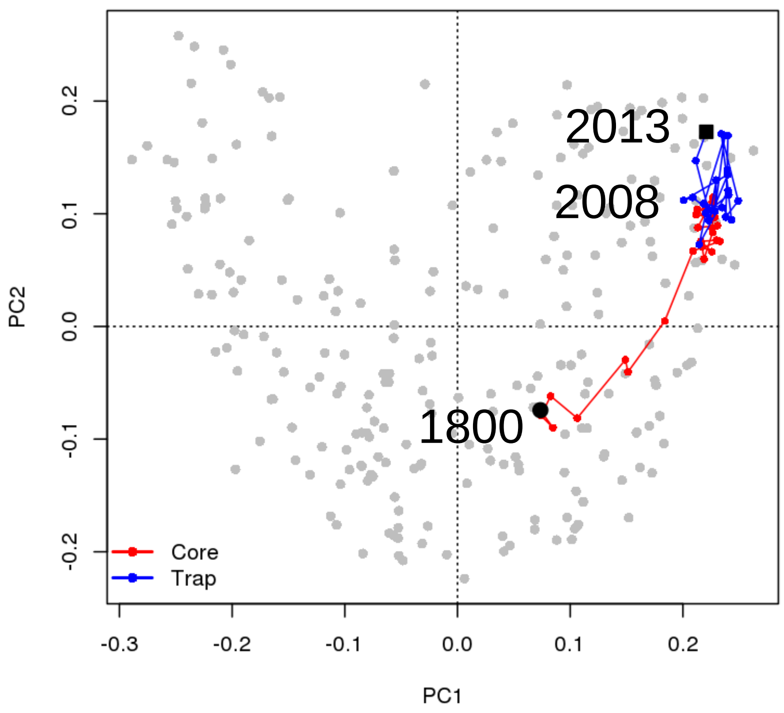
Sediment core (1790 – 1990) + sediment trap (1991- 2013)



Battarbee et al. *Ecological Indicators*, 2014, 37, 365-380

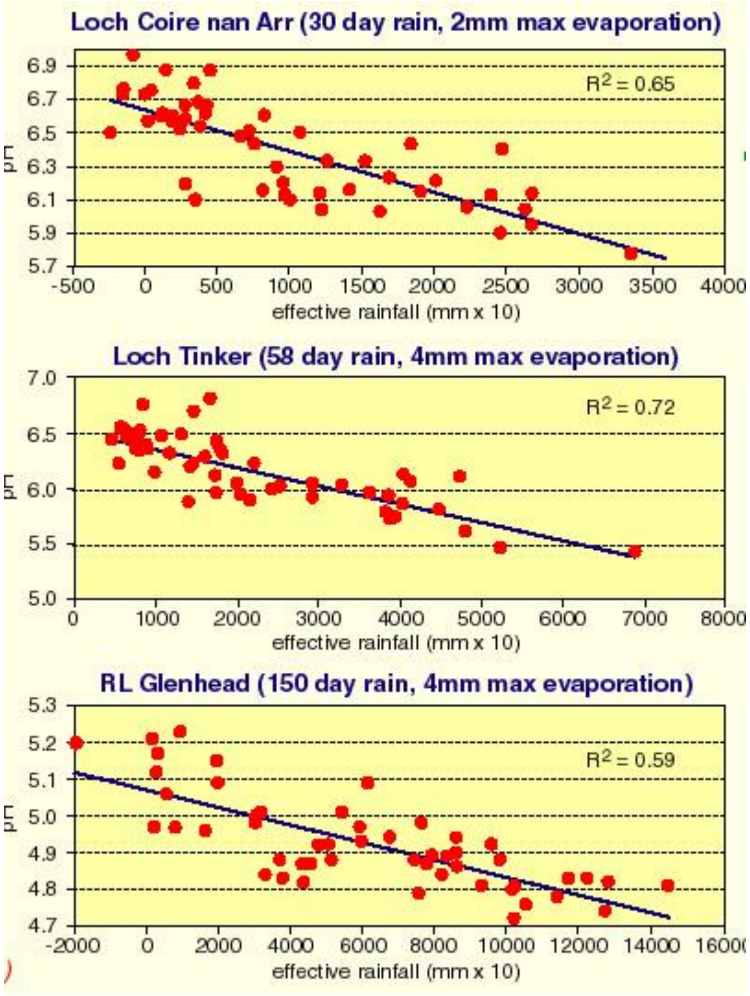
PCA of diatom assemblage data from the Round Loch of Glenhead combining sediment core data (red) and sediment trap data (blue) and comparing trajectories from 1800 AD to 2008 AD and 1800 AD to 2013 AD

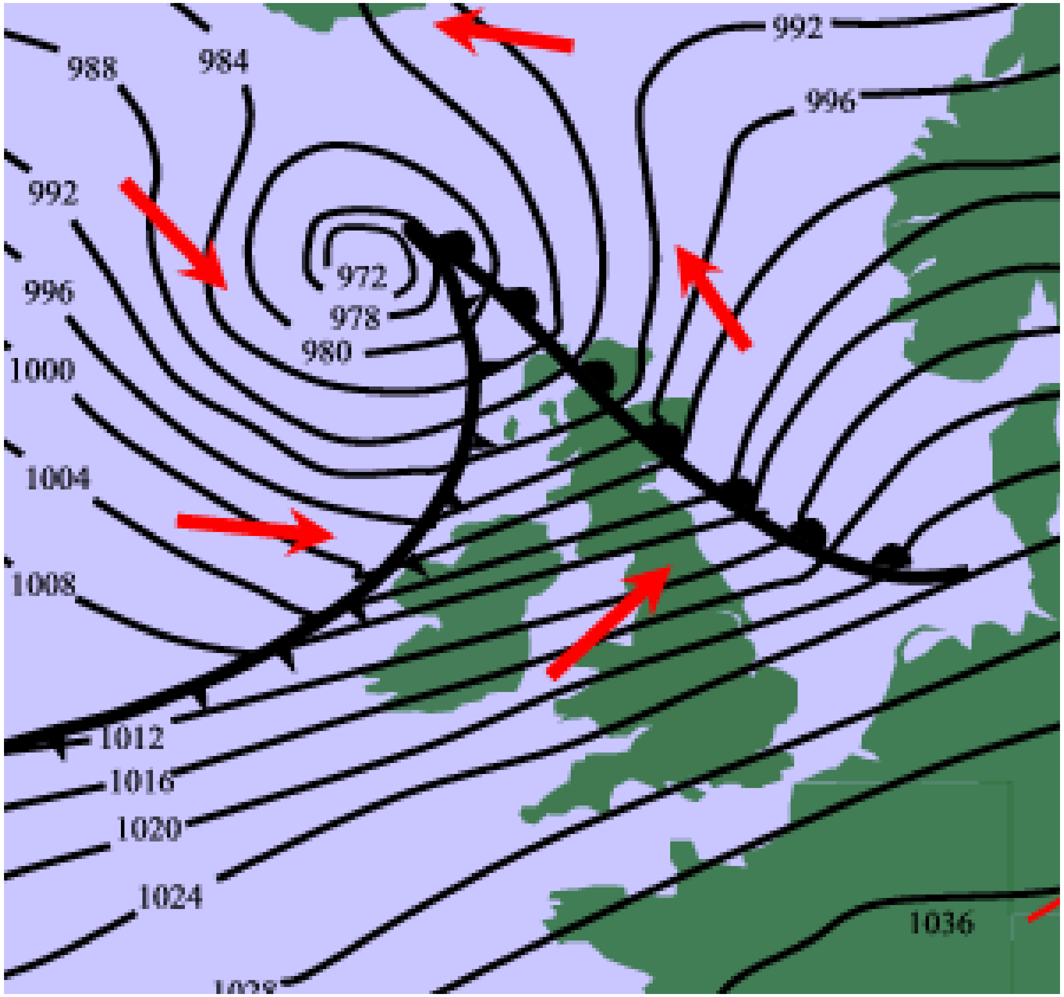




Battarbee et al. *Ecological Indicators*, 2014, 37, 365-380

Increased **precipitation** exacerbated by sea-salt rich storms leads to lower pH in runoff from base poor soils





Monteith, personal communication

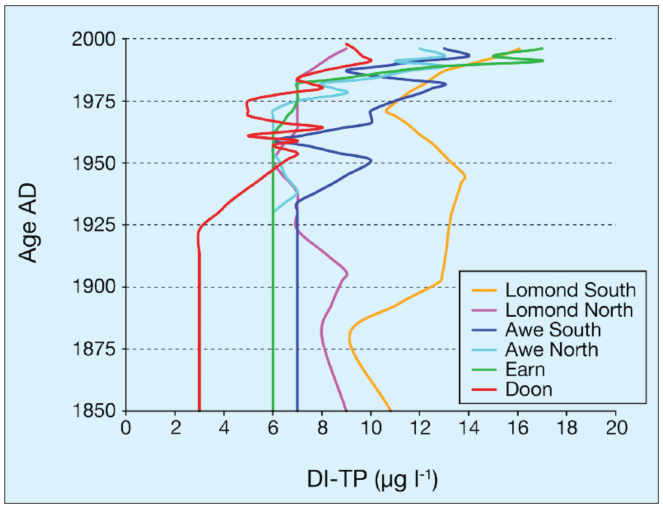
http://www.kayarchy.co.uk/html/03thesea/008predicting.htm

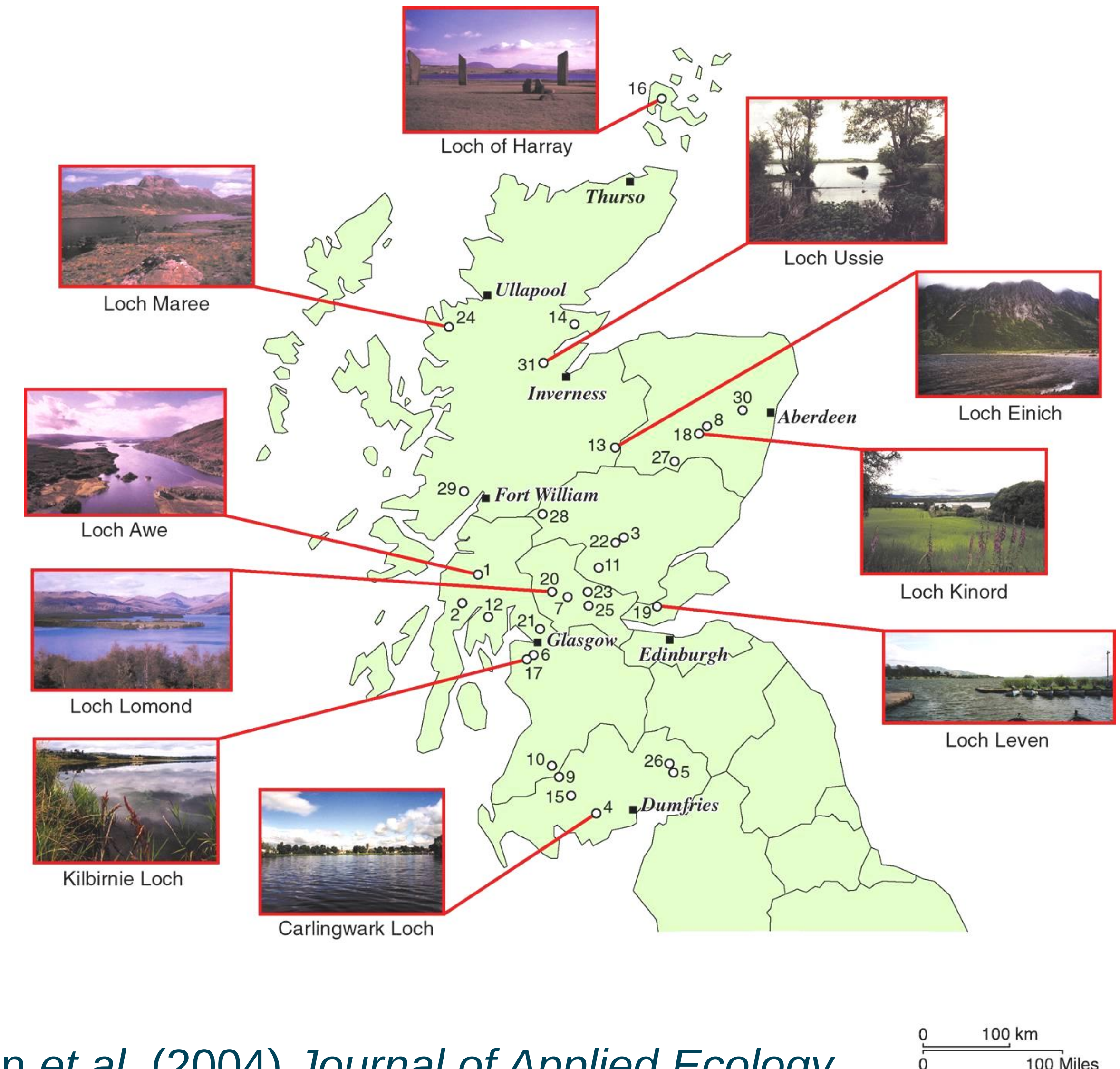
Acidification and climate change - summary

- Acidification caused by sulphur and nitrogen deposition from fossil-fuel combustion
- UK emissions of sulphur dioxide and nitrogen oxides have declined greatly since 1980
- Chemical and biological data from the Upland Waters Monitoring Network show signs of recovery during the 1990s but little improvement since ca. 2008
- Increasing precipitation coupled with increasing storminess may be causing more acidic runoff, inhibiting further recovery

Lowland waters

Assessing eutrophication and reference conditions for Scottish freshwater lochs using subfossil diatoms

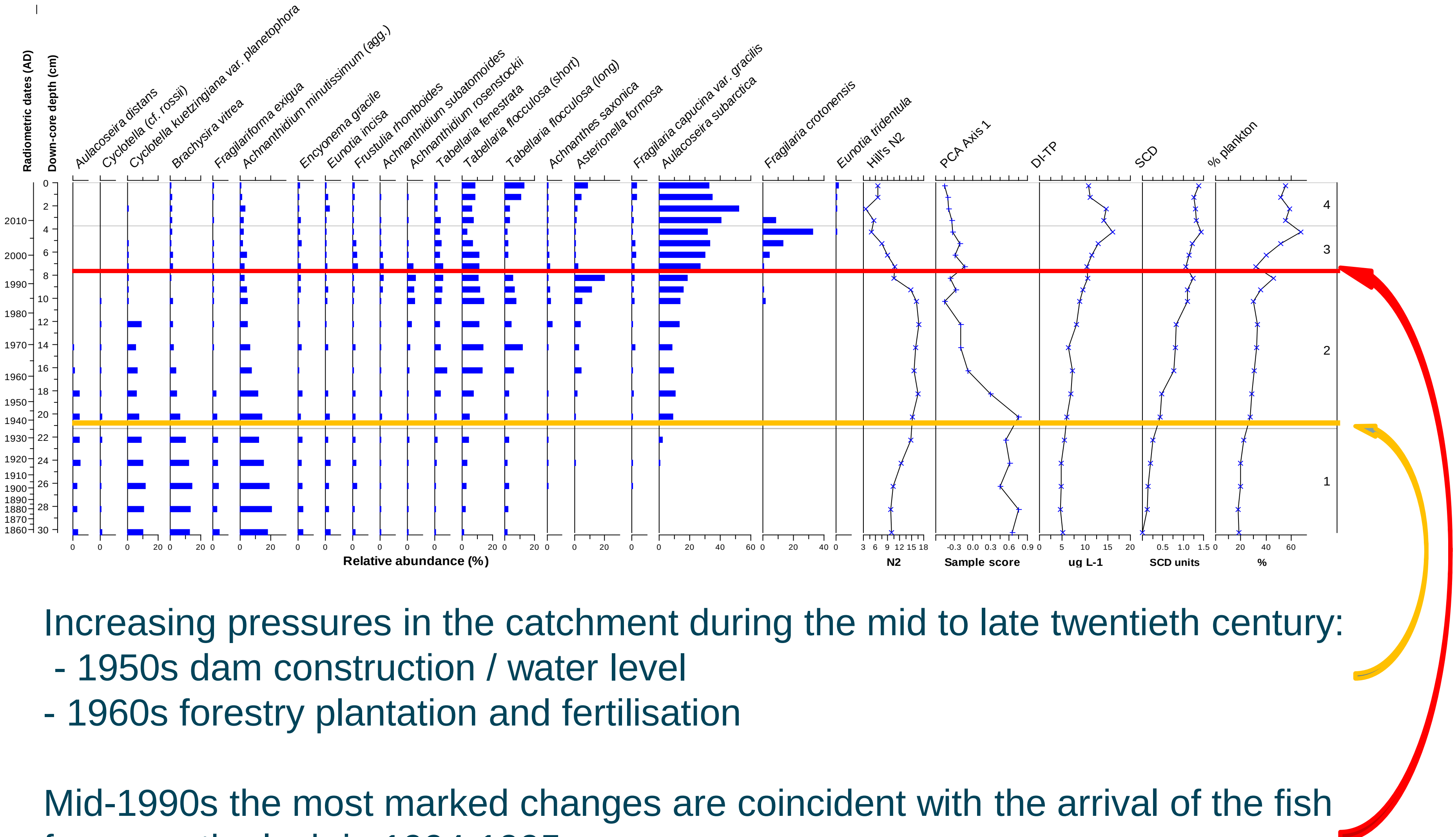




Bennion *et al.* (2004) *Journal of Applied Ecology*

SNIFFER
SCOTLAND & NORTHERN IRELAND FORUM FOR ENVIRONMENTAL RESEARCH

1. Identifying causes of enrichment e.g. Loch Shin



Increasing pressures in the catchment during the mid to late twentieth century:
- 1950s dam construction / water level
- 1960s forestry plantation and fertilisation

Mid-1990s the most marked changes are coincident with the arrival of the fish farms on the loch in 1994-1995

Bennion *et al.* (2016) Report to SEPA & the Forestry Commission

2. Determining baselines and degree of ecological change

Site name	Site code	SCD
Loch Awe North	AWEN	0.6575
Loch Awe South	AWES	0.7395
Loch of Butterstone	BUTT	0.6720
Carlingwark Loch	**CARL**	**1.0979**
Castle Loch	**CASL**	**1.1471**
Castle Semple Loch	**SEMP**	**1.1793**
Loch Davan	DAVA	0.5439
Loch Doon	**DOON**	**1.2136**
Loch Earn	**EARN**	**1.6281**
Loch Eck	**ECK**	**0.4138**
Loch Eye	EYE	0.8250
Loch of Harray	HARY	0.7907
Kilbirnie Loch	**KILB**	**1.3653**
Loch Kinord	KINO	**0.3135**
Loch Leven	LEVE	0.7974
Loch Lomond North	LOMON	**0.2199**
Loch Lomond South	LOMOS	0.6585
Loch of the Lowes	**LOWE**	**1.1771**
Loch Lubnaig	**LUBN**	**0.2224**
Loch Maree	**MARE**	**0.1291**
Lake of Menteith	MENT	0.9438
Mill Loch	MILL	0.6831
Loch Rannoch	RANN	**0.2526**
Loch Shiel	**SHIE**	**0.2439**
Loch of Skene	SKEN	0.8665

Squared chord distance measures of floristic (diatom) change

Scores: 0 to 2
0: exactly the same
2: completely different

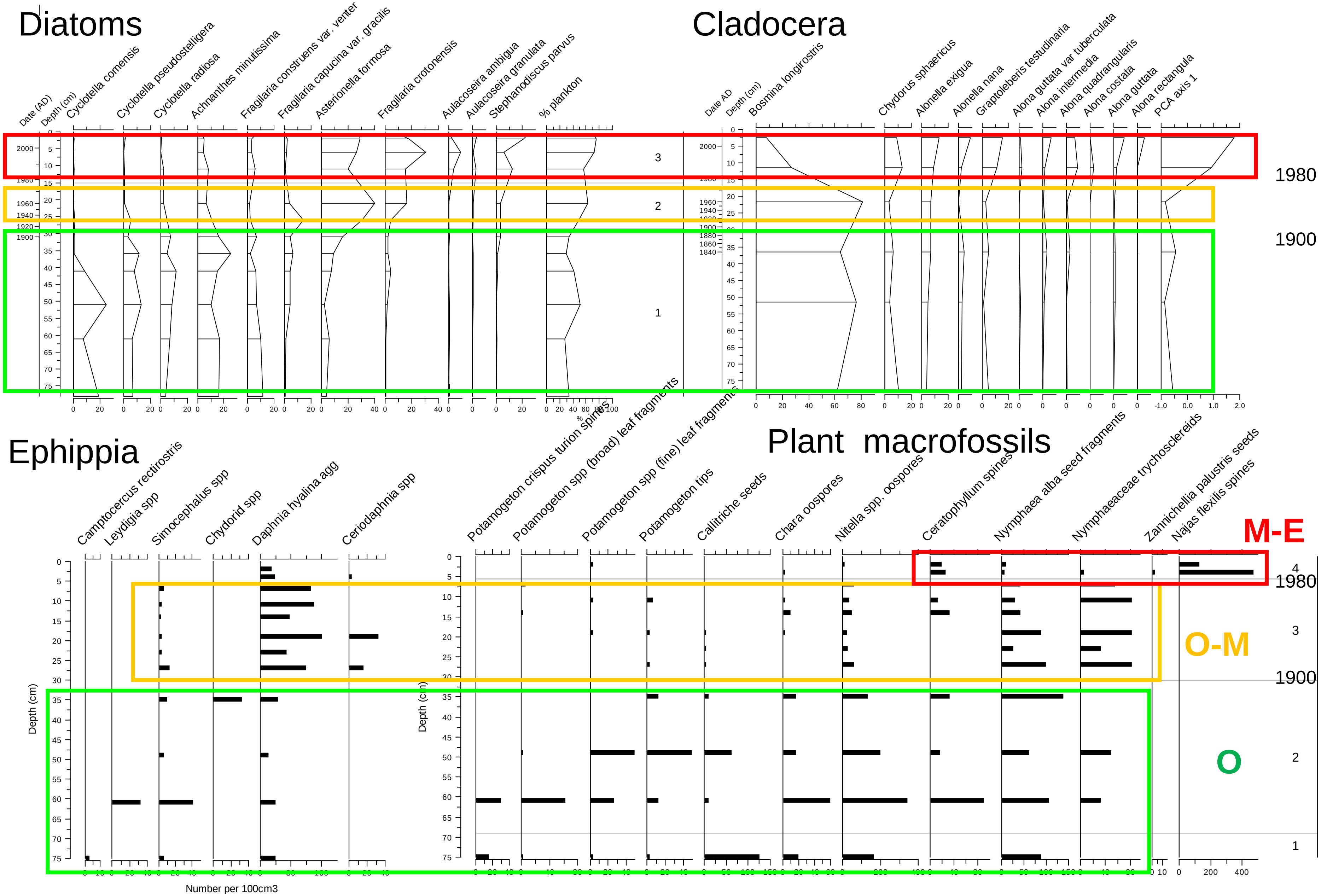
<0.3 significantly similar at the 1st percentile
<0.4 significantly similar at the 2.5th percentile
<0.5 significantly similar at the 5th percentile
<0.6 significantly similar at the 10th percentile

Top

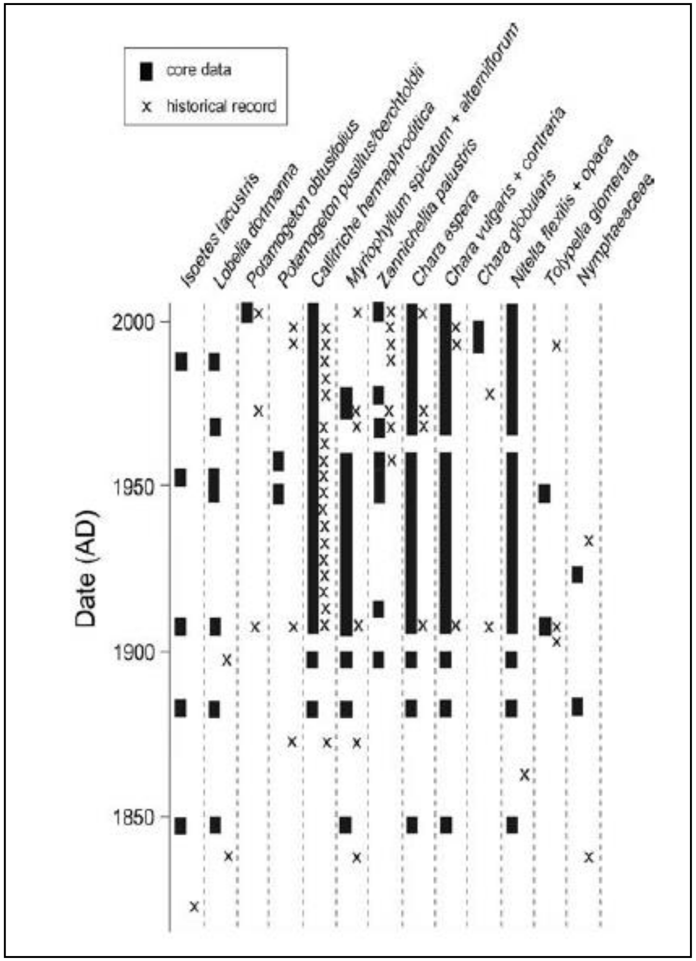
Bottom
(c 1850 AD)

Bennion & Simpson (2011) JOPL

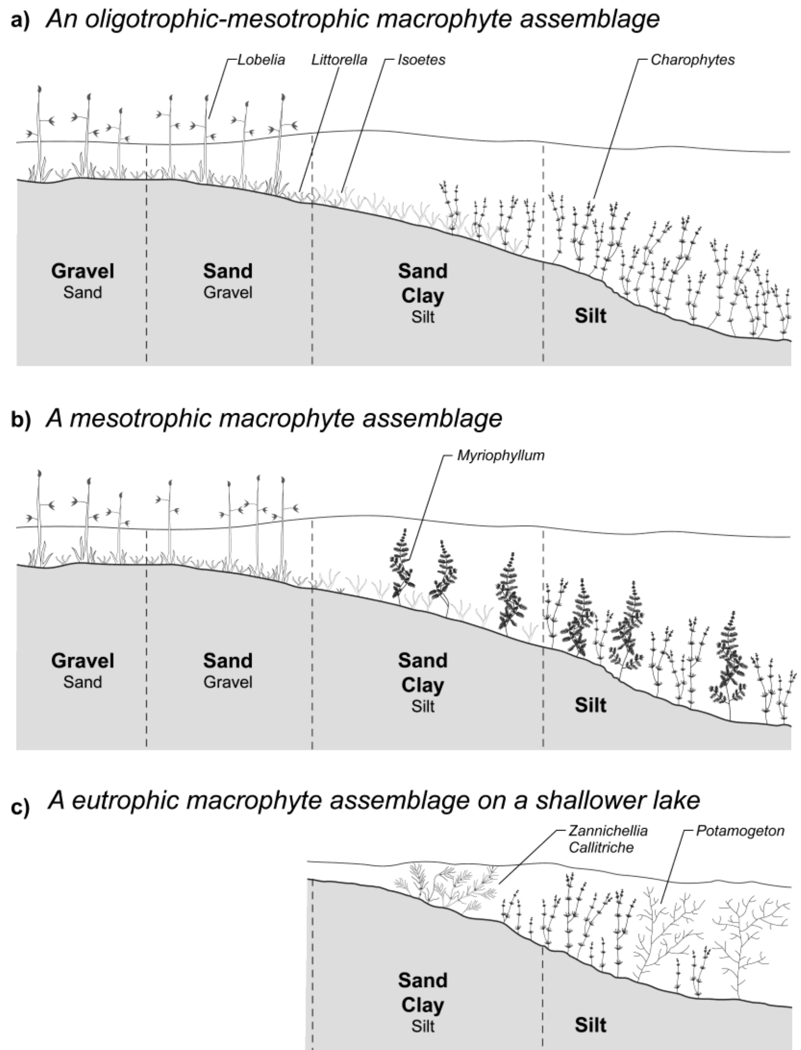
3. Ecological response to enrichment e.g. Loch Monzievaird



Comparison of palaeo and historical records for Loch Leven



The two approaches combined give a more complete picture of macrophyte community change over time than either method in isolation



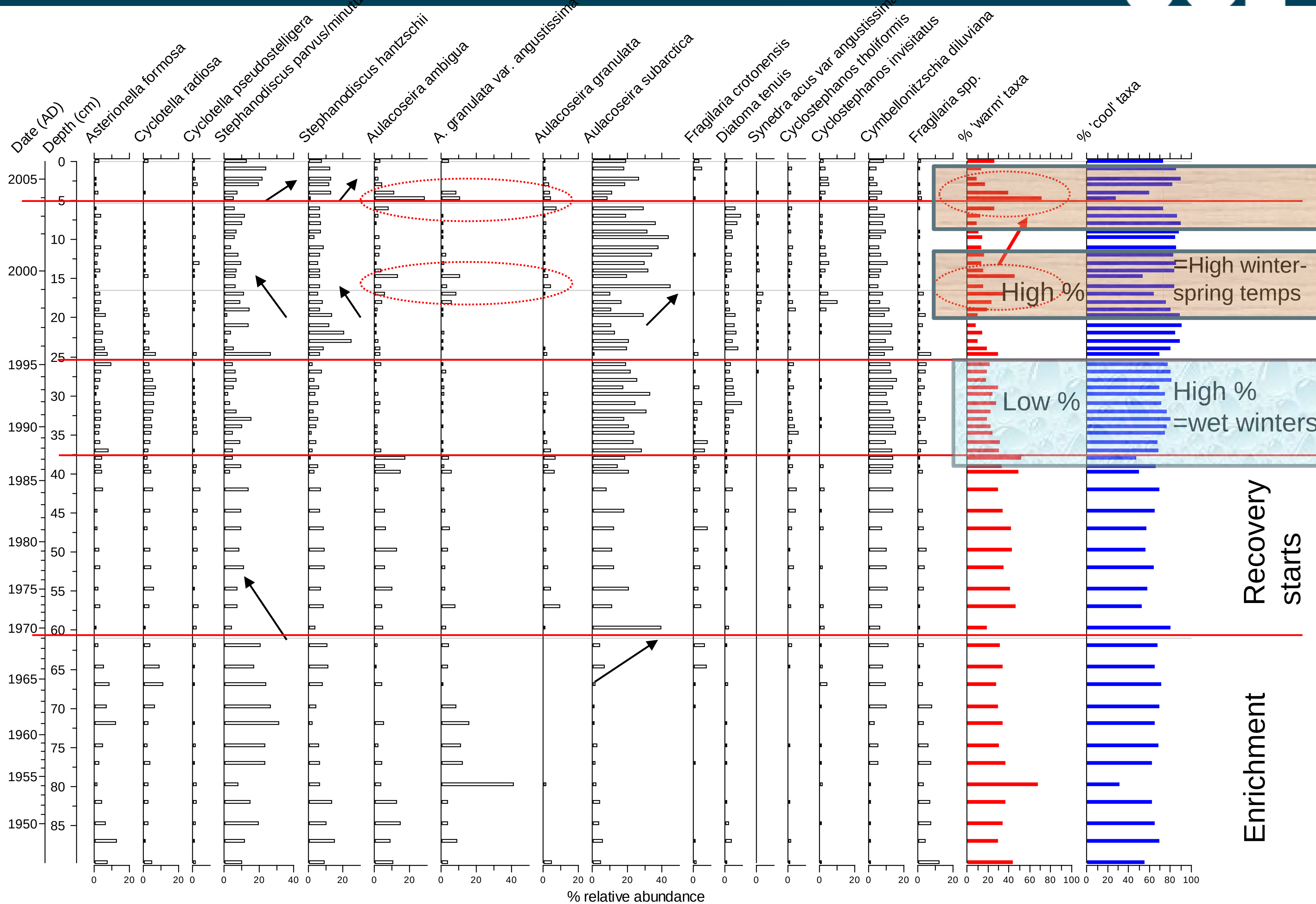
Oligotrophic-mesotrophic lake with characteristic soft-water macrophytes

Early influence of nutrient-enrichment and promotion of a taller growing elodeid community

A more nutrient-rich flora and more organic sediments (following lake lowering)

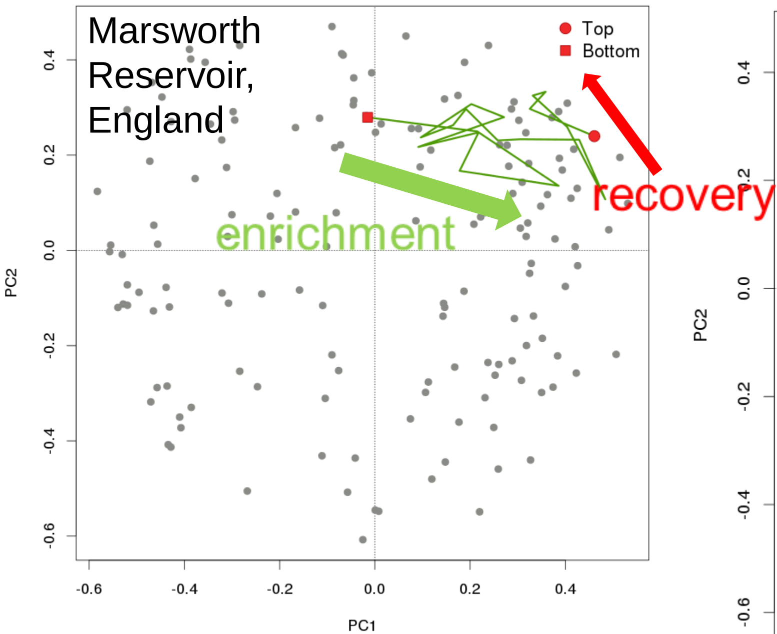
Salgado *et al.* (2010) JOPL

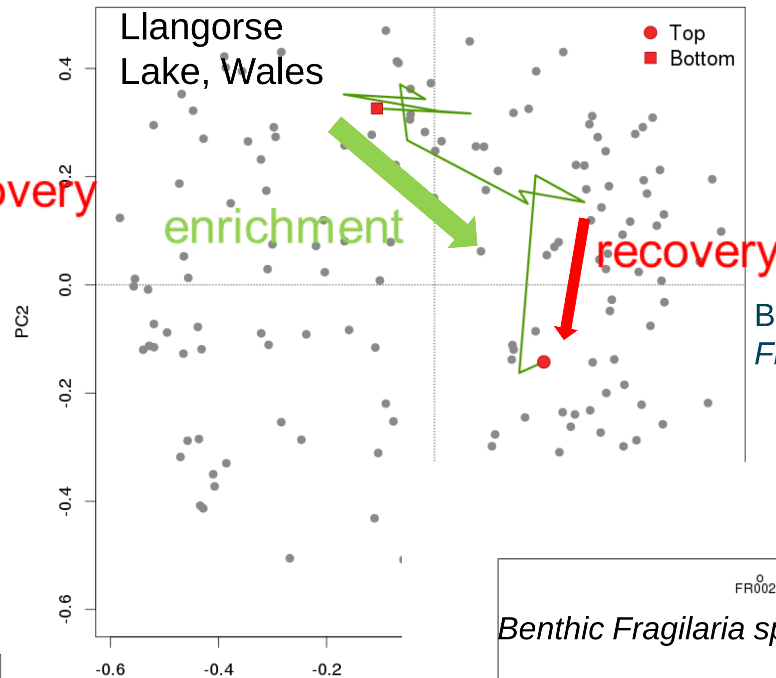
5. Insights into climate-nutrient interactions e.g. Loch Leven



Bennion et al. (2012) Freshwater Biology

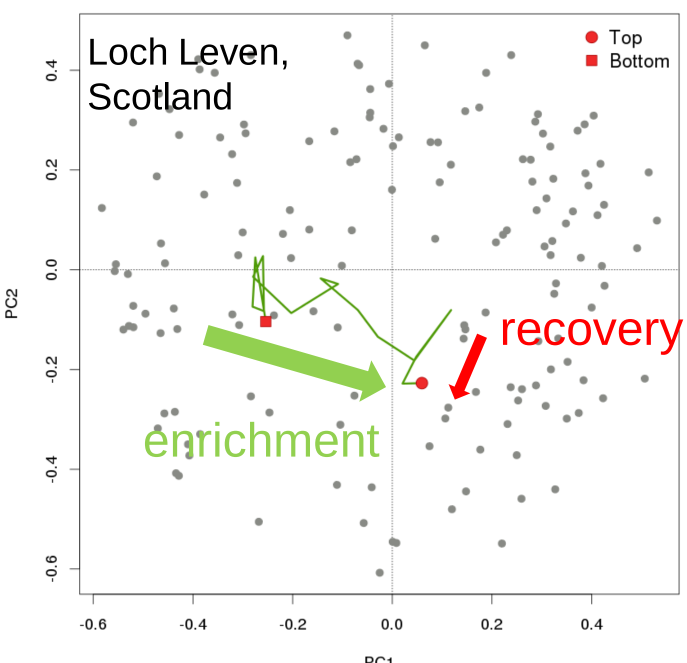
6. Assessing recovery trajectories and timescales

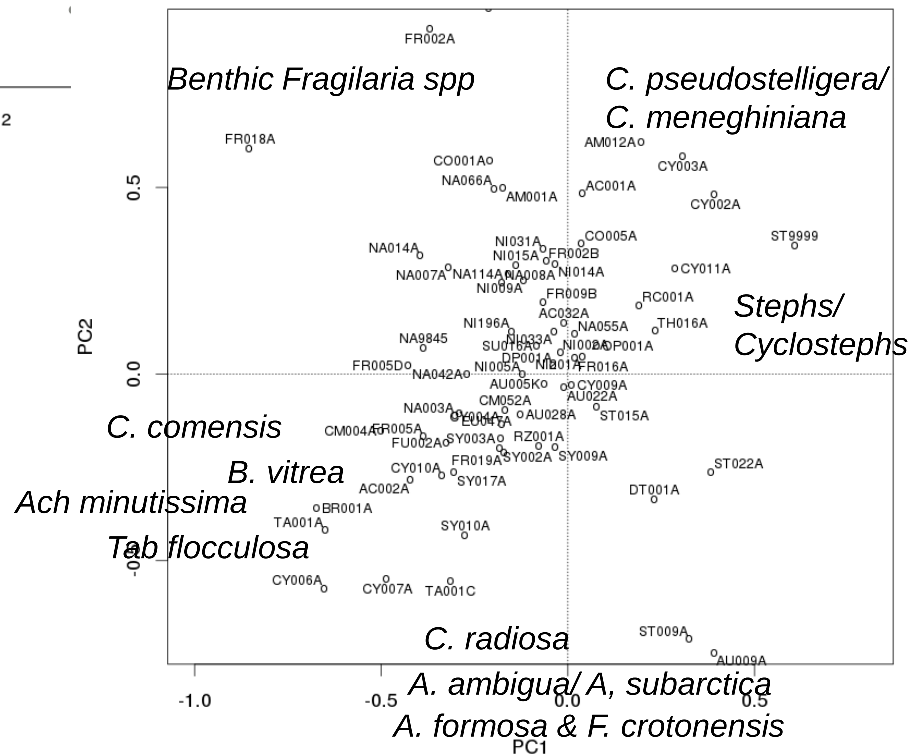




Timetracks of diatom shifts in shallow lake cores plotted passively on a PCA of training set samples

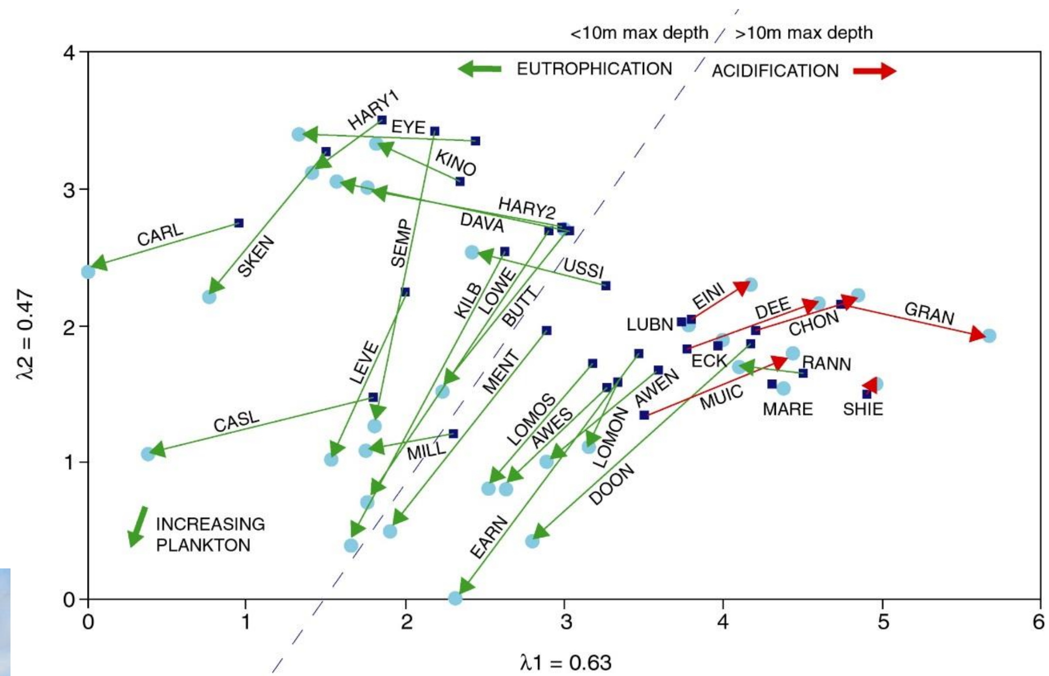
Bennion et al. (2015) *Frontiers in Ecology and Evolution*



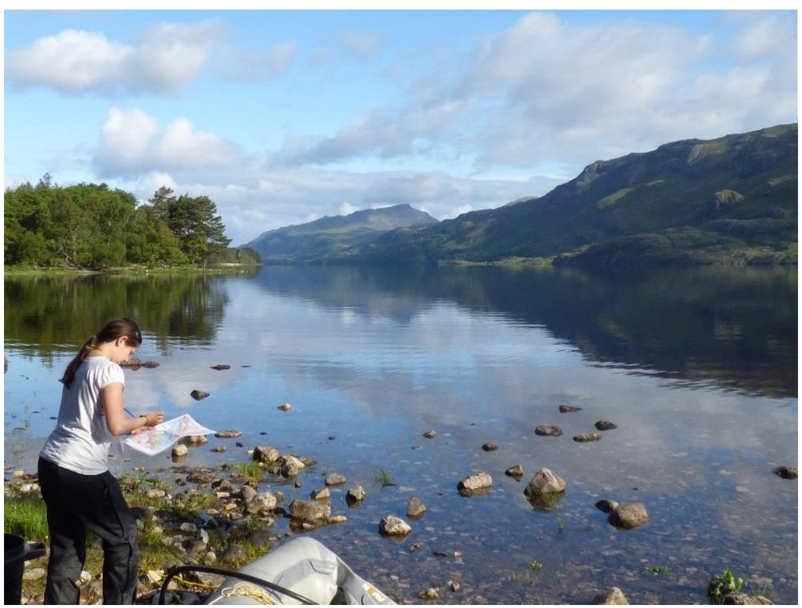


Recent responses of Scottish freshwater lochs to changes in nutrient loading and climate change

Lucia Lencioni
SNH funded PhD studentship
UCL



Bennion *et al.* (2004) *Journal of Applied Ecology*

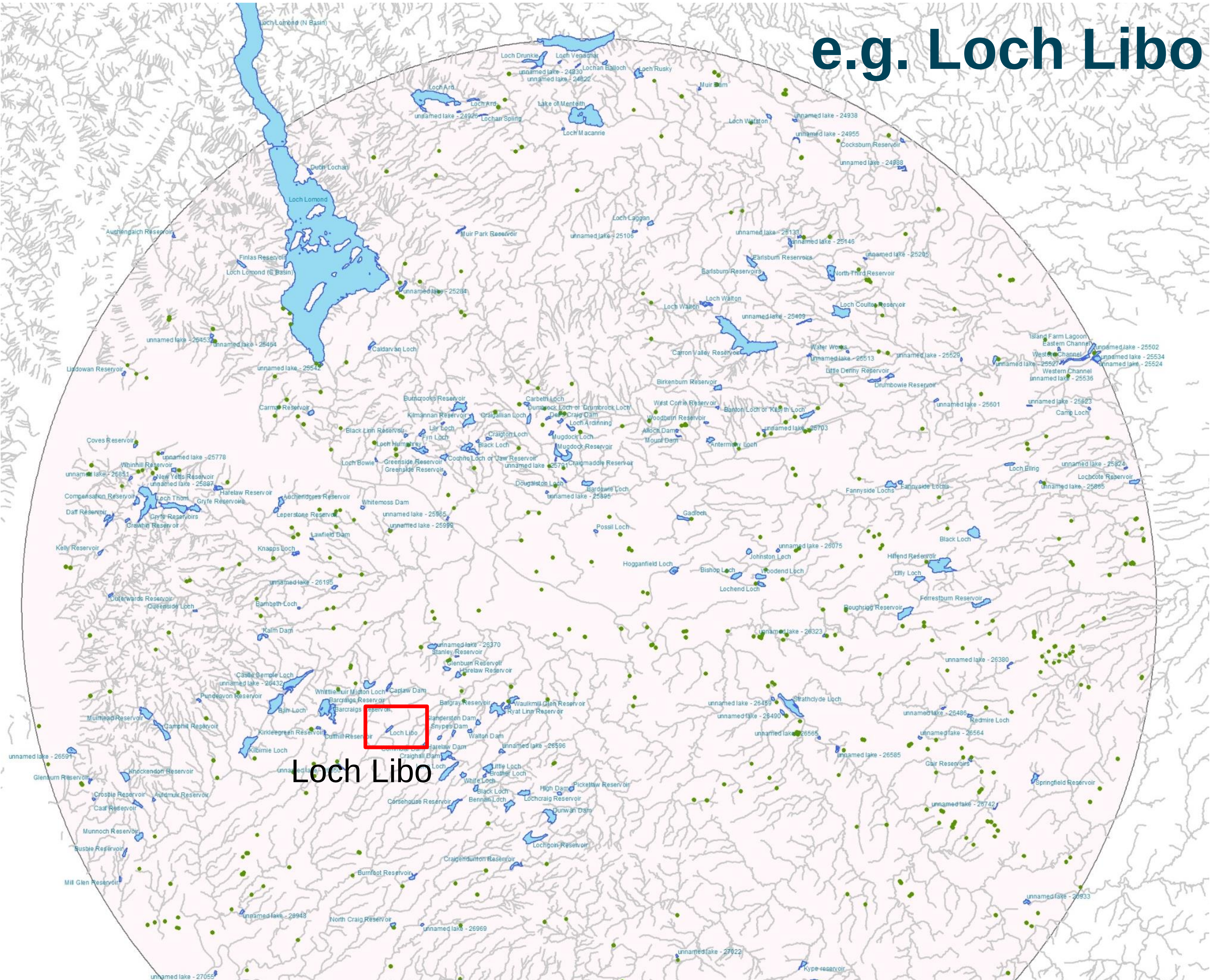


6. Assessing recovery trajectories and timescales

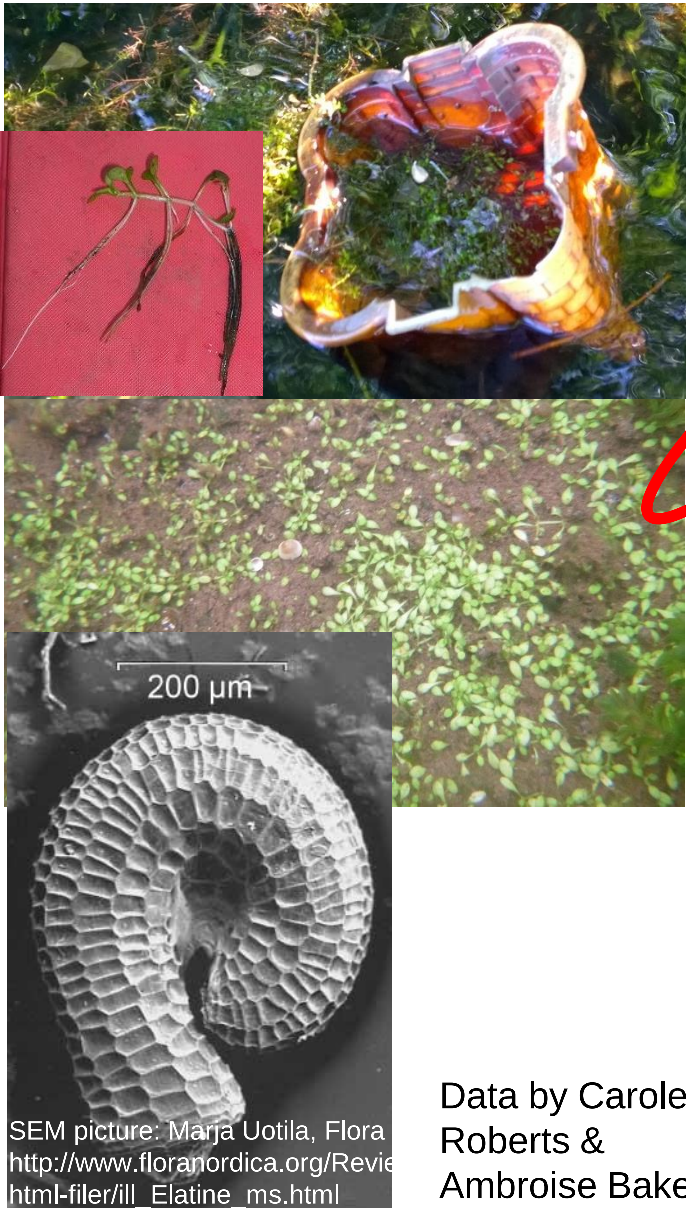
Aims:

- Compare contemporary diversity to pre-1850s diversity within 24 lakes (Glasgow, Cumbria, Norfolk).
- Pre-1850 used as ecological reference state.
- Focus on plants, diatoms and caddisflies across the 3 Hydroscapes.
- Identify biodiversity loss over time for key sites and locate biodiversity refuges in the surrounding landscape.

e.g. Loch Libo

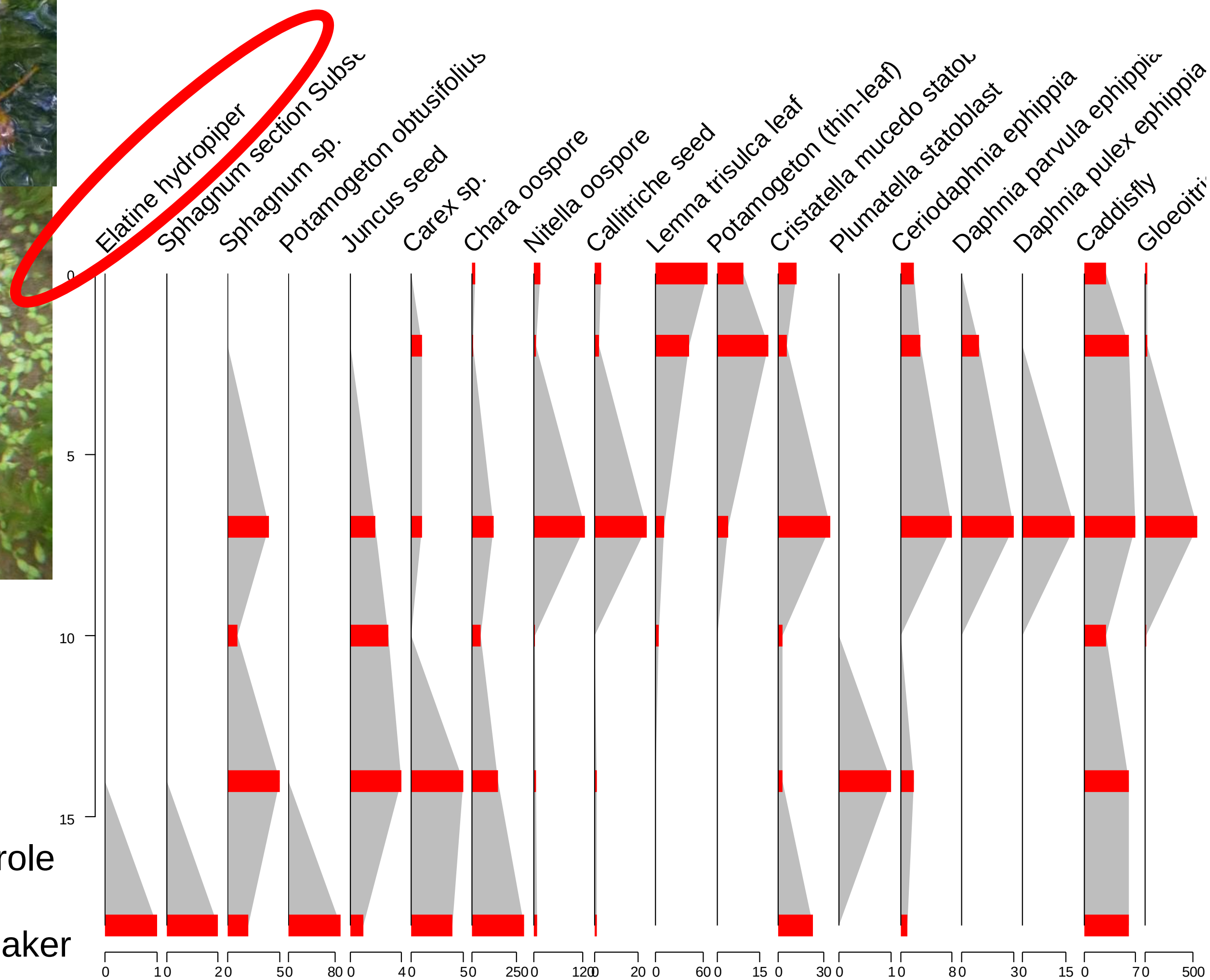


Loch Libo, Greater Glasgow, 1850 compared to today



SEM picture: Marja Uotila, Flora http://www.floranordica.org/Revie html-filer/ill_Elatine_ms.html

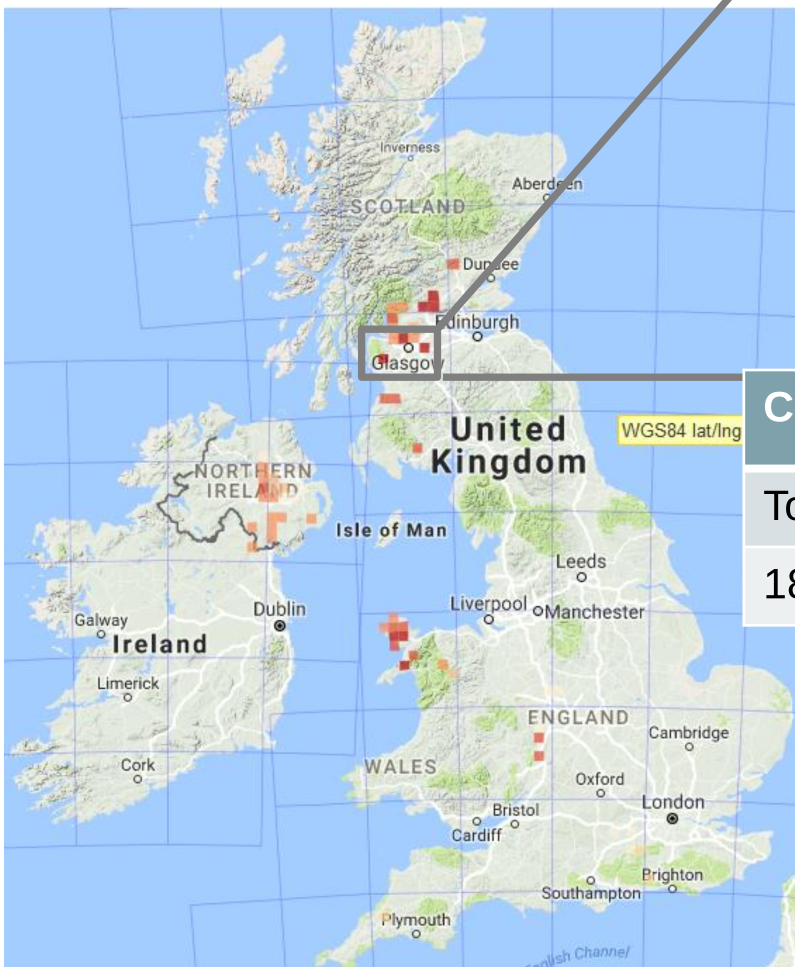
Elatine hydropiper Eight-stamened Waterwort



Data by Carole Roberts & Ambroise Baker

Elatine hydropiper, Glasgow, 1850 and today

Today's distribution



NBN Atlas https://nbnatlas.org/

C.Semple	
Top Sed.	☺
1850s	☺

Bardowie	
Top Sed.	☺
1850s	??

Loch Libo	
Top Sed.	×
1850s	☺

Lochend	
Top Sed.	??
1850s	??

Plant macrofossil data

7. Informing conservation of rare species

Using palaeolimnology to understand the ecology of a rare bird species – common scoter

Hannah Robson - PhD
UCL-IMPACT, SNH, WWT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Higher Education Network
Why I love my PhD

My PhD could save an endangered species with time-travelling mud

I'm a bug person in a bird person's world, but my work might just solve the mystery of the disappearing common scoter

Hannah Robson
Research student at University College London

Mon 1 Feb 2016 07.00 GMT

117 | 1

Understanding the habitat and decline of *Najas flexilis* (Willd.) Rostk. & Schmidt in the UK using ecology and paleoecology

Isabel Bishop - PhD
SNH, UCL-IMPACT

See talk by Isabel Bishop on Friday

Summary: Environmental change revisited

1. Fuller understanding of timing, rates and causes of eutrophication and acidification in Scottish fresh waters

2. Better definition of baselines (reference conditions) and degree of ecological change

3. More complete understanding of ecological response
   (a shift away from chemical inferences to ecological response)

4. Long-term and palaeoecological datasets used increasingly in combination, e.g. for disentangling multiple stressors, assessing variability

4. Greater insights into climate-nutrient interactions

5. An assessment of recovery trajectories and timescales – confounding factors

6. Informing conservation of rare species

Future/ongoing research:

- Legacy pollutants, food-chain effects, remobilisation (Neil Rose's work)
- Emerging pollutants, e.g. microplastics
- Recovery pathways – in light of climate change and other stressors
- Role of connectivity (NERC Hydroscape)

Any questions?

Thank you to numerous colleagues for providing ideas and data, especially Viv Jones, Neil Rose, Simon Turner, Handong Yang, Carl Sayer, Ewan Shilland, Isabel Bishop, Lucia Lencioni, Hannah Robson, Gina Clarke, Tom Davidson

‘Sampling’ Scottish lochs