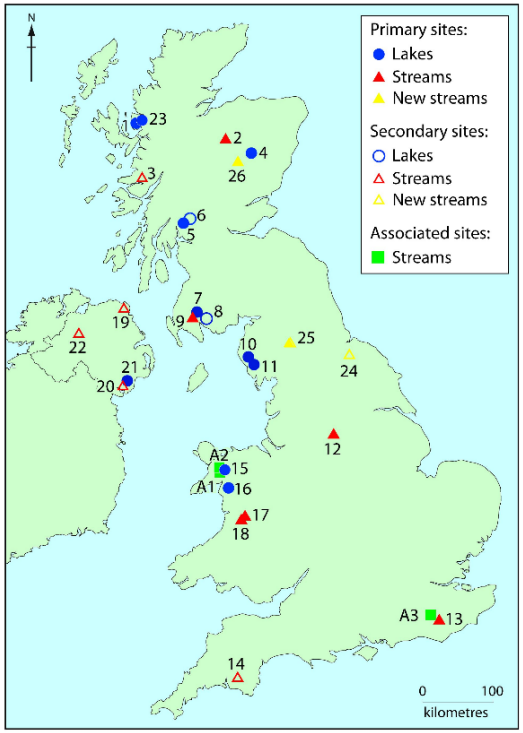
30 years of aquatic macrophyte monitoring with the UK Upland Waters Monitoring Network

Ewan Shilland & Don Monteith

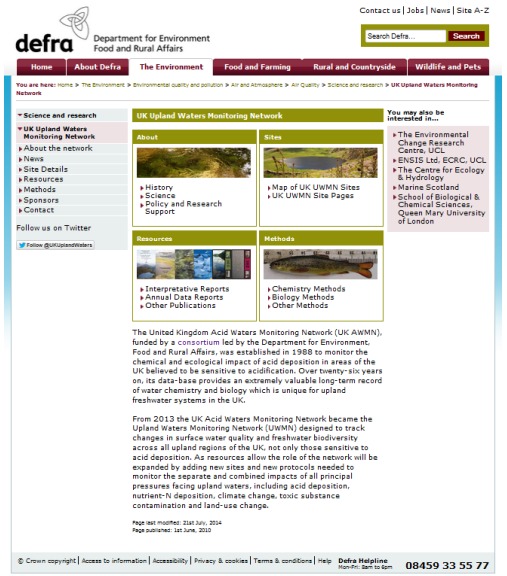
(based on a science partnership of UCL, CEH, QMUL and SG; supported by DEFRA, DOENI, Forestry Commission, NRW, SEPA, SG, SNH, WG, NERC CEH, ENSIS Ltd. & several volunteers)

UWMN Introduction

- Set up in 1988 to assess the chemical and biological response of acidified lakes and streams to emission reductions
- Originally 22 sites across UK in N-S, E-W gradients, with afforested and non-afforested pairs and NW “control” sites
- Water chemistry, fish, invertebrates, macrophytes, diatoms, temperature & physical variables at some sites eg flow
- Demonstrated the effects of reductions in S emissions – reduced xSO4
- Clear recovery evidence from chemistry but biological lags
- Despite N emission reductions demonstrated variable changes in NO3
- Demonstrated upwards trends in Dissolved Organic Carbon (DOC)



1. Loch Coire nan Arr (site discontinued)
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
25. ECN-Troutbeck
26. Baddoch Burn
A1. Afon Cwm-du
A2. Afon Cwm Marchnad
A3. Broadstone Stream



UWMN Macrophyte Sampling & Funding

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	2014	2015	2016	2017
Loch Coire nan Arr																														
Allt a Mharcaidh																														
Allt na Coire nan Con													spate								spate		spate			half	spate	spate	spate	spate
Lochnagar																											half			
Loch Chon																														
Loch Tinker																														
Round Loch of																														
Loch Grannoch																														
Dargall Lane																										half				
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Coneyglen Burn																														
Loch Coire Fionnaraich																														
Danby Beck																										half				
Baddoch Burn																														
							DTM ill																							

	No planned sampling
	Funded, sampled and analysed
	Funded but unsampled (usually due to spate)
	Unfunded, sampled and analysed
	Unfunded, sampled but not analysed
	Unfunded and not sampled
	Funded sampling

1988 - 1990 Paul Raven.
1991 - 2007 Don Monteith.
2003 - 2017 Ewan Shilland.

UWMN Macrophyte Methods - Streams

- Fixed 50 m section of stream
- Transect every 5 m from 0-50 m inclusive, substrate and macrophyte taxa (if any) recorded at three equidistant points.
- In the 5 m stream sections between each transect the stream bed is surveyed and the total amount of filamentous algae, plant cover (expressed as a percentage of submerged stream bed) and floristic composition of the plant assemblages are estimated visually
- Substrate composition of the stream bed and percentage shade also recorded in these 5 m sections
- Digital photographs taken of each 5 m section
- Major morphological features and the location of notable growths of plants in the channel are annotated on to large scale sketch maps.
- Data summarised in annual reports showing estimated percentage of submerged stream bed throughout the 50 m length covered by each taxon.

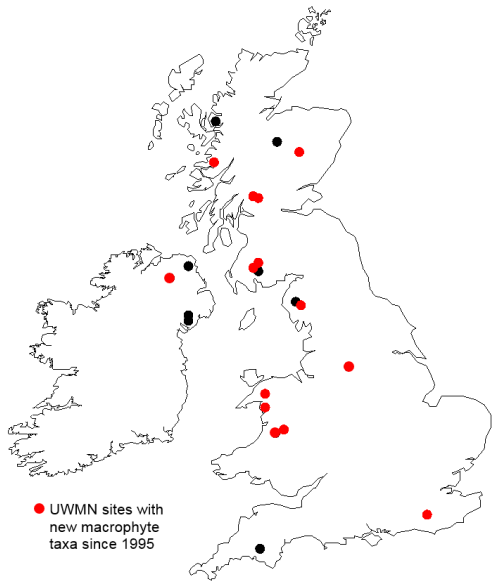
UWMN Macrophyte Methods - Lakes

- Inshore survey
  - Inshore zone viewed either by walking the shoreline, wading or from a slow-moving boat. Emergent, floating and submerged macrophytes recorded and major stands annotated on a large scale map.
- Transect survey
  - Two to four fixed-point survey transects of 60 m in length. A fixed line is deployed along the transect and two replicates of water depth, substrate type, amount of plant material and relative abundance of species recorded at 10 m intervals, with an additional site 5 m from the shore.
- Trawl survey
  - Two to four transverse trawls are made across the lake by trawling a double headed rake attached to a long rope behind a boat travelling at a steady speed. Each traverse sub-divided into five approximately equal trawl sections for which the amount of plant material recovered and relative abundance of individual macrophyte taxa are recorded.
- Since 2009 Common Standards Monitoring Methodology for lake macrophyte sampling performed alongside the UK UWMN protocol.
  - Two to four additional 100 m shoreline transects
  - Strandline species recorded
  - Lake transects using both methods.
  - Long day..

UWMN Macrophyte Results

site	species	sample years																						
LAKES		95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Lochnagar	*Subularia aquatica*	X	•	X	•	X	•	X	•	X	•	X	•	•	•	✓	•	•	✓	•	✓	•	•	•
Loch Chon	*Elatine hexandra*	✓	•	✓	•	✓	•	X	•	X	•	X	•	•	•	•	•	•	✓	•	•	•	•	•
	Subularia aquatica	✓	•	✓	•	✓	•	✓	•	✓	•	✓	•	•	•	•	•	•	✓	•	•	•	•	•
	Chara virgata	X	•	X	•	✓	•	✓	•	✓	•	✓	•	•	•	•	•	•	✓	•	•	•	•	•
Loch Tinker	*Subularia aquatica*	✓	•	✓	•	X	•	X	•	✓	•	✓	•	•	•	✓	•	•	✓	•	•	•	•	•
Round Loch of Glenhead	*Myriophyllum alterniflorum*	X	•	X	•	X	•	X	•	✓	•	✓	•	•	•	✓	•	•	✓	•	✓	•	•	✓
Burnmoor Tarn	*Elatine hexandra*	✓	•	X	•	X	•	X	•	X	•	X	•	•	X	•	•	•	✓		✓	•	•	•
	Chara virgata	X	•	X	•	X	•	X	•	✓	•	✓	•	•	✓	•	•	•	✓	•	✓	•	•	•
	Nitella translucens	X	•	X	•	X	•	X	•	X	•	X	•	•	✓	•	•	•	✓	•	✓	•	•	•
	Potamogeton berchtoldii	X	•	X	•	X	•	X	•	X	•	X	•	•	X	•	•	•	✓	•	✓	•	•	•
Llyn Llagi	*Callitriche hamulata*	X	•	X	•	✓	•	✓	•	✓	•	✓	•	•	•	✓	•	✓	•	✓	•	✓	•	✓
	Nitella flexilis agg.	X	•	X	•	X	•	X	•	X	•	X	•	•	•	✓	•	✓	•	✓	•	✓	•	✓
	Elatine hexandra	X	•	X	•	X	•	X	•	X	•	X	•	•	•	✓	•	✓	•	✓	•	✓	•	✓
Llyn Cwm Mynach	*Eleogiton fluitans*	X	•	X	•	✓	•	✓	•	✓	•	✓	•	•	✓	•	✓	•	✓	•	✓	•	•	✓
	Isoetes lacustris	X	•	X	•	✓	•	✓	•	✓	•	✓	•	•	X	•	X	•	✓	•	✓	•	•	✓
STREAMS																								
Allt na Coire nan Con	*Fontinalis antipyretica*	X	X	X	X	X	•	X	X	X	X	X	X	✓	•	✓	•	✓	✓	✓	•	•	•	•
Dargall Lane	*Blindia acuta*	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•	•
River Etherow	*Hygrohypnum ochraceum*	X	X	X	X	X	X	X	X	X	X	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Hyocomium armoricum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓	✓	✓	✓
Old Lodge	*Hyocomium armoricum*	X	X	X	X	X	✓	X	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Afon Hafren	*Hyocomium armoricum*	X	X	X	X	X	X	X	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fontinalis antipyretica	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	X	X	X	✓	✓	X	X	✓
	Marsupella emarginata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	✓	X	X	✓	✓
Afon Gwy	*Hyocomium armoricum*	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	✓	X	✓	✓	✓	✓	✓	✓	✓
Coneyglen Burn	*Hyocomium armoricum*	X	X	X	X	X	X	X	X	X	X	X	X	•	•	•	•	✓	•	•	•	✓	•	✓

Key. ✓ species recorded during survey, X species not recorded during survey, • no survey



Recovery – lake macrophytes

UKUWMN lake sites with new macrophyte taxa since 1995

Lochnagar (*Subularia aquatica,* 2009)
Loch Chon (*Chara virgata,* 1999)
Loch Tinker (*Subularia aquatica,* 1995)
Round Loch of Glenhead (*Myriophyllum alterniflorum*, 2003)
Burnmoor Tarn (*Chara virgata*, 2003, *Nitella translucens,* 2008*, Potamogeton berchtoldii,* 2012)
Llyn Cwm Mynach (*Eleogeton fluitans*, 1999)
Llyn Llagi (*Subularia aquatica,* 1993,*Callitriche hamulata* 1999, *Nitella flexilis* agg*.,* 2009, *Elatine hexandra* 2009)

Increasing ANC (Acid Neutralising Capacity – overall buffering capacity against acidification) allows species that extract carbon from the water column, rather than sediments, to establish.

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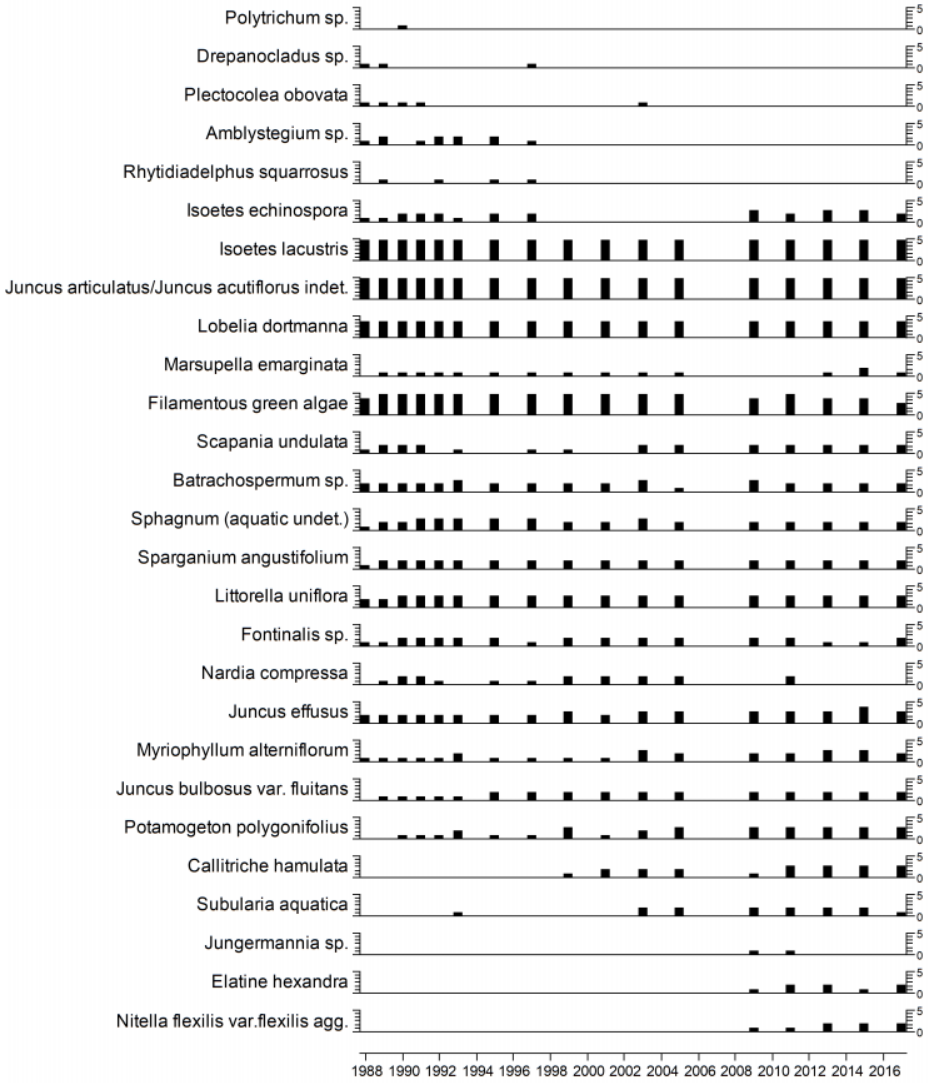
UWMN Macrophyte Results – Lakes



Llyn Llagi shows the greatest signs of macrophyte recovery

Gained several new submerged plant species:

- *Subularia aquatica* 1993
- *Callitriche hamulata* 1999
- *Nitella flexilis* agg. 2009
- *Elatine hexandra* 2009

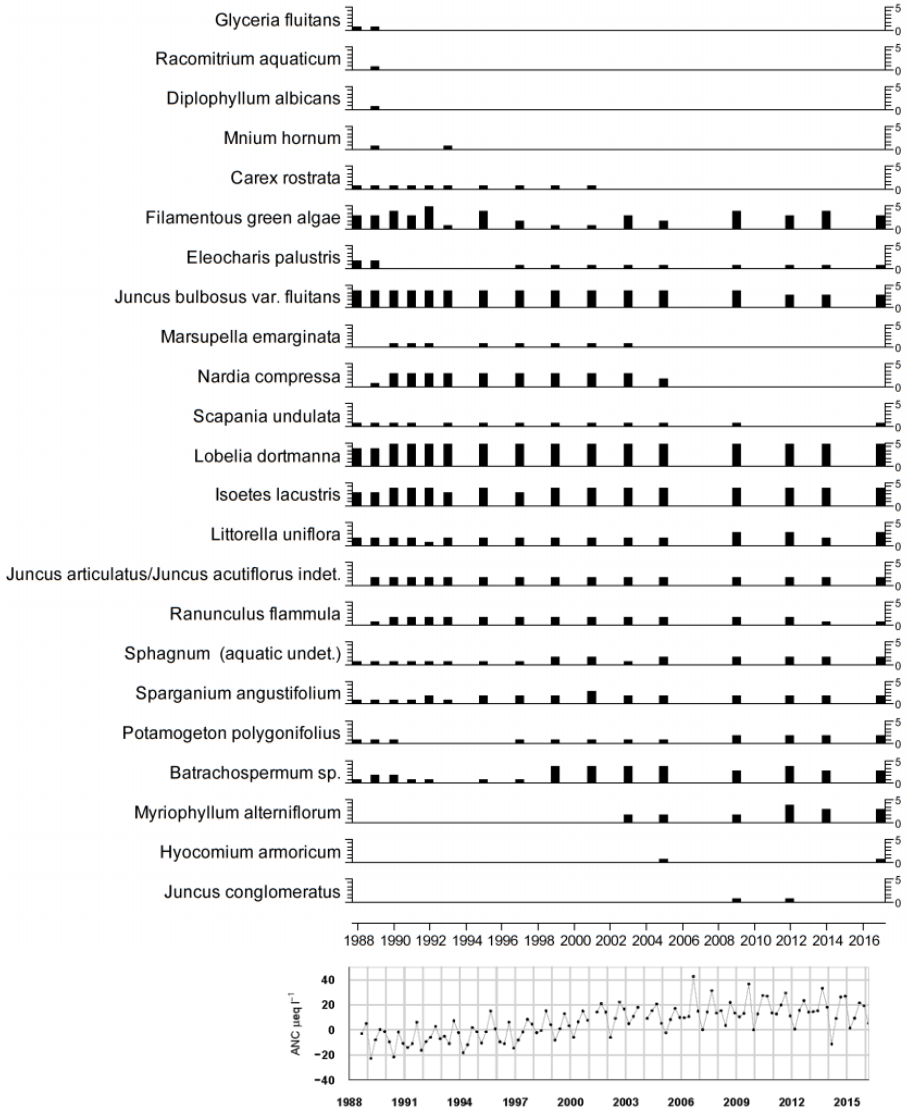
Site has moved from the C1 to the C2 category in Duigan *et al*'s. (2007) lake classification scheme

UWMN Macrophyte Results – Lakes

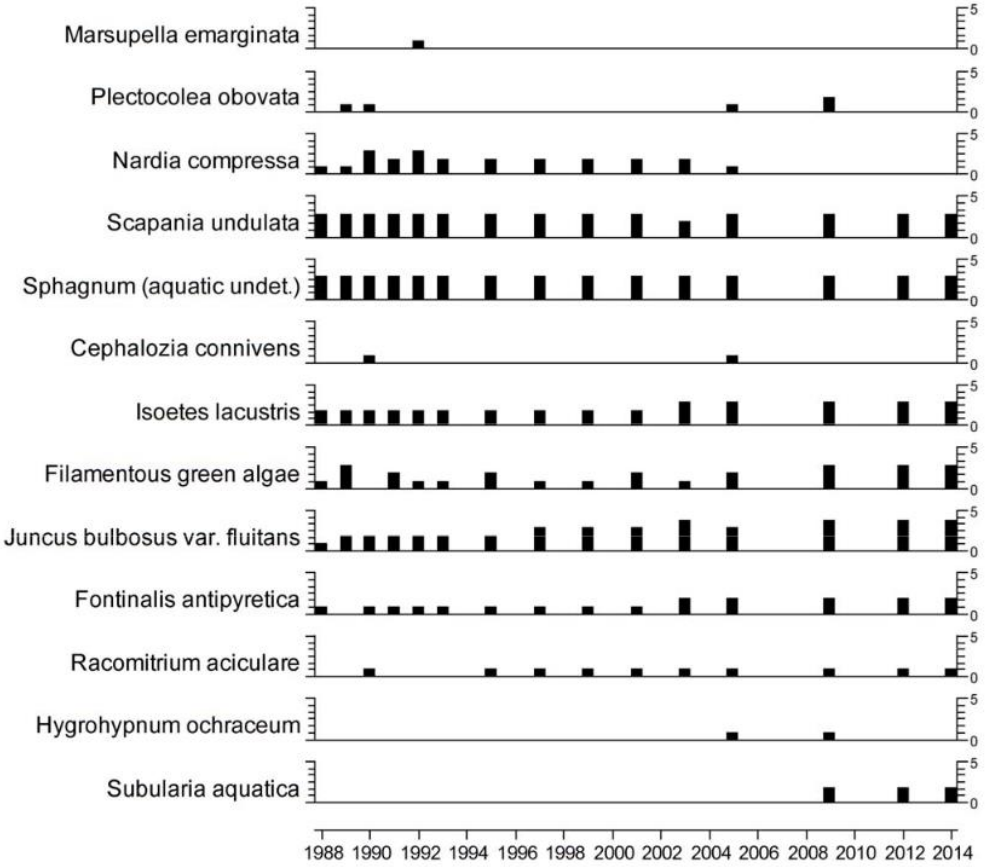
Round Loch of Glenhead

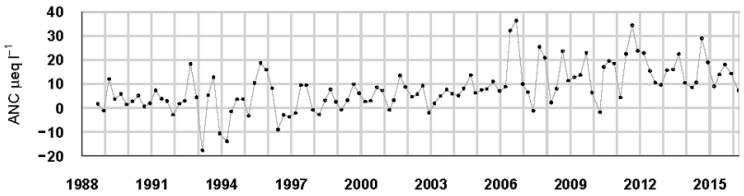
The elodied species *Myriophyllum alterniflorum*, increasingly established in the Round Loch of Glenhead after 2003.

ANC (Acid Neutralising Capacity – overall buffering capacity against acidification) ~10 microequivalents



UWMN Macrophyte Results – Lakes





Lochnagar

Increase in area of *Juncus bulbosus*

Gained *Subularia aquatica* in 2009 – again at around 10 microequivalents ANC.

JNCC joint altitude record with nearby Sandy Loch – also possible response to changing temperatures and ice environment.

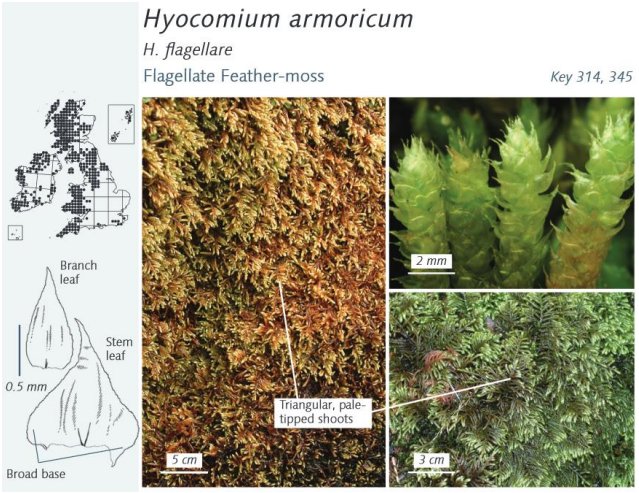
Ruderal annual – seeds prolifically

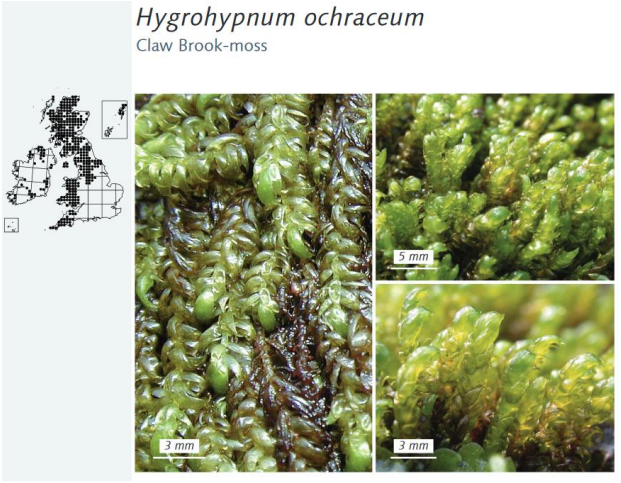
Recovery – stream macrophytes

UKUWMN stream sites with new macrophyte taxa since 1995

Allt na Coire nan Con (*Fontinalis antipyretica*, 2007)
Dargall Lane (*Blindia acuta,* 2003)
River Etherow (*Hygrohypnum ochraceum*, 2005 *Hyocomium armoricum,* 2010)
Old Lodge (*Hyocomium armoricum,* 2000)
Afon Gwy (*Hyocomium armoricum,* 2008)
Afon Hafren (*Hyocomium armoricum,* 2002*, Fontinalis squamosa,* 2009*, Marsupella emarginata,* 2012)
Coney Glen Burn (*Hyocomium armoricum,* 2011)

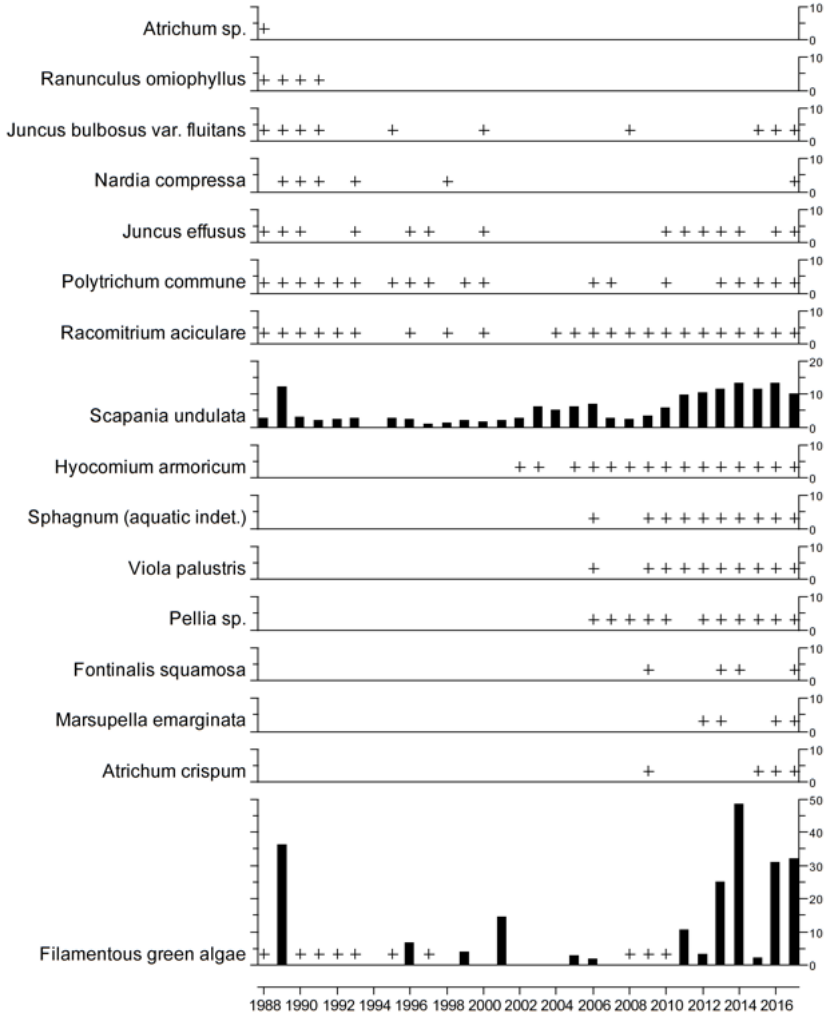
Bryophyte floras getting gradually richer.
New species usually less acid-tolerant mosses.
Hyocomium armoricum has been recorded when average ANC in the streams has risen above around 10 µeq l^{-1}





Images BBS

UWMN Macrophyte Results – Streams

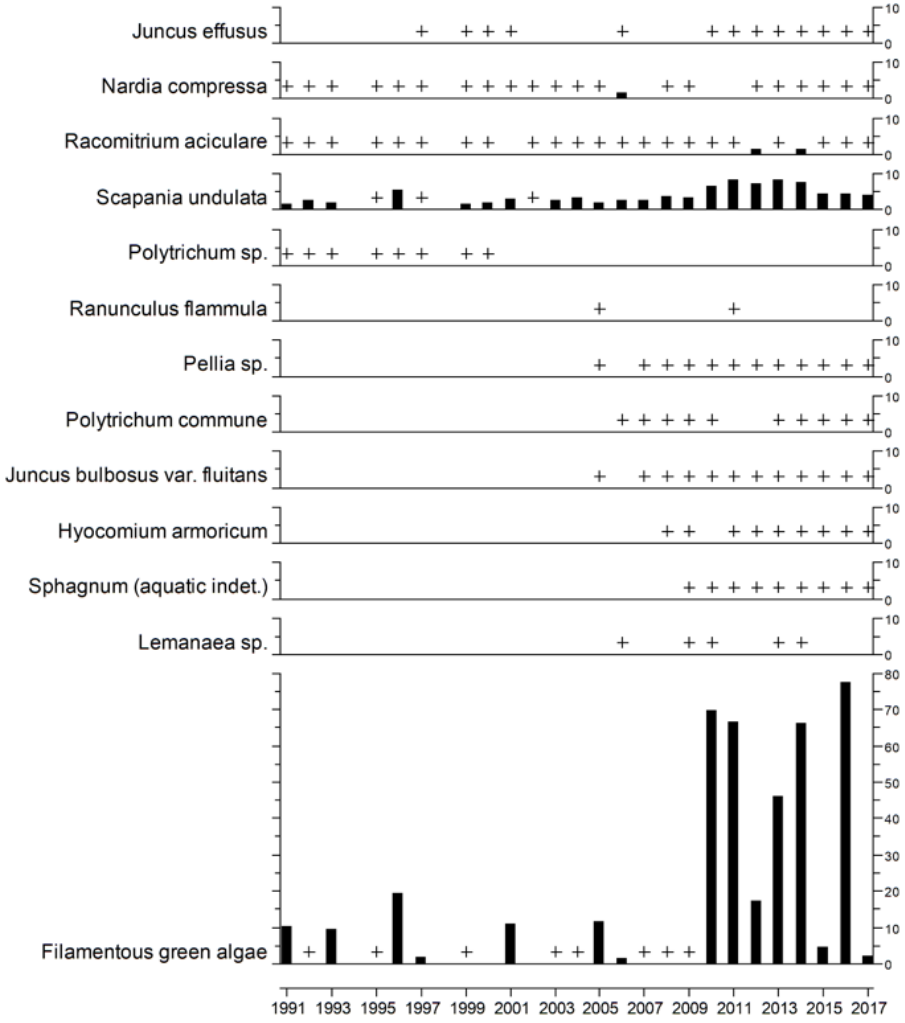


Afon Hafren

Three additions to the submerged taxa:
Hyocomium armoricum
Fontinalis squamosa
Marsupella emarginata

Possible increases in Filamentous algae
Significant linear changes in inverts and

UWMN Macrophyte Results – Streams



Afon Gwy

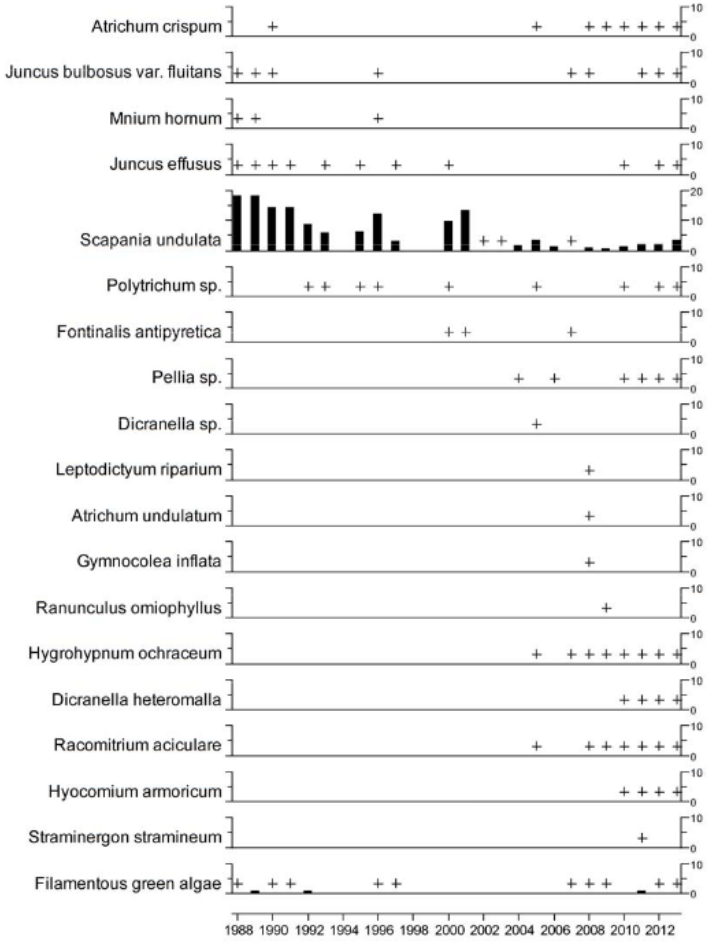
Hyocomium armoricum established in 2008

Sporadic acid-sensitive *Lemanaea sp.* alga after 2006.

Increases in Filamentous algae

Significant linear changes in inverts and diatoms

UWMN Macrophyte Results – Streams



River Etherow

Two new submerged taxa:
Hyocomium armoricum
Hygrohypnum ochraceum

"Flashy" site on W Pennines and prone to high flow events

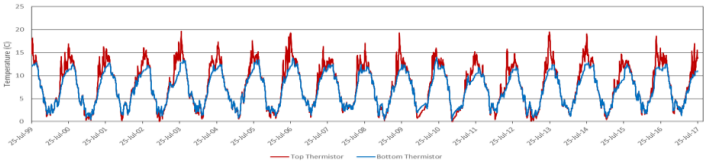
UWMN Macrophyte findings so far

- Macrophyte species richness increasing slightly at over half of the sites.
- New taxa have been found in seven out of eleven lake sites and seven out of eleven stream sites.
- Of the sites with new taxa nine are unafforested and five forested.
- Species composition at eight sites has not changed significantly since the study onset. Whilst this includes a few cleaner "control" sites it also includes sites with improving trends in deposition and surface chemistry eg Scoat Tarn,
- Changes due to improving deposition not expected at "control sites" and no apparent signs of climate driven taxa changes
- No sites are exhibiting significant species losses. Where change is occurring macrophyte diversity is generally increasing.
- Macrophyte changes tend to lag behind chemical improvements and responses of diatoms and invertebrates – isolation/dispersal?
- Increasing ANC allows species that extract carbon from the water column to establish - at lake sites with new species the taxa that have arrived are those unable to extract carbon directly from lake sediments. This is consistent with reduced acidity, increased ANC and the subsequent higher availability of inorganic carbon in the water column for plant metabolism.
- The primary changes observed in UWMN streams have been the more recent detection of aquatic mosses, albeit in very small amounts, at sites previously dominated almost solely by acid tolerant liverworts. In some sites *Hyocomium armoricum* has been recorded when average ANC in the streams has risen above around 10 µeq l^{-1}
- Aquatic mosses tend to dominate the least acidic streams on the Network.

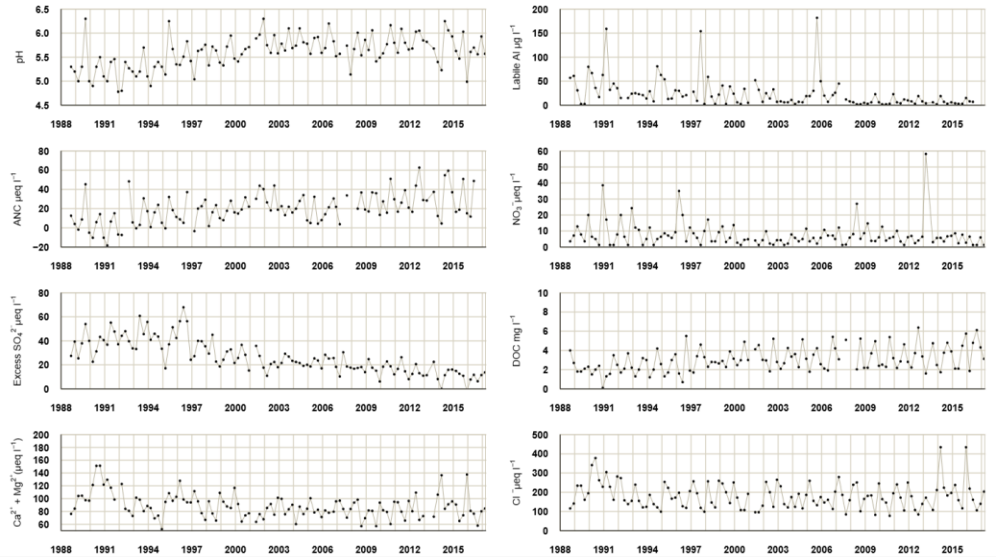
UWMN Macrophytes – what next

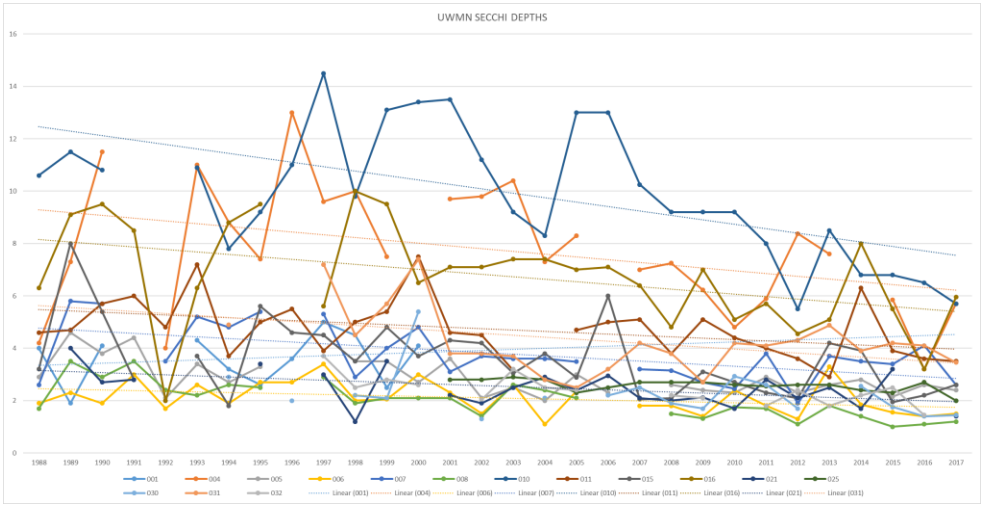
- PhD. Accepted onto the London NERC Doctoral Training Partnership 2018.
- Microscope ID stream & lake bryophyte voucher backlog
- Database results – eg historic transect data
- Literature review
- Possibility to include data from Water Framework Directive, SAC/SSSI site surveys, River Habitat Surveys – harmonisation with UWMN datasets
- Rigorous data analysis – explore drivers of change: 1. Lakes 2. Streams
  - Acidity changes – main or secondary driver?
  - Climate - changes in flow/hydrology/storminess/sea salt events/lake exposure?
  - Climate – changes in minimum/maximum temperatures?
  - Nutrients esp. N deposition – increases in fil alg?
  - Lakes increasing DOC / light regime changes?
  - Biomass/productivity changes – PVI?
  - Changes in biotic pressures – grazing/biofilms?
- Add current biomonitoring metrics to database – explore development of low alkalinity metrics?
- 3. Lake sediment DNA/macrofossils – explore viability of sediDNA technique/taphonomy against 30-year recorded time-series, establish reference conditions and compare to current trajectories with changes in eg climate, nutrients. Test seed bank viability to determine recolonisation pathways – sediment v dispersal

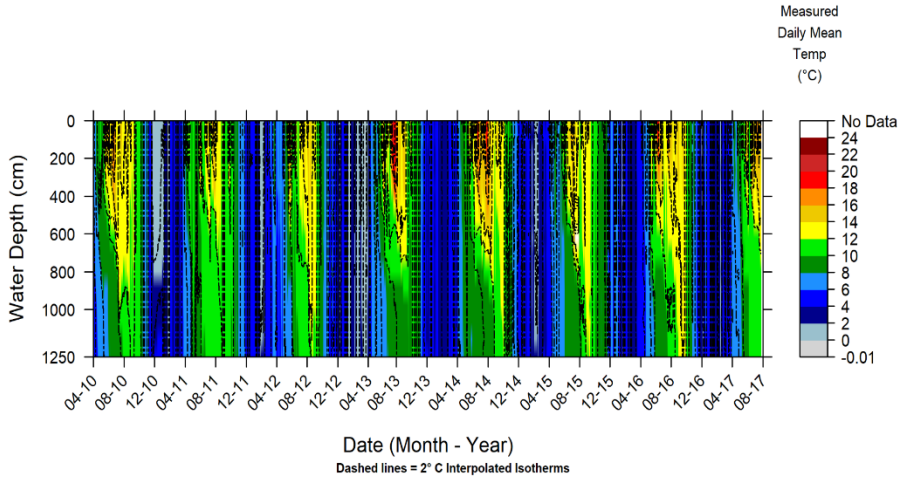
UWMN Supporting Data



- Water chemistry, including DOC, Al
- Deposition chemistry
- Biology – fish/inverts/diatoms
- Flow for some sites eg Mharcaidh/Dargall Lane
- Temperature / lake thermal regime
- Lake Secchi depths
- O2 profiles
- Stream physical/morphological data (including fish section HABSCORES)
- Planning on TLS scans of stream sections 2018
- Food webs - plants not included (Clare Gray IC)
- Heavy metals







Questions?

Thanks to the funders

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